Radio and Satellite Tracking and Detecting Systems for Maritime Applications

by

Ivan Skoryk (21345503)

Submitted in fulfilment of the requirements of the Doctor of Technology degree in Information Technology in the Department of Information Technology, Faculty of Accounting and Informatics, Durban University of Technology, Durban, South Africa

April, 2014

Supervisor: Prof. Dimov Stojče Ilčev

Co-supervisor: Prof. Oludayo Olugbara

DECLARATION

I, Ivan Skoryk declare that this dissertation is a representation of my own work both in conception and execution. This work has not been submitted in any form for another degree at any university or institution of higher learning. All information cited from published or unpublished works have been acknowledged.

____________________ ____________________

Student Name Date

Approved for final submission

____________________ ____________________

Supervisor Date

Abstract

The work described in this thesis summarizes the author's contributions to the design, development and testing of embedded solutions for maritime Radio and Satellite tracking and detecting systems. In order to provide reliable tracking and detecting facilities of ships have to be integrated Convectional Maritime Radio Communications (CMRC) and Maritime Mobile Satellite Communications (MMSC) systems. On the other hand, Global Mobile Satellite Communications (GMSC) as a part of Global Communication Satellite Systems (GCSS) has to be integrated with Global Navigation Satellite Systems (GNSS) of the US GPS or Russian GLONASS systems.

The proposed local maritime Radio VHF Communication, Navigation and Surveillance (CNS) systems and devices, such as Radio Automatic Identification System (R-AIS) or VHF Data Link (VDL), Radio Automatic Dependent Surveillance - Broadcast (RADS-B) and GNSS Augmentation VDL-Broadcast (GAVDL-B) are introduced.

The new technology deigns of global Satellite CNS maritime equipment and systems, such as Global Ship Tracking (GST) as enhanced Long Range Identification and Tracking (LRIT), Satellite AIS (S-AIS), Satellite Data Link (SDL), Satellite Automatic Dependent Surveillance - Broadcast (SADS-B) and GNSS Augmentation SDL (GASDL) are discussed and benefits of these new technologies and solution for improved Ship Traffic Control (STC) and Management (STM) are explored.

The regional maritime CNS solutions via Stratospheric Communication Platforms (SCP), tracking of ships at sea via Space Synthetic Aperture Radar (SSAR) or Inverse Synthetic Aperture Radar (ISAR)and Ground Synthetic Aperture Radar (GSAR) are described.

The special tracking systems for collision avoidance with enhanced safety and security at sea including solutions of captured ships by pirates through aids of the MMSC, SCP and Radars are introduced and the testing methodologies employed to qualify embedded hardware for this environment are presented.

During the voyage of the ship in good weather conditions and when navigation devices on the bridge are in order, then can be used very well AIS, LRIT, anti-collision Radar and other on-board equipment. However, at very bad weather conditions sometimes surveillance Radar and Radio HF Transceiver cannot work, but may work only GPS Receiver and L/C-band Satellite Transceiver, while Radio VHF Transceiver will have extremely reduced coverage, what is not enough for safe navigation and collision avoidance. Therefore, during those critical circumstances, when the safety of navigations very important, it will be not necessary to ask "Where am I", but "Where are nearby ships around me"? At this point, it should be needed the newest techniques and equipment for enhanced STC and STM, such as GST, S-AIS, SDL, SADS-B and GASDL.

Terrorists exploit surprise in successful pirate actions worldwide and security forces are generally unaware of the source of these attacks at sea. In today's information age, terror threats may originate with transnational organizations or exploit the territory of failed, weak or neutral states. Thus, countering piracy by eliminating the terrorists on land is the best solution, however, it might not be feasible and even though it's successful could require many years.

In the thesis, the general overview of Radio and Mobile Satellite Systems (MSS) for ship communication and tracking systems is conducted as well, including the space platform and orbital mechanics, horizon and geographic satellite coordinates and classification of spacecraft by Geostationary Earth Orbits (GEO) and Non-GEO orbits.

Acknowledgements

I would like in particular to thank my supervisor, who is Prof. Dimov Stojče Ilčev, for providing me with the amazing opportunity to be a part of the Research Group in Space Science and for his continual mentoring me throughout the past two years of my studying, who also always has been available to answer to all my never-ending questions and who's wealth of ability and knowledge is unmatched by anyone I have met before. Research Group in Space Science is truly a unique and growing place, and I am honoured to have a part in its research and activities.

I must also thank my Co-supervisor Prof. Dr. Oludayo Olugbara and the other IT Department members with challenging assignments and allowing me to work in their laboratory, otherwise my research and studying would have been almost impossible. The entire DUT staffs always have been extremely helpful, but in particular I would like to thank Prof. Sibusiso Moyo and Prof. Gerhard Prinsloo for continual support and facilitation.

I cannot thank enough all of my friends who contributed into my past few years an amazing experience and helped me maintain my moral state, dreams and expectations, those who accompanied me on my outdoor adventures, which is so far away from home and those who provided me a help and reliable path into my future research world and to take new horizons of contemporary science.

I also would like to thank my previous supervisor, who is PhD Shirokov Igor Borisovish, for mentoring me during my bachelor and master studies and giving me inestimable practical and theoretical knowledge and skills at the Sevastopol National Technical University in Ukraine, either for helping to transit me into a new city, which is Durban in Republic of South Africa.

Finally, I am indebted to my parents and younger sister for their unconditional support and encouraging me in all my ventures and for the values they bestowed upon me.

Preface

This research is providing unique practical and theoretical solutions for tracking of ships and detecting of them via radio and space applications. The thesis is prepared in order to form a bridge between potential researchers and current needs in the field of maritime transportation in designing more cost effective and reliable tracking and detecting systems for ships.
In the thesis are included tracking or telemetry systems as radio and satellite networks and equipment, which are able to provide Position, Speed and Velocity (PSV) and to follow up the mobile objects at sea, on the ground and in the air. In fact, this issue can also get attribute detecting, but it is for mobile applications only.
The thesis also includes detecting systems for providing just position of mobile and fixed objects using images via satellites, airships and aircraft. However, it is obvious, that detecting system cannot provide velocity and time of detected objects.
The new augmented GPS or GLONASS networks for maritime Communications, Navigation and Surveillance (CNS) solutions are providing enhanced tracking and detecting concepts for modern transportation systems and their fleets at sea, on land and in the air.
This thesis consists of 7 chapters on the following particular subjects:
Chapter 1: INTRODUCTION gives a short background to the development of Radio and Space systems, overview, concepts and applications of GMSC for maritime tracking and detecting networks and applications.
Chapter 2: AIMS AND OBJECTIVES introduce the main scope and overview of this thesis for current and new radio and space tracking and detecting systems, which are principal tasks to provide enhanced safety and security in navigation of ships at open oceans, in sea passages, costal waters, approaching to the anchorages and inside of seaports. Here is introduced basic concepts of GEO and Non-GEO satellite and other systems as well.
Chapter 3: TEORETHICAL FRAMEWORK discusses the fundamental principles of the space platforms and orbital parameters, laws of satellite motions, new types of launching systems, satellite orbits and geometric relations, spacecraft configuration, payload structure and type of satellite orbits.
Chapter 4: RADIO TRACKING AND DETECTING SYSTEMS provides research and introduction of current and new proposed radio solutions for tracking and detecting of ships and other mobiles.
Chapter 5: SPACE TRACKING AND DETECTING SYSTEMS presents all current and new proposed solutions for modern tracking and detecting systems via satellites, airships and aircrafts.
Chapter 6: EXPERIMENTAL FRAMEWORK describes design and practical approaches of proposals for enhanced radio and space tracking and detecting solutions.
Chapter 7: ANALYSIS OF RESULTS AND CONCLUSION comments adequate software and concludes solution concepts of radio and space tracking and detecting systems.

Contents

Abstract 3
Acknowledgements 4
Preface 5
List of Figures 11
List of Tables 17
Chapter 1 18
INTRODUCTION 18
1.2. Overview 19
1.2.1. Development of Mobile Radiocommunications 22
1.2.2. Evolution of Satellite Communications 24
1.2.4. Early Progress in Mobile Satellite Communications and Navigation 25
1.3.1. Definition of Global Mobile Satellite Communications (GMSC) 27
1.3.2. Definition of Global Navigation Satellite Systems (GNSS) 28
1.3.3. Network Architecture of GMSC 28
1.3.3.1. Space Segment and Configuration of MSC Links 29
1.3.3.2. Ground Segment and Networks 29
1.4. GMSC Applications 30
1.4.1. Maritime Mobile Satellite Communications (MMSC) 30
1.4.1.1. Maritime Transportation Augmentation System (MTAS) 30
1.4.1.2. Service for MMSC Users 31
1.5. International Coordination Organizations and Regulatory Procedures 31
1.6. Satellite Communications Organizations and Operators 32
1.6.1. International Satellite Communications Organization 33
1.6.2. Former International MSS Operators 35
1.7. Frequency Designations and Classification of Services 35
1.7.1. Fixed Satellite Service (FSS) 38
1.7.2. Mobile Satellite Service (MSS) 39
1.7.3. Radio Navigation Satellite Service (RNSS) 40
1.7.4. Radio Determination Satellite Service (RDSS) 41
1.7.5. Radio Location Satellite Service (RLSS) 42
1.7.6. Electro-Optical Space Surveillance (EOSS) 43
1.7.7. Space Automatic Identification System (SAIS) 44
Chapter 2 45
AIMS AND OBJECTIVES 45
2.1. Structure of the Ships Tracking and Detecting Systems 47
2.1.1. Statements of the Problems 48
2.1.1.1 The Lack of a Reliable Ships Tracking and Detecting Systems 48
2.1.1.2. Unreliable Systems for Tracking and Detecting of Pirated Ships 48
2.1.1.3. Inadequate Systems for Identification and Detecting of Ships 48
2.1.2. Rationale and Benefits of Research 49
2.1.3. Limitations of Study 50
2.2. Developing Aim of GNSS for Ship Tracking and Detecting 50
2.2.1. Characteristics of GNSS Networks 51
2.2.2. Implementation of GNSS1 Networks for Satellite Determination 53
2.2.2.1. Passive Satellite Determination 53
2.2.2.2. Active Satellite Determination 54
2.2.2.3. Hybrid Satellite Determination 55
2.2.3. GNSS1 Applications 56
2.2.3.1. Maritime Navigation Satellite System (MNSS) 56

2.2.3.2. Land Navigation Satellite System (LNSS) ... 56
2.2.3.3. Aeronautical Navigation Satellite System (ANSS) ... 57
2.2.4. Implementation of GNSS1 Networks for Tracking and Detecting Systems ... 57
2.2.4.1. General Structure of Tracking and Detecting Network ... 57
2.2.4.2. Tracking Data Processing in Tracking Control Centre ... 58
2.2.4.3. Data Processing and Operations of Mobile Tracking Terminal ... 59
2.3. Current GCSS Networks for Tracking and Detecting of Ships ... 60
2.3.1. Inmarsat GEO Network ... 60
2.3.1.1. Inmarsat Space Segment ... 61
2.3.1.2. Inmarsat Ground Segment and Networks ... 63
2.3.2. Iridium Big LEO Satellite Network ... 67
2.3.4. Globalstar Big LEO Satellite Network ... 71
2.3.5. Orbcomm Little LEO Satellite Network ... 74
2.4. Pico, Nano and Micro (CubeSat) Satellite Networks ... 76
2.5. Stratospheric Communication Platform (SCP) Networks ... 79
2.5.1. SCP Aircraft Networks ... 81
2.5.2. SCP Airship Networks ... 82
2.5.3. Satellite Optical Downlink and High Data Link via SCP ... 83
Chapter 3 ... 84
THEORETICAL FRAMEWORK ... 84
3.1. Platforms and Orbital Mechanics ... 84
3.1.1. Space Environment ... 84
3.1.2. Laws of Satellite Motion ... 85
3.1.2.1. Parameters of Elliptical Orbit ... 86
3.1.2.2. Parameters of Circular Orbit ... 87
3.2. Horizon and Geographic Satellite Coordinates ... 88
3.2.1. Satellite Distance and Coverage Area ... 89
3.2.2. Satellite Look Angles (Elevation and Azimuth) ... 92
2.2.3. Satellite Track and Geometry (Longitude and Latitude) ... 95
3.3. Spacecraft Launching and Station-Keeping Techniques ... 97
3.3.1. Direct Ascent Launching ... 97
3.3.2. Indirect Ascent Launching ... 98
3.4. Types of Orbits for Mobile and Other Satellite Systems ... 98
3.4.1. Low Earth Orbits (LEO) ... 100
3.4.1.1. Little LEO ... 102
3.4.1.2. Big LEO ... 102
3.4.2. Circular Orbits ... 102
3.4.2.1. Medium Earth Orbits (MEO) ... 102
3.4.2.2. Geostationary Earth Orbits (GEO) ... 103
3.4.2.3. Geosynchronous Inclined Orbits (GIO) ... 104
3.4.3. Highly Elliptical Orbits (HEO) ... 105
3.4.3.1. Molnya Orbit ... 106
3.4.3.2. Tundra Orbit ... 107
3.4.3.3. Loopus Orbit ... 107
3.5. Polar Earth Orbits (PEO) ... 107
3.5.1. Low PEO ... 108
3.5.2. High PEO ... 109
3.6. Hybrid Satellite Orbits (HSO) ... 109
Chapter 4 ... 112
RADIO TRACKING AND DETECTING SYSTEMS ... 112
4.1. Shipborne S and X-band Surveillance Radars ... 112
4.1.1. Radar Signal Characteristics and Display ... 113

4.1.2. Radar Components 113
4.1.2.1. Power Supply and Modulator 113
4.1.2.2. Transceiver, Antenna System and Indicator 114
4.1.3. Digital Display Processing and External Inputs 117
4.1.3.1.MovableRange Markers and Bearing Lines 117
4.1.3.2. Target Trails and Guard Zones 118
4.1.3.3. Intermittent and Night Operations 119
4.1.3.4. Gyrocompass, Log, GPS and AIS Inputs 119
4.1.3.5. Chart Information Display 119
4.1.4. Radar Radiation Beam 120
4.1.5. Atmospheric and Weather Effects on Radar Display 121
4.1.6. Anti Piracy Radar Detecting 122
4.1.7. Modern Shipborne Surveillance Radars 125
4.2. Coastal or Ground HF Surveillance Radars 128
4.2.1. Coastal ISR HFSWR System 128
4.2.1.1.Multi-static ISR HF Radar 129
4.2.1.2.Components of HF Radar 131
4.2.1.3.Networksof HF Radar 131
4.2.1.4.Types of HF Radar Transceivers 131
4.2.2. Ship Classification using Multi-Frequency HF Radar 132
4.2.3. Coastal HF Radar Surveillance of Pirate Boats 133
4.2.3.1. System Architecture for Anti-Piracy Mission in Strait of Malacca 133
4.2.3.2. Deployment of HFSWR for Anti-Piracy Mission of the Somali and Aden Coasts 135
4.2.4. Coastal HF Jindalee Operational Radar Network (JORN) 136
4.2.5. Different Projects of Coastal HF Radars for Vessels Detecting 138
4.3. Radio Multiband and Multifunctional Radio Direction Finders (RDF) 141
4.3.1. Koden Shipborne Multib and MF/HF/VHF KS-5551 RDF 142
4.3.2. Taiyo Shipborne VHF TD-L1630RDF 142
4.3.3. Plath Shipborne VHF/UHF DFP 2400 and DFP 2055RDF 144
4.3.4. Rhotheta Shipborne and Coastal SAR VHF/UHF 4-band RT-500-M RDF ... 144
4.3.5. Rhotheta Coastal VHF/UHF 4-band RT-800 RDF 145
4.3.5. Rhotheta Coastal VHF 2-band RT-1000 RDF 146
4.3.6. ELTA System for Air/Vessel Traffic Control RDF EL/K-7029 147
4.3.7. Rohde & Schwarz (R&S) Determination of Vessel Bearings in Coastal Waters 148
4.4. Radio VHF Automatic Identification System (R-AIS) 150
4.4.1. CNS Systems R-AIS Class A Station 151
4.4.2. IcomMA-500TR Class B AIS Transponder 152
4.4.3. Basic Technical Details of AIS Transponder 153
4.4.4. CNS Systems AIS Base Station (BS) 154
4.4.4.1.CNS Systems AIS Base Station VDL 6000/FASS 155
4.4.4.2.CNS Systems AIS Base Station VDL 6000/FASS Advanced 156
4.4.5.CNS Systems AIS Base and Ship Station Software 157
4.5. Radio AIS (R-AIS) Airborne VDL System 158
4.5.1.CNS Systems VDL 6000 Airborne R-AIS Transponder 159
4.5.2.F3 Protec-A Airborne R-AIS Transponder 159
4.5.3.SAAB R4A Airborne R-AIS Transponder 160
4.5.4.Avionetics TX-20 Airborne R-AIS Transponder 160
4.6. Radio Local Ship Tracking (R-LST) for Anchorage Areas and Seaport Networks 161
4.7. Radio Automatic Dependent Surveillance - Broadcast (RADS-B) 163

4.7.1. Overview of Aeronautical RADS-B 163
4.7.2. Overview of New-proposed Maritime RADS-B 163
4.8. Radio GNSS Augmentation VDL-Broadcast (GAVDL-B)............................... 165
4.9. Radio Search and Rescue Transponder (SART).. 167
Chapter 5 168
SPACE TRACKING AND DETECTING SYSTEMS 168
5.1. Overview of the Satellite Long Distance Identification and Tracking (LRIT) System 168
5.1.1.Development of Satellite Asset Tracking (SAT) Networks and Equipment ... 169
5.1.2. Inmarsat Standard-C and mini-C GEO Solutions.. 170
5.1.3. Inmarsat-D+ and IsatData Pro/IsatM2M Solutions 173
5.1.4. Iridium and Globalstar Non-GEO (Big LEO) Solutions 174
5.1.6. Development and Improvements of LRIT.. 178
5.1.6.1. Operational Concept of LRIT Network Architecture 178
5.1.6.2. Operational Requirements of LRIT Ground and Onboard Equipment.... 180
5.2. Global Ship Tracking (GST) Network and Equipment 184
5.3. Regional Ship Tracking (RST) via Stratospheric Communication Platforms (SCP) 185
5.4. Space Automatic Identification Systems(Space-AIS) 186
5.4.1. Satellite Automatic Identification Systems(S-AIS) Network 186
5.4.1.1. Enhancements of Surveillance and Security... 188
5.4.1.2. Improvement of Counter Piracy and Suspicious Movement 188
5.4.1.3. Better Facilitated Fisheries and Environmental Monitoring................... 189
5.4.1.4.More Reliable Search and Rescue Operations... 189
5.4.2. Nano Satellite AIS (Nano S-AIS) 191
5.4.3. Stratospheric Communication Platform AIS (SCP-AIS) Network................ 191
5.4.4. Integration of R-AIS and S-AIS with SCP-AIS 193
5.4.5. Space AIS Information Management System (IMS) 196
5.5. Satellite Data Link (SDL) Tracking Messages Service 198
5.6. Satellite GNSS Augmentation SDL (GASDL)... 199
5.6.1. Development of ASAS Network for GASDL over Africa and Middle East .. 201
5.6.2. ASAS System Configuration 202
5.7. Satellite GASDL via RSAS networks.. 203
5.8. Satellite Automatic Dependent Surveillance - Broadcast (SADS-B) 204
5.8.1.Oceanic Sailing Guidance and Control (OSGC) 205
5.8.2.Coastal Movement Guidance and Control (CMGC) 206
5.9. Space Remote Sensing System (SRSS) 207
5.9.1.Satellite Synthetic Aperture Radar (SSAR)... 207
5.9.1.1.Ships Surveillance and Detecting via SSAR TerraSAR-X Spacecraft..... 212
5.9.1.2. Ships Surveillance and Detecting via SSAR Radarsat Spacecraft........... 216
5.9.1.3. Vessels Detecting System (VDS) via SSAR 221
5.9.2.Platforms Synthetic Aperture Radar (PSAR) 225
5.9.2.1. Platforms Synthetic Aperture Radar (PSAR) onboard Airship 226
5.9.2.2. Platforms Synthetic Aperture Radar (PSAR) onboard Aircraft.............. 227
5.9.3. Electro-Optical Space Surveillance (EOSS) 228
5.9.3.1. EOSS Sensors onboard GEO and Non-GEO Satellite Constellations..... 228
5.9.3.2.EOSS Sensors onboard SCP or UAV 232
5.9.4. Aerial Digital Photogrammetric Systems 233
5.9.4.1.Aerial Metric and Large Format Camera Systems 234
5.9.4.2. Thermal Infrared Aerial Scanners... 235
5.9.4.3.Space Light and Laser Surveillance Radars... 236
5.10. Satellite Distress Beacons for SAR Operations 236

Chapter 6 ... 238
EXPERIMENTAL FRAMEWORK ... 238
6.1. Proposing of Radio Systems for Ships Tracking and Detecting ... 238
6.1.1. Discreet Installation of Radar Transmitter Onboard Ship ... 238
6.1.1.1. Calculations of SART Application Efficiency ... 239
6.1.1.2. Comparison of Ultimate Effectiveness for Real Signal Receiving Efficiency ... 241
6.1.2. Improvements of AIS Tracking and Detecting Equipment ... 242
6.1.2.1. Analyses of VHF-band AIS Antenna for Satellite Tracking ... 242
6.1.2.2. Calculation and Design of Helical VHF Antenna ... 246
6.1.2.3. Implementation and Testing of Helical VHF Antenna ... 247
6.1.3. Proposal of Over Horizon Radar (OTH) for RSA Sea Area ... 249
6.2. Stratospheric Communication Platform (SCP) Systems ... 250
6.2.1. Video Surveillance from SCP ... 250
6.2.2. Surveillance Radar from SCP ... 251
6.3. Maritime Satellite System ... 255
6.3.1. Discreet Installation of Tracking System onboard Ships ... 255
6.3.2. Tracking and Surveillance of Ships with SSAR Spacecraft ... 256
6.3.2.1. System Organization of Ship Tracking and Surveillance by SSAR Satellite ... 258
6.3.2.2. Practical Determination of Ships by SSAR Satellite ... 259
6.3.3. Preposition to Utilize S-AIS Network through L/C-band ... 262
6.3.4. Testing of GST Terminal in Durban's Harbour ... 263
Chapter 7 ... 265
ANALYSIS OF RESULTS AND CONCLUSION ... 265
7.1. Results and Summery of Satellite Anti-piracy Solutions ... 265
7.1.1. Analyze of Discreet Installation of Ships Tracking Terminals ... 265
7.1.2. Analyze of Anti-piracy SSAR Solutions ... 266
7.2. Results and Summery of Radio Anti-piracy Solutions via SART Transmitter ... 266
7.3. Result and Summery of Anti-piracy Solutions via SCP ... 266
7.4. Results and Summery of Improvements of R-AIS Equipment ... 268
7.4.1. Comparison of Whip VHF versus QHA Antenna for R-AIS System ... 268
7.4.2. Benefits of Deployment R-AIS and S-AIS Networks through L/C-band ... 268
7.5. Experiment Analyze of Tracking and Detecting Equipment ... 269
7.5.1. Recommendation for Future Satellite Coverages ... 269
7.5.2. Outputs for Future Research and Developments ... 269
7.6. Additional Software and Firmware for CNS Systems ... 270
7.6.1. Software for R-AIS Systems ... 270
7.6.2. Lidar Software ... 270
7.6.3. Software for SSAR Solutions ... 271
7.6.3.1. Analyze of SSAR Simulation Toolbox ... 271
7.6.3.2. Analyze of SSAR Software ... 271
7.7. Conclusion ... 272
LIST OF ACHRONIMS ... 273
LIST OF REFERENCES ... 277

List of Figures

Figure 1.1. First Spark Gap – Courtesy of Book: by Ilcev 20
Figure 1.2. First Rx and Tx Designed by Popov – Courtesy of Book: by Ilcev 21
Figure 1.3. Marconi with his first Radio – Courtesy of Book: by Ilcev 22
Figure 1.4. Sputnik 1 & Explorer 1 – Courtesy of Book: by Ilcev 24
Figure 1.5. Intelsat V MCS – Courtesy of Book: by Galic 33
Figure 1.6. Marisat Space and Ground – Courtesy of Book: byNovik 34
Figure 1.7. Fixed Satellite Network – Courtesy of Book: by Gallagher 38
Figure 1.8. Mobile Satellite Network– Courtesy of Book: by Ilcev 39
Figure 2.1. GPS and GLONASS Spacecraft – Courtesy of Presentation: by Ilcev 50
Figure 2.2. GPS and GLONASS Integrated GNSS1 Network – Courtesy of Presentation: by Ilcev 52
Figure 2.3. Modern Augmented GPS Receivers for all Mobile Applications – Courtesy of Book: by Ilcev 52
Figure 2.4. Passive Satellite Determination – Courtesy of Book: by Ilcev 53
Figure 2.5. Active Satellite Determination – Courtesy of Book: by Ilcev 54
Figure 2.6. Hybrid Satellite Determination – Courtesy of Book: by Ilcev 55
Figure 2.7. GNSS1 Applications – Courtesy of Presentation: by Ilcev 56
Figure 2.8. GNSS1 Tracking and Detecting Network – Courtesy of Presentation: by Ilcev. 57
Figure 2.9. PVT Data Processing in TTC – Courtesy of Presentation: by Ilcev 58
Figure 2.10. Diagram of Mobile Data Unit – Courtesy of Presentation: by Ilcev 59
Figure 2.11. Comparison of 3 Inmarsat Satellite Generations – Courtesy of Book: by Ilcev 61
Figure 2.12. Inmarsat GEO Coverage –Courtesy of Book: by Ilcev 61
Figure 2.13. Inmarsat-4 and Forthcoming Inmarsat-5 Spacecraft–Courtesy of Brochure: by Inmarsat 62
Figure 2.14. Inmarsat I-4 Global Coverage Map –Courtesy of Brochure: by Inmarsat 62
Figure 2.15. Inmarsat Ground and Users Networks –Courtesy of Book: by Ilcev 63
Figure 2.16. Block Diagram of CES Terminal–Courtesy of Book: by Ilcev 64
Figure 2.17. Maritime CES Terminal–Courtesy of Book: by Ilcev 65
Figure 2.18. Inmarsat Ground Network–Courtesy of Book: by Ilcev 66
Figure 2.19. Inmarsat IsatData Pro 600 –Courtesy of Brochure: by SkyWave 66
Figure 2.20. Iridium GMSC Network –Courtesy of Book: by Ilcev 67
Figure 2.21. Iridium Satellite Network –Courtesy of Book: by Ilcev 68
Figure 2.22. Iridium Spacecraft –Courtesy of Brochure: by Iridium 69
Figure 2.23. Iridium Satellite Coverage –Courtesy of Brochure: by Lloyd 69
Figure 2.24. Iridium Mobile Tracking Devices –Courtesy of Brochure: by Beam 70
Figure 2.25. Iridium Personal Satellite Trackers –Courtesy of Brochure: by Iridium 70
Figure 2.26. Globalstar GMSC Network –Courtesy of Book: by Ilcev 71
Figure 2.27. Globalstar Satellites and Spacecraft Constellation–Courtesy of Brochure: by Globalstar 72
Figure 2.28. Globalstar Coverage by Satellites –Courtesy of Brochure: by Globalstar 72
Figure 2.29. Globalstar Coverage by Gateways –Courtesy of Brochure: by Globalstar 73
Figure 2.30. Globalstar Simplex and Duplex Units –Courtesy of Brochure: by Globalstar.. 73
Figure 2.31. Orbcomm System Overview –Courtesy of Brochure: by Orbcomm 74
Figure 2.32. Orbcomm Satellite Constellation and Spacecraft –Courtesy of Brochure: by Orbcomm 75
Figure 2.33. Orbcomm Satellite Units –Courtesy of Brochure: by Orbcomm 76
Figure 2.34. NTS/AISSat and SumbandilaSat Satellite Platforms –Courtesy of Brochure: SFL/US 77
Figure 2.35. NTS Interior Details –Courtesy of Brochure: SFL 78

Figure 2.36. Satellite, SCP and Cellular Networks–Courtesy of Book: by Ilcev 79
Figure 2.37. Transition from TTP to SCP –Courtesy of Book: by Ilcev 80
Figure 2.38. Prototype of HAP Aircraft Altus–Courtesy of Brochure: by AVCS/NATO 81
Figure 2.39. TAO SCP Airship–Courtesy of Brochure: by TAO... 82
Figure 2.40. Optical Links from Satellites via SCP–Courtesy of Book: by Ilcev 83
Figure 3.1. Elliptical and Circular Satellite Orbits - Courtesy of Book: by Galic 86
Figure 3.2. Geometric Projection of Satellite Orbits - Courtesy of Books**:** by Zhilin........... 89
Figure 3.3. GEO Configuration and Look Angle Parameters - Courtesy of Books: by Pratt 91
Figure 3.4. Elevation and Azimuth Angle Maps - Courtesy of Book: Ilcev.......................... 93
Figure 3.5. Look Angle Parameters and Graphic of Geometric Coordinates – Courtesy of Book: by Zhilin 94
Figure 3.6. Satellite Installation in Circular and Synchronous Orbit - Courtesy of Book: by Pascall 97
Figure 3.7. Type of Satellite Orbits and Tracks**–**Courtesy of Book: "Satellite Com. Systems" by Evans... 99
Figure 3.8. LEO MSS Diversity and Handover **–**Courtesy of Book: by Evans................... 101
Figure 3.9. LEO Satellite Orbits and Tracks **–** Courtesy of Book: by Pascall..................... 108
Figure 3.10. LEO Combination of GEO and HEO Constellations **–**Courtesy of Book: by Ilcev.. 110
Figure 3.11. Combination of GEO and PEO and GEO and LEO Constellations **–** Courtesy of Book: by Ilcev 110
Figure 3.12. Combination of MEO and HEO and MEO and LEO Constellations **–** Courtesy of Book: by Ilcev 111
Figure 4.1. Radar Antenna (Left) and Display (Right) – Courtesy of Brochure: by Sea-Hawk Radars 113
Figure 4.2. Block Diagram of Basic Radar System – Courtesy of Paper: by Radar Navigation 114
Figure 4.3. Block Diagram of Basic Radar System – Courtesy of Brochure: by Kelvin Hughes Radars 115
Figure 4.4. CRT and LCD Radar Displays – Courtesy of Manual: by Navigation Using Radar 116
Figure 4.5. EBL, VRM and Radar Target Trails – Courtesy of Manual: by Navigation Using Radar 117
Figure 4.6. Guard Zones – Courtesy of Manual: by Navigation Using Radar 118
Figure 4.7. Free space Radiation Pattern– Courtesy of Manual: by Radio Navigation....... 120
Figure 4.8. Radiation Diagram – Courtesy of Manual: by Radio Navigation 120
Figure 4.9. Radiation Diagram – Courtesy of Manual: by Radio Navigation 121
Figure 4.10. Pirates in Action– Courtesy of Brochure: by Anti Piracy Radar..................... 123
Figure 4.11. Detected Pirates Boat– Courtesy of Brochure: by Anti Piracy Radar............. 123
Figure 4.12. Sharp Eye– Courtesy of Brochure: by Eunavfor 124
Figure 4.13. Solid State Radar– Courtesy of Brochure: by Piracy Detecting...................... 125
Figure 4.14. FAR-28x7 Series of X and S-band Shipborne Radar – Courtesy of Brochure: by Furuno 126
Figure 4.15. Keyboard and Palm Control Unit of Furuno FAR-28x7 Radar – Courtesy of Brochure: by Furuno 126
Figure 4.16. ARPA/AIS Target Display of Furuno FAR-28x7 Radar – Courtesy of Brochure: by Furuno 127
Figure 4.17. System Layout of Typical Bistatic Two-site HF Radar – Courtesy of Brochure: by ISR 129
Figure 4.18. Multi Frequency Radar Transmit LPA and Receive LRA– Courtesy of Brochure: by ISR 130
Figure 4.19. Radar Measurements of Small Boats – Courtesy of Brochure: by ISR........... 133

Figure 4.20. Radar HF Surveillance and Remote Sensing of Pirate Ships – Courtesy of Paper: by S.J. Anderson 134
Figure 4.21. Reported Piracy Incidents at Somalia Coast and Gulf of Aden – Courtesy of Booklet: by OCIMF 135
Figure 4.22. Coverage Areas and Receiving Antenna of JORN – Courtesy of Paper: by JORN........ 136
Figure 4.23. JORN Transmit Antenna and Coordination Centre – Courtesy of Paper: by JORN........ 137
Figure 4.24. Key JORN Operating Principles – Courtesy of Paper: by JORN........ 137
Figure 4.25. Transceiver/Control Sites of HF Radar – Courtesy of Paper: by IARU 138
Figure 4.26. Wellen Radar in Ligurian Sea – Courtesy of Paper: by NURC 139
Figure 4.27. Sea Sonde Radial Coverage Map – Courtesy of Paper: by CODAR 140
Figure 4.28. Radio MF/HF/VHF DF KS-5551 – Courtesy of Brochure: by Koden........ 142
Figure 4.29. Radio VHF DF TD-L1630– Courtesy of Brochure: by Taiyo 143
Figure 4.30. Radio VHF DF TD-L1630– Courtesy of Brochure: by Plath 144
Figure 4.31. Radio SAR VHF/UHF 4-band RT-500-M RDF– Courtesy of Brochure: by Rhotheta 145
Figure 4.32. Coastal Radio SAR RT-800 and RT-1000 Equipment – Courtesy of Brochure: by Rhotheta 146
Figure 4.33. Network Configuration of Coastal VTS – Courtesy of Brochure: by Rhotheta 147
Figure 4.34. Coastal RDF Service and Antenna for VTS Network – Courtesy of Brochure: by ELTA 148
Figure 4.35. Coastal DDF 100M RDF and Antenna ADD 090M for VTS – Courtesy of Brochure: by R&S........ 149
Figure 4.36. Maritime AIS Network – Courtesy of Brochure: by IMO 150
Figure 4.37. Maritime VDL Classs A R-AIS Stations – Courtesy of Brochure: by CNS Systems 151
Figure 4.38. Maritime Classs B R-AIS – Courtesy of Brochure: by ICOM........ 152
Figure 4.39. Maritime SOTDMA AIS Transmissions– Courtesy of Brochure: by NavSoftware 153
Figure 4.40. Maritime AIS Base Stations – Courtesy of Brochure: by CNS Systems 154
Figure 4.41. Maritime AIS Base Stations – Courtesy of Brochure: by Trans Maris........ 154
Figure 4.42. Maritime AIS Network and Display – Courtesy of Brochure: by AIS 155
Figure 4.43. Radar vs AIS – Courtesy of Photo: by AIS 156
Figure 4.44. Aircraft R-AIS – Courtesy of Brochure: by Avionetics 158
Figure 4.45. Aircraft R-AIS Transponders – Courtesy of Brochure: by CNS Systems and L3 159
Figure 4.46. Aircraft R-AIS Transponders – Courtesy of Brochure: by SAAB and Avionetics 160
Figure 4.47. Maritime R-LST Network – Courtesy of Manual: by Ilcev 161
Figure 4.48. Aircraft VDL-4 Equipment – Courtesy of Brochure: by CNS Systems........ 162
Figure 4.49. Vehicle and Helicopters VDL-4 Equipment – Courtesy of Brochure: by CNS Systems 162
Figure 4.50. Maritime RADS-B Network – Courtesy of Manual: by Ilcev........ 164
Figure 4.51. Local VHF Augmentation System (LVAS) – Courtesy of Manual: by Ilcev . 165
Figure 4.52. Radio SART– Courtesy of Manual: by Ilcev 167
Figure 5.1. Configuration of SAT System– Courtesy of Paper: by Ilcev/Skoryk 169
Figure 5.2. Inmarsat Standard-C and mini-C Equipment– Courtesy of Paper: by Ilcev/Skoryk 170
Figure 5.3. Message Display, Keyboard and Emergency Devices – Courtesy of Paper: by Ilcev/Skoryk........ 171

Figure 5.4. Message Terminal and Capsat Printer – Courtesy of Brochure: by Sailor........ 171
Figure 5.5. Standard-D+ Units – Courtesy of Brochure: by SkyWave 173
Figure 5.6. IsatData/IsatM2MUnits – Courtesy of Brochure: by SkyWave........................ 174
Figure 5.7. Iridium SAT Trackers – Courtesy of Brochure: by Quake and E-Track/NSE Systems 175
Figure 5.8. Globalstar SAT Trackers – Courtesy of Brochure: by Axonn 176
Figure 5.9. Orbcomm SAT Trackers – Courtesy of Brochure: by Magellan, Stellar and Quake 177
Figure 5.10. LRIT Guide to Requirement and Implementation – Courtesy of Manual: by AMSA 178
Figure 5.11. LRIT System Architecture – Courtesy of Manual: by AMSA........................ 180
Figure 5.12. Inmarsat LRIT Network – Courtesy of Brochure: by Furuno 181
Figure 5.13. Inmarsat-C SAS Onboard Equipment for LRIT Solutions – Courtesy of Brochure: by JRC.. 182
Figure 5.14. Inmarsat SatMail-C Service – Courtesy of Brochure: by KDDI..................... 182
Figure 5.15. Inmarsat-D+ Network and Service – Courtesy of Brochure: by KDDI 183
Figure 5.16. Iridium LRIT Solutions – Courtesy of Brochure: by Iridium 183
Figure 5.17. GST Network for Maritime CNS – Courtesy of Manual: by Ilcev 184
Figure 5.18. GST Operational Diagram – Courtesy of Paper: by Ilcev/Skoryk 184
Figure 5.19. RST Network for Maritime CNS – Courtesy of Manual: by Ilcev 185
Figure 5.20. RST Operational Diagram – Courtesy of Paper: by Ilcev/Skoryk 186
Figure 5.21. Satellite AIS Network – Courtesy of Manual: by Ilcev.................................. 187
Figure 5.22. Satellite AIS Network – Courtesy of Paper: by Ilcev/Skoryk 190
Figure 5.23. Operational results of S-AIS Network – Courtesy of Manual: by Ilcev 190
Figure 5.24. Coverage of AIS Networks and Nano-AIS – Courtesy of Paper: by Ilcev/Skoryk 191
Figure 5.25. SCP AIS Network – Courtesy of Paper: by Ilcev/Skoryk 192
Figure 5.26. Maritime AIS Network via SCP (SCP-AIS) – Courtesy of Manual: by Ilcev 192
Figure 5.27. Maritime Shore and Satellite AIS Networks – Courtesy of Manual: by Ilcev 193
Figure 5.28. Coverage Area with one SCP-AIS– Courtesy of Manual: by Ilcev 193
Figure 5.29. Inter-platform AIS Network – Courtesy of Paper: by Ilcev/Skoryk 194
Figure 5.30. SCP-AIS vs R-AIS Network **–** Courtesy of Paper: Ilcev/Skoryk.................... 195
Figure 5.31. SCP-AIS vs R-AIS Network **–** Courtesy of Paper: Ilcev/Skoryk.................... 195
Figure 5.32. Coastal SCP-AIS Network **–** Courtesy of Paper: Ilcev/Skoryk....................... 196
Figure 5.33. Satellite and SCP Airship IMS AIS Network **–** Courtesy of Paper: Ilcev/Skoryk 197
Figure 5.34. Satellite Data Link (SDL) **–** Courtesy of Paper: Ilcev/Skoryk 198
Figure 5.35. Global Satellite Augmentation System (GSAS) **–** Courtesy of Book: by Ilcev 200
Figure 5.36. ASAS Space Segment **–** Courtesy of Book: by Ilcev 201
Figure 5.37. ASAS Space and Ground Segments **–** Courtesy of Book: by Ilcev 202
Figure 5.38. GNSS Augmentation SDL (GASDL)**–** Courtesy of Paper: by Ilcev............... 203
Figure 5.39. Satellite SADS-B**–** Courtesy of Presentation: by Ilcev 204
Figure 5.40. Satellite OSGC **–** Courtesy of Presentation: by Ilcev..................................... 205
Figure 5.41. Satellite OSGC **–** Courtesy of Presentation: by Ilcev..................................... 206
Figure 5.42. Remote Sensing Solutions via Satellites **–** Courtesy of Presentation: by Sea Space 207
Figure 5.43. Synthesized Expanding Beamwidth and Shadowing**–** Courtesy of Presentation: by Radar tutorial 208
Figure 5.44. SSAR Phase Array Antenna **–** Courtesy of Presentation: by Radar tutorial ... 209
Figure 5.45. Value of PRF and Principle of SSAR Operation **–** Courtesy of Brochure: by Radar tutorial 209

Figure 5.46. SSAR Foreshortening and Layover –Courtesy of Presentation: by Radartutorial 211
Figure 5.47. Terra SAR-X Spacecraft and Operational Parameters –Courtesy of Presentation: by Astrium 212
Figure 5.48. Image of Captured Ship by Pirates–Courtesy of Presentation: by Astrium 213
Figure 5.49. Localization of other Ships in the area of m/t Enrico Iveoli–Courtesy of Presentation: by Astrium........ 214
Figure 5.50. Ships Tracking and Detecting Service –Courtesy of Presentation: by Astrium 214
Figure 5.51. Oil Spill Detecting and Sea Ice Monitoring Service–Courtesy of Presentation: by Astrium 215
Figure 5.52. Radarsat Spacecraft and Operational Parameters –Courtesy of Presentation: by Radarsat........ 216
Figure 5.53. Radarsat-2 Spacecraft –Courtesy of Presentation: by Radarsat 216
Figure 5.54. ScanSAR and Stripmap Beam Modes–Courtesy of Presentation: by Radarsat 218
Figure 5.55. Radarsat Ground Segment and Processing Facilities–Courtesy of Presentation: by Radarsat........ 219
Figure 5.56. Radarsat-2 Reception Coverage–Courtesy of Presentation: by Radarsat........ 219
Figure 5.57. Radarsat SAR Ships Monitoring and Detecting–Courtesy of Presentation: by Radarsat........ 220
Figure 5.58. Radarsat SAR Fishing Vessels Monitoring and Detecting–Courtesy of Presentation: by Radarsat........ 220
Figure 5.59. SSAR Doppler and Phase History–Courtesy of Presentation: by ESA........ 222
Figure 5.60. SSAR Doppler and Phase History–Courtesy of Presentation: by NOAA....... 223
Figure 5.61. SSAR 50, 25 and 8 m Resolutions of Ships Images–Courtesy of Presentation: by Metaaps 225
Figure 5.62. SSAR Identification of Suspicious and Pirated Vessels –Courtesy of Presentation: by Ilcev........ 225
Figure 5.63. PSAR for Ships Detecting –Courtesy of Presentation: by Ilcev 226
Figure 5.64. Synthetic Aperture Radar Equipment –Courtesy of Presentation: by Ilcev/Bendisch........ 227
Figure 5.65. PSAR Aircraft and onboard Equipment–Courtesy of Presentation: by Aero Mission........ 227
Figure 5.66. Ikonos Satellite Network for Image Collection–Courtesy of Presentation: by GeoEye........ 229
Figure 5.67. Components of Ikonos Spacecraft and Camera Telescope–Courtesy of Manual: by GeoEye........ 230
Figure 5.68. Ikonos Images of San Francisco and Rio de Janeiro –Courtesy of Presentation: by GeoEye........ 230
Figure 5.69. Ikonos Images of m/v Sirius Star –Courtesy of Brochure: by GeoEye........ 231
Figure 5.70. Ikonos Image of Ship and Comparison of Images–Courtesy of Manual: by GeoEye........ 232
Figure 5.71. RC Leica and RMK Carl Zeiss Aerial Cameras–Courtesy of Brochures: by Leica/Zeiss 233
Figure 5.72. Photogrammetry and Infrared Sensor–Courtesy of Brochure: by San-Lo/Bendisch 234
Figure 5.73. Aerial Multispectral and Stereo Cameras –Courtesy of Presentation: by Ilcev 234
Figure 5.74. Onboard Processing Workstation and Infrared Image of Ship–Courtesy of Presentation: by Ilcev........ 235
Figure 5.75. Cospas-Sarsat Network–Courtesy of Presentation: by Ilcev........ 236

Figure 5.76. Cospas-Sarsat Network–Courtesy of Presentation: by Ilcev 237
Figure 6.1. Diagram of SART and Surveillance Radar – Courtesy of Presentation: by Ilcev/Skoryk 238
Figure 6.2. Ship Detecting Distance with and without onboard SART – Courtesy of Presentation: by Skoryk 241
Figure 6.3. Inclination of AIS Dipole Antenna – Courtesy of Presentation: by Skoryk 242
Figure 6.4. Dipole Antenna Radiation Pattern – Courtesy of Presentation: by Skoryk....... 243
Figure 6.5. Dipole Radiation Pattern at Different Antenna Gains – Courtesy of Presentation: by Skoryk 244
Figure 6.6. Ship Equipped with HGA – Courtesy of Presentation: by Skoryk.................... 244
Figure 6.7. Transmission with LGA – Courtesy of Presentation: by Skoryk 245
Figure 6.8. Graphic of Possible S-AIS via VHF Antenna – Courtesy of Presentation: by Skoryk 245
Figure 6.9. QHA Radiation Pattern and Model – Courtesy of Presentation: by Skoryk 246
Figure 6.10. Experimental Sample of the QHA Antenna – Courtesy of Presentation: by Skoryk 247
Figure 6.11. Measuring of Radiation Pattern of QHA Antenna – Courtesy of Presentation: by Skoryk 248
Figure 6.12. Radiation Pattern of QHA Antenna – Courtesy of Presentation: by Skoryk... 249
Figure 6.13. OTH Radar Radiation Pattern – Courtesy of Presentation: by Skoryk 249
Figure 6.14. South African Coverage with OTH – Courtesy of Presentation: by Skoryk... 250
Figure 6.15. Video Surveillance via SCP – Courtesy of Presentation: by Skoryk 250
Figure 6.16. Observation of Sea Surface – Courtesy of Presentation: by Skoryk 251
Figure 6.17. Footprints Shapes of Observations Beams – Courtesy of Presentation: by Skoryk 252
Figure 6.18. Structure of Radar Tracking Beam – Courtesy of Presentation: by Skoryk.... 253
Figure 6.19. Ship Tracking Process – Courtesy of Presentation: by Skoryk 254
Figure 6.20. Target Detecting with the Tracking Beam – Courtesy of Presentation: by Skoryk 254
Figure 6.21. Ship's Navigation Bridge and Equipment – Courtesy of Presentation: by Skoryk 255
Figure 6.22. Discrete Installation of GAT Equipment onboard Ships – Courtesy of Presentation: by Skoryk 255
Figure 6.23. Basic Principle of SSAR Operations – Courtesy of Presentation: by Skoryk. 257
Figure 6.24. System for SSAR Imaging of Area of Pirated Ships – Courtesy of Presentation: by Skoryk 258
Figure 6.25. Two SSAR Image Layers of South Africa – Courtesy of Presentation: by CSIR 259
Figure 6.26. SSAR and LRIT Image Layers – Courtesy of Presentation: by CSIR 260
Figure 6.27. Ships Images Placed in Zoomed SSAR Image – Courtesy of Presentation: by CSIR.. 260
Figure 6.28. Ships detection by Cell Averaging CFAR Detector – Courtesy of Presentation: by CSIR.. 261
Figure 6.29. Reported Ships Actual and False Detection – Courtesy of Presentation: by CSIR 262
Figure 6.30. Diagram of L/C-band S-AIS Adapter – Courtesy of Presentation: by Skoryk 263
Figure 6.31. QPro Transceiver and Antenna – Courtesy of Brochure: by Quake 263
Figure 6.32. Defined Geographic Regions of QPro – Courtesy of Presentation: by Skoryk264

List of Tables

Table 1.1. Frequency Bands Designation.. 36
Table 1.2. Frequency Spectrum for MSS Service Links.. 36
Table 1.3. Frequency Spectrum for MSS Feeder Links... 37
Table 2.1. Summary of Characteristics of the First GNSS Generation (GNSS1).................. 51
Table 2.2. Summary of Characteristics of the Second GNSS Generation (GNSS2) 51
Table 3.1. The Values of Times Different than the Synchronous Time of Orbit................... 88
Table 3.2. The Form for Calculation of Azimuth Values 95
Table 3.3. The Properties of Four Major Orbits... 100
Table 3.4. Molnya and Tundra Orbit Parameters... 106
Table 4.1. Performances of Civilian and Military Systems 134
Table 4.2. Frequency Bands for RT-500-M RDF 145
Table 5.1. Comparison of Third Generation of Inmarsat SAT Solutions 174
Table 5.2. Key System Parameters of RCM 218
Table 5.3. Comparison of Radarsat-1 and Radarsat-2 Spacecraft.. 220
Table 5.4. Ikonos Satellite Sensors Characteristics.. 231
Table 5.5. Optical (O) vs Radar (R) Images of the same Ship... 232
Table 6.1. Function of Spatial Resolution Relationships... 257
Table 7.1. Comparison of SCP and Satellite Systems.. 267

1. Chapter 1

INTRODUCTION

This chapter presents the principal structure of functionality, applications and necessary elements of tracking system from the history of implementation of the first radio equipment invented by the great Russian professor Alexandr Stepanovich Popov till today modern radio systems. For the first time in the world Popov's radio system was applied to the ships for radiocommunication purposes as a part of today determination and tracking solutions. Afterwards, radio navigation and radar systems as applications of onboard radio equipment, working with special frequencies for determination position of mobiles on the Earth surface, such as radiolocation and radiodetermination systems were developed.
Officially, the equipment for radiolocation known as radar was invented by the British Sir Robert Watson-Watt in 1935, so it then became the first radar used in battle. There was a race between Brittan and Germany who could produce the best radar for their national defense forces. Nevertheless, the Germans were unable to reveal its full potential. The British had won the race and utilized the full power of the radar technology. A radiolocation is the process of finding some objects locations like ships through the use of radio waves, such today is surveillance radar. Radar is measuring instrument in which the echo of microwave radiation backscattered pulse is used to detect and locate distance to the objects.
Radiodetermination is the determination of the Position, Velocity and Time (PVT) or other characteristics of fixed and moving objects, or obtaining of related information to these parameters, by means of the propagation properties of radio waves.
Radionavigation is the application of special equipment working at assigned frequencies which are dedicated to determine a position of moving objects on the Earth and de facto is type of radiodetermination. The radionavigation system solely, therefore, is an on-directional devices and technique in which only mobile stations can know its own position, others cannot. The basic principles of Radionavigation are measurements of directions, distances or ranging by measurement of travel times, then partly also is determining velocity by means of Doppler shift and other parameters.
Finally, tracking is the Radio or Satellite solutions integrated with the Global Navigation Satellite System (GNSS) such as the US GPS or Russian GLONASS satellite networks used for the observing of persons or objects on the move and supplying a timely ordered sequence of respective location PVT data via VHF or Satellite transceivers and Internet to a control centre, which is capable to serve for depicting the motion on a display like radar capability. This system is important for enhanced traffic control and management of ships, collision avoidance including improved safety and security, but cannot provide position data of near by ships in certain navigation area. However, these positioning data of all ships sailing in certain sea area can be provided to any ship upon its request by new Radio and Satellite CNS systems and networks.
The fleet management system is applied as a tracking and detecting application using GPS or GLONASS system and composing tracks from subsequent mobile's positions. Each mobile to be tracked needs to obtain special equipment onboard oceangoing ships such as GPS or GLONASS receivers integrated with radio or satellite transceivers to relay the obtained coordinates via cellular, VHF or satellite networks to a home station.
The fleet management is required by: large fleet operators of ships; forwarding operators of heavy cargo, containers, and valuable shipping; operators who have high equipment and cargo costs; and operators who have a dynamic workload.

1.1. Abstract

The safety of navigation through all past ages has been a primary preoccupation for all seamen and shipping owners. Distress and disasters at sea are frequently caused by the blind forces of Mother Nature or by human factors have occurred during the course of many centuries on ships and in the life of seafarers. In the past time, seafarers sailed at seas without incoming information about the trip, navigation and weather conditions in ocean environments. At that time, only audio and visual transfers of information from point to point were used. However, no earlier than the end of the 19th century, new disciplines were developed, such as the transmission of news and information via wire initially, then by radio (wireless) and latterly, via modern satellite and stratospheric platform communications systems. The facts about airplanes and land vehicles are well determined and clear because these transport mediums have more reliable environments and routes than ships. After a disaster with airplane, train, truck or bus it is much easier to find out their positions and to provide distress alert, search and assistance.
With the exception of enhanced safety and security demands in navigation of ships and collision avoidance at open ocean, sea passages, coastal navigation, approaching to the anchorages and inside of seaports, an important question is the utilization and development of new maritime or other mobile radio and satellite CNS systems, tracking, detecting and determination, including logistics.

1.2. Overview

Communication satellites provide the bridges for a number of new, specialized markets in commercial and private telecommunications and make ties between nations. In the course of more than 40 years they have obtained global links in the public and private Terrestrial Telecommunication Network (TTN). Soon after Mobile Satellite Communications (MSC) and Navigation came to serve navy, ground and air forces worldwide and for economic reasons, they also provided commercial MSC. For 30 years, MSC was used, particularly because ocean-going vessels have become dependent for their commercial and safety communications on MSS for communication and tracking purposes. Although, aircraft and land vehicles started before ships, due to many unsuccessful experiments and projects they have had to follow the Inmarsat maritime MSC service and engineering evidently leads. Thus, the modified ship's Mobile Earth Stations (MES) are today implemented on land (road or railway) vehicles and aircraft for all civil and military applications, including remote or rural locations and industrial onshore and offshore installations.
The GPS, DGPS, GLONASS and other new satellite navigation and determination systems provide precise positioning data for vessels and aircraft and also serve land navigation and fleet vehicle management. Because of the need for new, enhanced services, these systems will be augmented with satellite communications and ground surveillance facilities. At the end of this race the new mobile satellite revolution has come, whereby anyone can carry a personal handheld telephone simultaneously using satellite or cellular/dual systems at sea, in the car, in the air, in the street, in rural areas, in the desert, that is to say everywhere and in all positions. These integrated systems will soon be implemented, with new stratospheric platform wireless systems using aircraft or airships.
The word **communications** is derived from the Latin phrase "**communication**", which stands for the social process of information exchange and covers the human need for direct contact, communications and mutual understanding. The word "**telecommunications**" means to convey and exchange information over distance (**tele**) by the medium of electrical signals via space applications.

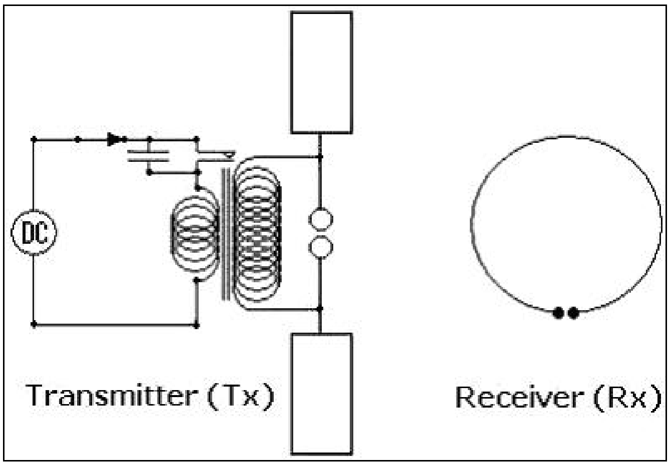

Figure 1.1. First Spark Gap – Courtesy of Book: by Ilcev

In general, telecommunications are the conveyance of intelligence in some form of signal, sign, sound or electronic means from one point to a distant second point. In ancient times, that intelligence was communicated with the aid of audible callings, fire and visible vapor or smokes and image signals. We have come a long way since the first human audio and visual communications, in case you had forgotten, used during many millennia. In the meantime primitive kinds of communications between individuals or groups of people were invented. Hence, as impressive as this achievement was, the development of more reliable communications and so, wire and radio, had to wait a couple of centuries more.

The invention of the telegraph in 1844 and the telephone in 1876 harnessed the forces of electricity to allow the voice to be heard beyond visual and shouting distance for the first time. The British physicist M. Faraday and the Russian academic E. H. Lenz experimented with electric and magnetic phenomenon and formulized a theory of the Electromagnetic (EM) induction at the same time. The British physicist James C. Maxwell published in 1873 his classical theory of electromagnetic radiation, proving mathematically that electromagnetic waves travel through space with a speed precisely equal to that of light.

The famous German physicist Heinrich Rudolf Hertz during 1886 experimentally proved Maxwell's theoretical equations. He demonstrated that HF oscillations produce a resonant effect at a very small distance away from the source and that this phenomenon was the result of electromagnetic waves. Practically, Hertz used the damped oscillating currents in a dipole antenna, triggered by a high-voltage electrical capacitive spark discharge, as his Transmitter (Tx) source of Radiowaves (RW). Thus, his detector in some experiments was another dipole antenna connected to a narrow spark gap as Receiver (Rx). A small spark in this gap signified detecting of the radio waves. When he added cylindrical reflectors behind his dipole antennas, Hertz could detect radio waves about 20 meters from the Tx in his laboratory, see **Figure 1.1.** So, it is after Hertz that the new discipline of Radio technology is sourced and after whom the frequency and its measuring unit Hertz (Hz) are named.

An English physician, Sir Oliver J. Lodge using the ideas of others, realized that the EM resonator was very insensitive and he invented a "coherer". A much better coherer was built and devised by a Parisian professor, Edouard Branly, in 1890. He put metal filings (shut in a glass tubule) between two electrodes and so a great number of fine contacts were created. This coherer suffered from one disadvantage, it needed to be "Shaken before use". Owing to imperceptible electric discharges, it always got "baked" and blocked.

The Russian professor of physics Aleksandar S. Popov in 1894 successfully realized the first practical experiments with EM waves for the transmission of radio signals. In the same year, he succeeded in making a reliable generator of EM waves, when the receiving or detecting systems in common use still were not at all satisfactory.

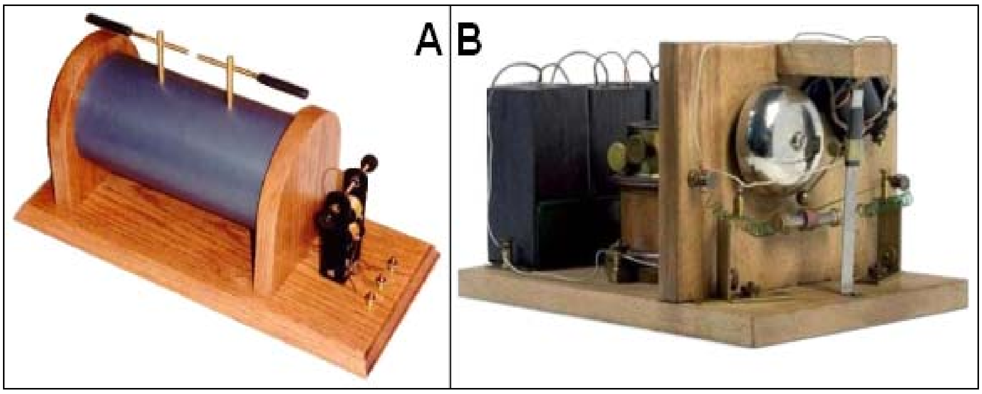

Figure 1.2. First Rx and Tx Designed by Popov – Courtesy of Book: by Ilcev

Using the inventions of his predecessors and on the basis of proper experiments, Popov elaborated the construction of the world's first radio receiver with a wire-shaped antenna system in the air attached to a balloon, see **Figure 1.2 (A).** In 1895, Popov improved Branly's receiver by the insertion of choke coils on each side of the relay to protect the coherer and also by replacing the spark gap with a vertical antenna insulated at its upper end and connected to the ground through the coherer. He then mounted a small bell in serial connection with the coherer's relay anchor, whose ringing effected automatic destabilization and successive unblocked function of the receiver system. On 7 May 1895, he demonstrated his new apparatus to the members of the Russian Physic-Chemical Society: a lightning conductor as an antenna, a metal filings coherer and detector element with telegraph relay and a bell. The relay was used to activate the bell, which is announcing the occurrence of transmitting signals and in this way serving as a decoherer (tapper) to prepare the receiver to detect the next signals. This was the first telegraph station in the world, which could work without any wires. In May the same year, he reported sending and receiving radio signals across a 550 m distance. Soon, instead of a bell he contrived to use a clock mechanism to realize direct, fast destabilization of metal filings in the coherer upon receipt of the signals. In December 1895, he announced the success of a regular radio connection and on 21 March, 1896 at the St. Petersburg University, he demonstrated it in public. Finally, on 24 May 1896 Popov installed a pencil instead of the bell and sent the first wireless message in the world the distance of 250 m between two buildings, conveying the name "GENRICH GERZ" (the name of Hertz in Russian) by Morse code using his homemade transmitter and receiver. In March, 1897, Popov equipped a coastal radio station at Kronstadt and the Russian Navy cruiser Africa with his wireless apparatus and in summer, 1897, Popov started to make experiments at sea, using radios on board ships before the entire world. In 1898, he succeeded in relaying information at a distance of 9 km and in 1899, a distance of 45 km between the island of Gogland and the city of Kotka in Finland. With all his inventions Popov made advances on the discoveries of Hertz and Branly and created the groundwork for the development of maritime radio.

In 1895, a few months later than Popov, a young Italian experimenter, Guglielmo Marconi, started to use radio and was the first to put EM theory into practical application. By the next year, he had sent Morse code messages at a distance of 2 miles. Moving to England to obtain patents on his equipment, he demonstrated radio reception over 8 miles. In 1897, he exhibited the use of radio between ship and shore and, according to Western literature practically started the use of maritime radio. By the same year, Marconi succeeded in getting his wireless telegraphy transmissions officially patented for the first time in the world. The owners of the Dublin Daily Express in Ireland invited Marconi to conduct wireless reports of the Kingston Regatta of July, 1898 from the steamer Flying Huntress, the first ship equipped with a commercial wireless system.

Figure 1.3. Marconi with his first Radio – Courtesy of Book: by Ilcev

Using an antenna hung from a kite to increase the effective height of his masts and a LF of 313 kHz at 10 kW of power, on 12 December 1901 Marconi crackled out the first wireless message to span an ocean in the form of Morse code; three dots forming the letter "s". This telegraph signal was sent from Newfoundland in Canada and received in Cornwall on the west coast of England, see photo of Marconi with his first Radio Equipment in **Figure 1.3**.
Unlike Popov, Marconi was a good businessman and was able to turn his research into a financial and manufacturing empire. He designed radio Sailor as a first used Morse Sender for transmitting distress messages and later for commercial ship to shore and vice versa direction at the turn of the 20 century.
In 1900, R. Fessenden made the first transmission of voice via radio in the USA, Fleming in 1904 discovered the diode valve, while their countryman and pioneer Lee de Forest developed and used a triode valve, which made it possible to use radio not only for radiotelegraphy but for voice communications. As early as 1907, he installed a triode valve mobile radio on a ferryboat operating on the Hudson River near New York City(Ilcev, SD 2005a).

1.2.1. Development of Mobile Radiocommunications

The very impressive development of mobile radio for maritime use at first and later on for aero applications, initiated mobile distress and safety radio. Once the principles of radio were understood, mobile radio has been a matter of the steady development of technology to extend communications accessibility, coverage and reliability by reducing the size, cost and power consumption of equipment and improving efficiency. With further innovations an age-old barrier between ships and shore was eliminated and possibility to communicate with mobile radios independent of space and time were created. These early radio devices were primitive by today's standards, incorporating spark transmitters, which blasted their signals across almost the entire radio spectrum. It is supposed that the first vessel to have a Ship Radio Station (SRS) was the American liner St. Paul, equipped in 1899. The next one, early in the following year was the German vessel s/s Kaiser Wilhelm der Grosse.
Thereafter, mobile radio spread rapidly throughout the shipping and safety business. By 1899, however, A. S. Popov had been the first in the world who successfully carried out demonstrations of mobile wireless telegraphy communications at a distance of 20 miles between warships of the Black Sea fleet.
The first recorded use of radio for saving life at sea occurred early in March, 1899. The lightship on the Goodwin Sands near Dover on the south coast of England was fitted with

one of the first seaborne Marconi SRS and used it to report to the Coastal Radio Station (CRS) that the German steamer Elbe had run aground(Rappaport 1996).
Then, in 1905, the Morse code "SOS" (that does not mean Save Our Souls) was adopted by German ships for signifying distress while the British marine, working with Marconi operators, wanted to keep CQD (General Call Disaster that some translated by Come Quick Disaster) as a distress signal. It was first decided to use SOE, but the small "E" dot can easily be lost in QRM and one suggested to replace it with an S, as in repeating three time the small dot the operators had much more chance to arrest the attention of anyone hearing it, hence SOS, that was adopted at the Berlin Radiotelegraphic Convention in 1906 as the official international standard for distress calls. In the Berlin Conference also were adopted two radio frequencies, 500 and 1000 kHz were earmarked for correspondence (Lee, WC 1982).
But Marconi operators were slow to conform and until 1907 Marconi companies continued to work with the "CQD", associating it if necessary to SOS. Therefore, after the collision of two passenger ships, the British s/s Republic and the Italian s/s Florida, running in thick fog in the early hours of 23 January 1909, the radio officer on board the s/s Republic sent for the first time in history the distress signal: “CQD MKC (call sign of s/s Republic), CQD MKC, CQD MKC” and text: “Republic rammed by unknown steamship, 26 miles southwest of Nantucket, badly in need of assistance”. After the catastrophe of liner s/s Titanic in the early hours of 15 April 1912, radio officer sent CQD distress call.
The maritime radiotelephony distress signal MAYDAY was adopted in 1927 at Hanover in Germany. The name of this signal derives from the French phrase “M’aidez”, which means, “Help me”.
The first international SOLAS (Safety of Life at Sea) Convention was adopted during 1914 in London, partly as a result of the Titanic disaster. It stipulated Morse telegraphy on 500 kHz Radio Frequency (RF) and battery-operated backup radio unit. Ships carrying more than 50 passengers were required to carry radio devices with a range of at least 100 Nm and larger ships had to maintain a continuous radio watch with a minimum of 3 radio officers. At the Conference in Washington in 1927 the Regulations were established as a supplement to bring into force three safety calls in radiotelegraphy for distress, urgency and security, SOS, XXX and TTT, respectively. These three signals were obligatory only on 500 kHz, with a silence period of 3 minutes after every 15th and 45th minute(Grewal, I and Kaplan 1994).
Soon after implementing radiotelegraphy, the first radiotelephone call was realized using amplitude modulation between s/s America and CRS Deal Beach, New Jersey in the USA. In such a way, at the Conference in Madrid radio stations call signs and frequency bands were determined, the International Telecommunications Union (ITU) was established and Radio Regulations (RR) adopted. At the Conference in Atlantic City in 1947 a supplementary ITU RR was adopted and a new radiotelephony distress frequency of 2,182 kHz accepted, instead of the old one on 1,650 kHz, with silence periods of 3 minutes after every 00th and 30th minute. Three telephone safety calls were previously used for distress, urgency and security such as: MAYDAY, PANPAN and SECURITE, respectively, on 2,182 kHz and more recently, on 156.8 MHz (16 VHF maritime channel).
The new era of transistors had been commenced and later on in the period of revolutionary integrated circuits started after 1957. All those technologies were adopted onboard of aircraft including use of frequency modulation with a new ARQ system for use in aeronautical radio telex(Johnson 1999; Maral and Bousquet 2011).
Finally, the new era of transistors commenced successfully and later on the period of revolutionary integrated circuits started after 1957. In the meantime, was the change to frequency instead amplitude modulation with a new ARQ system for use in maritime radio telex services.

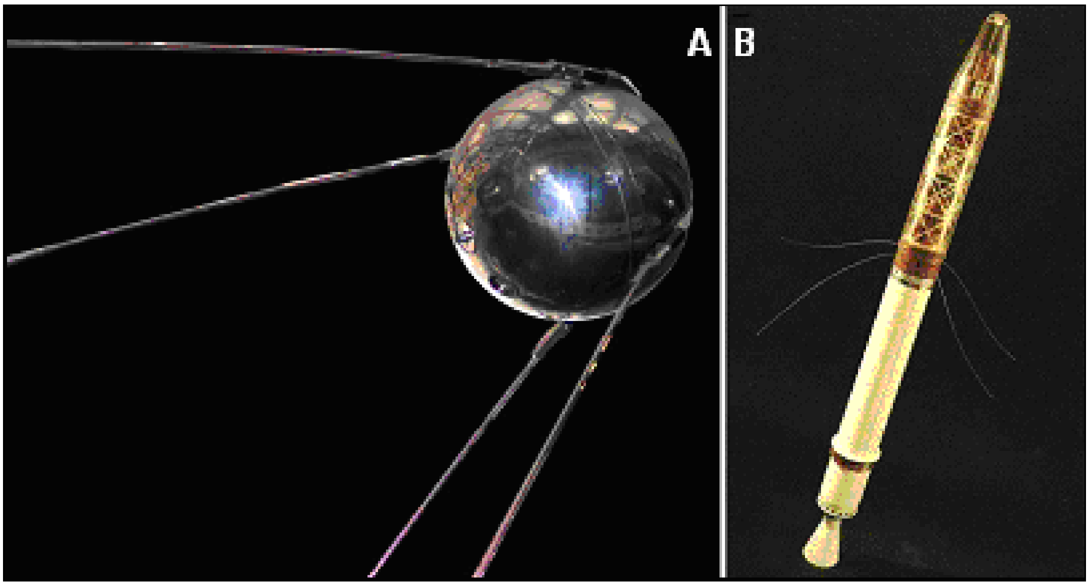

Figure 1.4. Sputnik 1 & Explorer 1 – Courtesy of Book: by Ilcev

1.2.2. Evolution of Satellite Communications

The first known annotation about devices resembling rockets is said to have been used by Archytus of Tarentumin, who invented in 426 B.C. a steam-driven reaction jet rocket engine that flew a wooden pigeon around his room. Devices similar to rockets were also used in China during the year 1232. In the meantime, human space travel had to wait almost a millennium, until Sir Isaac Newton's time, when we understood gravity and how a projectile launched at the right speed could go into Earth orbit.

Finally, the twentieth century came with its great progress and the historical age of space communications began to unfold. Russian scientist Konstantin Tsiolkovsky (1857–1935) published a scientific book on virtually every aspect of space rocketing(Kosmodemyansky 2000). He propounded the theoretical basis of liquid propelled rockets, put forward ideas for multi-stage launchers and manned space vehicles, space walks by astronauts and a large platform system that could be assembled in space for normal human habitation. A little later, the American Robert H. Goddard launched in 1926 the first liquid propelled engine rocket.

At the same time, between the two World wars, many Russian and former USSR scientists and military constructors used the great experience of Tsiolkovsky to design many models of rockets and to build the first reactive weapons, particularly rockets called "Katyusha", which one Soviet Red Army used against German troops at the beginning of the Homeland War (Second World War). Thus, towards the end of the Second World War, many military constructors in Germany started with experiments to use their series V1 and V2 rockets.

After that, in October 1945, the British radar expert and writer of science fiction books Arthur C. Clarke proposed that only three communications satellites in Geostationary Earth Orbit (GEO) could provide global coverage for TV broadcasting(Calcutt and Tetley 1994).

The work on rocket techniques in Russia and the former USSR was much extended after the Homeland War. The satellite era began when the Soviet Union shocked the globe with the launch of the first artificial satellite, Sputnik I, on 4 October 1957, shown in **Figure 1.4 (A).** This launch marked the beginning of the use of artificial Earth satellites to extend and enhance the horizon for radiocommunications, navigation, weather monitoring and remote sensing and signified the announcement of the great space race and the development of satellite communications. That was soon followed on 31 January 1958 by the launch of US satellite, Explorer I, illustrated in **Figure 1.4(B)** and so, the development of satellite communications and navigation and the space race began.

The most significant progress in space technology was on 12 April 1961, when Yuri Gagarin, officer of the former USSR Air Forces lifted off aboard the Vostok I spaceship from Bailout Cosmodrome and made the first historical manned orbital flight in space.

1.2.4. Early Progress in Mobile Satellite Communications and Navigation

The International Maritime Organization (IMO), known as the Intergovernmental Maritime Consultative Organization (IMCO) until 1982, was established in Geneva in 1948,and came into force ten years later, meeting for the first time in 1959(Paulsen 1982).

The first successful experiments were carried out in aeronautical MSC. The Pan Am airlines and NASA program in 1964 succeeded in achieving aeronautical satellite links using the Syncom III GEO spacecraft. The frequencies used for experiments were the VHF band (117.9 to 136 MHz), which had been allocated for Aeronautical MSC (AMSC).

The first satellite navigation system, called Transit was developed by the US Navy and become operational in 1964. The majority of the Transit receivers has worked since 1967 and has already attracted about 100,000 mobile and fixed users worldwide. The former USSR equivalent of the Transit was the Cicada system developed almost at the same time.

Following the first AMSC experiments, the Radiocommunications Subcommittee of the IMCO, as early as 1966 discussed the applicability of the MSC system to improve maritime radiocommunications. This led to further discussions at the 1967 ITU WARC for the Maritime MSC (MMSC), where it was recommended that detailed plan and study be undertaken of the operational requirements and technical aspects of systems by the IMCO and CCIR administrations. Thus, at the 1971 WARC, 2 x 14 MHz of spectrum, contiguous with the MMSC spectrum was allocated at L-band for Distress and Safety satellite communications and 2 x 4 MHz of frequency spectrum for MMSS and AMSS needs.

The first truly global MSC system was begun with the launch of the three Marisat satellites in 1976 by Comsat General. Marisat was a GEO spacecraft containing a hybrid payload: one transponder for US Navy ship's terminals operating on a government UHF frequency band and another one for commercial merchant fleets utilizing newly-allocated MMSC frequencies. The first official mobile satellite telephone call in the world was established between vessel-oil platform “Deep Sea Explorer”, which was operated close to the coast of Madagascar and the Phillips Petroleum Company in Bartlesville, Oklahoma, USA on 9 July 1976, using AOR Coast Earth Station (CES) and GEO of the Marisat system.

The IMCO convened an international conference in 1973 to consider the establishment of an international organization to operate the MMSC system. The International Conference met in London two years later to set up the structure of the International Maritime Satellite (Inmarsat) organization. The Inmarsat Convention and operating agreements were finalized in 1976 and opened for signature by states wishing to participate. On 16 July 1979 these agreements entered into force and were signed by 29 countries. The Inmarsat officially went into operation on 1 February 1982 with worldwide maritime services in the Pacific, Atlantic and Indian Ocean regions, using only Inmarsat-A Ship Earth Station (SES) at first. Moreover, the Marecs-1 B2A satellite was developed by nine European states in 1984 and launched for the experimental MCS system Prodat, serving all the mobile applications(Calcutt and Tetley 1994).

In 1985, the Cospas-Sarsat satellite Search and Rescue (SAR) mobile system was declared operational. Three years later the international Cospas-Sarsat Program Agreement was signed by Canada, France, USA and the former USSR. In 1992, the Global Maritime Distress and Safety System (GMDSS), developed by the IMO experts, began its operational phase.

Hence, in February 1999, the GMDSS became fully operational as an integration of Radio MF/HF/VHF (DSC), Inmarsat (Berzins *et al.* 1989)and Cospas-Sarsat LEOSAR and GEOSAR systems(Levesque 1993). Recently is developed Cospas-Sarsat MEOSAR system as additional integrated infrastructure.

The Transit system was switched off in 1996 to 2000 after more than 30 years of reliable service of Global Navigation Satellite System (GNSS). By then, the US Department of Defense was fully converted to the new Global Positioning System (GPS). Thus, the GPS service could not have the market to itself, the ex-Soviet Union developed a similar system called Global Navigation Satellite System (GLONASS) in 1988. Either Transit or Cicada provided intermittent two-dimensional (latitude and longitude when altitude is known) fixing position every 90 minutes on average and was best suited to marine navigation, the GPS or GLONASS system provides continuous position and speed in all three dimensions, equally effective for navigation and tracking at sea, on land and in the air.

In 1985, Inmarsat Geostationary Earth Orbit (GEO) initially developed the Standard-C for MMSC and later Inmarsat-D+ satellite communication system examined the feasibility of adding navigational capability using GPS or GLONASS for tracking and determination of all mobile applications.

Although, the ESA satellite navigation concept, called Navsat, dates back to the 1980s, the proposed project has received relatively little attention and even less financial support. Since 1988, the US-based Company Qualcomm has established the Omni TRACS service using GEO constellation for vehicle messaging and tracking. Soon after, Eutelsat promoted a very similar system Euro TRACS integrated with GPS and the GEO satellites systems.

The USA Federal Communications Commission (FCC) in 1995 is reasonably encouraging toward private development of the Radio Determination Satellite System (RDSS), which would combine positioning fixing with short messaging for tracking of all mobile assets. However, since then were proposed many RDSS systems in the USA, however today are operational only three Low Erath Orbit (LEO) satellite voice and data communication systems, such as Globalstar, Iridium and Orbcomm, which service includes tracking and determination of all mobile applications as well.

At the beginning of this millennium three Regional Satellite Augmentation Systems (RSAS), known as Satellite Based Augmentation System (SBAS) were developed for mobile CNS: the US Wide Area Augmentation System (WAAS), Japanese MTSAT Satellite-based Augmentation System (MSAS) and European Geostationary Navigation Overlay System (EGNOS). Recently were proposed for development the Russian System of Differential Correction and Monitoring (SDCM), Chinese Satellite (Sino) Navigation Augmentation System (SNAS), Indian GPS/GLONASS and GEOS Augmented Navigation (GAGAN) and African Satellite Augmentation System (ASAS) for Africa and Middle East region. All these RSAS systems have to be fully comparable and integrated in Global Satellite Augmentation Systems (GSAS) infrastructure.

Hence, these systems will augment the two operating military satellite navigation systems, the US GPS and the Russian GLONASS and make them suitable for safety critical applications such as flying aircraft or navigating ships through narrow channels and port approaches. This system is a joint project of the ESA, the European Commission (EC) and Euro control (the European Organization for the Safety of Air Navigation) and will become fully operational for commercial using in 2004. The European Union contribution is the Global Navigation Satellite System (GNSS) as a precursor to a new system known as Galileo. This full GNSS, under development in Europe, is a joint initiative of the EC and the ESA in order to reduce dependency on the GPS service. The target of new the Galileo project should start with operations by 2005 and to become completely operational by 2008. In addition, China is developing an own GNSS system known as Compass.

In the meantime several very interesting projects are developing in Europe, Japan and the USA for new mobile and fixed multimedia Stratospheric Platform Communication Systems powered by fuel or the Sun's energy and manned or unmanned aircraft or airships equipped with transponders and antenna systems at an altitude of about 20–25 km(Miura and Oodo 2001).

1.3. Development of Global Mobile Satellite Systems (GMSS)

Once the principles of radio were understood, mobile radiocommunications have been a matter of steadily developing and perfecting the radio technologies, extending accessibility and the possibility of radio networks, enhancing range, extending coverage and reliability, reducing the size, cost and power consumption of radio devices and improving efficiency. With further MSC innovations an age long barrier was eliminated between vessels and shore sites, including all mobiles, facilities were created to provide mobile offices in ships and all vehicles and to communicate with CES independently of space, place and time. The world is going to reduce communications barriers and move people across borders, so the new mobile satellite industry must ensure that mobile communications and navigation services will be responsive to these extraordinary changes and globalization trends.

The MSC systems and technology also offer other benefits and perspectives. In many developing countries telephone density is still at a low level in urban and non-urban areas, because the cost of upgrading such facilities through wireless or TTN means is prohibitive for much of the world areas. Remote, rural and mobile service sectors in many regions are outside the reach of communications facilities, so the new MSS technology, with its instant ubiquitous coverage, may provide cost-effective solutions for developing countries(Swan and Devieux Jr 2003).

1.3.1. Definition of Global Mobile Satellite Communications (GMSC)

The GMSC is GCSS of GEO or Non-GEO satellite systems, which refers to all mobile communications solutions that provide global MSC service directly to end users from a satellite segment, ground satellite network and TTN landline and/or radio infrastructures. The term GMSC means not only global coverage, but also includes local or regional MSS solutions as an integral part of the worldwide telecommunications village. Namely, some of the regional and local MSC systems can be afterwards integrated worldwide to establish a Global MSC network.

The GMSC solutions as modern structures began providing communication links to vessels initially in the 1970s and later to other mobiles. It must be noted that GMSC provides global and regional coverage in a new technological era in which terrestrial and wireless voice, data and video systems are combined with MSC applications to provide communication services available anytime and anywhere. Additionally, new satellite technologies, such as Personal and Very Small Aperture Terminals (VSAT), have also allowed global personal and commercial mobility. In fact, some of the new GEO or Non-GEO Personal systems have entered the field of MSC solutions, which for the past 20 years has been occupied predominately by Intergovernmental Satellite Organizations. In recent years, a growing number of international and private entities have been prepared to develop and invest in satellite technology, such as Inmarsat, Iridium, Globalstar and Orbcomm systems.

At the same time, satellite technology continues to advance, so satellite mobile terminals have become smaller, better and cheaper. Some GMSC systems now being developed are the initiative of the private sector or consortiums. This implies that there should be changes in policy, particularly in countries that do not foresee sufficient private participation in the telecommunication sectors to allow these systems to thrive and to realize their potential.

As mentioned, GMSC systems can provide global or regional coverage. This capability has raised questions about national sovereignty, integrity and security of a country covered by a particular GMSC network. Generally speaking, communication networks in the concerned country must always comply with national regulations that govern integrity and assistance to law enforcement and security agencies. These typically have requirements for national routing, location determination, call monitoring and legal interception(DIMOV ; Swan and Devieux Jr 2003).

1.3.2. Definition of Global Navigation Satellite Systems (GNSS)

The first generation GNSS, known as GNSS-1 are represented by currently operating US GPS and Russian GLONASS systems. Both systems provide basic navigation facilities of Position, Velocity and Time (PTV) for ships and all kinds of mobiles. Thus, as defined by the experts on the ICAO/GNSS panel, plans for some system augmentations in addition to the basic GPS and GLONASS constellations in order to achieve the level of performance suitable for augmented civil aviation applications in oceanic flight and also for enhanced maritime routing applications worldwide, especially in narrow passages, coastal navigation and approaching ports.

The GPS network is a satellite-based all-weather, full jam resistant, continuous operation radio navigation system, which utilizes precise range measurements from the GPS satellites to determine exact position and time anywhere in the world. This system provides military, civil and commercial maritime, land and aeronautical users with highly accurate worldwide three-dimensional, common-grid, position/location data, as well as velocity and precision timing to accuracies that have not previously been easily attainable. The GPS service is based on the concept of triangulation from known points similar to the technique of "resection" used with a map and compass, except that it is done with radio signals transmitted by satellites. The GPS receiver must determine when a signal is sent from selected GPS satellites and the time it is received. Nothing except a GPS receiver is needed to use the system, which does not transmit any signals; therefore they are not electronically detectable. Because they only receive RF satellite signals, there is no limit to the number of simultaneous GPS users.

The Russian Federation (former USSR) provides the GLONASS service from space for accurate determination of position, velocity and time for mobile or fixed users worldwide and in all-weather conditions anywhere. Therefore, three-dimensional position and velocity determinations are based upon the measurement of transit time and Doppler Shift of RF signals transmitted by GLONASS satellites.

The GNSS consists in many players with similar GMSC systems and three major segments:

1) The Space Segment has 24 satellites (21 functioning satellites and 3 on-orbit spares) and is controlled by a proprietary satellite operator or service provider.

2) The Control Segment is operated by Master Control and Monitor Stations and is integrated part of Ground Segment.

3) The User Segment is represented by the military/civil authorities for maritime, land and aeronautical users located worldwide. This segment offers Standard Positioning Service (SPS) and Precise Positioning Service (PPS), available to all users around the world. Access to the SPS does not require approval by a certain service provider, but PPS is only available to authorized users via the service provider administration(DIMOV ; Swan and Devieux Jr 2003).

1.3.3. Network Architecture of GMSC

The increased availability of MSS and GNSS solutions means that many mobiles and individuals will have radio connections and determinations at their disposal whenever and wherever they are traveling, including worldwide shipping, long-distance road and railway haulage, transcontinental flights and universal personal handheld terminals. The new MSC technology is very attractive to mariners, drivers and aviators alike. As stated, MSS began in the 1970s for vessels and latter for all other mobile systems.

The MSC system consists in space and ground segments, represented by communications GEO and Non-GEO satellites and the ground segment comprises different types of MES and Networks, respectively.

1.3.3.1. Space Segment and Configuration of MSC Links

The space segment provides the connection between the subscribers on shore and mobile users via CES or Gateways. In the other words, it consists in one or more operational or spare spacecraft in a corresponding constellation. The satellite constellation can be formed by a particular type of orbit, such as GEO and Non-GEO. Non-GEO orbits can be LEO, Polar Erath Orbit (PEO) and High Elliptical Orbit (HEO) or combinations of these orbits(Montenbruck and Gill 2000). The satellites can be independent or connected with each other through the Inter-Satellite Link (ISL). The space segment can be shared among different radio networks in different areas in time and space.

There are also constellations of multipurpose satellites, which platform can serve more than two payloads, such as a combination of meteorological and navigational payloads, etc.

An MSC link is a Radio Frequency (RF) connection between CES and MES via GEO or Non-GEO satellites. The part of the MSC link between the CES and satellite is called the feeder link, while the link between the MES and the satellite is called the service link. Both feeder and service links consist in an uplink from the ground towards a satellite and a downlink in the opposite direction (satellite to ground), and both falls under the category of MSS. The feeder link of the CES is categorized as a fixed utilization in MSS and not at all as a part of the Fixed Satellite Service (FSS) as is stated in the MSS Handbook published by ITU, page 78. Therefore, the location of CES in MSS is fixed and is not a part of FSS, although some CES in MSS can also provide FSS(Evans 1999).

1.3.3.2. Ground Segment and Networks

The ground segment consists of two major network elements: user mobile or portable terminals and ground support stations. The user network comprises four main categories of user terminals whose characteristics are highly related to its applications and operational environments as follows:

1. Mobile Earth Stations (MES)– The MES group of terminals is designed for the group usage and installation onboard collective transport systems such as SES mounted on ships, Vehicle Earth Station (VES) onboard road and rail vehicles and Aircraft Earth Station (AES) onboard aircraft. Otherwise, the MES terminals are composed of in-mobile and out-mobile and outdoor equipment such as: Above Deck Equipment (ADE) and Below Deck Equipment (BDE) for ships including indoor and outdoor for vehicles and aircraft.

2. Personal Earth Stations (PES) – The PES often refer to handheld or palmtop devices for personal utility and carriage in hand, pocket and bag, which can be used for safety communication and tracking solutions.

3. Transportable Earth Stations (TES) – The TES terminals are typically similar in dimensions to that of a briefcase or laptop computer. As the name implies, these terminals can be transported from one remote or rural site to another; however, operation while mobile will not normally be supported. Every TES contains the transceiver modem and antenna units, and can also serve as indoor equipment.

4. Fixed Earth Stations (FES) – The FES terminals are similar to public urban payphones or fixed office units containing antenna and transceiver units.

The Ground Network consists in six main network elements, which support, maintain and control the space segment and user network as follows:

1. Coast Earth Stations (CES) – The CES infrastructure is actually a Gateway station for MSC service and provides an interface to the satellite access network and existing TTN, such as PSTN/PLMN/ISDN via local exchanges. A single CES can be associated with a particular global and one or more spot beams in MSS or FSS networks.

2. Network Control Centres (NCC) – The NCC, also known as the Network Management Station (NMS), is connected to the Customer Information Management System (CIMS) to coordinate access to the satellite resource and perform the logical functions associated with Network Management (NMF) and Control Functions (NCF).
3. Satellite Control Centre (SCC) – The SCC monitors the current performance of a certain space segment and controls the satellite's position in orbit.
4. Network Coordination Stations (NCS) – One NCS serves one ocean region to monitor and communication traffic control within four Inmarsat ocean regions: Atlantic Ocean Region West (AORW), East (AORE), Indian Ocean Region (IOR) and Pacific (POR). Each NCS communicates with CES terminals in its own ocean region using special interstation signaling links, with other NCS cites and with NCC located in Inmarsat Headquarters, making possible the transfer of information throughout the system.
5. Rescue Coordination Centre (RCC) – The RCC operates a system responsible for promoting the efficient organization of SAR service and for coordinating the conduct of distress and SAR operations with other MES units, such as ships and helicopters, within a certain on-scene region.
6. Terrestrial Telecommunications Network (TTN) – The TTN element is a local ground exchange service, which provides an interface between subscribers ashore and Gateways, on one side and SES or other mobile users on the other side.

1.4. GMSC Applications

The present GMSC systems are in use for maritime, land and aeronautical applications. Recently, several Personal mobile multipurpose applications using GEO and Non-GEO satellites have been developed and introduced. The lately developed regional networks using stratospheric aircraft and airships will be introduced as very low satellite systems.

1.4.1. Maritime Mobile Satellite Communications (MMSC)

The commercial MMSC systems are designated for very large and medium ocean-going vessels, passenger cruisers, small coastal and river ships, fishing boats, pleasure yachts and rescue boats. These systems are also available for naval vessels, offshore rigs and platforms, including any kind of off/onshore infrastructures. The MMSC system is a successor to the Conventional Maritime Radiocommunications system, which for almost a century was very successful on the commercial and distress scene at sea. In fact, the biggest MSS operator for MMSC is Inmarsat, while other global and regional GEO or Non-GEO systems for MMSC are Iridium, Globalstar, Optus, Thuraya, MSAT, Orbcomm and other systems.

1.4.1.1. Maritime Transportation Augmentation System (MTAS)

The development of the MTAS was to identify the possible applications for enhancement of global Digital Selective Call (DCS) of MF/HF/VHF radio and satellite CNS and safety systems including transport security, tracking and control of vessels and freight at sea, on lakes and rivers and the security of passengers on board cruisers and hovercrafts. These enhancements include many applications for the better traffic, management and operation of vessels and they are needed more than ever because of world merchant fleet expansion. Just the top 20 world ships registers have about 40,000 units under their national flags. Above all, the biggest problem today is that merchant ships and their crews are targets of the types of crime traditionally associated with the maritime industries, such as piracy, robbery and recently, a target for terrorist attacks.
Thus, IMO and flag states will have a vital role in developing International Ship and Port Security (ISPS). The best way to implement ISPS is to design a Port Control System by

special code augmentation satellite tracking, monitoring and surveillance of all vehicle circulation in and out of the port area. The establishment of MTAS will meet most of these requirements and will complement the services already provided by marine radio beacons.

1.4.1.2. Service for MMSC Users

The first-class two-way MMSC will be essential for mariners to contact and constantly exchange information between vessels, owners, agents, shippers, port authorities, families and friends, or to deal with emergencies, distress and rescue situations at sea. Navy ships can use these facilities for fleet defense, tactical, emergency and information purposes. Therefore, shippers will be nearer to their fleet units, using not only commercial MSC but also reliable tracking, determination, distress and internship communications and will also have important 24-hour Maritime Safety Information (MSI), such as Weather (WX) and Navigation Warning (NX).

1.5. International Coordination Organizations and Regulatory Procedures

International coordination in MSC has been carried out by the International Coordination Organizations, which include ITU, IMO, ICAO, IHO, WMO and MSUA, as major players for regulation and policies.
1. International Telecommunications Union (ITU) – The ITU organization of the United Nations (UN) with all member inter governments has carried out the entire international coordination and regulation of mobile radio and satellite communications by the ITU RR including assigning the frequency bands(Sector). Numerous provisions of the telecommunication services applicable or useful to all stations have been defined and introduced by the general RR articles and manual on mobile radio service and in a special manual for use by the Maritime Mobile and Maritime Mobile-Satellite Services. The ITU also publishes many additional lists of recommendations concerning RR, mobile systems, radiocommunications, etc. The administrative structures established by the ITU Convention comprise a Secretariat headed by the Secretary General, an Administrative Council, Registration Board for RF and Consultative Committees for radio and telecommunications. The entire terminology, definition of radio and satellite services, technical standards and frequency allocations are defined in the RR and drafted by the World Administrative Radio Conference (WARC) of the ITU, which is covering the spectrum needs of numerous telecommunications for Radio HF/VHF and Satellite MSS. The task of the International Radio Consultative Committee (CCIR) is to form study groups to consider and report on the operational and technical issues relating to the use of radio and satellite communications, while the International Telecommunications Consultative Committee (CCIT) offers the same services(MacLean 2007).
2. International Maritime Organization (IMO) – The service and regulations reaching development, studies and agreements of the Maritime Safety Committee regarding distress and safety at sea are providing by the IMO. It consists in an Assembly, a Council and 4 main Committees: Maritime Safety; Marine Environment Protection; Legal and Technical Cooperation. There is also the Facilitation Committee and a number of sub-committees, which support the work of the main technical committees. Since its establishment in 1959, IMO and all its member governments have striven to enhance the International Convention for the Safety of Life at Sea (SOLAS – 1974). In addition, in 1972 IMO, with the assistance of CCIR, commenced a study of satellite communications systems, which resulted in the establishment, in 1979, of the Inmarsat Organization.
With the continuing support of CCIR, ITU, WMO, IHO, Cospas-Sarsat and Inmarsat, IMO has developed the GMDSS system in early 1999, following almost 30 years of careful preparation. Concurrently with the revision of the SAR Convention, the IMO and ICAO

technical experts jointly developed the International Aeronautical and Maritime Search and Rescue Manual (IAMSAR), published in three separate volumes covering: Organization and Management, Mission Coordination and Mobile Facilities. Therefore, the IAMSAR Manual revises and replaces both the IMO Merchant Ship Search and Rescue Manual (MERSAR), first published in 1971 and the IMO Search and Rescue Manual (IMOSAR), first published in 1978. The MERSAR Manual was the first step towards developing the 1979 SAR Convention and it provided guidance for those who, during emergencies at sea, may require assistance from others or who may be able to provide assistance themselves. In particular, it was designed to aid the master of any vessel who might be called upon to conduct SAR operations at sea for persons in distress. The second IMOSAR Manual was adopted in l978. It was designed to help governments to implement the SAR Convention and provide guidelines rather than requirements for a common maritime search and rescue policy, encouraging all coastal states to develop their organizations on similar lines and enabling adjacent states to cooperate and obtain mutual assistance. It was also updated in 1992, with the amendments entering into force in 1993. This manual was aligned as closely as possible with the ICAO Search and Rescue Manual to ensure a common policy and to facilitate consultation of the two manuals for administrative or operational reasons. In such a way, MERSAR was also aligned, where appropriate, with IMOSAR(Balkin 2006).

3. International Civil Aviation Organization (ICAO) – The ICAO mission is similar to the IMO service, but is serving to civil aviations and Regulations and Recommendations(Weber 2000).

4. International Hydrographic Organization (IHO) – T he IHO is a consultative and technical organization providing standardization of nautical charts and documents, ocean mapping, bathymetry and related publications, technical assistance and training. The main activity of IHO related to MSS is radio Navigational Warnings (NX) implemented by the GMDSS as an integrated Radio and Satellite communication system provided by Inmarsat and Cospas-Sarsat systems. Thus, the GMDSS system has improved the dissemination of Maritime Safety Information (MSI), taking advantage of modern mobile communications technology. The far offshore navigation warnings are broadcast via Inmarsat-C Enhanced Group Call (EGC) Safety NET Service, whilst polar areas warnings are covered by DCS HF radio services and coastal area warnings are transmitted via DCS MF/VHF radio and NAVTEX on a single frequency, timeshared and automatic broadcast(Bekiashev and Serebriakov 1981a).

5. World Meteorological Organization (WMO) – The WMO coordinates entire global scientific activity to allow prompt and accurate weather information, Weather Warnings (WX) and tropical storm forecasting and other services for public, private and commercial use, including the international shipping and airline industries, sent by GMSC media(Bekiashev and Serebriakov 1981b).

6. Mobile Satellite Users Association (MSUA) –The MSUA was established in 1992 as a non-profit association to promote the interests of users of MSS.

1.6. Satellite Communications Organizations and Operators

Government and intergovernmental satellite communication organizations including all satellite operators and providers are divided into international, offering almost global service, regional, usually covering a few countries or entire continents and domestic, for local service only. The GMSC system operators are the only entity responsible for the operation of the GEO or Non-GEO space and ground network configurations providing global, regional or domestic coverage(Ilcev, SD 2005a).

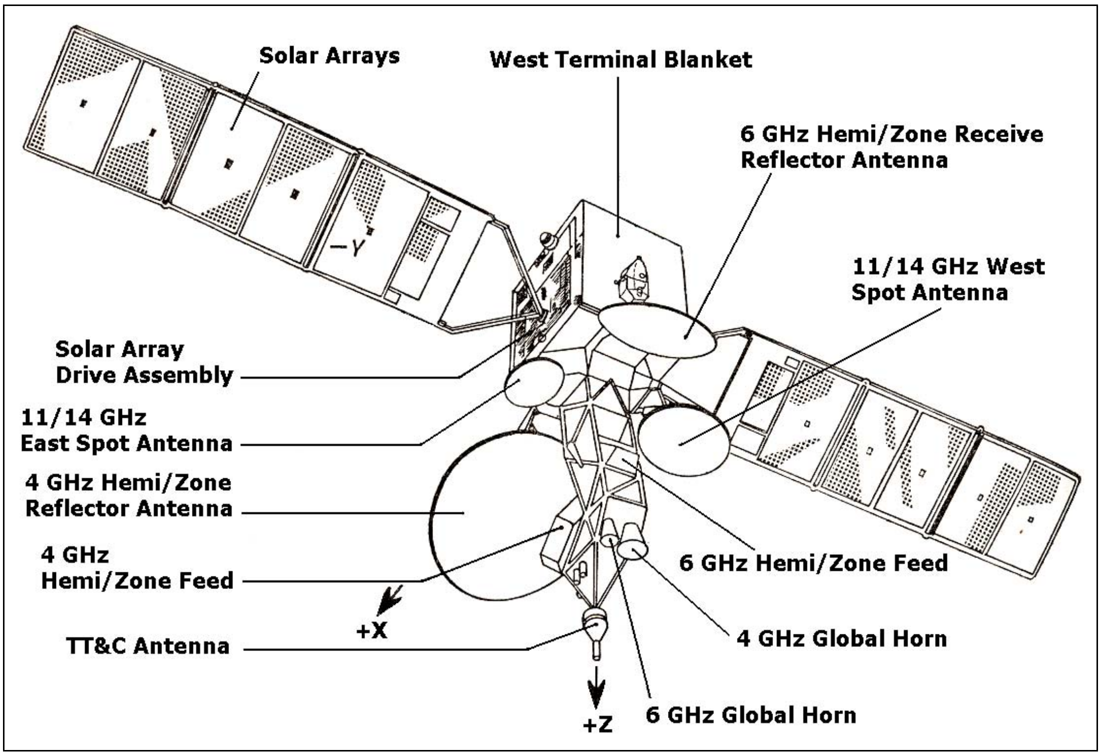

Figure 1.5. Intelsat V MCS – Courtesy of Book: by Galic

1.6.1. International Satellite Communications Organization

The FSS were the first to develop and there was rapid recognition that these new global possibilities needed the creation of some kind of international organizations. International satellite communications organizations and operators are Intelsat, Inmarsat, Intersputnik, Eutelsat, ESA and other global, multinational or intergovernmental operators serving to fixed and mobile users outside domestic and regional boundaries.

1. Intelsat - The Intelsat international organization based in Washington is established on 20 August 1964. The 11 member countries signed and agreement creating the Intelsat, the first open worldwide satellite communications network appointed by Comsat Corporation as its first manager. Intelsat fixed system started to offer transatlantic satellite services in 1965 and today is operator of many current and future planned GEO satellite constellations for FSS and FSS. Since 1990s, Intelsat has developed K and V-VIII series of GEO satellite constellations for FSS. The Intelsat provided as well as MSS using payloads carried by its GEO spacecraft Intelsat V MCS series. The Inmarsat organization leased capacity on Intelsat V MCS flights F5 through F8 for MMSC service shown in **Figure 1.5.** These four satellites used portions of the L-band (from 0.5 to 1.7 GHz) and C-band assigned for such purposes by the ITU. Today, Intelsat is providing own MMSC service on Ku-band known as VSAT Marlink(Alper and Pelton 1984).

2. Inmarsat – The Inmarsat organization is the only international and nonmilitary MSC provider offering voice, data and video service, which includes data service for positioning and tracking messaging. In the early 1970s the IMO, then known as the IMCO, began to consider the possibility of using MSS to improve maritime communications, not least for safety purposes. Inmarsat was established on 16 July 1979 by the major maritime nations to finance this project, which is to investigate using satellites to form links with vessels and offshore oilrigs at sea. On 1 February 1982, Inmarsat officially took control of satellites previously operated by three Marisat spacecraft providing MMSC and later on service for all mobile applications as well. In the next stages Inmarsat leased satellites from ESA, Intelsat and Marecs, after building own GEO constellations of Inmarsat 2, 3 and 4 spacecraft(Doyle 1977).

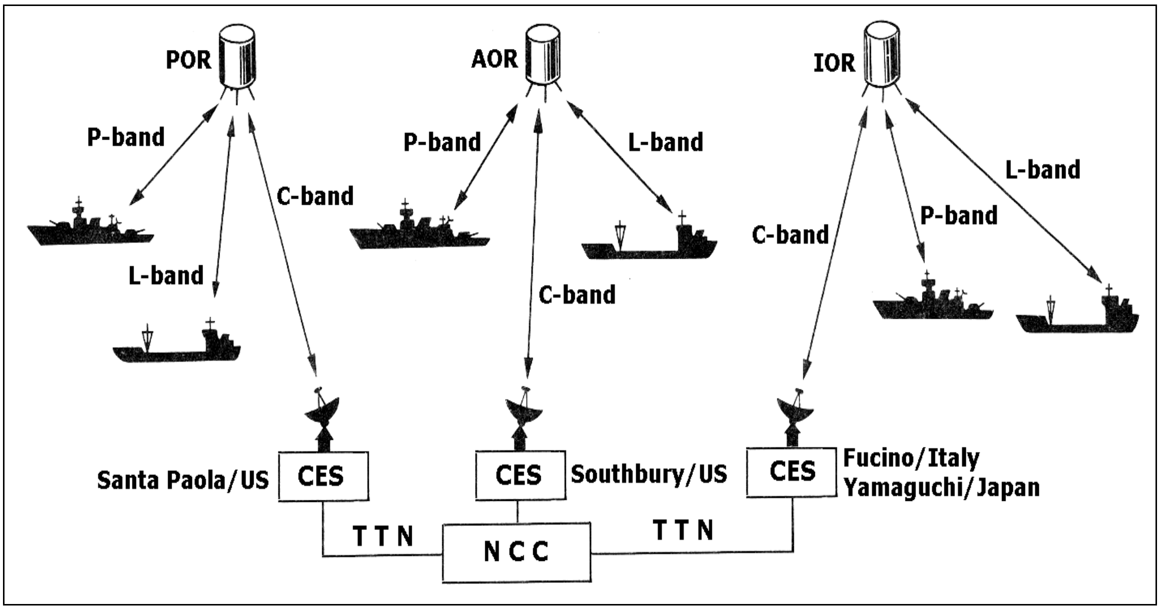

Figure 1.6. Marisat Space and Ground – Courtesy of Book: byNovik

3. Intersputnik – The Russian Federation (ex-Soviet Union, is not a member of Intelsat. Instead, in 1971 it created a similar multinational organization named Intersputnik, which provides FSS for its 14 member states and a number of other associated countries. This system uses the families of former Soviet communications satellites, such as Molniya, Raduga and Gorizont, using GEO, HEO and PEO satellite coverage. This Organization also provides MSS networks for maritime and other mobile applications, using payloads carried by its GEO spacecraft Gorizont (Horizon), Raduga (Rainbow) and Morya (Seamen), such as: Volna (Wave), Morya and Gals (Tack) networks(Downing 1985).

4. ESA – The idea of creating an independent space organization in Europe goes back to the early 1960s when six European countries: Belgium, France, Germany, Italy, Holland, and UK, associated with Australia, to develop and build own FSS and MSS systems. In 1975, a Convention was endorsed at the political intergovernmental level to set up the European Space Agency (ESA), which entered into force on 31 October 1980. Since then ESA have been joined by 4 new members from Europe, while some other European states have expressed their interest to join ESA. In addition, the Cooperation agreements have also been signed to allow Canada to participate in certain ESA programs and to sit on the ESA Council. Apart from construction, launch and operation of the spacecraft, ESA has developed Artemis MSS, derived from former Prodat MSS for all three applications. At present ESA members are developing GSNS named Galileo and satellite augmentation systems EGNOS for maritime, land and aeronautical satellite CNS(Bonnet and Manno 1994).

5. Eutelsat – The European Telecommunications Satellite (Eutelsat) organization was founded in 1977 by representatives of 17 members of the European Conference of PTT and telecommunication Administrations, with headquarters based in Paris. Its major mandate was to establish and run the European satellite communications system. The constitution and financing of Eutelsat are modeled on those of Intelsat. In 1977 Eutelsat started work in 1977 with ESA on the exploitation of the Orbital Test Satellite (OTS) experimental communication boards and on the design of the operational European Communications Satellite (ECS) series for FSS and MSS service. Therefore, Eutelsat is providing regional MSS for all three applications with the current Emsat MSC system for maritime and land applications and the EutelTRACS system for mobile tracking and messaging. The latter system is developed by technical cooperation with Qualcomm, a US-based company, to establish communication network and equipment infrastructures(Fenech *et al.* 2001).

1.6.2. Former International MSS Operators

Former global international and regional MSS organizations and operators were Marisat, developed by the US-based Comsat Company Marecs, which was formed by European nations and Prodat was a project of ESA.

1. Marisat MSS – The World's first MMSC system as an application of the GEO system was unveiled in 1976 with three satellites and ocean networks Atlantic, Pacific and Indian. The Hughes Aircraft Company, known today as Boeing Satellite Systems, under contract to Comsat General Corp, built three multifrequency spacecraft called Marisat (Maritime Satellite), for the space segment of the world's first MMSC operator. The Comsat General was developed a Marisat UHF transponder in a band from 240 to 400 MHz (P-band) for US Navy vessels, illustrated in **Figure 6.** Because there was sufficient margin for additional payload, L and C-band transponders were installed on three Marisat satellite AOR, IOR and POR to provide commercial MSC for maritime applications.

Fixed CES for mobile service were located at Santa Paola for POR, in Southbury for AOR and in Fucino and Yamaguchi for IOR. The Marisat system was controlled by NCC located in Washington. Satellite Tracking, Telemetry and Command (TT&C) are also conducted over C-band frequencies. However, the governments of many other countries were not quite content for the control of MSC with their ships to rest with a foreign commercial corporation. Owing to this problem, in 1976 under the aegis of IMCO an agreement was drawn up for the establishment of an Inmarsat organization, initially for maritime and later for land and aeronautical services.

2. Marecs MSS – The ESA organization developed Maritime European Communications Satellite (Marecs) project covering study, development, launch and in-orbit operations of communication spacecraft to be integrated in a global MMSC. Initially ESA members in 1973 developed the experimental Maritime Orbital Test Satellite (MAROTS). The Marecs satellite was part of the GMSC system configured to provide high quality MMSC between SES and CES with automatic connection to the TTN. The Marecs satellites have operated for Inmarsat first generation MMSC network.

3. Prodat MSS – Initially ESA has developed Prosat MSS project primarily consisted for two-way low rate data system for short messaging and tracking system. The next project was referred as a Promar and finally was developed the low cost digital data service known as Prodat available for all mobile applications on 1.6 GHz band to the satellite and in turn to ground on 6 GHz carrier. The Prodat program conducted successful trials with low data terminals using the Marecs satellite. Also two L-band MSC payloads are being procured by ESA to promote European MSS via Italsat 1-F2 and Artemis satellites(Ilcev, SD 2005a).

1.7. Frequency Designations and Classification of Services

The assignment of a radiocommunications frequency, band or channels is performed by an authorized administration for radiocommunications via platform, satellite or space stations to use an RF spectrum or frequency channels under specified conditions. The allocation of a RF band makes possible its entry in the Table of Frequency Allocations of a given RF band for terrestrial or space radiocommunications service.

In satellite communication fields the frequency bands are often denoted with alphabetical symbols such as L to Ka-bands. Frequency band numbers and names are defined by the ITU RR, ITU Tables of Frequency Allocations in general or for a particular band and the mentioned alphabetic symbols by the IEEE Standard Radar Definitions. The radio spectrum shall be subdivided into nine RF bands and designated by progressive whole numbers, in accordance with **Table 1.1.**

Table 1.1. Frequency Bands Designation

Band No.	Abbreviation	Band name	Name	Symbol	Frequency
4	VLF	Very Low Frequency	Myria m		3-30 kHz
5	LF	Low Frequency	Km		30-300 kHz
6	MF	Medium Frequency	Hm		300-3000 kHz
7	HF	High Frequency	Dam		3-30 MHz
8	VHF	Very High Frequency	m		30-300 MHz
9	UHF	Ultra High Frequency	dm		300-3000 MHz
				L-band	1-2 GHz
				S-band	2-4 GHz
10	SHF	Super High Frequency	cm		3-30 GHz
				C-band	4-8 GHz
				X-band	8-12 GHz
				Ku-band	12-18 GHz
				K-band	18-27 GHz
				Ka-band	27-40 GHz
11	EHF	Extremely High Frequency	mm		30-300 GHz
12	VEHF	Very Extremely High Frequency	deci mm		300-3000 GHz

In a more general sense, frequency designations for MSS are used by a number of different administrations for their national or international MSS networks and can be systematized into two main categories:

1. Frequency Allocations for Service Links – The frequency allocation for service links in current mobile satellite communications for commercial use are in L-band at 1.5 GHz (downlinks) and at 1.6 GHz (uplinks). In addition to the L-band designations, there are other MSS frequency band allocations for service links between MES and spacecraft, shown in **Table 1.2.**

Table 1.2. Frequency Spectrum for MSS Service Links

Uplink (MHz) - Tx Earth (MES)-Spacecraft	Downlink (MHz) – RxSpacecraft-Earth MES)	Comments
128 and 240 except 121.5 and 406.025 243 except 1645.5-1646.5 1610-1621,35 1626.5-1660.5 except 1645.5-1646 148-149.9 148-150.05 312-315 399.9-400.05 & 406-406.1 454-460 1610-1626.5 2660.2-2690 1980-2010 27500-30000 1215-1260	 1544.5 1544-1545 2483.5-2500 (Globalstar) 1525-1559 except 1544-1545 400.505-400.645 (Faisat) 137-138 (Leo One) 387-390 400.15-401 400.505-400.645 (Faisat) 2483.5-2500 2500-2535 (N-Star) 2170-2200 17700-20200	Distress and safety band allocated for former SAMSARS and DRCS system, respectively Distress/safety bands allocated for Cospas-Sarsat system Commercial/Distress bands allocated for Inmarsat system Principal current frequency allocations for MSS at L-band using by MMSS, MLSS and AMSS applications New MSS frequency allocations made in WARC-92, WRC-95 and WRC-97 for GEO and Non-GEO MSS and RDSS applications; last allocation will take effect from January 2005 Satellite component of IMT-2000 worldwide Frequency allocations for GNSS applications Teledesic

New frequency bands below 3 GHz were allocated for MSS at WARC-92 and WRC-95. The new allocations below band of 1 GHz are very narrowly designated for only LEO configurations, while GEO satellites are excluded from most of the terms. Very soon, it will be clear which of the new bands above 1 GHz should be used for MSS via GEO satellites and the rest will be available for Big LEO systems and satellites in other Non-GEO constellations. Moreover, there are also Land Mobile Satellite System (LMSS) allocations for land vehicles at 14.0–14.5 GHz.

2. Frequency Allocations for Feeder Links – The feeder links between LES and satellites are illustrated for most MSS in **Table 1.3.**

In such a manner, all radio frequency allocations can be designated for global and regional satellite coverage. The subcategories of frequency allocation are divided into three regions and among three mobile applications. All frequencies used between satellite and MES are part of MSS and can be classified into three main allocations: MMSS for ships, LMSS for land vehicles and AMSS for aircraft. Some allocations differentiate among the MMSS, the LMSS and the AMSS scheme and are somewhat complex in detail. However, the regional frequency allocations for corresponding countries are systemized into Regions 1, 2 and 3, respectively.

In addition, there are also allocations for other services within these frequency bands in some countries but most of these shared allocations are of secondary status. Finally, new Ka-band allocations are being studied by NASA for commercial MSS and may present a feasible opportunity.

The ITU has defined many communication services within its RR that can be carried out by satellite systems and has developed many rules for worldwide RR of the services in order to maximize the peaceful use of outer space. In this instance, depending on the specific purpose and services, satellite communications can be classified into several services, as explained later. In effect, many of these services have been provided under the auspices of special satellite organizations set up to develop, operate and market the service.

Table 1.3. Frequency Spectrum for MSS Feeder Links

Uplink (GHz) - Tx Earth-Spacecraft	Downlink (GHz) - Rx Spacecraft-Earth	Comments
0.148-0.14855	0.1370725-0.1379275	E-Sat
0.148-0.15005	0.400150-0.401000	Leo One
0.150-0.15005	0.400505-0.400645	Faisat (WARC-92)
6.345-6.425	4.120-4.200	N-Sat
6.425-6.725	3.400-3.629	Inmarsat, Thuraya
5.091-5.250	6.875-7.075 5.091-5.150 temporary 5.150-5.216 from 2010	New MSS frequency allocations made in WRC-95 for GEO and Non-GEO MSS and RDSS applications (ICO, Globalstar)
15.45-15.65	15.40-15.70	
13-13.25	10.75-10.95	MSAT
14.236-14.250	12.736-12.750	Emsat
14 & 30	11 & 20	MTSAT
29.1-29.3	19.4-19.6	Iridium

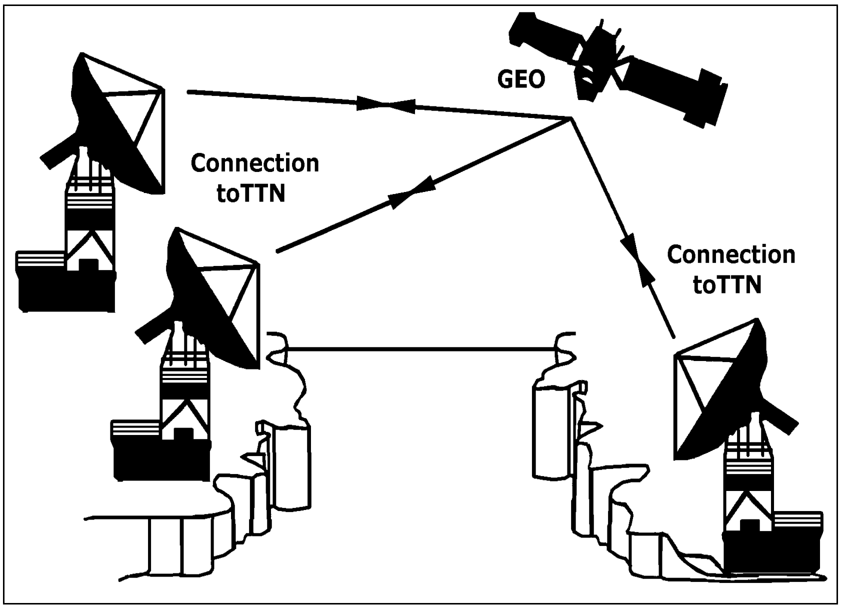

Figure 1.7. Fixed Satellite Network – Courtesy of Book: by Gallagher

As already mentioned, classification of an MSC service can be achieved by considering the role played by the geographical extent of network coverage on international, regional and local bases. All these organizations set up to handle these classes of satellite systems have a similar structure, only specific where the service spans national boundaries. Otherwise, the main classification of the satellite service in connection with the types of users has been realized on fixed and mobile units. Other satellite services can be meteorological, remote sensing, surveying, and so on(Gallagher 1989).

1.7.1. Fixed Satellite Service (FSS)

The FSS enables a radiocommunication links between two or more FES terminals at given positions, when one or more satellites are used, as illustrated in **Figure 1.7.** In this sense, the given position may be a specified point or any fixed point within a particular area. In some cases this particular service includes satellite-to-satellite links, which may also be operated in certain inter-satellite services. Moreover, the FSS solutions may also include feeder links for other space communication services, including MSS or MSS LES can provide service for FES as well.

The FSS signals are relayed between many FES, which are relatively large, complex and expensive systems. The FES terminals are connected to the conventional TTN and the service is intended for long distance voice, video and data communications. According to the WARC-85/88 principle plan the FSS shares frequency bands with terrestrial networks in the 4/6, 12/14 and 20/30 GHz, which guarantees every country equal access to the GEO space constellations.

A typical example of FSS is the Intelsat, one of the pioneers in satellite communications and networking. The first generation of the Intelsat system operated in the C band (4/6 GHz). At present, many regional systems such as Optus in Australia and JCSAT in Japan operate in the Ku band (30/14 GHz), such as Olympus and CS, which provide coverage throughout most of Europe and Japan, respectively. This service may include Satellite Voice and new VSAT networks.

The additional FSS organizations and operators are the Russian Intersputnik, European Eutelsat and ESA including other global, multinational or intergovernmental operators serving outside domestic and regional boundaries.

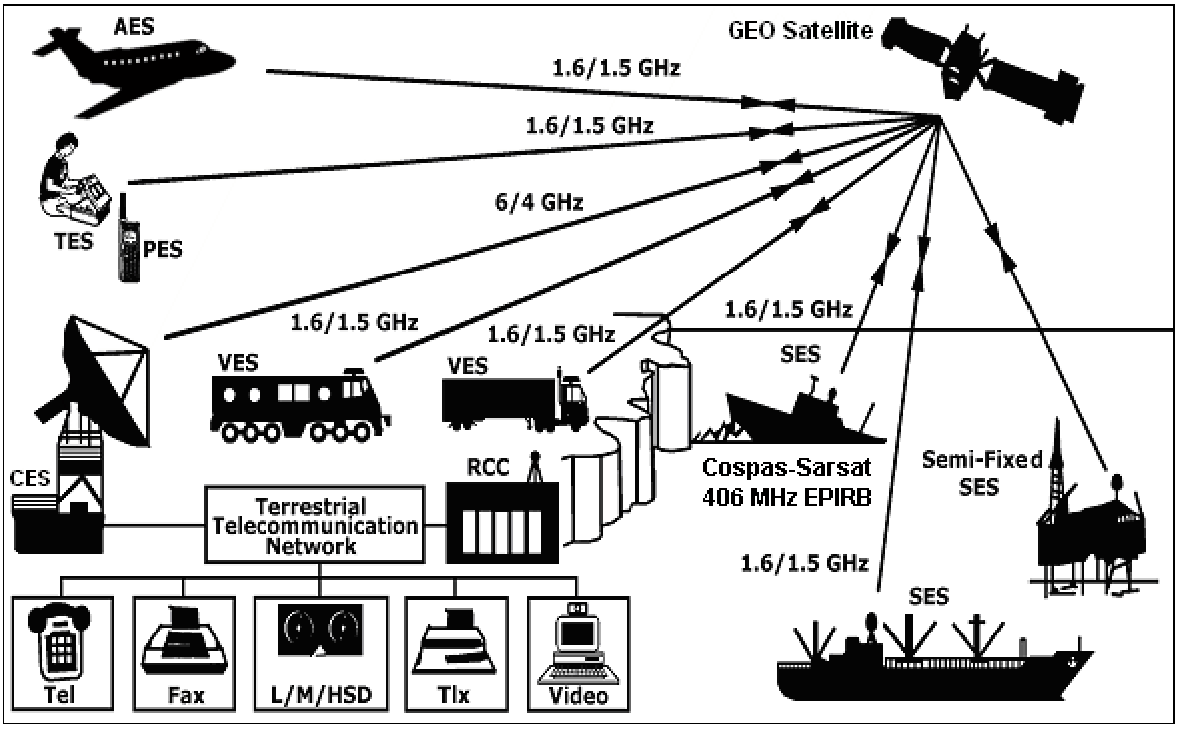

Figure 1.8. Mobile Satellite Network– Courtesy of Book: by Ilcev

1.7.2. Mobile Satellite Service (MSS)

The MSS consists of three types of GMSC services: maritime, land and aeronautical and may include the space segment, Mobile and Land Earth stations (MES and CLES) with all mobile applications (SES, VES, AES, TES, PES), Coordination and Control stations, RCC, other control centres and TTN interface with subscribers, shown in **Figure 1.8.**

The MSS enables satellite linkage between MES and one or more space stations or between space stations used for this service, or between two or more MES by means of one or more space stations. This service may also include service and feeder links necessary for its operations and in such a way MES can be connected via service link to the satellite and from the satellite via feeder link to the CES.

However, the Land Earth Stations (LES) in MSS can be CES for both maritime and land applications and Ground Earth Station (GES) for aeronautical application. In a more general sense, this modern classification can be a provisional proposal but for the moment gives the reasonable ideas for future establishment some practical universal nomenclature of GMSC terms. The LES is a special Earth Station in MSC located at a specified fixed point or within a specified area on land, to provide a feeder link for MSS. The Base Earth Station (BES) or Gateway is an Earth station in mobile or fixed satellite service located at a specified fixed point, or within a specified area on land, to provide a feeder link for the MSS, especially for Non-GEO systems.

Satellite radio beacons for indicating distress emergency position is a special Earth station in the MSS, the emissions of which are intended to facilitate SAR operation for distress in maritime, land and aeronautical applications, EPIRB, PLB and ELT, respectively.

The service link is a connection between MES and satellite, while the feeder link means of a duplex connection between CES or GES in the given location and spacecraft of the various MSC services operate in frequency bands allocated to the FSS. Thus, the given location of MSS may be at a specified fixed point or at any point within specified areas. Therefore, a satellite link comprises one uplink and one downlink performing radio linkage between a transmitting and receiving Earth station.

1. Maritime Mobile Satellite Service (MMSS) –The MMSS is a service in which MES is located on board merchant or military ships, other floating objects, rigs or offshore units, hovercrafts and/or survival craft stations providing commercial, logistic, tracking, defense and safety communications. The special maritime Emergency Position Indicating Radio Beacon (EPIRB) terminal, either portable or fixed stations on board ships may participate in this service as well. The EPIRB is a special Earth station in the MMSS, the emission of which is intended to facilitate urgent SAR operation via Cospas-Sarsat system for vessels in distress. The MMSS service enables satellite links between CES and SES, between two or more SES and/or between associated ships and other satellite communications stations in all positions at sea or in ports.

The SES is the MES in the MMSS system capable of surface movement at sea within the geographical limits of a country or continent. In distinction from conventional radio system, a ship fitted with SES in or near a port may operate with CES or other SES in cases of distress and commercial operations. The CES is a maritime Earth station located at a specified fixed point on the coast to provide a feeder link for MMSS. The SES is an Earth station fixed on board ships or other floating objects, which can provide communications links with subscribers onshore via CES and communications spacecraft. The ship on scene radiocommunications and alert service performs a distress and safety service in the MMSS between one or more SES and CES, or between two or more nearby SES, or between SES and RCC in which alert messages are useful to those concerned with the movement and position of ships and of ships in distress(Wu *et al.* 1994).

2. Land Mobile Satellite Service (LMSS) – The LMSS is a service in which MES is located on different types of road or rail civil or military vehicles, providing logistics, tracking and business communications, or it can be a TES terminal. The land emergency Personal Locator Beacon (PLB) terminal may also participate in this service.

3. Aeronautical Mobile Satellite Service (AMSS) –The AMSS is a service in which MES is located on different types of civil or military aircraft providing commercial, logistics, tracking, traffic control, management and safety communications. The special Emergency Locator Transmitter (ELT) terminal either portable or fixed onboard aircraft may also participate in the SAR operations in distress and emergencies at sea, on the ground and for aeronautical applications.

4. Personal Mobile Satellite Service (PMSS)–The PMSS is a service in which MES is handled by individuals and serving everyone in wherever position possessing handset satellite phones or tracking devices(Ippolito *et al.* 1981; Elbert 2004; Ilcev, SD 2005a).

1.7.3. Radio Navigation Satellite Service (RNSS)

The RNSS is recognized by ITU as a safety service, which can be used for the purposes of safety navigation and secure sailing or flight including obstruction warnings. The RNSS is an on-directional system, in which only mobile stations can know its own position, others cannot. Thus, to improve such kind of service it is necessary to integrate MSC transceivers onboard mobiles, which may sent Position, Velocity and Time (PVT) data to area Traffic Control Centre (TCC) and in the same time to receive PVT of near by mobiles processed in TCC. This service may include:

1. Maritime Radio Navigation Satellite Service (MRNSS) – This is a special service in which Earth Station or/and satellite navigation equipment is located on board ships.

2. Land Radio Navigation Satellite Service (LRNSS) – This is a special service in which Earth stations or/and satellite navigation equipment is located on board land vehicle.

3. Aeronautical Radio Navigation Satellite Service (ARNSS) – This is a special service in which Earth stations or/and satellite navigation equipment is located on board aircraft(Forssell 2008).

1.7.4. Radio Determination Satellite Service (RDSS)

With the recent development of MSC systems and the diversified demands for reliable communication, there has been increasing necessity to utilize the position of the mobile object as the information. This idea is proposed and has been developed prototype in various countries of the world as the Radio Determination Satellite System (RDSS).

The RDSS is a special MSC service that combines two-way digital communications, highly accurate positioning and digital interconnection to satellite communication networks for the purpose of radio determination involving the use of one or more space stations and may include feeder links necessary for its own operations.

According to the ITU definition, RDSS system is special service provides the satellite radio determination of the PTV data and other characteristics of each moving object and all mobile applications, or to obtain information relating to these parameters by means of the propagation properties of radio waves.

The GEOSTAR system began its initial operations in 1988 and was the first regional RDSS system to provide regular service to all mobile users within the territories of the entire United States, Southern Canada and Northern Mexico territory. This system employs a spread spectrum of Code Division Multiple Access (CDMA) modulation technique allowing multiple customers to use the system simultaneously, without preassigned coordination with fellow users. Position-location information is currently determined by employing an existing radio determination receiver, such as Loran-C, GPS or GLONASS, in the mobile user terminal. In the early 1990'sposition-location of mobile station was determined at a central Ground Earth Station by time-differential ranging of the user terminals via two or more GEO satellites. This system is a medium data rate of 15.625 Kb/s position reporting service, which employs ancillary message communications.

Today, a typical global RDSS service provides Inmarsat, Globalstar, Iridium and Orbcomm MSS, which provides two-way voice and data communications, positioning and tracking services in a self-consistent manner. Using these MSS, a mobile station has the possibility to determinate its own position, when other user stations can also know that position, for example, handheld, fixed and other Earth stations or a station installed in an office or onboard mobiles. In distinction from a radio navigation one-directional system, the RDSS system is a bi-directional system. Namely, this service is dedicated to provide positioning, tracking, determination and logistics employing the US GPS or Russian GLONASS onboard receivers integrated in one unit together with GEO or Non-GEO satellite transceiver. In such a way, it can be used GEO Inmarsat system or Non-GEO systems, such as Globalstar, Iridium and Orbcomm.

The newest GNSS development is the Chinese BeiDou Navigation Satellite System (BDS) provides both RNSS and RDSS. The RDSS users can obtain positioning by responding the Master Control Center (MCC) inquiries to signal transmitted via GEO satellite transponder. The positioning result can be calculated with elevation constraint by MCC terminal. Thus, the primary error sources affecting the RDSS positioning accuracy are the RDSS signal transceiver delay, atmospheric trans-mission delay and GEO satellite position error. During GEO orbit maneuvers, poor orbit forecast accuracy significantly impacts RDSS services. A real-time 3-D orbital correction method based on wide-area differential technique is raised to correct the orbital error(Grewal, MS *et al.* 2007).

However, results from the observation shows that the method can successfully improve positioning precision during orbital maneuver, independent from the RDSS reference station. This improvement can reach 50% maximum rate. Accurate calibration of the RDSS signal transceiver delay precision and a digital elevation map may have a critical role in high precise RDSS positioning services.

1.7.5. Radio Location Satellite Service (RLSS)

The Radiolocation Satellite Service (RLSS) is a radiodetermination-satellite service used for the purpose of radiolocation. Thus, radiolocation is the process of finding the location or position of something or moving objects through the use of radiowaves in space. The RLSS solutions are passive radiodetermination-satellite service used for the purpose of radiolocation. This service may also include the feeder links necessary for its operation.

This system generally refers to passive equipment and ground uses, particularly such as Space Synthetic Aperture Radars (SSAR) fixed onboard GEO or Non-GEO spacecraft or Stratospheric Communication Platforms (SCP). In fact, for SSAR via SCP can be used airship or aircraft at about 20-25 Km in the stratosphere, which also are known as Unmanned Aerial Vehicle (UAV) or High Altitude Platforms (HAP).

In addition, for location of fixed and moving objects can be used Ground Synthetic Aperture Radar (GSAR) mounted on shore or onboard ships or helicopters. All systems are part of radiodetermination and also can be used in Real Time Locating Systems (RTLS) for tracking valuable fixed and mobile assets. This system is also similar to radionavigation, but radiolocation usually refers to passively finding a distant object rather than actively one's own position.

The Radio Detection and Ranging (RADAR) device is passive electronic equipment an object detecting system, which uses radiowaves to determine the range, altitude, direction and speed of moving including fixed objects. It can be used to detect moving objects such as ships, aircraft, spacecraft, guided missiles, ground vehicles, clouds, weather formations and so on, including can determine terrain and fixed objects at ground. The radar dish or antenna transmits pulses of radio waves or microwave, which bounce off any object in their path. The object returns a tiny part of the wave's energy back to a dish or antenna and receiver, which are usually located at the same site as the transmitter.

Other systems similar to radar technology using other parts of the Electromagnetic (EM) spectrum is Light Detection and Ranging (LIDAR), which uses visible light from laser rather than radiowaves and Laser Detection and Ranging (LADAR), which uses light to determine the distance to an object. Since the speed of light is well known, LADAR can use a short pulsed laser to illuminate a target and then time how long it takes the light to return. The advantage of LADAR over radar is that LADAR can also image the target at the same time as determine the distance. They are both acronyms that represent one type of remote sensing technology that can determine the distance between a sensor and an object. Coupled with the known location of the sensor, the range information can be used to produce a highly detailed 3-dimensional map of the object(Mullen *et al.* 1995).

The LIDAR system was on the scene when the technology started to emerge in the 1950's. As the technology gained adoption by the military the term LADAR emerged. The guess is that LADAR was popular with the defense community due to its similarity to radar, using a similar range finding technology that uses a different type of EM signals. Today, LIDAR is typically used by folks interested in mapping terrain or collecting information about the atmosphere. Whereas, LADAR is used for location smaller point targets like vehicles or other man-made objects.

The LADAR system works by firing photons (lasers) at a given object or area (terrain), it then measures the time of flight of photons (time to reflect back), this enables a Charge Coupled Device (CCD) style setup to encode each photon as a pixel and produce a 3D image of the object or area. This is the same technique used in LIDAR systems except instead of determining the speed of the object, LADER creates 3D images with the data, this relies on the assumption that the objects being modeled are stationary or the images produced will not show the object as it appears in real life(Gavan and Peled 1991).

1.7.6. Electro-Optical Space Surveillance (EOSS)

Ship detecting from space is an important application for maritime traffic surveillance and control of ship movements. However, fewer efforts were devoted to research on automatic detecting from optical satellite and stratospheric platforms imagery.
The major advantage of satellite imagery is that the satellite can be positioned to take images of anywhere on the planet. Being in space, it is more efficient for a satellite to allow the Earth to revolve below it than to physically move to the necessary location. Satellites still need to take into account the location of the Sun to acquire visible light surveys so many satellites try to remain in a sun-synchronous orbit.
Below is a list of benefits and weaknesses for both satellite imagery and airship or aircraft SCP or HAP photography.
1. Speed – Satellites have advantages over HAP, because they are capable of collecting large amounts of data in relatively small amounts of time and can take the photographs quickly once locked on to an area. The sizes of these pictures are very large and allow the complete area to be captured using less images in a shorter space of time.
The HUP photography used to be a slow and time consuming process. The amount of time taken to capture an area depends greatly on its size and shape. The dawn of digital photography cameras has made the acquisition of HAP photography considerably quicker. However, newest cameras are making this faster still by recording strips of data rather than individual frames.
2. Level of Details (Resolution) – Satellites generally reside several hundred kilometers above the Earth's surface. Although satellite imagery has improved greatly over years it is still lower resolution than aerial photography. High resolution satellite imagery as high as 50cm per pixel is readily available, up to 41cm in the case of spacecraft GeoEye-1.
The HUP photography has the distinct advantage of having the lens closer to the ground fixed and moving objects. By adjusting the flying height of the HAP capturing the data it is possible to improve the resolution of photos. Most HAP photography was flown with a resolution of between 50cm to 12.5cm per pixel. However, with the new technologies of photographic cameras it is possible with photos with 10cm per pixel. In some cases this can be as low as 5cm or 2.5cm per pixel.
3. Weather Conditions – Both satellite imagery and HAP photography can suffer from environmental conditions. Being higher up in the atmosphere means that satellites have more weather conditions to cope with. Thin cloud that may not stop aerial photography can still have a large effect on the quality of satellite imagery.
With relation to the position of the platforms in orbit and other requirements for different areas the satellite may be needed for clearer area. In this case the window of opportunity for photography may pass and it may be some time before the satellite can be repositioned. It is worth noting that radar data is not affected by weather conditions and it is cloud penetrating, so can be collected at any time.
Although HAP photography can be affected by adverse weather conditions there is still the possibility of photographing areas in the thin or high level cloud which might stop the use of satellites. This has a small bearing on the quality of the final image and can normally be rectified during the post-processing stage. Thus, there are also far more airships and aircraft available for taking photographs than there are satellites so if one plane is needed where the weather is clearer, then another may be available to take its place.
4. Types of Data – Many modern satellites can collect a variety of data, such as standard photographic imagery, color infrared and in some cases LIDAR and radar data. The main problem with satellite data types is that when new or improved technology is released it is impossible to change the sensors and cameras in any satellite.
After daily operation aircraft or helicopters are landing and have possibility for removing the old device and replacing it with the new one, while airship or some aircraft HAP would soar

over a particular region to provide an array of telecommunication services. At the end of the mission, HAP would be glided back on the ground for maintenance. Hence, between landings, the HUP carries a communications payload and operates for up to six months continuously in the stratosphere above the weather and commercial air traffic.

5. Post-processing – Imagery acquired by satellite usually consists of far fewer “shots” than that taken by aircraft. The extra distance means that more area can be covered in one pass - at the deficit of detail. Satellites usually capture data in strips (similar to a continual video of the area) and allow a larger amount of data to be acquired per digital file. This requires far less post-processing than if it were to capture individual “frame” images.

Early aircraft photography was made up of tens of thousands of individual photographs. Recent developments in aircraft camera design have moved away from these traditional images towards the satellite’s method of capturing strips of imagery instead. In such a way, this has greatly reduced the amount of post-processing work required but, with its lower flying height, there are still more images than with the higher levitation of satellites(Viggh *et al.* 1997).

1.7.7. Space Automatic Identification System (SAIS)

Current terrestrial-based Automatic Identification System (AIS) of ships provides only limited service nearby shorelines in the range of VHF radio system and are not able to provide global coverage. The GEO and LEO Non-GEO (LEO) satellite systems can provide new Satellite AIS (SAIS) for an onboard of broadcast system that transmits a ship’s identification, position and other critical data, which can be used to assist in the ship’s navigation and tracking facilities for improving maritime safety and security. The SAIS systems overcome many of these issues thanks to a fully satellite service and coverage, which is able to monitor maritime vessels, including landed aircraft at sea well beyond the coastal regions in a cost-effective and timely fashion.

2. Chapter 2

AIMS AND OBJECTIVES

The main aim and objective of this thesis is to carry out a general overview of the current and new Radio and Space Tracking and Detecting systems of ships navigating at open oceans, sea passages, in the cramped channel strips, costal waters, approaching to the anchorages and inside of seaports. The more critical scenario is when the ship is sailing across oceans and coastal areas in very bad weather condition, when visible and audibility is zero, when sometimes is not possible to use surveillance radar and when is very difficult to detect surrounded ships for collision avoidance.

To provide more reliable, affordable and effective situation onboard ship will be necessary to employ all necessary tracking and detecting equipment and systems supported by Maritime Radio and Space Communication, Navigation and Surveillance (CNS) solutions. Some of this equipment is part of the Global Maritime Distress and Safety System (GMDDS) developed by IMO, Inmarsat and Cospas-Sarsat systems.

1. Modern Radio Tracking and Detecting Systems and Equipment – These systems usually use traditional MF, HF, VHF, UHF and SHF-band integrated or autonomous CNS equipment onboard of ships, vehicles and aircraft such as follows:

1. Shipborne S and X-band Surveillance Radars;
2. Coastal HF Surveillance Radars for coastal and seaport monitoring and management;
3. Radio Multiband and Multifunctional Direction Finders for ships and personal detecting;
4. Radio VHF Automatic Identification System (R-AIS) is a most attractive system at present for tracking and detecting of ships in coastal navigation;
5. Radio AIS (R-AIS) Airborne VDL System for fitting onboard airplane and helicopters for use in SAR, monitoring and coastal surveillance mission of ships and aircrafts in distress.
6. Radio Local Ships Tracking R-LST or Radio VHF Data Link (R-VDL) is new solution suitable to support CNS functions of ships at anchorages and ships and vehicles in seaports;
7. Radio Automatic Dependent Surveillance - Broadcast (RADS-B) is a new system that uses VHF radio transmissions from ships to provide position, velocity, positional integrity, sailing identity, and other data that have been detected and computed by onboard ship sensors;
8. Radio GNSS Augmentation VDL-Broadcast (GAVDL-B) is also modern Local VHF Augmentation System (LVAS) system able to transmit and receive augmentation GNSS signals for maritime CNS solutions and enhanced collision avoidance system; and
9. Radio Search and Rescue Transponder(SART) for identification of lifeboat and survival craft by marine surveillance radar during distress alert.

2. Modern Space Tracking and Detecting Systems and Equipment – These systems usually use VHF, UHF and SHF-band integrated or autonomous onboard mobiles CNS equipment such as follows:

1. Satellite Long Distance Identification and Tracking (LRIT) (Shuang and Junzhong 2007)system is providing positioning data for detecting and monitoring of seagoing ships sent by onboard satellite equipment via GEO Inmarsat or Big Low Earth Orbit (LEO) Iridium networks;
2. Global Ship Tracking (GST) network and equipment for regional and global Satellite Asset Tracking (SAT) of vessels via Inmarsat, Iridium, Globalstar, Orbcomm and other satellite constellations. In comparison with LRIT new proposed GST can provide the same automatic positioning data to the Ship Control Centers (SCC) and is designed to provide vice versa positioning data of adjacent ships in a sailing area of any ship that is requesting these critical data, what LRIT cannot. This unit is also very suitable for tracking of pirated ships;

3. Regional Ship Tracking (RST) via SCP or UAV will provide transmission of automatic positioning data for all ships sailing in this region and each ship in this region will be able to receive positioning data for all adjacent ships for improved collision avoidance;
4. Space Automatic Identification Systems (Space-AIS) uses new proposed satellite and SCP solutions that will serve all ships sailing across oceans out of the R-AIS and VHF range.
5. Satellite Data Link (SDL) Tracking Messages Service similar to aeronautical VDL Mode 4 system, which is able to provide a satellite broadcast link supporting ship's navigation and surveillance functions via Short Burst Messages (SBM) and High Speed Data (HSD) service for CNS purposes;
6. Satellite GNSS Augmentation SDL (GASDL) is new Regional Satellite Augmentation System (RSAS) system able to transmit and receive augmentation GNSS signals for maritime CNS solutions and enhanced collision avoidance system;
7. Satellite Automatic Dependent Surveillance - Broadcast (SADS-B) system is new satellite broadcasting from ships known as service Oceanic Sailing Guidance and Control (OSGC) and Coastal Movement Guidance and Control (CMGC) providing Position, Velocity and Time (PVT), positional integrity, ship identity and other data that have been detected and computed by onboard ship sensors for enhanced safety and security in deep sea navigation;
8. Space Remote Sensing of vessels via Space Synthetic Aperture Radar (SSAR), Ladar or Lidar and Electro-Optical Space Surveillance (EOSS) using the existing facilities of GEO and Non-GEO satellite constellations including SCP or UAV platforms; and
9. Satellite Distress Beacons for SAR Operations.

When is question about for the ship detecting, identification and its classification, it will be necessary to go to the wide area of monitoring and it may be possible only through satellite tracking and detecting approach, which monitors and covers coastal as well as the oceanic zone. Thus, the satellite solutions including SSAR have been widely used to detect targets of interest with the advantage of the operating capability in all weather and luminance free conditions. It is crucial to monitor and manage ships in extremely bad weather conditions, in dense fog with visibility zero, severe wind and high swells. In such very critical weather conditions is essentially important that ship's captain has to know the position of the adjacent ships using any suitable solutions for safe navigation and collision avoidance. At this point, in EU waters, European Maritime Safety Agency (EMSA) is operating the solutions of Safe Sea Net and Clean Sea Net systems, which provide the current positions of all vessels, ice breakers and oil spill monitoring information in and around EU waters in a single picture to Member States using current R-AIS, LRIT and SSAR images. In many countries, a similar system has been developed and the key of the matter is to integrate all available data.

This thesis describes the preliminary design concept for an integration system of Radio and Space tracking and detecting data for intensive vessel traffic monitoring, management, safe navigation and enhanced collision avoidance. The remote sensing of SSAR sensors is used to acquire image data over a large coverage area, either through the space borne or airborne platforms including SCP or UAV stratospheric stations. The reports of R-AIS and S-AIS should be also obtained on the same date as of the SSAR acquisition for the purpose to perform integration test globally. Land-based RADAR can provide ship's positions detected and tracked in near real time in coastal navigation. The GST equipment onboard ships are the best solution for tracking and determination of ships in distress alert or emergency situation.

In general, SSAR are used to acquire image data over a large coverage area, R-AIS reports and other VHF radio solutions are obtained from ship based transmitter (Tx) in VHF range, Long range radio solutions are able to obtain global monitoring and surveillance, S-AIS and other space solutions will generate regional or global remote sensing of ships, shore radars are able to monitor continuously ships for a limited area and ship's radars can monitor sea and coastal areas below horizon.

Here is also important to introduce space communication and its advantages over terrestrial communication, the types of satellite available and their comparative study, what constitute

impairments in the propagation channel will be discussed, also the major technology models describing various types of environment will be reviewed and he investigation of few of the popular models and their implementation will be conducted.
In particular the aims of this study are to:
1. Examine the unpublished at-sea observer data to determine if areas with particularly high species richness or numerical abundance vary with location;
2. Collate and analyze satellite tracking results to determine if any areas show high densities of all tracked ships; and
3. If appropriate recommended potential of technology recourses on the basis of at-sea different observation and/or satellite tracking results.
In this study is developed individual ship monitoring, tracking and detecting of pirated ships at sea by discrete installation of proposed GST equipment onboard ships that are planning to navigate in areas operated by pirates. In addition, is elaborated new type of proposing open circuit quadrifilar helix antenna, which may be used for both in the same time Radio and Satellite AIS and that it will improve communication facilities and range of radiation. The further work is calculation of real quadrifilar helix antenna and testing in real environment. The last goal of research is proposed for development of all radio and space systems via SCP or UAV platforms using airships or aircraft in about 20 Km in stratosphere.

2.1. Structure of the Ships Tracking and Detecting Systems

This dissertation contains main aspects of radio and space tracking and detecting systems, which are going to be considered, researched and introduced in this thesis. In the statements of these subsections are described in details problems of existing maritime tracking and detecting, their improvements and integration with new systems for automatic identification of ships. In effect, modern solutions and proposals for determination of ships via satellites and stratospheric platforms, significant problems of pirating merchant vessels at sea and a description of the ship tracking and monitoring system for the South African coastal waters are also included. In accordance to the stated problems in this thesis are proposed aims and objectives that will provide research and studies of several above stated systems for radio and space solutions for tracking and detecting of vessels sailing at open oceans, sea passages, in coastal navigation, approaching to anchorages and in the seaports involving different space technologies. Such described aspects in this thesis are as follows:
1. The fundamental reason of conducting this research and study is to show the sense and the core of the research scope and actuality of these techniques and technologies, which propose several essential solutions as the actuality of the conducted study. In the rationale of the study are emphasized main aspects of proposed solutions that are practically useful and reasonable as applications;
2. Benefit of study mainly shows how this research material can help for other specialists and other researches in this field of similar science. Also shows how output of work as the results of this thesis can be useful to be applied for real solutions;
3. Developments in this study show that the proposed material and technique can be realized and implemented practically in the reality. Some part of the thesis contains more theoretical and analytical character because this research is strongly dedicated to the design, development and implementation of new projects, which have to improve tracking and detecting facilities of ships, to enhance safety and security in all stages of navigation and to upgrade collision avoidance in critical weather and traffic situation. The additional overview of all further chapters gives clear information about main structure of this research.

2.1.1. Statements of the Problems

There is a big variety of tracking system for different mobiles such as: ships and sea rigs, land vehicles (road and rails), aircraft, persons, animals and etc. Modern tracking systems for maritime applications are developed in high level, but still there are problems of reliability of existing tracking networks and equipment, respectively. Several problems of tracking system for maritime applications can be further emphasized.

2.1.1.1 The Lack of a Reliable Ships Tracking and Detecting Systems

Presently there are not some suitable systems that may work in any extreme weather or bad propagation situations and provide reliable tracking, detecting, determination and enhanced collision avoidance service. Sometimes ship sailing in extremely bad weather circumstances is not able to get situation of other ships in the vicinity, because surveillance radar is not getting a picture on the screen and other communication equipment have limited range. At this pint, current LRIT and AIS networks are not providing position and course of all ships in vicinity of ship requesting these data. The most reliable system is new proposed Global Ship Tracking (GST) system via GEO or Not-GEO satellite constellations, which will be detailed introduced in Chapter 5 of this thesis. In addition, the Regional Ship Tracking (RTS) via Stratospheric Communication Platforms (SCP) or UAV will be introduced.

2.1.1.2. Unreliable Systems for Tracking and Detecting of Pirated Ships

Today, piracy on merchant ships in certain sea areas is an actual “hot problem”. When pirates capture a ship, they switch-off all communication and navigation equipment onboard of the ship in order to hide the ship from the ship monitoring, tracking and detecting system. Since the pirated ship will not be able to use LRIT, R-AIS and other onboard equipment that can compromise the position and course of the captured ship by pirates. Hence, disabled navigation equipment onboard of the ship is completely useless and the ship becomes as a “piece” of a metal dish at sea. This is an important problem that still needs to find reasonable and reliable solutions to prevent capturing of ships by pirates or if a ship is captured, then to prevent the possibility to switch off hidden onboard tracking and detecting equipment. In order to solve stated problems for merchant ships, which are captured by pirates, several antipiracy solutions involving contemporary space technologies and solutions were defined in this thesis. These solutions are supposed to use discrete tracking devices onboard of a pirated ship and other radio and satellite possibilities, which can be installed and utilized from the shore, other ships and space technologies.

2.1.1.3. Inadequate Systems for Identification and Detecting of Ships

The Radio Automatic Identification System (R-AIS) networks and equipment that is used for tracking of ships exchanging positioning data with control centers have a problem to provide large service coverage. This is very important to glean position of ships in range of VHF coverage, but is more important to obtain a position of ships sailing in deep sea zones, far a way from VHF range(Schwehr and McGillivary 2007). In addition, the R-AIS system is using VHF-band for transmission of messages and so it needs direct Line-of-Sight (LOS) between ships R-AIS and Ground Base Station antennas, what sometimes is a problem in fiords, between islands, in channels and during very extreme weather conditions when clouds and dense fog are merged with the sea surface. In this critical situation cannot even work ship surveillance radar. Also, it may cause the master of the vessel to become more focused on the graphical displays rather than on keeping a proper lookout.

Finally, the glow from R-AIS screen may cause temporary visual impairment at night, which may hamper decision making, and so errors are resulting from improper equipment settings may contribute to an incident occurring.
For these reasons recently are proposed new solutions of global Space AIS (S-AIS) via GEO and Not-GEO satellite constellation and Stratospheric Communication Platforms (SCP) or UAV. The current professional MSS Inmarsat, Iridium, Globalstar and Orbcomm two way systems can be used for reliable GST or even S-AIS networks worldwide, which network will be introduced in this chapter. However, today, the most attractive solutions are S-AIS Nano or Cube Sat systems of very small spacecraft(Pranajaya *et al.* ; Narheim *et al.* 2008). The biggest problem of this type of spacecraft is that their design lifetimes are also much shorter than for instance the Iridium satellites. Due to the drag and use of non-radiation-hardened commercial components, Cube Sats are generally expected to have an operational lifetime of a few months to over a year, what is not adequate for professional solutions.
The more serious project of S-AIS is recently proposed by Little LEO Orbcomm MSS to use the VHF frequency band R-AIS onboard ships equipment and antenna via new launched Orbcomm S-AIS spacecraft. In such a way, both radio and satellite AIS systems can use the R-AIS onboard ship antenna for communication with Base Stations and other ships in LOS. In order to provide reliable radio communication with satellite will be considerate another type of antenna with different radiation pattern suitable for R-AIS and S-AIS system. At this point both systems will operate using the same VHF-band. However, this frequency band inherent several disadvantages in contrast to microwave frequency bands, thus here proposed a new solution to implement S-AIS radio communication through L and C-band via existing GEO and Not-GEO satellite networks like Inmarsat, Iridium and Globalstar.
As stated before, originally R-AIS was as radio system which could provide tracking traffic between ships and onshore AIS base station in LOS along of coast line. Radio communications between R-AIS units have been arranged in VHF-band antenna mounted on board of the ship and connected to R-AIS ship-born transponder. The VHF whip antenna doesn't suit for reliable radio communication with Orbcomm communication satellites. In Chapter 6 Will be done analysis of this whip VHF antenna to identify disadvantages and proposed another kind of an antenna for the VHF AIS system. This antenna is QHA and should be calculated for VHF band, and should be assembled and conducted experimental testing of its characteristics. In addition, the VHF-band has a high level of noise in radio channels, which suppress useful received data, and so, this aspect needs to be analyzed and find out solution for improvements.

2.1.2. Rationale and Benefits of Research

The research for this thesis is dedicated to solve technical problems with regards to physical equipment (hardware) and networks of tracking and detecting system, rather than improving software or creating new techniques of data processing. It is important to conclude that all tracking systems and devices cannot operate without applying adequate software and even IT and processing technology in the control centre. Every tracking mobile terminal or devices, satellite networks and data processing in the control center use a certain software, firmware and operating systems for data receiving, processing and distribution among of systems units. Essentially the IT technology and techniques are debugged and perfectly operate in every node of any existing tracking equipment. In such a way, software and firmware have today surpassed previous evolution in the development of modern radio and satellite devices and networks. Accordance with this fact, the most part of the work is dedicated to improve physical parts of tracking systems and propose new application, solutions, networks and projects. Therefore, this study and research give many new solutions in radio and satellite tracking and detecting systems and networks.

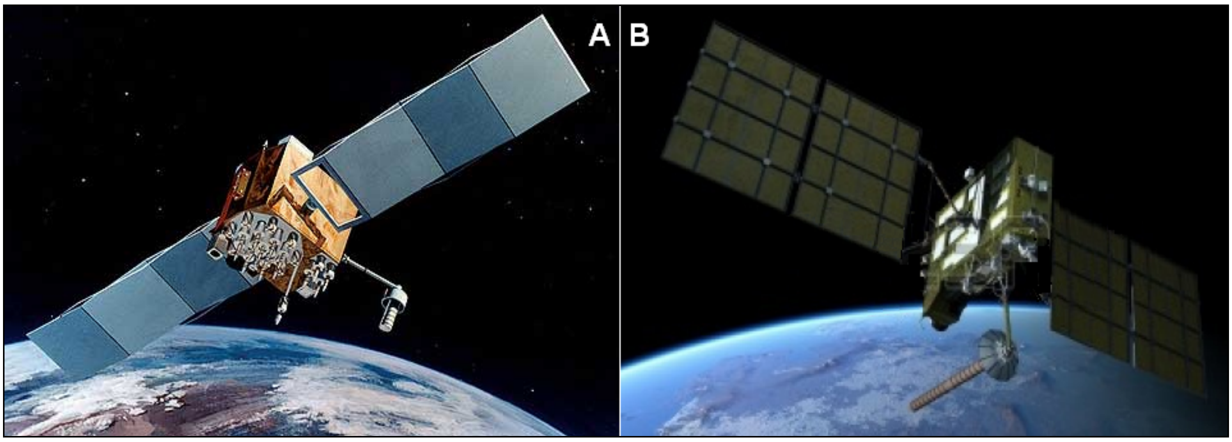

Figure 2.1. GPS and GLONASS Spacecraft – Courtesy of Presentation: by Ilcev

The theoretical and experimental framework include experiments, which can be completely applied as proposals and projects for real applications. Also theoretical and practical analyzes of tracking equipment and networks can be useful for other researchers and operational developers. This research doesn't contain any science fiction study, and gives possibilities for development of real applications.

2.1.3. Limitations of Study

The study and research are limited by only practical implementations of the proposed ideas and development of projects for tracking and detecting systems. These proposed projects of tracking and detecting system can be considered and developed only in the theoretical framework. Because, to realize practical implementations of some project, explained in this thesis, is necessary to consider more technical details, needs a long period for developing of them, adequate workshops and adequate funds. In addition, this research and projects need to be involved additional different workshops and research groups, such as mechanical, electrical, computer and electronics engineering, IT and computer science, physics and others technical disciplines as well.

2.2. Developing Aim of GNSS for Ship Tracking and Detecting

Today, two operating Global Navigation Satellite Systems (GNSS) such as the US Global Positioning System (GPS)(Parkinson and Spilker 1996), illustrated in **Figure 2.1 (A),** and Russian (Former-USSR) Global Navigation Satellite System (GLONASS) (Hofmann-Wellenhof *et al.* 2007), illustrated in **Figure 2.1 (B),** which name in Russian is “Глобальная Навигационнаяа Спутниковая Система (ГЛОНАСС)”. Both networks are part of the first generation of GNSS known as GNSS1 used for civilian and military applications serving maritime, land (road and railways and aeronautical applications. The GPS or GLONASS receivers are very important navigation aids onboard of any merchant ships. It is important to say that both GNSS1 systems are providing a significant impact on ship's oceanic navigation, providing accurate positions, but duty officers on the Navigation Bridge cannot use them to get the position of adjacent ships.
The new second generation of GNSS known as GNSS2 is in development phase, such as the Chinese Compass and European Galileo. The Compass or Beidou GNSS2 system provides regional coverage of China territory and in 2 years has to provide global coverage(Shu-Sen 2008). The Galileo is the GNSS2 system dedicated to be operational in 2013 for global coverage, but is a big question about the future of this project.

2.2.1. Characteristics of GNSS Networks

What has most significantly changed navigation techniques is the advent of GNSS, which started with the launch of the Soviet Union GLONASS project. In fact, the satellite navigation system was conceived in the late 1960s, and formal requirements were completed in 1970. The government of the Soviet Union made a decision to develop the system in 1976. Design work was carried out by specialists led by Vladimir Cheremisin at NPO PM in Krasnoyarsk-26. The first launch took place in 1982, so today GLONAS network has 24 operational satellites. The US GPS satellite network used by the NAVSTAR GPS started later with the program in 1974 and in 1978 the contract was extended to build an additional three Block I satellites, however the first GNSS satellite in the system of 24 spacecraft, Navstar 1, was launched on 22 February 1978. The GPS satellite constellation of is operated by the 50th Space Wing of the United States Air Force.
In **Table 2.1** is presented comparison of the the first GNSS generation characteristics, such as GLONASS and GPS spacecraft.

Table 2.1. Summary of Characteristics of the First GNSS Generation (GNSS1)

Title	**First Generation of GNSS (GNSS1)**	
GNSS1	GLONASS (Russian)	GPS (USA)
Quantity of Satellites	24	24
Type of Satellite Constellation	LEO	LEO
Satellite's Orbit Inclinations	$64{,}8^0$	55^0
Altitude of Satellites	19,100 Km	20,200 Km
Period of Circulation	11,15 hours	11,58 hours
Frequency Bands and Modulation/Channel Distribution	L1 = 1602/L2 = 1246 MHz BPSK/FDMA	L1 = 1575.42/L2 = 1227.6 MHz QPSK/CDMA
Types of Codes and Signal Characteristics	SP (standard precise code) HP (high precise code) Repetition of SP = 1ms Repetition of HP = 1week Chipping rate of SP = 1.023 Mb/s Chipping rate of HP = 10.23 Mb/s	C/A (code) P (precise code) Repetition of C/A = 1ms Repetition of P = 1week Chipping rate of C/A = 1.023 Mb/s Chipping rate of P = 10.23 Mb/s
Accuracy (horizontal, vertical and speed)	Horizontal (SP) = 5-10 m Vertical = 15 m Velocity vector = 10 m/s	Horizontal (C/A) = 5-10 m Vertical = 15 m Velocity vector = 10 m/s

As stated above, in the nearest future will be finalized and deploy GNSS-2, such as recently developed Chinese' Compass or Beidou for local service and European Galileo still in phase of development. In **Table 2.2** is presented comparison of the characteristics of the second GNSS generation, such as Compass and Galileo spacecraft(Wang *et al.* 2001).

Table 2.2. Summary of Characteristics of the Second GNSS Generation (GNSS2)

Title	**Second Generation of GNSS (GNSS2)**	
GNSS2	Compass or Beidou (China)	Galileo (Europe)
Quantity of satellites	35	30
Type Satellite Constellation	27 MEO/3 IGSO/5 GEO	30 MEO
Frequency Bands and Modulation/Channel Distribution	E2 = 1561/E2 = 1589 MHz E6 = 1268/E5b = 1207 MHz QPSK and BPSK/CDMA	E5a = 1176.45/E5b = 1207.14 MHz E5(E5a+ E5b) = 1207.14 MHz E6 = 1278.75/E1 = 1575.42 MHz BPSK and BPSK(m)/CDMA
Accuracy (horizontal, vertical, speed)	Horizontal (C/A) = 3 - 5 m Vertical = 3 - 5 m	Horizontal (SP) = 4 - 5 m Vertical = 4 - 5 m

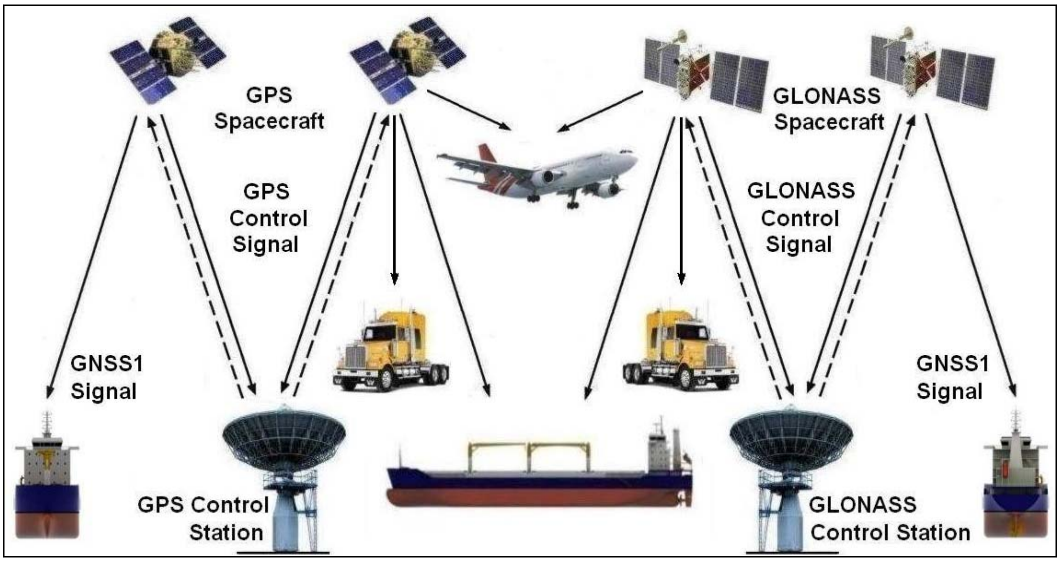

Figure 2.2. GPS and GLONASS Integrated GNSS1 Network – Courtesy of Presentation: by Ilcev

The GPS and GLONASS space segment consists of 24 GNSS1 spacecraft each and ground segment, which consist Ground Control Station (GCS) and Users Segment, illustrated in **Figure 2.2.** The GNSS1network is providing service for maritime, land (road and railway) and aeronautical applications, which are receiving GNSS1 signals by onboard installed mobile GPS or GLONASS receivers. The GNSS1 systems and accuracy are upgraded by VHF or Satellite augmentation of GPS or GLONASS solutions. In such a way, there is Differential GPS (DGPS) developed by the US Coast Guard, which modern name is Local VHF Augmentation System (LVAS). On the other hand, there is modern Regional Satellite Augmentation System (RSAS) or Satellite-Based Augmentation System (SBAS), developed by the USA, Europe, China, Russia, China and India. The new project African Satellite Augmentation System (ASAS) is proposed by the Research Group in Space Science at DUT.

The GNSS1 system is providing two types of GPS and GLONASS receivers, such as common not augmented and augmented. In **Figure 2.3 (A)** is shown Raytheon GPS/WAAS augmented GPS receiver. The WAAS satellite signal is compatible with GPS, so new WAAS-enhanced GPS receivers will not be much more expensive than not augmented GPS receivers (possibly 50 US$ or more). Some type of GPS receivers or chart plotters can be upgraded with WAAS software without additional cost, by contacting the manufacturer to be converted for WAAS signal utilization. This promises to be the best electronic navigation system for recreational users or small ships, with GPS a close second. In **Figure 2.3 (B)** is presented Garmin GPS receiver for vehicles, which has integrated mapping system for easier navigation on the roads and get chosen destination. In **Figure 2.3 (C)** is shown Garmin WAAS LPV Receiver GNS 480 for all types of aircrafts. The main component of this unit is a 15-channel receiver that updates the aircraft's position at a rate of five times per second(Jones *et al.* 2013).

Figure 2.3. Modern Augmented GPS Receivers for all Mobile Applications – Courtesy of Book: by Ilcev

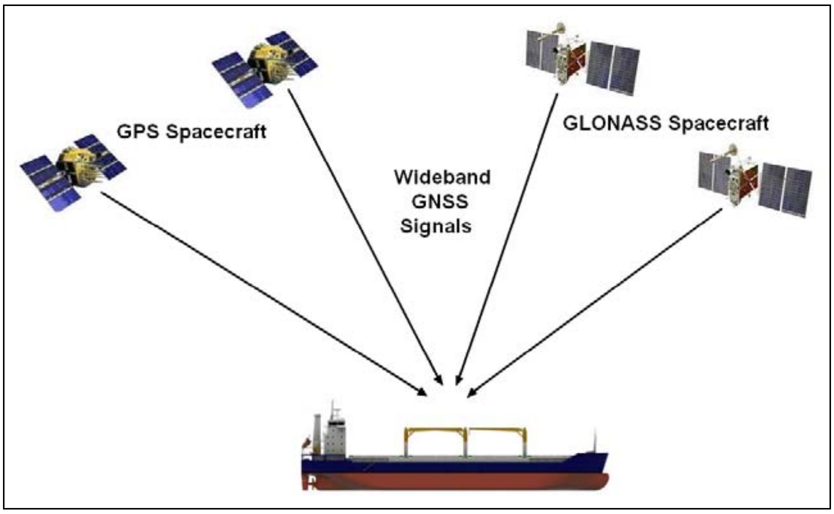

Figure 2.4. Passive Satellite Determination – Courtesy of Book: by Ilcev

2.2.2. Implementation of GNSS1 Networks for Satellite Determination

The implementation aim of GNSS1 is deployment of the Global Determination Satellite System (GDSS) for positioning and location of mobiles by satellite GNSS1 networks, which has been used to help meet the navigation requirements especially for ships and aircraft. Previous developments of GNSS1 systems have given rise to a demand for their implementation for GDSS in general and for tracking and detecting systems of all mobiles in particular. The mobile service providers and operators worldwide, who offers global and low-cost determination and positioning facilities, will serve to all markets and get a profit from large and expanding mobile customer base solutions. There are three main GDSS, which can be used in mobile determination, tracking and detecting.

2.2.2.1. Passive Satellite Determination

In a passive system the GNSS1 signals are transmitted as a continuous stream of data, which are picked up by mobile onboard receivers. The users then take navigation data the received GNSS1 and calculate own position on the navigation chart(Levanon 2000). This system requires the users to have nothing more than an GPS or GLONASS GNSS1 receiver and is the best solution when it is the mobile user, rather than a static observer, who needs to know where he is and at frequent intervals. Ships, aircraft and land vehicles (road and rail) come into this category.

Passive systems, as shown in **Figure 2.4**, have been in operation for a long time, they are well established for the future use and generally have the following features:

1) For a two-dimensional fix, three satellites must be visible to the mobile or fixed users. Four satellites are required for a three dimensional-fix.

2) The mobile and fixed users can determine their position independently and without alerting others to their presence. The number of users and the frequencies for obtaining determination updates are not limited by system power or bandwidth. In particular, these systems tend to be economical by the number of users is large or when frequent position updates are required. The system costs are independent of the number of users and the amount of usage.

3) Equipment costs are low because the user is not required to have an Tx, though he may carry communications equipment for other purposes. These devices can be readily used in conjunction or combination with other systems such as GPS, GLONASS and Loran-C.

4) The Space and especially Ground Segments are simple, partly because all users share the responsibility for own position calculations.

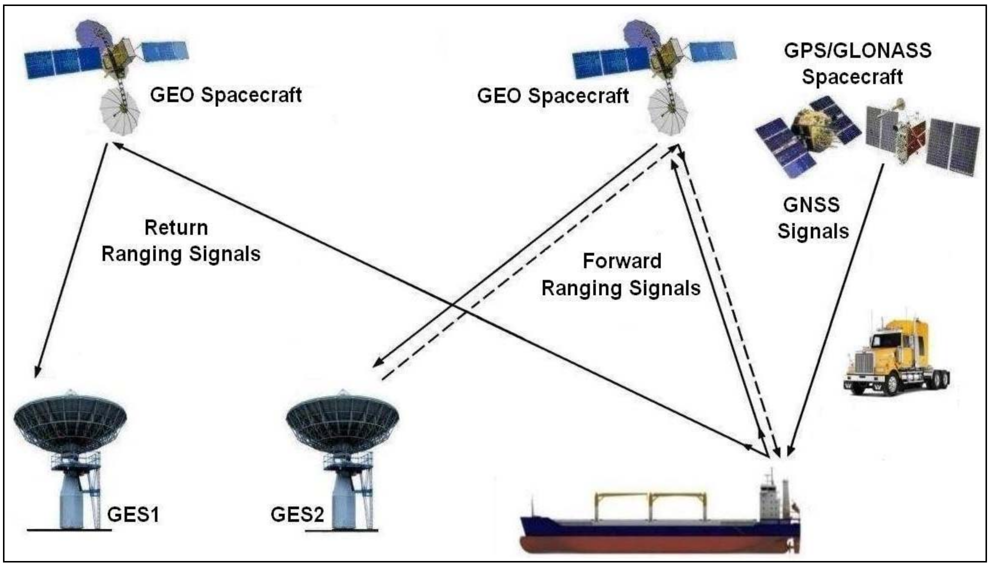

Figure 2.5. Active Satellite Determination – Courtesy of Book: by Ilcev

2.2.2.2. Active Satellite Determination

In an active GDSS system the mobile users are getting signals from GNSS1 spacecraft and then transmit return range signal (solid line) to the satellite transponder and Ground Earth Stations (GES1 or GES2). Thus, their position is calculated by the ground operator's central computing facility, and via GES2 position data can be relayed back as a forward range signal (interrupted line) to the mobile units or to any other mobiles in nearby locations, shown in **Figure 2.5**. At present in the Northern Hemisphere are deployed several interoperable solution of the GNSS1 augmentation system of GPS or GLONASS signals, known as RSAS networks.

However, in the Southern Hemisphere is proposed ASAS network for the entire African continent and the Middle East region. The mobile user's position can be determined only when the mobile transmits the necessary signal via satellite communication equipment onboard mobiles, such as ships and aircraft. Typically, the signal travels via satellite to a ground central facility, where the position is then calculated. Since the position of the user is known at the central facility, the active system can be used for surveillance, especially for more accurate ships sailing and aeronautical flight, which include maritime or air traffic control.

Surveillance is a basic need of traffic controllers, who have to know the position of mobiles accurately and to be determined quickly for more precise collision avoidance. At this point, the marine and aeronautical sectors are calling for similar facilities for vessel and aircraft tracking. More recently, some sectors of the land mobile community have also identified a requirement for surveillance services(Montenbruck and Gill 2000). Managers of tracking fleets and railway rolling stock, for example, would be able to keep track of special cargoes such as hazardous or perishable goods. Active systems have the following characteristics:

1) Two-dimensional active mobile position fixing requires two visible GNSS satellites, while three-dimensional requires three.

2) The mobile user must be able to communicate with the central facility. Namely, it does not need computing capacity, since position calculations are handled centrally.

3) Active radio determination systems can provide information on the position of one user in relation to another, which is important for maritime and aeronautical applications for enhanced safety and improved collision avoidance.

4) The central facility can improve positioning accuracy through the use of data from reference locations, such as very precise GNSS1 reference receivers.

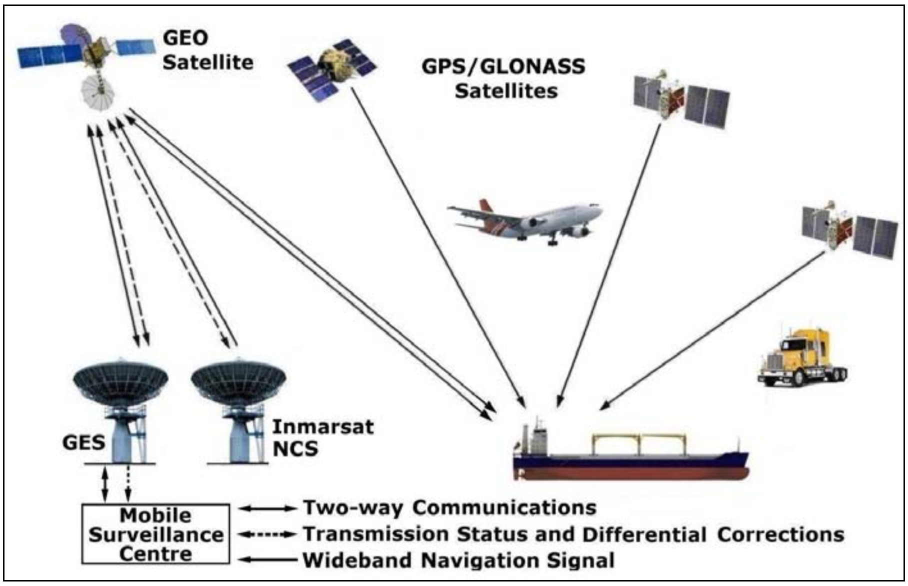

Figure 2.6. Hybrid Satellite Determination – Courtesy of Book: by Ilcev

2.2.2.3. Hybrid Satellite Determination

In a hybrid satellite determination system, ships and other mobile user receives ranging signals on their GNSS1 onboard receivers from a number of satellites and at this point their position is calculated by measuring the time or phase differences of the signals. Therefore, ranging information can be supplied where two or more satellites are visible to the mobile unit, shown in **Figure 2.6.** The precise data derived from the GNSS1 onboard system can be transmitted via GEO satellite communication transponder to the Mobile Surveillance Centre processor. In vice versa direction processed data from all ships or mobiles located in a certain area will get the GNSS1 augmentation signal via GES and navigation satellite transponder. The Network Coordination Station (NCS) is providing coordination between mobile users and GES via GEO satellites. Thus, the Hybrid Satellite Determination system is very suitable and important for developing maritime and other mobile satellite CNS solutions of RSAS for enhanced traffic control, safety and improved collision avoidance at sea and in the air.

The measurements are the same as those that take place with the Loran-C, GPS or GLONASS system, which are then transmitted via satellite to a central facility, where the user’s position is computed and displayed on the like radar screen. The central facility of normally designates which satellites are to be used. A hybrid system allows both the user and the central facility to calculate the position using the CNS system augmented data. In maritime determination, the ships user would probably perform onboard navigation calculations, since one usually needs to communicate navigation data as well as surveillance. The RSAS CNS augmented system is providing the possibility of Oceanic Sailing Guidance and Control (OSGC) for all ships in ocean navigation, which traffic controller can send to any ship position of nearby ships for awareness and collision avoidance(Alizadeh-Shabdiz 2009).

In addition, this system provides Coastal Movement Guidance and Control (CMGC), which enables a traffic controller to control all vessel movements in coastal navigation, sea channel, approaching to the anchorage and ports and all movement in harbors. On the other hand, the central facility would perform the position determination calculations and use the results for surveillance purposes for traffic control of most land vehicles.

Therefore, hybrid systems have most of the advantages of active systems, while offering compatibility with GPS, GLONASS and any potential civilian satellite navigation system. Characteristics of hybrid systems include spectrum efficiency, better accuracy, uniformity and integrity, commercial potential, simplified user equipment, flexible control and so on.

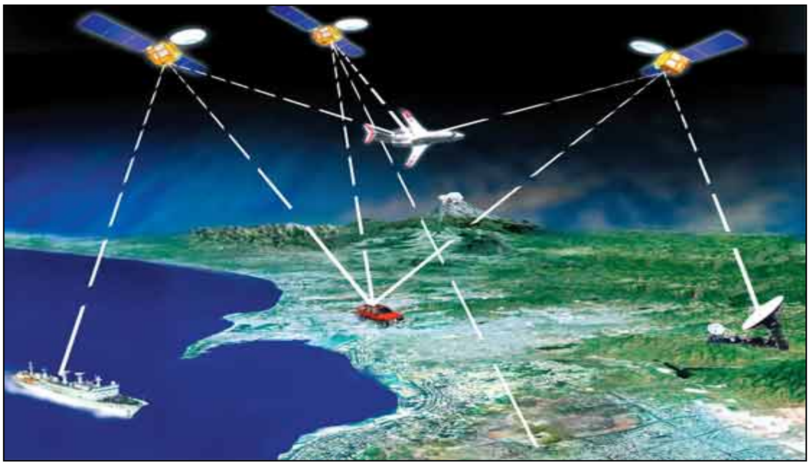

Figure 2.7. GNSS1 Applications – Courtesy of Presentation: by Ilcev

2.2.3. GNSS1 Applications

The GNSS technologies are being utilized in numerous civil and military applications that range from leisure hiking to spacecraft launching guidance. In any event, the old and new applications affect all sectors of transportation such as maritime, land and aeronautical, which architecture is presented in **Figure 2.7.**

2.2.3.1. Maritime Navigation Satellite System (MNSS)

The GNSS1 system has been deployed onboard, at first of military and after on merchant ships, which enhances navigation for all types of vessels. Thus, several nations developed local area DGPS networks to increase system accuracy for coastal navigation, approaches to anchorage and harbor, inside of seaports and for usage in the rivers. The Commonwealth of Independent States with Russia is considering the implementation of a local area differential GLONASS network. Wide area differential GPS has been utilized by the US Coast Guard and offshore explorations for several years. Thus, DGPS plays a large role is in Vessels Traffic Services (VTS). The combination of a data link and differential GNSS1 receiver permits the broadcast of the vessel's position to a control centres. The VTS system is used for collision avoidance on ships and to expedite the flow of traffic during periods of restricted visibility and upon the occurrence of ice in the sea. It can be used in conjunction with the Electronic Chart Display Information System (ECDIS), which displays a vessel's position in relation to charted objects, navigation aids and unseen hazards.

2.2.3.2. Land Navigation Satellite System (LNSS)

The surveying community has relied on differential GPS to achieve measurement accuracy in the millimeter range. Similar techniques are in use within the railroad communities to obtain train location with respect to an adjacent set of tracks. The GPS system is a key component in Intelligent Transportation Systems (ITS). In terms of vehicle applications, the GNSS1 system will be used for route guidance, tracking and emergency short messaging. Integrating a GNSS1 receiver with a street database, digital moving map display and processor will allow the vehicle driver to obtain directions and/or the shortest most efficient route. In such a way, a vehicle position can be automatically reported to a control center for road, rail and even port fleet management. The activation of a "panic" button by the vehicle driver broadcasts an emergency message, vehicle characteristics and vehicle location to law enforcement authorities for assistance, similar to Cospas-Sarsat Personal Locator Beacon (PLB) devices.

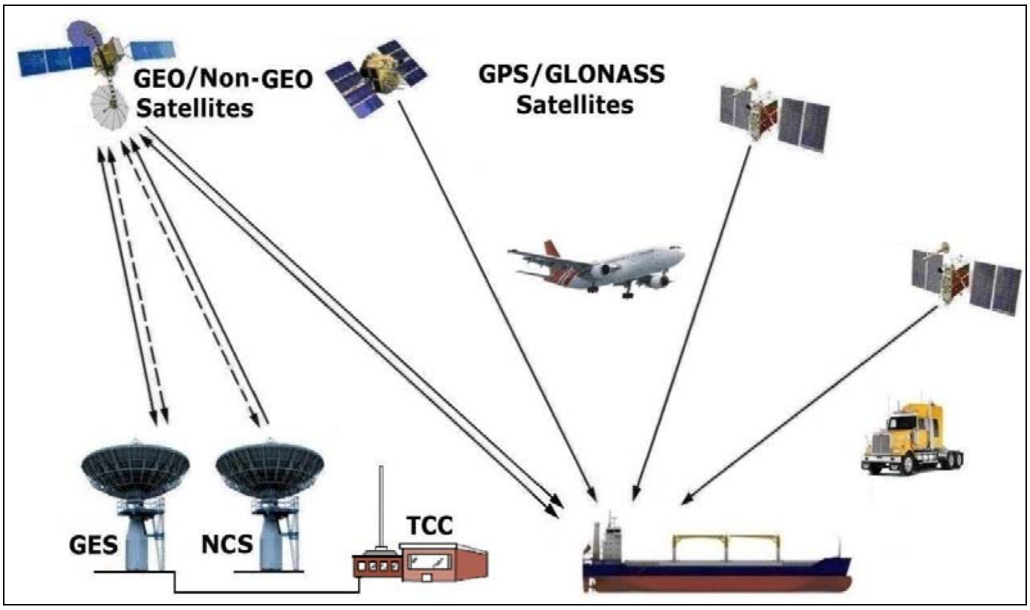

Figure 2.8. GNSS1 Tracking and Detecting Network – Courtesy of Presentation: by Ilcev

2.2.3.3. Aeronautical Navigation Satellite System (ANSS)

The aviation community and ICAO have propelled the utilization of a GNSS1 and various augmentation systems to provide better guidance for the en-route precision approach phases of flight. Thus, the ICAO requirement defines a system that contains at least one or more satellite navigation systems as a GNSS. The continuous global coverage capability of GNSS1 permits the aircraft to fly directly from one location to another, provided factors such as obstacle clearance and required procedures are adhered to. Incorporation of a data link with the GNSS1 receiver enables the transmission of aircraft locations to other aircraft and/or to Air Traffic Control (ATC). This function, called Automatic Dependent Surveillance System (ADSS), is in use in some Pacific Ocean Regions as an outgrowth of ICAO FANS working group activities. The key benefits are ATC monitoring for collision avoidance and optimized routing to reduce travel time and, consequently, fuel consumption. The new satellite ADSS solution is also being applied to airport surface surveillance of both aircraft and ground support vehicles.

2.2.4. Implementation of GNSS1 Networks for Tracking and Detecting Systems

The task of this research and thesis is not to elaborate in particular GNSS1 of GPS and GLONASS systems, but to implement both solutions for full satellite tracking and detecting networks of seagoing ships and rigs. The GNSS1 tracking and detecting system are solutions that provide Position information, Velocity and Time information (PVT) for real time monitoring of ship traffic via GEO or Non-GEO satellite and Information Technology (IT) at shore control center. In addition, and what is more important, this system provides to every ship individually by request or even automatically positions and course of nearby ships if onboard of a ship is installed mobile tracking terminal integrated with communication units.

2.2.4.1. General Structure of Tracking and Detecting Network

The tracking and detecting network are shown in **Figure 2.8.** Ships are getting GNSS1 signals from GPS or GLONASS and sending PVT data via GEO or Not-GEO spacecraft via GES to Tracking Control Centre (TCC) in coordination with NCS. The TCC then sends PVT data of all ships in vicinity of ship requesting this data for enhanced collision avoidance.

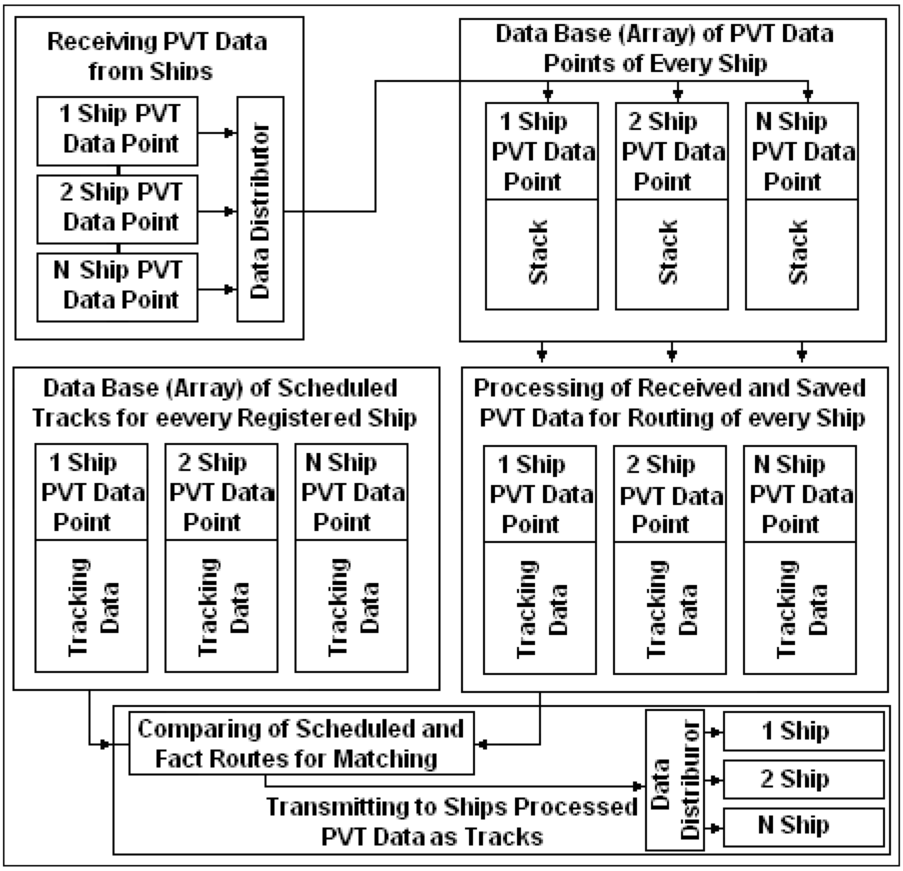

Figure 2.9. PVT Data Processing in TTC – Courtesy of Presentation: by Ilcev

The connection between GES and TCC provide via landline or IT Internet facilities. In the TCC site is deployed processing solutions, implemented adequate software to build tracking map of all ships with the help of the collected PVT data points of every ship in certain area and show them on like radar display. In such a way TCC site is receiving the PVT data sent by all ships in its monitoring area, processing and displaying on the screen. Thus, the tracking controller has possibility to monitor on display all traffic of ships in his area and on request of any ship to send PVT data of all ships in this area of tracking and detecting control. However, there is a technical possibility that certain ship can poll the PVT data directly from TCC site.

2.2.4.2. Tracking Data Processing in Tracking Control Centre

The tracking PVT data received from ships tracking devices by the TCC site will be processed and saved in the huge IT computer server centre. Diagram of data processing in TCC with PVT IT processor is shown in Figure **2.9.** The system is receiving PVT data points from all ships in a certain area, such as Ship 1, Ship 2 and Ship N, etc. In addition, PTV data points are memorized and stuck in the database for Ship 1, Ship 2 and Ship N, etc. and all PTV tracking data will be loaded in the database (array) of scheduled tracks for every registered ship. Then all received tracking PVT data points will be processed and saved for routing of every ship. After that, the system is providing comparison of scheduled and actual routing PVT data for matching and at the end to transmit all processed PVT data and tracks to all chips in certain area via data distributor unit, such as Ship 1, Ship 2 and Ship N, etc. Finally, this data array contain stacks facility with own number of each ship, and when PVT ship data points comes from particular ship tracking device, they are transmitted by distributor and saved automatically in an appropriate stack.

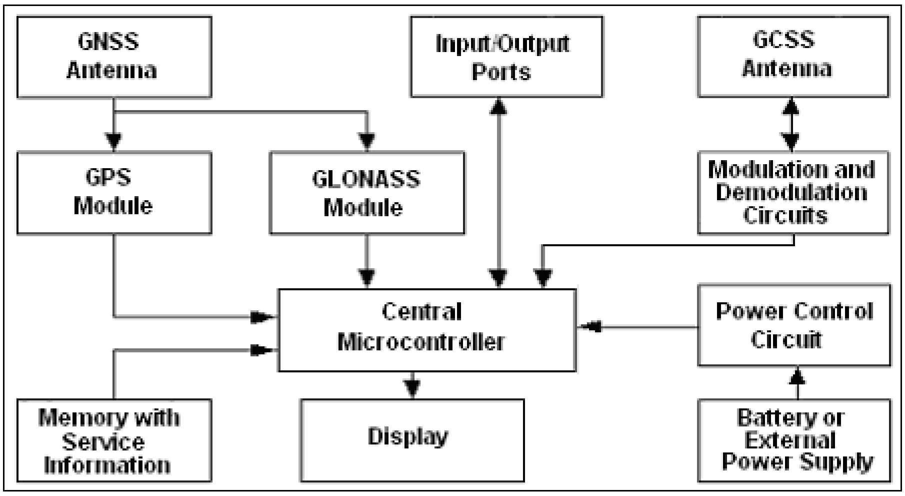

Figure 2.10. Diagram of Mobile Data Unit – Courtesy of Presentation: by Ilcev

All collected ships data points in data array flows to unit of processing of receiving data points, where singular ships position data points integrates into fact ships routes. All these integrated routes of ships can be presented in the monitoring centre on the monitoring display, where special staffs provide permanently safety and security at sea. This monitoring is special function and can be able or disable.
Important module is database of scheduled tracks, where prior saved data about all tracks of registered ships. Next pre-last unit is a comparator of scheduled and actual tracks of the ships, where comparing of scheduled and actual routes of ships occurred. Thus, if the comparator identifies some deviations between scheduled and fact routs, special massage with amendments will be put in result data to show about it in ship tracking device. Finally, results of comparing data tracks are transmitted to ships tracking device through a program distributor. If the ship is not registered in the database of scheduled tracks, then transmitted only result of integrated position data points of a particular ship to ship's tracking device without corrections of course.

2.2.4.3. Data Processing and Operations of Mobile Tracking Terminal

In order to provide tracking of any target mobile object by tracking system, such as a ship or aircraft, target object should have a mobile tracking terminal installed onboard. The main function of the mobile tracking terminal receives data from GNSS1 as geographical position data point, after adding service information about target object such as PVT, course, name of ship, call sign and ect, (service data programmed and saved in the memory inside of the mobile tracking terminal, once before operation) transmit them to the TCC IT site and receives back processed data which contain other important information.
In order to provide the possibility of direct data flow and control of mobile tracking terminal, it will be necessary to utilize firmware and arrange all these processes. In **Figure 2.10** is shown proposed, by the author of this thesis, general structure of the mobile tracking terminal, which can be integration of both GPS and GLONASS receivers or one of them will serve solely. However, each GNSS1 receiver has to be integrated with the Global Communication Satellite System (GCSS) Tx and receiver (Rx). Some satellite systems like Globalstar and Orbcomm are offering integration of GPS receiver and satellite Tx. In fact, every mobile tracking terminal contains hi-tech IT technology, which main part is a Central Microcontroller (CM). The CM unit controls interacting of data flows in hardware with the help of firmware. The firmware is a small program, which programmed ones by factory and this program essentially in the CM memory. The antenna for receiving data from GNSS1 spacecraft is connected to the GPS and GLONASS module because these two GNSS1 systems have different coding.

Both GPS and GLONASS modules give position data to CM unit. The CM unit prepares new data stream for transmitting to TCC IT site via GCSS. This stream contains position data point obtained from GNSS1 and service information which is being saved in special memory. When data stream is ready, the CM sends it to Modulation and Demodulation circuit (MDC) and through an antenna for the appropriate frequency band of GCSS data transmits via satellite of GCSS to the TCC IT site. After that, data processed in the TCC IT site will be sent back to one or more mobile tracking units through GCSS antenna, MDC and going to CM, which output data on the onboard ship display. In order to interface mobile tracking device with sensors and other nodes of the ship there is an Input/Output port (IOP), which provides possibility to be connected and also to control other ship peripherals. The battery or external power supply is very important units together with a power control circuit to monitor power supply's characteristics of all tracking mobile terminals.
It is obvious that IT technologies and techniques are developing very fast, especially software and firmware, which surpassed the development of hardware in several times. At the end, it can be concluded that although software or firmware are perfectly developed, they are still being limited in operation because of reduced abilities of hardware.

2.3. Current GCSS Networks for Tracking and Detecting of Ships

The current Global Communication Satellite System (GCSS) networks basically consist of the following main components:
1. Mobile tracking and detecting terminal installed onboard of the target object, such as a ship, land vehicles and aircraft;
2. GNSS1 network for getting geographical PVT of target objects by tracking terminal;
3. GCSS network for data transmitting to destination points;
4. Ground gateway (GES) and TCC IT site for receiving PTV data, processing and presenting all PVT data on TCC display; and
5. Ground gateway can send back TVT data to any ship in a certain area or send PVT data of all ships in vicinity on request of any ship or any ship can provide on its own pooling of PVT data of one or all ships in certain navigation area.
At present there are 4 GCSS mobile networks providing tracking and detecting service of ships and other mobile terminals, such as Inmarsat GEO, Iridium and Globalstar Big LEO and Orbcomm Little LEO(Septiawan 2004).

2.3.1. Inmarsat GEO Network

Inmarsat was established in 1979 as professional only GCSS named International Maritime Satellite Organization (Inmarsat). It is a not-for-profit international organization, set up at the behest of the IMO and a UN body, for the purpose of establishing a satellite communications network for the maritime community and ship management including distress and safety applications. It began trading in 1982 and was used the acronym "Inmarsat", which operates and maintains the Inmarsat Ground Network (IGN) constellation of nine GEO satellites and many mobile and ground terminals. Thus, this professional organization has over 30 years experience in designing, implementing and operating innovative satellite communication networks, including tracking and detecting of ships in conjunction with the IMO(Berzins *et al.* 1989).
Inmarsat was the world's first satellite operator offering a mature range of modern GCSS services to maritime, land, aeronautical and other mobile or semi-fixed users. The Inmarsat system together with IMO, Cospas-Sarsat and other organization established Global Maritime Distress and Safety System (GMDSS), which was implemented by IMO(Singh 2013).

Inmarsat Satellites	Inmarsat-2	Inmarsat-3	Inmarsat-4
No. Satellites	4	5	2 + 1
Coverage	1 Global Beam	7 Wide Spots 1 Global Beam	228 Narrow Spots 19 Wide Spots 1 Global Beam
Mobile Link EIRP	39 dBW	49 dBW	67 dBW
Channelization	4 Channel (4.5 to 7.3 MHz)	46 Channels (0.9 to 2.2 MHz)	588 Channels (EOL) (200 KHz)
S/C Dry Mass	700 Kg	1.000 Kg	3.340 Kg
Solar Array Span	14.5 m	20.7 m	45 m
Voice (4.8 Kb/s))	250	1.000	18.000
M4 (64 Kb/s)	N/A	200	2.250
PMC (384 Kb/s)s)	N/A	N/A	588

Figure 2.11. Comparison of 3 Inmarsat Satellite Generations – Courtesy of Book: by Ilcev

2.3.1.1. Inmarsat Space Segment

For the first decade of Inmarsat's operation, the space segment has been leased from Comsat (series of three Marisat satellites F1, F2 and F3), from ESA (series of two Marecs satellites A and B2) and from Intelsat (series of three Intelsat V-MCS A, B and D). These satellites were initially configured in three ocean regions: Atlantic (AOR), Indian (IOR) and Pacific Ocean Region (POR), each with an operational satellite and at least one spare in-orbit. Thus, this satellite constellation is known as the First generation of the Inmarsat network. Inmarsat was not responsible for TT&C, but operations were controlled by Inmarsat NCS in London.
The Second and Third Generation of Inmarsat Satellite Constellation consisted in four GEO I-3 and I-2 satellites, while current Fourth Generation Inmarsat Satellite Constellation is consisting three GEO I-4 spacecraft, which comparison is shown in **Figure 2.11.**In **Figure 2.12** shows the view of the Inmarsat global GEO constellation with 4 satellites. Normally, this coverage will be provided with 3 satellites only, but because of the coverage gap in the Western Pacific area is included 2 AOR spacecraft (AOR-East and AOR-West) for better overlapping.

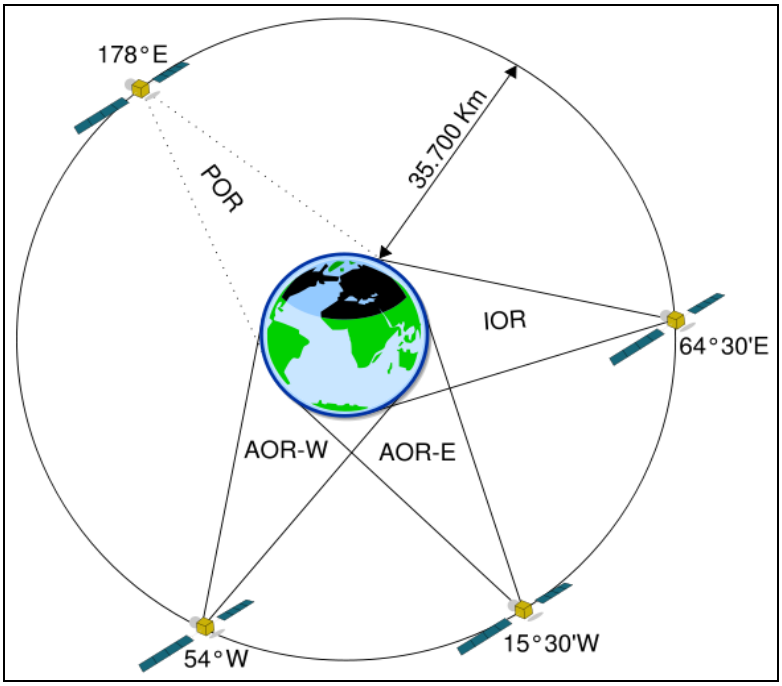

Figure 2.12. Inmarsat GEO Coverage –Courtesy of Book: by Ilcev

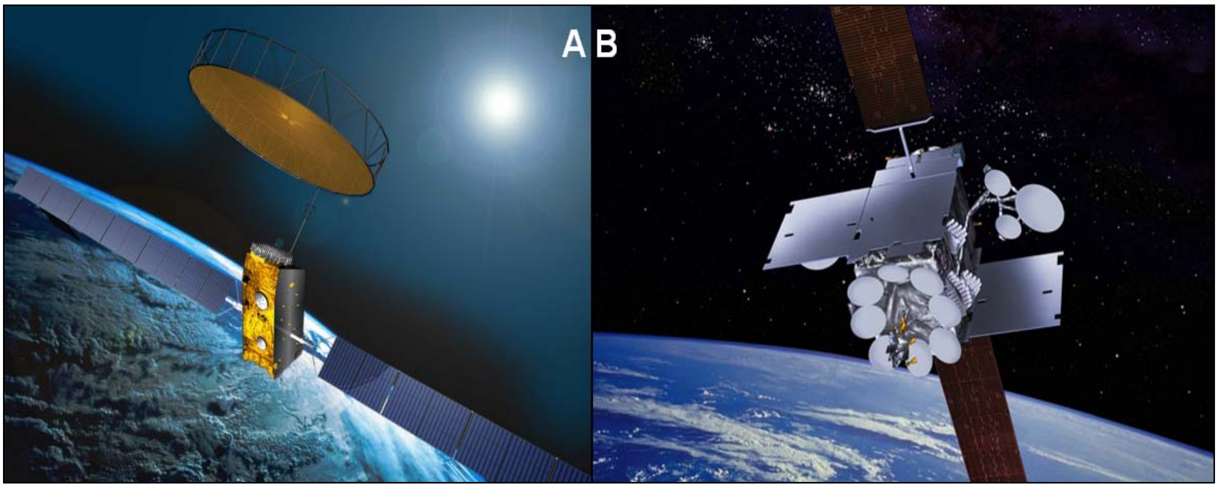

Figure 2.13. Inmarsat-4 and Forthcoming Inmarsat-5 Spacecraft–Courtesy of Brochure: by Inmarsat

Responding to the growing demands from corporate maritime and other mobile satellite users of high-speed Internet access and multimedia connectivity, Inmarsat built a fourth generation of satellites as a Gateway for the new mobile broadband network. Inmarsat has awarded European Astrium a 700 million US$ contract to build three Inmarsat I-4 satellites, which will support the new BGAN, shown in **Figure 2.13 (A).**

Inmarsat has contracted Boeing, the US aerospace manufacturing company, to build a new constellation of Inmarsat-5 satellites, which is part of a new 1.2 billion US$ worldwide wireless broadband network called Inmarsat Global Xpress. Boeing will construct three Inmarsat-5 (I-5) satellites based on its 702HP spacecraft platform, shown in **Figure 2.13 (B)**. The first Inmarsat-5 satellite was launched on 8 December 2013(Singh 2013).

In **Figure 2.14** is illustrated Inmarsat I-4 global network coverage following completion of the satellite-repositioning program, which ended on 24 February 2009. In such a way, to reflect the geographic locations covered by the satellites, Inmarsat refers to its three I-4 satellite regions as follows: I-4 Americas, I-4 EMEA (Europe, Middle East and Africa) and I-4 Asia-Pacific. Thus, the respective positions of each I-4 satellite are 98º W (I-4 Americas), 25º E (I-4 EMEA) and 143.5º E (I-4 Asia-Pacific)(Elbert 2004; Mishra *et al.* 2007).

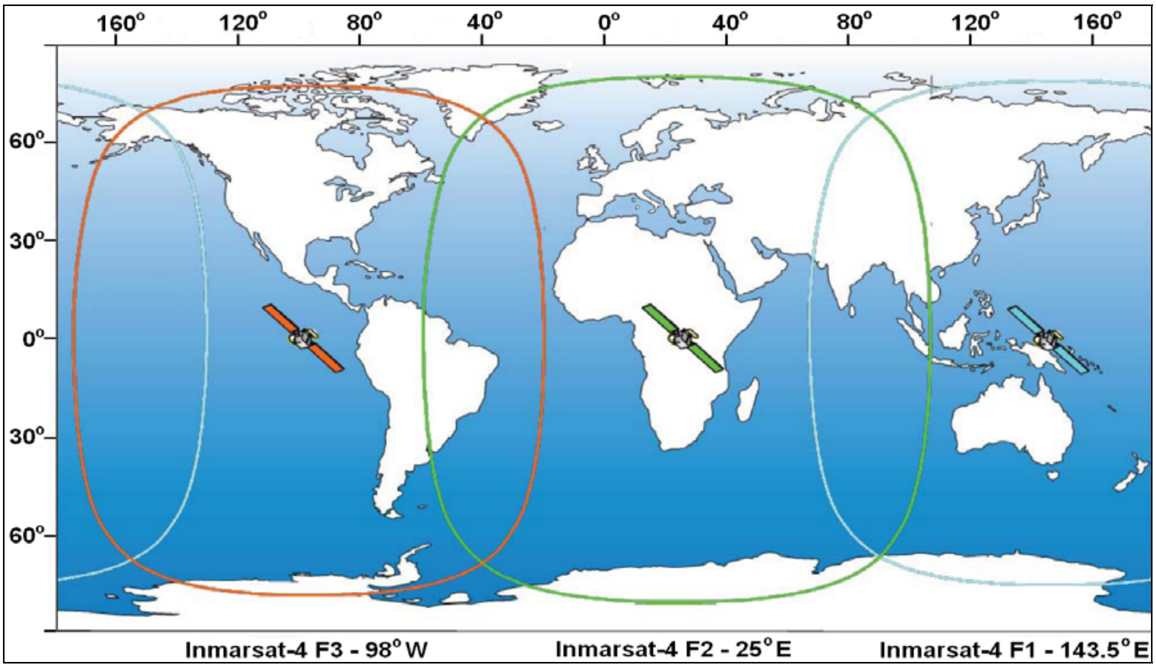

Figure 2.14. Inmarsat I-4 Global Coverage Map –Courtesy of Brochure: by Inmarsat

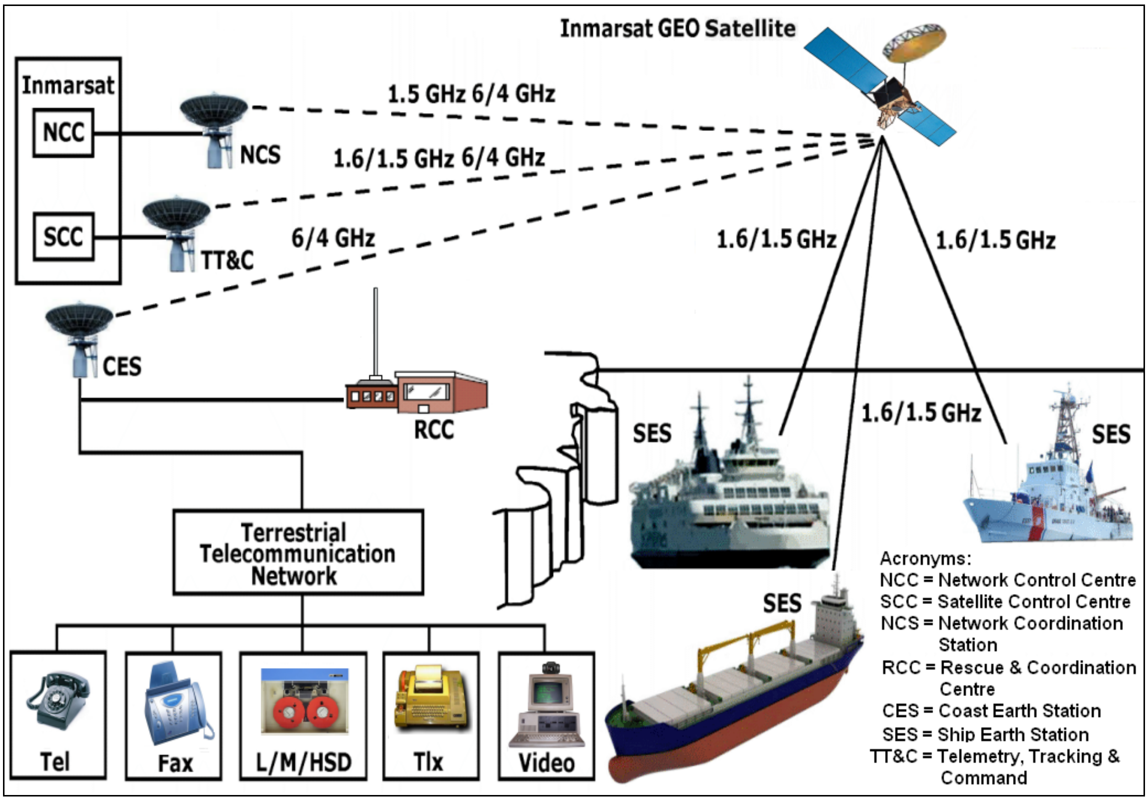

Figure 2.15. Inmarsat Ground and Users Networks –Courtesy of Book: by Ilcev

2.3.1.2. Inmarsat Ground Segment and Networks

The ground segment comprises a network of Coast Earth Stations (CES), which are managed by CES operators, Network Coordination Stations (NCS) and Network Operations Centre (NOC) situated in London, which diagram is illustrated in **Figure 2.15**. The major part of the ground segment and networks are mobile subscribers known as Mobile (MES) or Ship Earth Station (SES). Each CES operator provides a transmission link between CES and all SES in its coverage area via Inmarsat GEO satellite. On the other hand CES operator provides an interface with Terrestrial Telecommunication Network (TTN), capable of handling many types of voice (Tel) calls, Fax, Low (LSD)/Medium (MSD) and High Speed Data (HSD), Tlx and Video from SES terminals simultaneously over the Inmarsat networks.

Inmarsat network is controlled by the Network Control Centre (NCC) via NCS and Satellite Control center (SCC) via Telemetry, Tracking and Command (TT&C) station. Thus, the CES terminal can be also connected to the Rescue Coordination Centre (RCC) if some ships send distress alert via own SES. Each CES is transmitting signals at 6 GHz and receiving on 4 GHz, however, each SES terminal is transmitting signals at 1.6 GHz and receiving on 1.5 GHz. The SES terminals can transmit and receive track and detecting messages via LSD mode at about 600 bits/s.

The CES terminal is a powerful shore-based receiving and transmitting station with antenna systems serving in a Global Mobile Satellite Communications (GMSC) network. Because CES infrastructure is fixed site, thus, it can serve, but cannot be a part of the Fixed Satellite Service (FSS). In a more precise sense, every CES is a part of GCSS network, although it has a fixed location and can provide FSS(Sze and Ou 2007). The CES terminal is able to connect ships via any Inmarsat satellite and provide service for Inmarsat VSAT, Inmarsat Fleet Broadband, Inmarsat Fleet 33/55/77, Inmarsat B/M, mini-M, Inmarsat C, IsatM2M and Isat Data Pro (old solution Inmarsat D+). Each CES in the IGN is owned and operated by an Inmarsat Signatory with the mission to provide a range of services to all types of Mobile Earth Stations (MES).

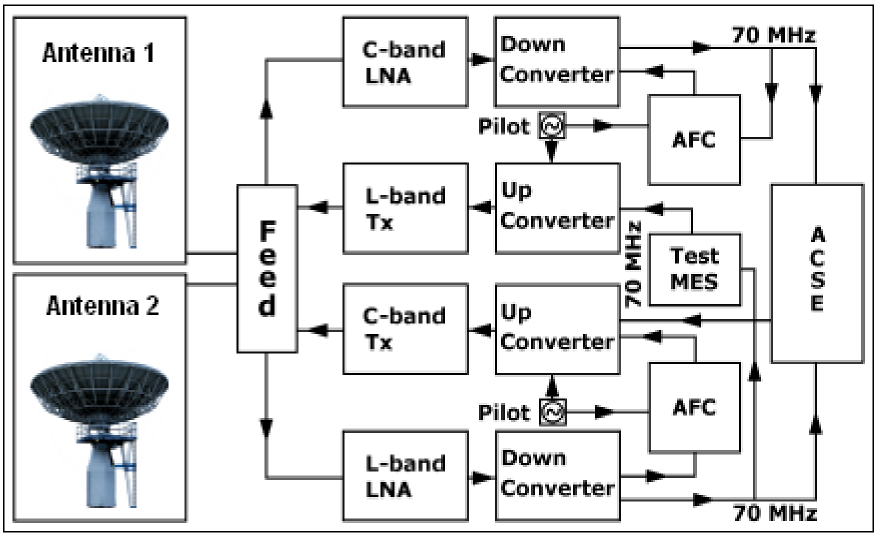

Figure 2.16. Block Diagram of CES Terminal–Courtesy of Book: by Ilcev

There are over 40 CES terminals located in more than 30 countries around the globe usually in the Northern Hemisphere. The MES operator and shore subscribers can choose the most suitable CES terminal, as long as they are within the same Ocean Region. The fundamental requirement for each Inmarsat CES terminal is that it can be capable of communicating reliably with all MES terminals, which block diagram is illustrated in **Figure 2.16.** Thus, the main CES components are Antenna Control Unit and Signaling Equipment (ACSE), Automatic Frequency Control (AFC), Up and Down Converters, Pilots, C and L-band Tx, C and L-band Low Noise Amplifiers (LNA), Antenna feeders and antenna systems.

The typical CES antenna for an entire IGN can be a Casse grain dish reflector of about 14 m diameter. Each CES can have a minimum of one operational and one spare antenna system in order to continue transmissions during maintenance.

The Communication RF Equipment is situated inside the CES building and must be able to operate in transmitting and receiving mode and to monitor the MSC L-band channels and respond to requests for frequency allocations by the NCS, to verify signal performance by loop testing between satellite and CES and to receive the C-to-L AFC. The AFC provides for Tx and Rx direction control to keep MES as simple and as cheap as practicable. A complete test of the CES equipment can be carried out without the cooperation of the MES because a separate test terminal is provided at each CES for this purpose. The Inmarsat system requires AFC to correct for Doppler shift (caused by inclination of the GEO) and errors in frequency translation in the satellite and LES. The total frequency shift from this cause without AFC could be more than 50 kHz.

The ACSE device is part of CES, whose principal purpose is to recognize requests for calls sent by MES, to set them and release. Thus, this requires response to and initiation of in-band and out-bands signaling over the satellite and the terrestrial path. The next ACSE tasks are to recognize distress calls sent by SES or aircraft (AES), to switch voice circuits between TTN circuit and the CES FM channel modem, to switch Tx circuits between TTN channels and the Time Division Multiple/TDM Access (TDM/TDMA) time slots, to determine Tx/Rx frequencies used by the FM channel unit in accordance with the channel allocations made by the NCS, to allocate TDM/TDMA time slots and to collect statistics for billings, international accountings (for transit calls), traffic analyses and management and maintenance purposes(Icev 2011). In this scenario, the ACSE block is sometimes specified to include all the communication equipment of CES terminals other than RF and IF equipment. For instance, these devices are such as: modulators and demodulators, data and voice channels, RF assignments to MES, line control subsystem, system control processor, etc.

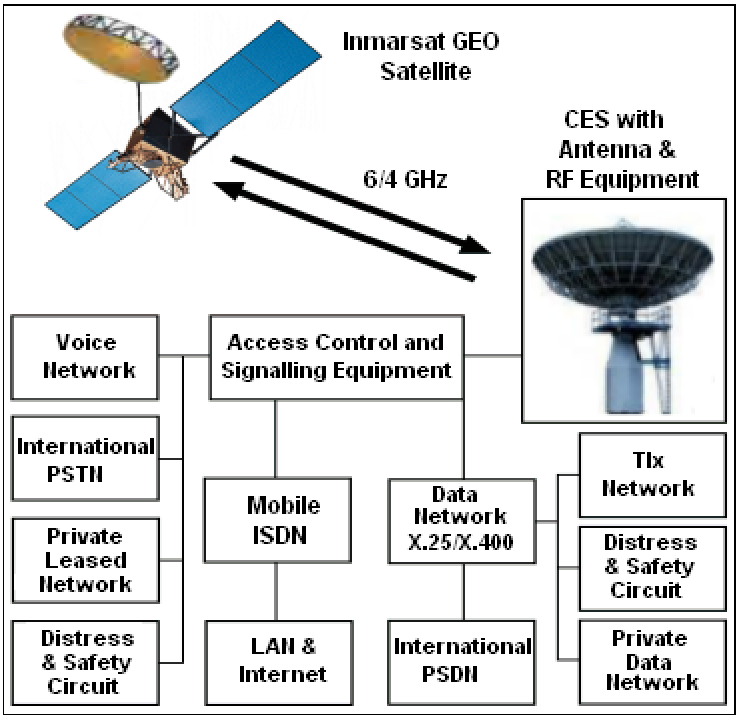

Figure 2.17. Maritime CES Terminal–Courtesy of Book: by Ilcev

The GMSC services offered by CES terminals vary depending upon the complexity of the station selected. For example, a typical CES could offer a wide range of services from and to the MES located in convenient ocean regions, such as two-way voice including Fax/Paging, Tlx, all data rate, Video, GAN/Internet and Mobile Emergency services (Distress, Urgency, Safety and Medical assistance calls). Multiplexing as a number of communication channels onto a single satellite link becomes possible by using duplex HSD, such as multiplexing six communication channels onto a single satellite connection using the Inmarsat duplex HSD service. The LSD is serving for transmissions of tracking and detecting messages.

The term CES is included in the generic name Land Erath Station (LES), which applies to Earth stations used for either maritime or land-based GMSC, illustrated in the configuration diagram **Figure 2.17.** At this point, there are numbers of Inmarsat CES terminals worldwide that can provide a communications service to SES and VES for tracking and detecting.

The Inmarsat system is offering the following CES for Maritime and Land Applications:

1. CES-A – The abandoned CES-A was the workhorse of MMSC since February 1982, when Inmarsat started to provide GMSC for shipping, fishery and offshore industries.

2. CES-B/M, Fleet, Fleet Broadband and VSAT – This CES terminal supports Inmarsat-B and M terminals. The Inmarsat-B digital system was introduced in 1994, while Inmarsat-M system entered into exploitation in 1993 to complement the Inmarsat-A. However, later were developed Fleet and VSAT standards, including Aero-M and other aeronautical standards.

3. CES-mini-M – The Inmarsat mini-M unit was launched in January 1997 with the same service as Inmarsat-M but with a smaller, lightweight and compact terminal to operate in the spot-beams of Inmarsat-3 satellites.

4. CES-C – The CES-C terminals were introduced in 1991 to complement Inmarsat-A by providing global low-cost two-way data communications for all types of MES installed on board vessels, fishing boats, yachts, supply craft, land vehicles, small aircraft and remote TES for rural and SCADA services.

5. CES-D/D+ and New Isat Data Pro– The Inmarsat CES-D/D+ and IsatData Pro supports MES and SCADA very small terminals with one-way (D) and two-way (D+) data messaging for all mobile tracking and detecting applications.

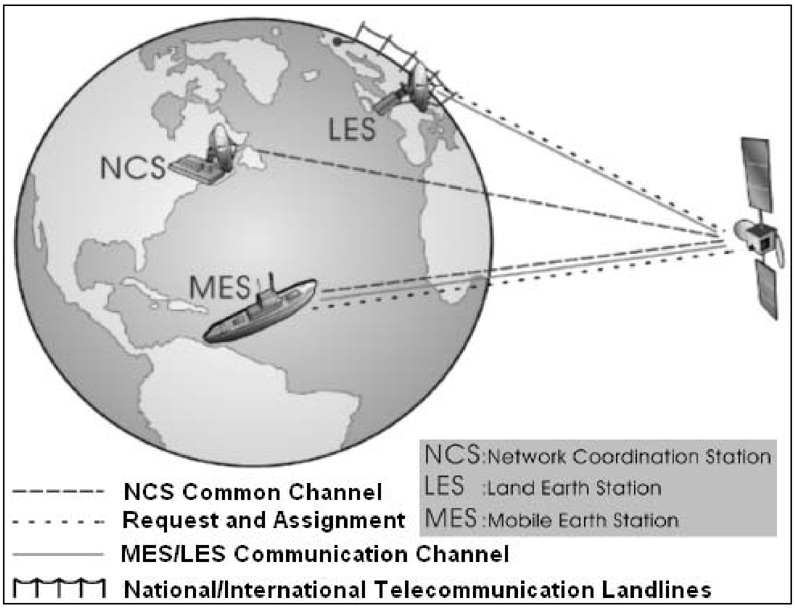

Figure 2.18. Inmarsat Ground Network–Courtesy of Book: by Ilcev

Each MES has always to be tuned to the Common Signaling Channel (CSC), to listen for assignments Requesting Channel (RC), when not engaged in passing traffic, namely MES is an idle state, while each LES also watches the CSC to receive their channel assignments(Lcev 2011). The CSC is also referred to as TDM0 and is the origin of all traffic. The IGN is interfaced to the TTN as a Gateway to all fixed subscribers, shown in **Figure 2.18.**

The tracking, detecting and remote sensing solutions for maritime applications are introduced in the chapter 5. These systems enable companies to track and monitor their fixed or mobile assets, giving them increased visibility of business operations, enhanced efficiency, and greater safety and security of assets, cargo and drivers, while lowering operational costs.

The new generation of Inmarsat tracking networks and equipment is know as Isat Data Pro, which is successor of the Inmarsat D+ system(Dong-qing *et al.* 2005). This unit uses a low data rate service, which is ideal for remote management of fixed assets including tracking and telemetry of mobiles. It can operate in near real-time anywhere in the world. With burst-mode communication and a gateway for store-and-forward messaging, Isat Data Pro also offers a convenient Web-based portal for adjusting settings. Applications can be run on the terminal to reduce data sent over the air. Suitable for mission-critical applications, it offers a wide range of protocols for data collection. This unit sends 6,400 bytes and receives 10,000 bytes, with a latency of 15-60 seconds depending on message size. Isat Data Pro is available across the globe, apart from the extreme Polar Regions. In **Figure 2.19 (Left)** is shown Inmarsat Isat Data Pro 600 Series Maritime Terminal, and **Figure 2.19 (Right)** shows Isat Data Pro 600 Series Land Terminal(SkyWave 2014).

Figure 2.19. Inmarsat IsatData Pro 600 –Courtesy of Brochure: by SkyWave

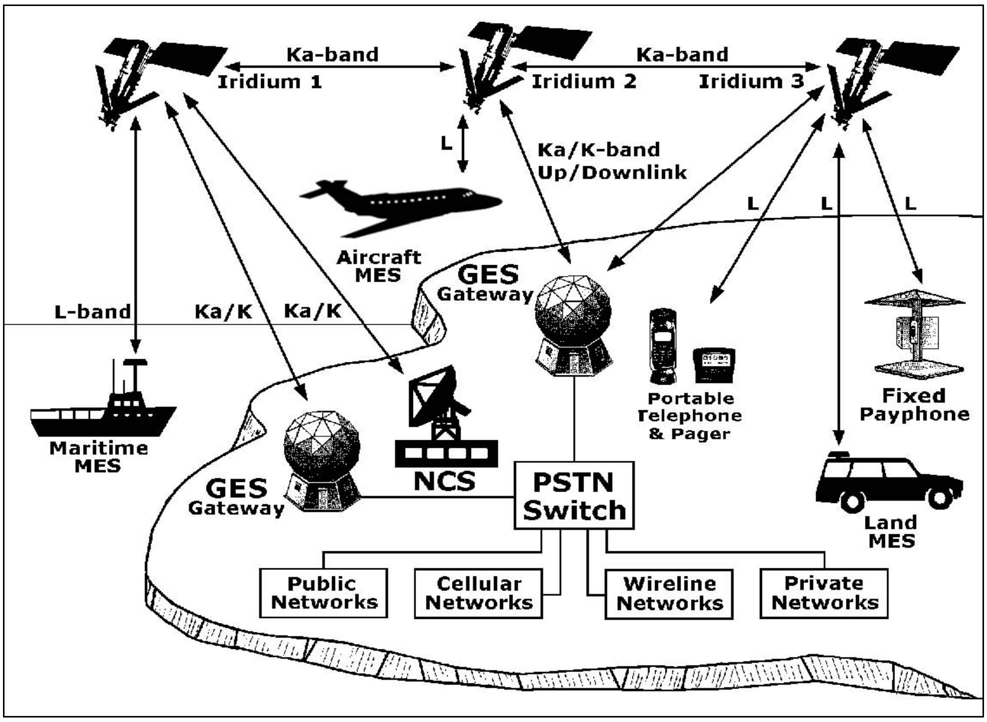

Figure 2.20. Iridium GMSC Network –Courtesy of Book: by Ilcev

2.3.2. Iridium Big LEO Satellite Network

The concept for the Iridium MSC system was proposed in late 1989 by Motorola engineers and after the research phase, Iridium LLC was founded in 1991, with an investment of about 7 billion US$. Maintaining its lead, Iridium LLC became operational MSC system on 1st November 1998. After a period of bankruptcy, the Iridium service was relaunched on March 28, 2001. This system was backed by 19 strategic investors from around the world and 17 investor partners also participated in the operation and maintenance of 3 ground station GES or Gateways that link the Iridium satellites for duplex voice and data service to terrestrial wireless and landline public telephone networks including mobile tracking and detecting. The Iridium system is a satellite-based network designed to provide truly global personal and mobile service of voice, facsimile, paging and data solutions, which also integrate the GPS capability with tracking equipment using voice and data communications. Iridium is only the system that provides complete coverage of the Earth, including Polar Regions, because uses crosslinks (inter-satellite links)(Maine *et al.* 1995).

The Company office is situated in Leesburg, Virginia where the Satellite Network Operations Centre is located and Gateway facilities in Tempe, Arizona and Oahu, Hawaii. The Iridium system comprises three principal components, such as space and ground segment including user network with mobile and personal subscribers using data trackers, phones and pagers, as illustrated in **Figure 2.20.**

The Iridium First generation of satellites is situated in a near-polar orbit at an altitude of 780 km. They circle the Earth once every 100 minutes traveling at a rate of about 26,856 km/h. Each satellite is cross-linked to four other satellites; two satellites in the same orbital plane and two in an adjacent plane, which are connected Ka-band inter-satellite links. The Iridium constellation consists in 66 operational satellites and 14 spares orbiting in a constellation of six polar planes. Each plane has 11 mission satellites performing as nodes in the data and telephony network. The 14 additional satellites orbit as spares are ready to replace any unserviceable satellite. This constellation ensures that every region on the globe is covered by at least one satellite at all times.

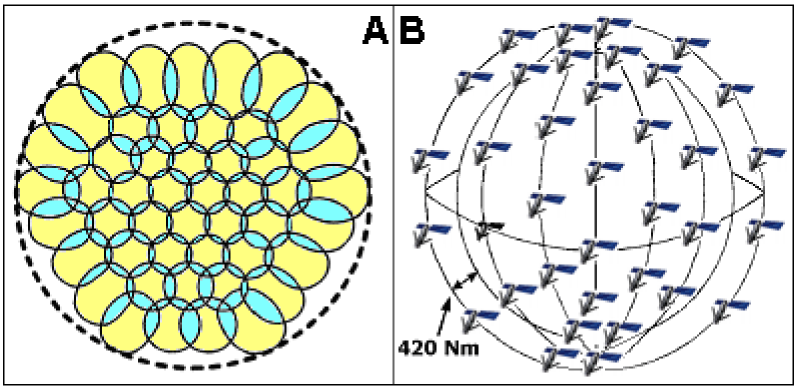

Figure 2.21. Iridium Satellite Network –Courtesy of Book: by Ilcev

Iridium satellite constellation only provides real global coverage and roaming over the entire Earth with 48 spot overlapping beams and the diameter of each spot is about 600 km, shown in **Figure 3.19 (A)**. The 66 satellites enable 3,168 cells, of which only 2,150 need to be active to cover the whole globe including both Polar Regions. At this point, each cell covers about 15 million km^2 and each satellite simultaneously serves an average of 80 and a maximum of 240 cells. The global throughput varies between nominally 171 and 500 thousand simultaneous calls. As the spacecraft moves with great speed, the user encounters adjacent beams about once a minute. The Iridium satellite constellation of 66 spacecraft is illustrated in **Figure 2.21 (B)**.

Each Iridium satellite is fitted with 3 antenna systems for communication with other adjacent spacecraft, Gateways and mobile terminals. Each antenna communicating with ground terminals will use 16 spot beams, making a cellular type honeycomb of 48 cells from each satellite. At this point, this allows considerable reuse of the same frequencies within different non-adjacent beams, something which is essential if frequency and system congestion is to be avoided. The outer beams will be turned off as satellites approach the poles, thus avoiding overlapping coverage and conserving power. The allocated frequency is divided into 12 sub bands and each sub band is reused four times on a single satellite. Since at high northern or southern latitudes some outer beams are not used, 2,150 spot beams are actually active to cover the globe, so the frequency reuse factor is 2,150/12 = 180. The system is designed for each spot beam to support 80 channels; hence the channel capacity worldwide is 2,150 x 80 = 172,000 channels. Uplink and downlink frequencies are identically allocated in the range around 1.6 GHz. At this point, using 50 Kb/s TDMA bursts in uplink and downlink, 4.8 Kb/s voice or 2.4 Kb/s data full duplex communication service is available(Fossa *et al.* 1998).

The Iridium system uses only one-way links at a time, which is known as time-duplexing and each user can rapidly switch modes between receive and transmit units. The use of one set of frequencies for up and downlinks simplifies the user's hardware. Like the Cellular systems, such as GSM system, the user will be handed-off between the beams in the same satellite and when required from one satellite to the next. In such a way, each Iridium satellite will have communication links to the satellite immediately ahead and behind on the same plane and up to four links with satellites on adjacent planes for cross or intersatellite hand-off. Ka-band intersatellite links with four cross-links on each satellite: front, back and two in adjacent orbits, provide reliable, high-speed communication between neighboring satellites and connect a subscriber to a GES via various possible paths. This flexibility improves call delivery efficiency and system reliability.

The new project for Iridium NEXT constellation (second generation) will also consist of 66 operational cross-linked, which intersects over the North and South poles. Iridium to begin launching the new satellite constellation of the originally planned 72 operational satellites and in-orbit spares, plus an additional nine ground spares with greater risk mitigation.

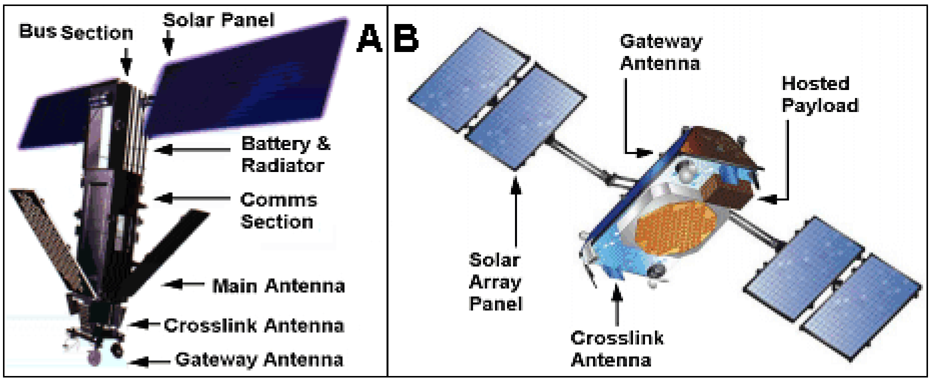

Figure 2.22. Iridium Spacecraft –Courtesy of Brochure: by Iridium

Iridium has entered into an Authorization to Proceed (ATP), which allows Thales Alenia Space Company to commence work on the development of satellites prior to completion of the financing, with the plan to commence the launch of the first satellites during the first quarter of 2015. The Iridium First generation spacecraft is shown in **Figure 2.22(A)** and the Second generation spacecraft is shown in **Figure 2.22(B)**, both with main components.
Each Iridium-NEXT satellites can provide an opportunity to fly an 50 Kg secondary sensor payload using 50 W average power. The mass of new spacecraft is 800 kg and it employs Proteus Bus,2 deployable solar arrays wit batteries lifetime of 10 years (design) and 15 years (planned). The NEXT spacecraft payload employs an L-band phased array antenna for generation of the 48-beam, the 4,700 km diameter cellular pattern on the Earth's surface for connection with subscribers/users. The Ka-band links are also provided for communication with ground-based Gateways and for crosslinks with adjacent spacecraft in orbit(Gupta 2011). Thus, the cross-linked 66 satellite constellation forms a global network allowing communications from a ground or airborne user in any location on Earth to virtually anywhere else on Earth, which coverage map is shown in **Figure 2.23.**
The ground network is comprised of the System Control Segment (SCS) as well as two Gateways (GES), which are connected into the terrestrial telephone lines. Because of inter-satellite links Iridium doesn't need more than 2 Gateways. Thus, the SCS is the central management component consisting three main integrated components: four TT&C sites, the Operational Support Network (OSN) and the Satellite Network Operation Centre or Network Control Station (NCS). The primary linkage between the SCS, the satellites and the Gateways is via K-Band feeder links and cross-links throughout the satellites.

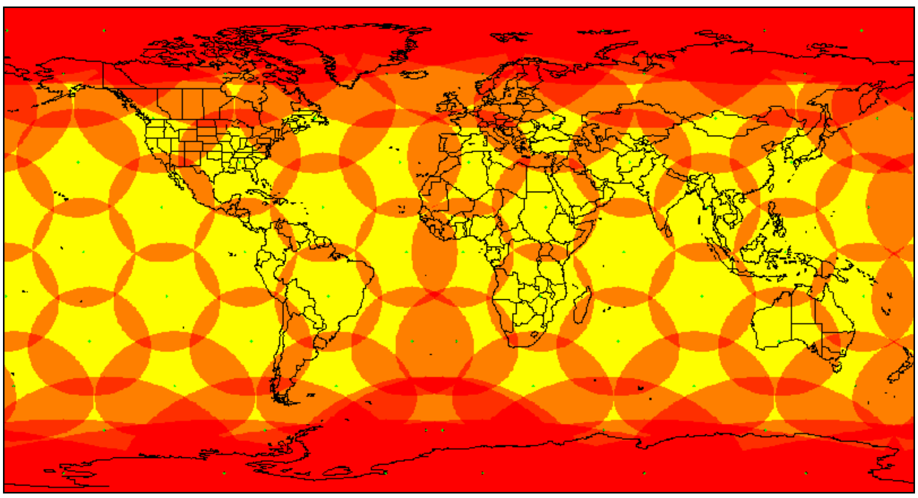

Figure 2.23. Iridium Satellite Coverage –Courtesy of Brochure: by Lloyd

Figure 2.24. Iridium Mobile Tracking Devices –Courtesy of Brochure: by Beam

The Iridium tracking satellite equipment enables receiving of GPS or GLONASS data and transmitting PVT to anywhere on the globe. The IridiTRAKRST430Beam unit is a small and lightweight tracking device with its inbuilt 16-channel GPS engine, Iridium Short Burst Data (SBD) modem and dual mode antenna, shown in **Figure 2.24 (A).** The SBD Modem RST425is a robust data terminal specifically designed to incorporate the Iridium 9601 SBD module for all mobile applications including maritime, shown in **Figure 2.24 (B).** The LeoTRAK RST480 is satellite and GSM mobile tracker, shown in **Figure 2.24 (C).**

The personal trackers are ideal for using as portable or onboard mobile tracking units, such as waterproof E-Track Epsilon Personal Tracker with full real-time autonomous unit providing global coverage, shown in **Figure 2.25 (A).** The second similar unit for personal tracking is GeoPro Personal Messenger, illustrated in **Figure 2.25 (B).** The Iridium NANO Personal Tracker shown in **Figure 2.25 (C)** is pocketsize and self-contained personal global satellite tracker. The weighs of unit is 170 grams, the volume is 4.0x2.2x0.8", with an internal rechargeable battery using AC adapter ad computer USB port or external solar charger. This unit provides the following features:

1. Power/Enter provides to turn device ON/OFF when hold down for two seconds or is used to select the highlighted item on the menu; 2. Arrow Up/Down/Right is serving to navigate the cursor, which arrow on left side is used to navigate the cursor or it is used to go back to the previous menu; 3. Check-In Soft Key is used to access the Check-In feature. 4. Way Point Soft Key is used to access the Way Point features; 5. USB Port is serving to charge the battery, update firmware or setup operating parameters using a computer; 6.The emergency key can be used to send an emergency alert, distress and notification to SAR and rescue forces; 7. Guard button protects emergency button from being accidentally activated; 8. LED is displays tracking and emergency statuses; 9. Antenna post is showing GPS antenna; and 10. Antenna post is showing Iridium antenna(IRIDIUM 2014).

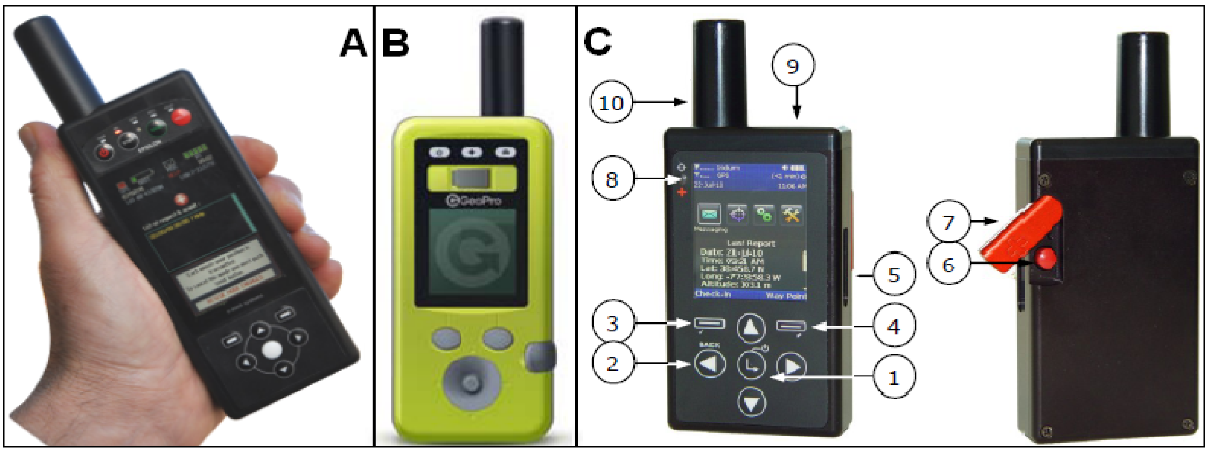

Figure 2.25. Iridium Personal Satellite Trackers –Courtesy of Brochure: by Iridium

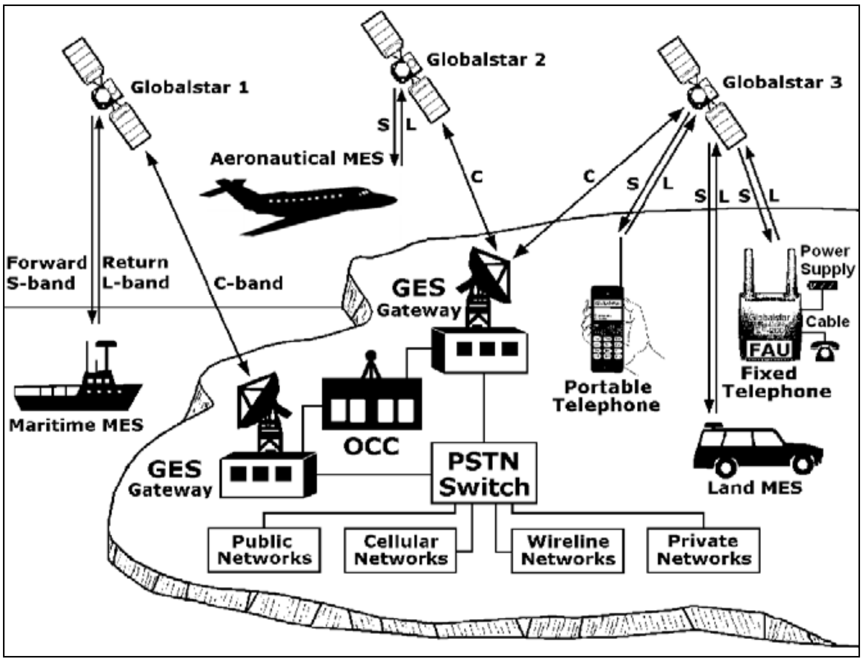

Figure 2.26. Globalstar GMSC Network –Courtesy of Book: by Ilcev

2.3.4. Globalstar Big LEO Satellite Network

Loral Space & Communications, with Qualcomm Incorporation developed the concept of the Globalstar system at a similar time to Iridium. Globalstar gained an operating license from the USA FCC in November 1996. Then, the first launch of four Globalstar satellites occurred in May 1998 by Delta rocket from Cape Canaveral and completed the deployment of 48 satellites plus four spares, using Delta and Soyuz-Ikar rockets.
The system uses Code Division Multiple Access (CDMA) and FDMA methods with an efficient power control technique, multiple beam active phased array antennas for multiple access, frequency reuse, variable rate voice encoding, multiple path diversity and soft handoff beams to provide high quality satellite service to users anywhere in the world, even when affected by propagation interference and environmental conditions. Globalstar CDMA is a modified version of the IS-95, which was originally developed by Qualcomm.
Globalstar is a LEO satellite-based digital telecommunications system that offers wireless telephone and other telecommunications services worldwide, starting from the end of the last century. The communications system is designed to provide worldwide digitally crisp voice, data and facsimile services to portable, mobile and fixed user terminals. To the user, operation of a Globalstar phone is similar to that of a cellular phone but with one main advantage: while a cellular phone works only with its compatible system in its coverage areas, the Globalstar system will offer worldwide coverage and interoperability with current and future public switched telephone and land mobile networks(Connolly *et al.* 1997).
The Globalstar system consists in three major segments such as: the Space, Ground and User segments including a Terrestrial Network, as shown in **Figure 2.26.** The Globalstar system has a constellation of 48 satellites in 8 planes with 6 satellites per plane inclined at 52o to the Equator at an altitude of 1,414 Km LEO and 4 in-orbit spares parked at a lower altitude. The low orbits permit low-power user phones, similar to the cellular units. Globalstar provides coverage from any point on the Earth's surface to any other point worldwide with multiple overlapping satellite beams for simplex data and voice/duplex data, exclusive of both Polar Regions. There are two problem areas in the satellite coverage: the first is over the Equator where the beam is narrow and the second is that is not covered well both Polar areas. Thus, some study on supplementing coverage with Molniya orbit satellites has been performed.

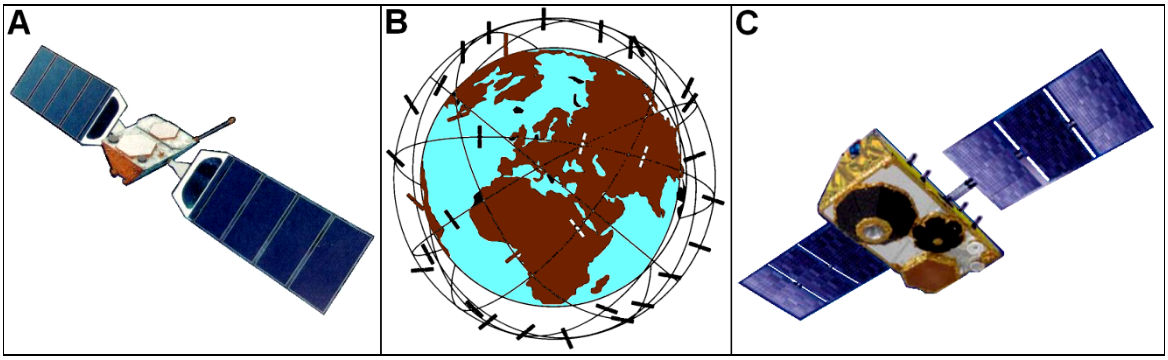

Figure 2.27. Globalstar Satellites and Spacecraft Constellation–Courtesy of Brochure: by Globalstar

The first generation of Globalstar satellite, spacecraft orbital planes and second-generation satellite are illustrated in **Figure 2.27(A),(B) and (C)**, respectively. Globalstar launched six new generation satellites in October of 2010, an additional six in July of 2011 and the rest to complete constellation will be launched in the near future. The payload is a “bent-pipe” transponder, which includes two antenna arrays with two sets of 16 spot beams on the Earth’s surface for service uplink (user-to-satellite) and reverse downlink; one horn antennas for feeder uplink (GES-to-satellite) and reverse downlink with transmitting and receiving antennas and circuitry for TT&C. Globalstar satellites function as a relay between the user segment and the ground segment, therefore, they merely transmit the signals received from user terminals to the Gateways and vice versa. Gateways or GES are similar to base stations in cellular systems, which user signals are relayed through satellites to the Gateways.
The satellite constellation is a 48/8/1 Walker Delta pattern with 52^0 inclinations is designed to provide global Earth coverage between 70^0 N and S latitudes, see **Figure 2.28.** Therefore, Globalstar provides coverage from any point on the Earth’s surface to any other point worldwide with multiple overlapping satellite beams for simplex low speed data for Satellite Asset Tracking (SAT) in integration with GPS receiver and voice/duplex data for mobile and personal applications, exclusive of both Polar Regions. The SAT service can include additional service known as Satellite Asset Tracking and Fleet Management (SATFM) of all mobile assets including ships, such as Global Ship Tracking (GST). The SATFM service is also integrated with GPS and can interface different sensors, such as for mileage, consumption of fuel, door control, temperatures and so on (Wiedeman and Viterbi 1993).

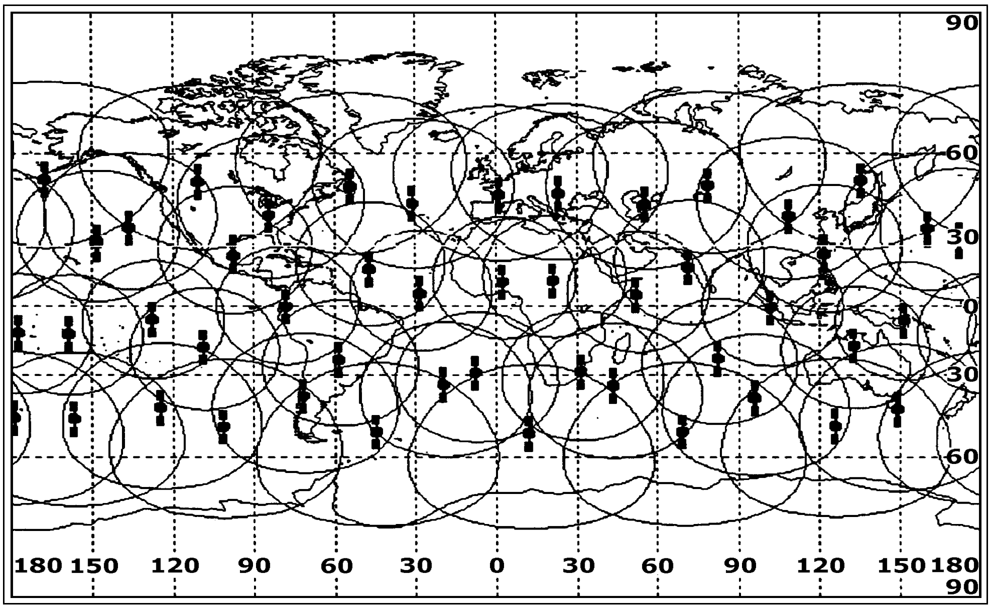

Figure 2.28. Globalstar Coverage by Satellites –Courtesy of Brochure: by Globalstar

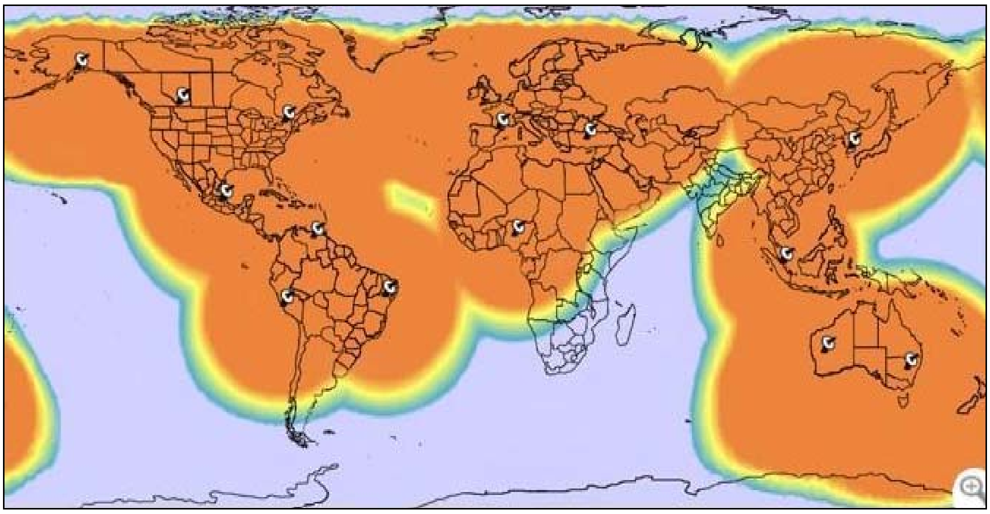

Figure 2.29. Globalstar Coverage by Gateways –Courtesy of Brochure: by Globalstar

The SAT service can include additional service known as Satellite Asset Tracking and Fleet Management (SATFM) of all mobile assets, including ships, such as Global Ship Tracking (GST). The SATFM service is also integrated with GPS and can interface with different sensors, such as for mileage, consumption of fuel, door control, temperatures and so on. Globalstar is also providing low speed data service for fixed assets known as satellite SCADA of M2M. In fact, these units transmit just a single packet message 3-times (the original transmission plus 2-repeats) per day in the frequency appropriate for the given regions in the coverage area.

The biggest problem with the Globalstar coverage is that at present this system is not providing inter-satellite connections, so this network needs number of additional Gateways worldwide, such as Southern Africa and large ocean areas worldwide. The simplex data coverage map for tracking and detection of mobiles and ships is shown in **Figure 2.29** with current 14 Gateways (GES) terminals indicated as ground satellite antenna units. To provide additional coverage of Southern Africa, the system needs one Gateway in this area. The additional problem of Globalstar is to provide full service coverage of ocean areas, which can be solved by installing more Gateways situated at sea platforms or islands.

Globalstar has reduced the size of its Simplex Transmitter Unit (STX) by 2/3 to provide additional opportunities for vehicle and asset tracking, illustrated in **Figure 2.30 (Left**). The STX3 is a low cost unit ideal for delivering remote sensing, mobile tracking and monitoring.

The Globalstar Spot Personal Tracker or Spot 1 was introduced to the market by Axonn in early 2008, shown in **Figure 2.30 (Right)**. With the Spot Tracker, people in emergency at sea or land can send emergency alert and getting assistance. This unit can use GPS data and sends its coordinates with a link to Google maps and a pre-programmed message via a commercial satellite network(GLOBALSTAR 2014).

Figure 2.30. Globalstar Simplex and Duplex Units –Courtesy of Brochure: by Globalstar

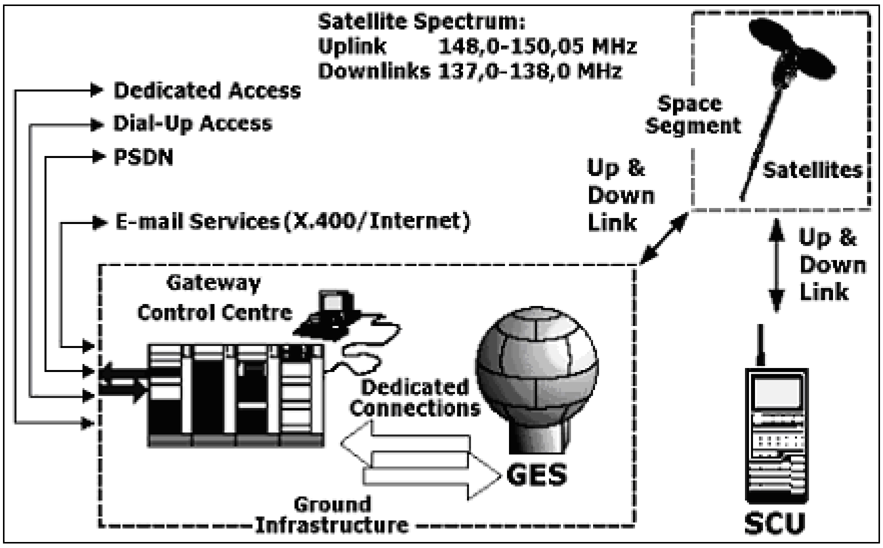

Figure 2.31. Orbcomm System Overview –Courtesy of Brochure: by Orbcomm

2.3.5. Orbcomm Little LEO Satellite Network

The Orbcomm system is a wide area packet switched and two-way data transfer network providing global mobile satellite communication, tracking and monitoring services between mobile, remote, semi-fixed or fixed Subscriber Communication Units (SCU) and Gateways (GES) with Gateway Control Centres (GCC) accomplished via the constellation of Little LEO satellites and Network Control Centres (NCC), shown in **Figure 2.31.** The system is capable of sending and receiving two-way alphanumeric packet messages, similar to the well-known two-way paging, SMS or E-mail. The Orbcomm network enables two-way monitoring, tracking and messaging services through the world's first LEO commercial satellite slow data communications system for tracking mobile assets such as ships, fishing boats, containers, vehicles, trailers, locomotives and rail cars, heavy equipment and aircraft including monitoring and controlling fixed sites. Fixed service is SCADA or M2M of electric utility meters, water levels, oil and gas storage tanks, pipelines and environmental projects and a duplex messaging service for consumers, commercial and government entities.

Orbcomm Global, L.P. Company, from Dulles, Virginia, USA equally owned by Teleglobe and the Orbital Sciences Corporation, provides global services via the world's first LEO satellite-based data communications system. The FCC granted Orbcomm a commercial license in October 1994 and the Commercial service began in 1998. Orbital Sciences was the prime contractor for the design project of Orbcomm satellites.

The Company owns and operates a network consisting in 36 Little LEO satellites and four terrestrial Gateways deployed around the world. Small, low-power and commercially proven SCU can connect to private and public networks, including the Internet, via these satellites and Gateways. Through this network, Orbcomm delivers information to and from virtually anywhere in the world on a nearly real-time basis. The Orbcomm mobile terminals provide a continuous 4.8 Kb/s stream of downlink packet messages, which is capable of transfer data even at 9.6 Kb/s.

Vital messages generated by a variety of applications are collected and transmitted by an appropriate mobile or fixed SCU to a satellite in the Orbcomm constellation. The satellite receives and relays these messages down to one of four US GES terminals. The GES then relays the message via satellite link or dedicated terrestrial line to the NCC. The NCC routes the message to the final addressee, through the Internet via E-mail to a personal computer, through terrestrial networks to a subscriber communicator or pager and to dedicated land telephone line or facsimile(Tandler 1996).

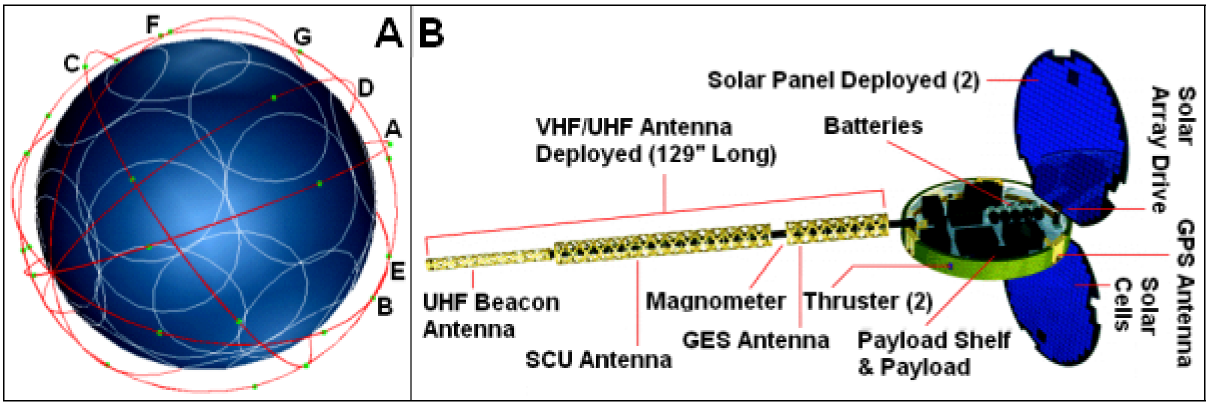

Figure 2.32. Orbcomm Satellite Constellation and Spacecraft –Courtesy of Brochure: by Orbcomm

Orbcomm satellite communication network consists in 36 operational spacecraft in Little LEO orbit at about 825 km above the Earth's surface. The main function of Orbcomm's satellites is providing link between SCU and switching capability at the US NCC, or a licensee's GCC in other countries, which satellite constellation is shown in **Figure 2.32 (A).** As mentioned, the last Orbcomm constellation consisted in 36 satellites in orbit:

1) Planes A, B and C are inclined at 45° to the equator and each contains eight satellites in a circular orbit at an altitude of approximately 815 km.

2) Plane D is also at 45° containing seven birds in a circular orbit at an altitude of 815 km.

3) Plane F is inclined at 70° and contains two birds in a near-PEO at an altitude of 740 km.

4) Plane G is inclined at 108° and contains two satellites in a near-polar elliptical orbit at an altitude varying between 785 km and 875 km. Plane E is in circular equatorial orbit.

The Orbcomm network depends on the number of satellites and Gateways in operation and the user's location. As the satellites move with the Earth, so does the approximately 5.100 km diameter geometric footprint of each satellite. This system provides redundancy at the system level, due to the number of satellites in the constellation. Thus, in the event of a lost satellite, Orbcomm will optimize the remaining constellation to minimize the time gaps in satellite coverage. Consequently, the Orbcomm constellation is tolerant of degradations in the performance of individual satellites(Coverdale 1995).

To date, 36 Orbcomm satellites have been launched, using Pegasus XL and Taurus launch vehicles. Each of the satellites is based on the Orbital Microstar satellite bus. Undeployed, the Orbcomm satellite resembles a circular disk and the spacecraft weighs circa 43 kg, measuring approximately 1 m in diameter and 16 cm in depth. Circular panels hinge from each side after launch to expose solar cells. These panels articulate on the 1-axis to track the Sun and provide 160 W. The satellite's electrical power system is designed to deliver circa 100 W on an orbit-average basis, near its expected EOL in a worst-case orbit. The satellite solar panels and antennas fold up into the disk (also called the "payload shelf") with the remainder of the payload during launch and deployment. Once fully deployed, the spacecraft length measures about 3.6 m from end to end with 2.3 m span across the solar panels disks. Long boom is a 2.6 m VHF/UHF gateway antenna. In **Figure 2.32 (B)** is shows the main parts of a fully deployed Orbcomm spacecraft.

Each Orbcomm spacecraft carries 17 data processors and seven antennas, designed to handle about 50,000 messages per hour. The Orbcomm satellite transponder receives by 2400 b/s at 148 to 149,9 MHz and transmits by 4800 b/s at 137 to 138 MHz and 400.05 to 400.15 MHz. The system uses X.400 (CCITT 1988) addressing and message size is typically 6 to 250 bytes (no maximum). The communication subsystem is the principal payload flown on the satellite, consisting in five major parts: Subscriber Section, Gateway Connections, Network Receiver/Computer, UHF Transmitter and Satellite Subscriber Antenna System(Meinecke *et al.* 1999).

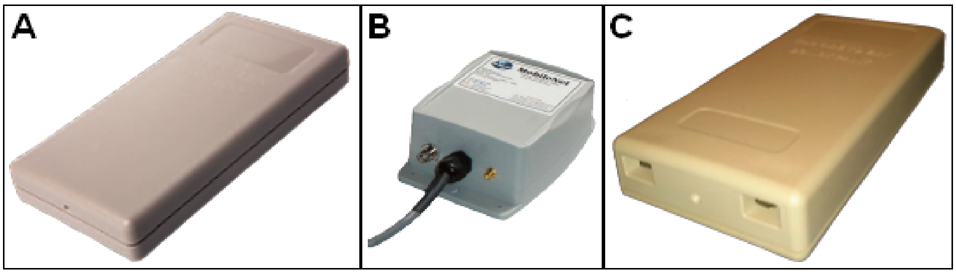

Figure 2.33. Orbcomm Satellite Units –Courtesy of Brochure: by Orbcomm

The Orbcomm has developed the following own satellite modems:
1. Orbcomm GT 500 GPS/Transmitter is completely sealed and rugged device for mobile asset tracking and M2M solutions, shown in **Figure 2.33 (A)**. The unit is using 1610-1626 MHz frequency band with CPDMA simplex Transmission. It has power supply by lithium internal batteries with life expectancy up to 5 years at 2 messages per day, so unit is ideal for discrete installation onboard ships and to send PVT data even after it hijacking by pirates.
2. Orbcomm HE 4000 GPS/ Transceiver is a ruggedized dual-mode tracking and monitoring solution that can be used for onboard many mobiles, shown in **Figure 2.33 (B).** This unit can use GSM/GPRS mode optionally and external power supply in the range of 9 to 32 V.
3. Orbcomm GT 600 GPS/Transmitter simplex and environmentally hardened device is for mobile tracking and M2M solutions, shown in **Figure 2.33 (B).**This unit is good operational to 1000 knots (515 m/s), so can be installed onboard aircraft(ORBCOMM 2014).

2.4. Pico, Nano and Micro (CubeSat) Satellite Networks

Recently many countries and some research centres started to provide research, design and developing of cost effective small satellites for LEO constellations. Thus, small satellites are categorized by their weight, such as Pico less than 1 – 5 Kg, Nano less than 10 – 50 Kg and Micro satellites less than 100 – 200 Kg, which measure less than 0.5 meter Another name for some of the smallest satellites is CubeSat, a term that is not used in the ITU resolution but often is applied to nanosatellites with a volume of one liter, or 10 centimeters cubed. The ITU regulations are not geared for these smaller satellites and until now there has been no consideration of how the rules might be adopted for them. In an effort to foster their use, a group of European countries submitted a late proposal to WRC-12 suggesting that the next ITU conference should consider the frequency bands and regulatory requirements for small types of satellites. The proposal was dated on 30 January 2012, for a conference that had already started on 23 January 2012. This proposal maintains that more than 500 of these smaller satellites are under development, which is putting pressure on currently used frequency bands, usually within the range of 137 MHz to 2,450 MHz.
In a further contrast to large GEO or medium MEO and LEO constellations, vastly more expensive communications and remote sensing satellites that are expected to operate 15 and up to 25 years or longer in space, these smaller satellites are typically launched as secondary payloads, which have limited lifetime and orbit control capabilities(Pranajaya *et al.*).
Therefore, these small satellite platforms and networks are ideal providing cost-effective missions for tracking, detecting and remote sensing, focusing on technological research and commercial proof-of-concept solutions. However, the only and very serious problems of these satellite systems is limiting factors causing their very short life time and because these systems never can be professional operators providing global satellite tracking and detecting systems. Based on different studies and examples in which Nano satellites were exposed to the different levels of radiation, some Cube Sat electronics Secure Digital(SD) cards especially are susceptible to errors from radiation.

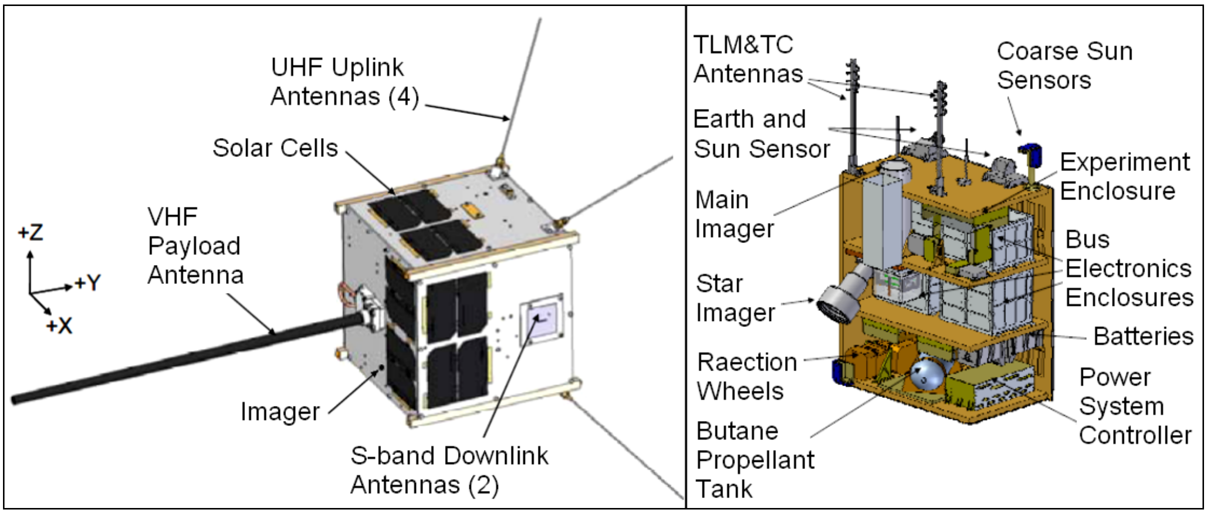

Figure 2.34. NTS/AISSat and SumbandilaSat Satellite Platforms –Courtesy of Brochure: SFL/US

To keep costs down, CubeSat payload components are typically not radiation-hardened, although there are several ways to mitigate the impact of radiation and single event upsets on electronics. Radiation can be mitigated to some degree through shielding and material choice. It can also be mitigated in finding adequate software by clever use of watchdog timers and "self-aware" coding where self-verification is consistently monitored.

Another problem causing small satellites is the short lifetime of the batteries. The lifetime of a battery is depending on the amount of charge cycles and the robustness for low voltage and the operating temperature range is an important factor. Also the weight and the size of the battery have to be minimized with a focus has to be on the space usability of the battery. To find the best battery for CubeSat these factors have to be solved with new battery types.

The values of CubeSat size are different, thus when orbit altitude changes from 200 to 600 Km, the lifetime increases from several days to several decades. The lifetime of a CubeSat lower than 300 Km will be 0-100 days. A 200 Km CubeSat mission requires carefully design due to its abbreviated lifetime. The CubeSat satellites from 300 to 400 Km are a danger of collision with the International Space Station (ISS), because that the orbit of ISS is usually maintained between 335 km perigee and 400 km apogee. A CubeSat in this altitude band could last for 0.5 to 2 years. In contrast, the lifetimes of higher altitude satellites than 600Km could be theoretically up to 25 years easily(Elbrecht *et al.* 2011).

The COM DEV Ltd launched Nanosatellite Tracking of Ships (NTS) spacecraft at the end of April 2008 following an unprecedented 8-month kick-off to launch cycle, which components are shown in **Figure2.34 (Left).** In **Figure 2.34 (Right)**is illustrated South African CubeSat SumbandilaSat, microsatellite designed by Stellenbosch University (SU) in Cape Town. This satellite launched 17 September 2009 by Russian Soyuz-2 launch vehicle from the Baikonur Cosmodrome with serves for Earth observation with design lifetime of 3 years at an orbit altitude of 500 Km (subject to average sun activity).

The University of Stellenbosch, SunSpace and the CSIR (Council for Scientific and Industrial Research) were key players in constructing SumbandilaSat. However, the CSIR's Satellite Application Centre (CSIR-SAC) is responsible for operations, telemetry, tracking, control as well as data capturing. This SumbandilaSat is part of a closely integrated South African space program and serves as a research tool to investigate the viability of affordable space technology. Furthermore, the data will be used to, amongst others, monitor and manage disasters such as flooding, oil spills and fires within Southern Africa. SumbandilaSat ceased to function due to damage it sustained during a solar storm in June 2010, when the power supply to the satellite's onboard

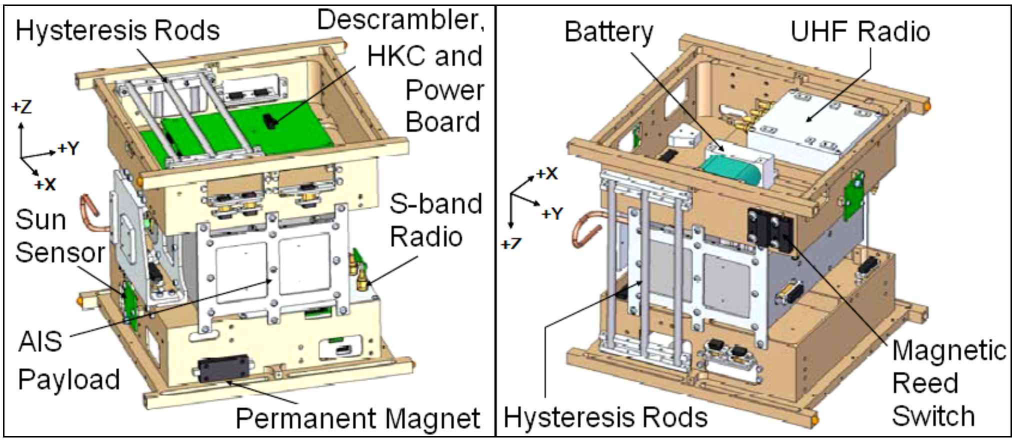

Figure 2.35. NTS Interior Details –Courtesy of Brochure: SFL

In the similar manner, the University of Toronto Institute for Aerospace Studies/Space Flight Laboratory (UTIAS/SFL) has been developed prototype of Generic Nanosatellite Bus (GNB) to fly a verity of payloads, ranging from S-AIS tracking solutions to precision formation flying. With the successful launch of the CanX-2 mission, technological validation is paving the way for the next generation of GNB derived CanX missions. The current GNB satellites in development include AISSat-1, CanX-3 (BRITE) and CanX-4&5, which new design of AIS Sat spacecraft with some components is shown in

Established in 1998, SFL offers end-to-end capability from mission design and space craft manufacturing to launch services and on-orbit operations. It is currently the only laboratory in Canada that has built and retains the capability to build very low-cost spacecraft such as microsatellites under 100 Kg and nanosatellites under 10 Kg for S-AIS maritime service, which interior details and components are illustrated in **Figure 2.35 (Left and Right).** The spacecraft structure comprised of two trays that accommodate all of the electronics(Esper *et al.* 2000).

The AIS system is a ship-to-ship and ship-to-shore system that is used as an aid for collision avoidance and vessel traffic management. Thus, the S-AIS signals consist of short messages broadcast by ships at 162 MHz and include information about the ship, its course, speed, crew and cargo. SFL currently has three operational spacecraft in orbit, such as the 53 kg MOST space telescope launched in 2003, the 3.5 kg CanX-2 technology demonstration and atmospheric science satellite launched in (2008) and the 6.5 kg AIS Sat NTS satellite for ship tracking in 2008(Newland *et al.* 2009; Bradbury 2011).

The approach taken in designing of the NTS spacecraft follows the micro space philosophy. The design is highly focused to meet a set of mission requirements. This approach is intended to result in a simplified design that is cost-effective and can be turned around in a relatively short period of time. Thus, the mission has been operating successfully for almost one year, exceeding its life requirement of one-month and goal of 6-months. The NTS is producing valuable results from its Automated Identification System (AIS) payload which was designed to collect messages from maritime vessels around the globe.

Thrusters offer a distinct advantage over reaction wheels and magnet in that they can contribute to station keeping and position control, not just attitude. In fact, for low orbits where drag is the primary disturbance force, satellite lifetimes are often very limiting to CubeSat missions. The addition of thrusters can prolong the operational lifetime of a satellite in low orbits.

The challenge today is to detect S-AIS signals from space for global ship tracking, detecting and monitoring. According to Zee, "COM DEV has developed innovative AIS technology that allows a space-based receiver to disentangle the colliding signals from many ships over very large areas. The technology has proven to work extremely well on board NTS.

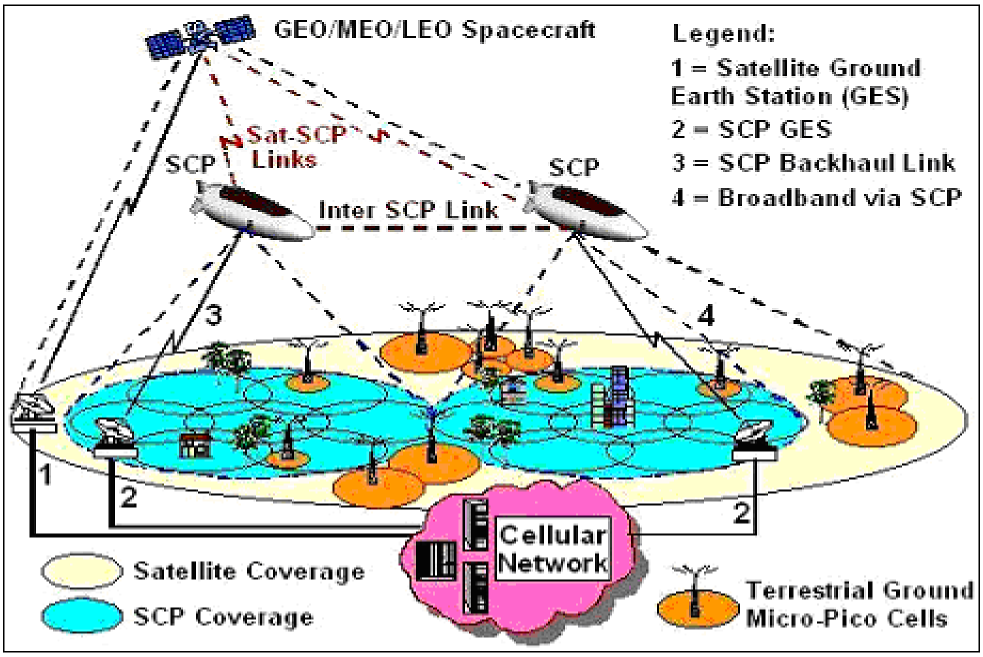

Figure 2.36. Satellite, SCP and Cellular Networks–Courtesy of Book: by Ilcev

2.5. Stratospheric Communication Platform (SCP) Networks

The Stratospheric Communication Platform (SCP), known as well as High Altitude Platforms (HAP) were defined in the World Radio Communications Conference (WRC) in 1997, in the Radio Regulations (RR) No. S1.66A as a station located on an object at an altitude of 20 to 50 Km and at a specified, nominal, fixed point relative to the earth [WRC-122, 97]. In this definition, it has not been determined yet if the object is manned or unmanned or even how itis powered. Thus, the common vision predicts that the design of this system will consist of one or more quasi-stationary SCP with Inter-Platform Links (IPL) as depicted in **Figure 2.36.**Thus,the same network can be developed without IPL, so all platforms have to communicate via GES or Gateways located in the overlapping arrears(Djuknic *et al.* 1997).
Thus, several countries are now proposing many alternative technologies for the development of such an object in the stratosphere. The SCP is to be positioned well above commercial airplane at an altitude that is high enough to provide service to a large area or spot footprint, providing communication, broadcasting, tracking, detecting and environment observation services with minimal ground network infrastructure.
There have been several recent developments in the space platforms arena of SCP scenario, especially for the design of data transfer and surveillance system for many international borders have demonstrated them to be a reliable and proven technology. In fact, a number of trials of small-scale airship have been conducted by companies in Japan, USA and Switzerland (StratoComm). Several programs are now focusing on space platforms, providing fixed and mobile wireless broadband and communications using local WiMAX and WiFi services. In the interim, StratoComm Corporation formed in 1992 has designed networks for Transitional Telecommunication Project (TTP) tethered system as a means to immediately enhance telecommunications capacity in under-served areas. This network became commercially available to provide service for about half a million customers and seamless transition from the aerostat-based systems to its SCP network that will serve about three million customers.
As a result, the SCP can easily provide LOS communication with a high elevation angle, whereby the links are relatively free of the influence of obstacles. The antenna and the radio equipment can be made smaller because the electric power supply required for transmission can be decreased.

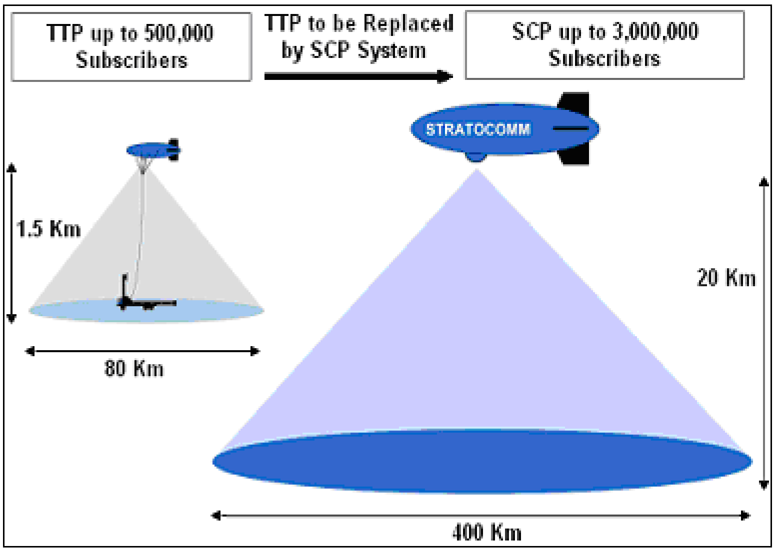

Figure 2.37. Transition from TTP to SCP –Courtesy of Book: by Ilcev

Furthermore, there is a minimal voice delay when used for voice and telephone service or data transfer, because the stratospheric platform is much closer to the ground than satellites, and hence the delay propagation is almost not an issue in this system.

The StratoComm platform is a Lighter-Than-Air (LTA) aerostat system positioned at an altitude point of approximately 1,500 meters over the region to which it is providing wireless telecommunications services. The aerostat is connected via high-strength steel and Kevlar tether to the ground cite, thereby maintaining its position and ability to support subscriber services, as well as providing access to power, operational control and data service via fiber optic cable and electrical conductors embedded within the tether.

The transitional aerostat station is approximately 37 meters in length and 12 meters at its widest point. It meets all US FAA requirements, including the presence of an emergency flight termination system and proper lighting. The aerostat carries an internally designed telecommunications payload weighing approximately 225 Kg, which is capable of supporting subscribers by broadband fast Internet, voice, data and video transmission with various combinations in a coverage area of 80 Km in diameter.

As is shown in **Figure 2.37** is provided transition from the old TTP to the more advanced SCP system. The SCP station doesn't interfere aircrafts flights, because SCP are located over 10 Km, however airship itself leverages LTA technology being made of very high strength and lightweight materials. In addition, the platform is accompanied by advanced propulsion systems that maintain proper positioning and is equipped with autonomous navigation, Telemetry Tracking and Command (TT&C) and communications payload stabilization systems. Airship located at 20 Km position over Earth is able to cover about 400 Km radius areas. The SCP airship can be launched by deploying a specified volume of helium separated from the air to maintain its shape. As it rises the helium expands and at the proper altitude and displaces all of the air within the STS. Once it is in the stratosphere the SCP is remotely controlled and moved into determined position. The integration of solar cells, batteries and fuel cells provides power for to the SCP airship during five-year planned deployment. The SCP also incorporates TT&C and redundant systems to serve as back-up measures, then features that are designed to provide the airship with a high level of availability, reliability and safety. The STS is being designed to hold approximately 1,000 Kg of communication payload capable of supplying focused fixed and mobile broadband, narrowband and wireless backbone services to approximately 3 million subscribers. However, the SCP airships are ideal networks for local or regional mobile communication, tracking and monitoring solutions.

Figure 2.38. Prototype of HAP Aircraft Altus–Courtesy of Brochure: by AVCS/NATO

The SCP configurations can be dynamically changed in milliseconds to reallocate capacity as needed, such as to highly trafficked commuter routes during peak travel times, to business districts on weekdays or to stadiums during events. In general, there are two main solutions of SCP, aircraft and airships divided into four categories:

1. Manned aircraft on fuel, which are flying in small circles for purpose as SCP and in any destination for observation and imaging applications around 48 hours or until fuel lasts;
2. Unmanned aircraft on fuel, which can fly until fuel lasts;
3. Unmanned plane on solar power can fly for minimum 6 month and get maintenance; and
4. Unmanned airship on solar power can hover in certain position for minimum 6 months and has to be landed for maintenance, so in its place will be located another airship(Konigorski *et al.* ; Ilcev, SD 2005a).

2.5.1. SCP Aircraft Networks

The new aircraft projects offer cost-effective systems by using special unmanned and solar powered engines with an estimated endurance of several months and piloted aircraft with fuel engine propulsion for operating on a daily basis, known as Unmanned Aerial Vehicles (UAV). This system will be more effective by development new systems such as: General Atomic, Halostar/Halo, Heliplat/HeliNet Hale, SkyTower Global and other forthcoming networks. These UAV network are ideal for mobile tracking and remotes sensing solutions.

Building upon its worldwide leadership in the new design, manufacture and deployment of UAV, General Atomics Aerial Vehicle Communications System (AVCS) is developing the next generation of SCP aircraft. The research team of the General Atomic together with the NASA, the US Navy and the Department of Energy (DOE) developed a prototype high-altitude aircraft, Altus, for the future AVCS Network project, shown in **Figure 2.38 (Left)**. This stratospheric aircraft will be ideal for Telecommunications Relay, Cellular Relay and Commercial Applications. At first, Altus was deployed in support of atmospheric research for the DOE, with future plans to use the high altitude capabilities to understand the genesis of and predict hurricane paths and damage potential, as well as many other advanced scientific applications.

The first unmanned, high altitude solar-electric aircraft designed under the NASA project was Pathfinder, developed in 1995 with a wingspan of about 29.87 m which flew to 15.39 and 21.79 km in 1995 and 1997, respectively, see **Figure 2.38 (Right)**. A second modified UAV Pathfinder program, known as Pathfinder-Plus, with a bigger wingspan of 36.88 m, flew to 24.44 km. This record flight was the 39th consecutive successful flight test of the Pathfinder platform. The next-generation of aircraft Centurion was a wingspan of 62.78 m, which test flown in 1998. The wingspan was then further extended to 75.28 m and the previous model of aircraft was renamed the Helios prototype(Ilcev, SD and Singh 2004).

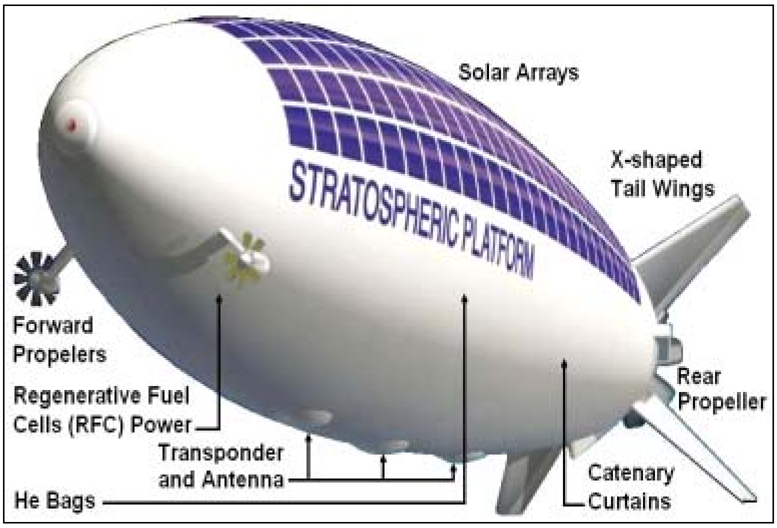

Figure 2.39. TAO SCP Airship–Courtesy of Brochure: by TAO

2.5.2. SCP Airship Networks

The new airship projects offer cost-effective systems for SCP by using special unmanned and non-fuel solar-cell powered balloons with an estimated endurance of several months. In comparison with aircraft and airship systems it is difficult now to say which one will be better for the future reliable SCP. There are several airships such as: Sky Station Global Network, Sky LARK Network, Strat Con (Strato Sat) Global Network, TAO Network, etc.
A Research and Development (R&D) program on SCP airship is in progress since April 1998. The final goal of this project is to realize the SCP airship, being capable of long duration station-keeping flight at about 20 Km in stratospheric. The achievements will enable advanced wireless fixed and mobile communications, digital direct broadcasting, modern broadband transmission and high-resolution observations and monitoring of the remote, rural and global environment. This advanced SCP program is promoted in collaboration with the Communications Research Laboratory of Japan (CRL), National Space Development Agency of Japan (NASDA), Japan Marine Science and Technology Centre (JAMSTEC) and the Telecommunications Advancement Organization (TAO) of Japan.
The stratospheric platform is an unmanned airship kept at a stratospheric altitude of about 20 Km for multimedia communications, tracking monitoring and remote sensing. It is equipped with communications payload, observation sensors or other equipment. The SCP system is designed similar to a satellite space segment as a relay station to receive signals from ground stations using feeder links and to retransmit them to subscribers using service links. Therefore, an airship like a satellite is carrying a payload with corresponding transponders and antenna system. The launch of SCP into position is much simpler than putting a satellite into any orbit. After careful preparation in the hanger space, the airship is launched in 4 Ascent phases through the troposphere and Interface location point in the stratosphere and finally, it shifts to the station-keeping position. The recovery phase goes in the opposite direction, namely, the airship is slowly moved from the station-keeping position towards the Interface point and from there descends down to the ground in 4 descent phases(Ilcev, SD 2005b).
The airship construction has a semi-rigid hull of ellipsoidal shape, with an overall length of about 200 m, shown in **Figure 2.39.** It is composed of an air-pressurized hull for maintaining a fixed contour and internal special bags filled with the buoyant helium gas. Thus, airship as an autonomous system is ideal for new Radio and Space CNS for all mobile applications and including for ships tracking, detecting and monitoring in hot area where operate pirates(Ilcev, SD and Singh 2004).

Figure 2.40. Optical Links from Satellites via SCP–Courtesy of Book: by Ilcev

2.5.3. Satellite Optical Downlink and High Data Link via SCP

Satellite optical links offer significantly higher bandwidth, but they are blocked by clouds. As a consequence downlinks from satellites to a ground station have a limited availability depending on the cloud situation over a site. For non-Earth Observation (EO) application like communications or broadcast content, a nearly hundred percent availability is required for the satellite link. This problem can be solved by using a relay station in form of an SCP, which has to be positioned above the clouds in about 20 Km altitude. Besides, an optical link from the satellite to the SCP would have 100% availability, as it is not hindered by clouds. The final "last mile" to the ground could then be bridged by a standard MW point-to-point link as used today in terrestrial applications, but with a large bandwidth compared to a satellite link due to the short distance. An optical link in parallel to the MW link could increase the bandwidth of the last 20 Km several times during cloud-free conditions.
In **Figure 2.40** are illustrated two scenarios for optical downlinks from two LEO satellites. Namely, relay link from a LEO satellite to the ground via SCP relay (left) and from a LEO satellite over a GEO satellite and a SCP airship (left). The "last mile" downlink from the SCP to a ground station would be either bridged by a high-bandwidth optical or microwave link. Therefore, in the SCP Relay scenario the data is sent directly via SCP to the ground site (SCP-GND). In the scenario GEO satellite (GEO-SCP) relay the data is first transmitted to a GEO satellite and then via SCP to the ground. The link SCP-ground can be established by an optical link or alternatively by an MW link. A network of interconnected SCP terminals could provide almost full availability also for optical SCP-GND links. Link duration between the LEO satellite and the SCP will be up to 12 minutes for each contact, with about 3-15 contacts depending on the geographic latitude of the SCP. In order to increase contact times a GEO satellite could be introduced. Link availability to the GEO satellite would be about half of the LEO orbit, i.e. about 12 hours per day. From the GEO satellite the data would be transmitted on a continuous link to the SCP. The increased link duration would be at the cost of significantly longer link distances with a more stringent link budget and the additional expenses of a GEO satellite(Ilcev, SD and Singh 2004; Horwath *et al.* 2006).

3. Chapter 3

THEORETICAL FRAMEWORK

This chapter describes orbital mechanics and their significance with regard to satellite use for Satellite Tracking and Detecting of ships, as more important chain in this field. Namely, here introduced the fundamental laws governing satellite orbits and the principal parameters that describe the motion of the Earth's artificial satellites. The types of satellite orbits are also classified, presented and compared from the MSC system viewpoint in terms of coverage and link performances.

The satellite Bus and payloads for communications and navigation (GNSS) are discussed. During the last two decades, commercial MSC networks have utilized GEO extensively to the point where orbital portions have become crowded; coordination between satellites is becoming constrained and could never solve the problem of polar coverage. However, Non-GEO MSC solutions have recently grown in importance because of their orbital characteristics and coverage capabilities in high latitudes and Polar Regions.

3.1. Platforms and Orbital Mechanics

The platform is an artificial object located in orbit around the Earth at a minimum altitude of about 20 km in the stratosphere and a maximum distance of about 36,000 km in the Space. The artificial platforms can have a different shape and designation, but usually they have the form of aircraft, airship or spacecraft. In addition, there are special space stations and spaceships, which serve on more distant locations from the Earth's surface for scientific exploration and research and for cosmic expeditions.

Orbital mechanics is a specific discipline describing planetary and satellite motion in the Solar system, which can solve the problems of calculating and determining the position, speed, path, perturbation and other orbital parameters of planets and satellites. In fact, a space platform is defined as an unattended object revolving about a larger one. Although it was used to denote a planet's Moon, since 1957 it also means a man-made object put into orbit around a large body (planet), when the former USSR launched its first spacecraft Sputnik-1. Accordingly, man-made satellites are sometimes called artificial satellites.

Orbital mechanics support a communication satellite project in the phases of orbital design and operations. The orbital design is based on a generic survey of orbits and at an early stage in the MSC project is tasked to identify the most suitable orbit for the objective MSC service. The orbital operation is based on rather short-term knowledge of the orbital motion of the satellite and starts with TT&C maintenances after the satellite is located in orbit. In effect, only a few types of satellite orbits are well suited for MSC and navigation systems.

3.1.1. Space Environment

The satellite service begins when a spacecraft is located as a platform in the desired orbital position in a space environment around the Earth. This space environment is a very specific part of the Universe, where many factors and determined elements affect the planet and satellite motions.

The Earth is surrounded by a thick layer of many different gasses and parts known as the atmosphere, whose density decreases as the altitude increases. Hence, there is no air and the atmosphere disappears at about 180 km above the Earth, where the Cosmos begins.

The endless environment in space is not very friendly and is extremely destructive, mainly because there is no atmosphere, the cosmic radiation is very powerful, the vacuum creates

very high pressure on spacecraft or other bodies and there is the negative influence of very low temperatures.
The Earth's gravity keeps everything on its surface. All the heavenly bodies such as the Sun, Moon, planets and stars have gravity and reciprocal reactions. Any object flying in the atmosphere continues to travel until it meets forces due to the Earth's gravity or until it has enough speed to surpass gravity and to hover in the stratosphere. However, to send an object into space, it first has to overcome gravity and then travel at least at a particular minimum speed to stay in space. In this case, an object traveling at about 5 miles/sec can circle around the Earth and become an artificial spacecraft.
An enormous amount of energy is necessary to put a satellite into orbit and this is realized by using a powerful rocket or launcher, which are defined as an apparatus consisting of a case containing a propellant (fuel) and reagents by the combustion of which it is projected into the space. As the payload is carried on the top, the rocket is usually separated and drops each stage after burnout and brings a payload up to the required velocity and leaves it in orbit. A rocket is also known as a booster, as a rocket starts with a low velocity and attains required height, where air drag decreases and it attains a higher velocity(Tribble 2003).

3.1.2. Laws of Satellite Motion

A satellite is an artificial object located by rocket in space orbit following the same laws in its motion as the planets rotating around the Sun. In this sense, three so important laws of planetary motion were derived by Johannes Kepler, as follows:
1. First Law – The orbit of each planet follows an elliptical path in space with the Sun in one focus. Motion lies in the plane around the Sun (1602).
2. Second Law – The line from the Sun to a planet or radius vector (r) sweeps out equal areas in equal intervals of time. This is the Law of Areas (1605).
3. Third Law – The square of the planet's orbital period around the Sun (T) is proportional to the cube of the semi-major axis (a = distance from the Sun) of the ellipse for all planets in the Solar system (1618).
Kepler's laws only describe the planetary motion if the mass of the central body insofar as it is considered to be concentrated in its center and when its orbits are not affected by other systems. These conditions are not completely fulfilled in the case of Earth's motion and its artificial satellites. The Earth does not have an ideal spherical shape and the different layers of mass are not equally concentrated inside of the Earth's body. Because of this, the satellite motions are not ideally synchronized and stable, thus the motions are namely slower or faster at particular orbital sectors, which presents certain exceptions to the rule of Kepler's Laws. Furthermore, in distinction from natural satellites, whose orbits are almost elliptical, the artificial satellites can also have circular orbits, for which the basic relation can be obtained by the equalizing the centrifugal and centripetal Earth forces.
Kepler's Laws were based on observational records and only described the planetary motion without attempting an additional theoretical or mathematical explanation of why the motion takes place in that manner. In 1687, Sir Isaac Newton published his breakthrough work "Principia Mathematica" with own syntheses, known as the Three Laws of Motion:
1. Law I – Every body continues in its state of rest or uniform motion in a straight line, unless it is compelled to change that state by forces impressed with it.
2. Law II – The change of momentum per unit time of a body is proportional to the force impressed with it and in the same direction as that force.
3. Law III – For every action there is always an equal and opposite reaction.

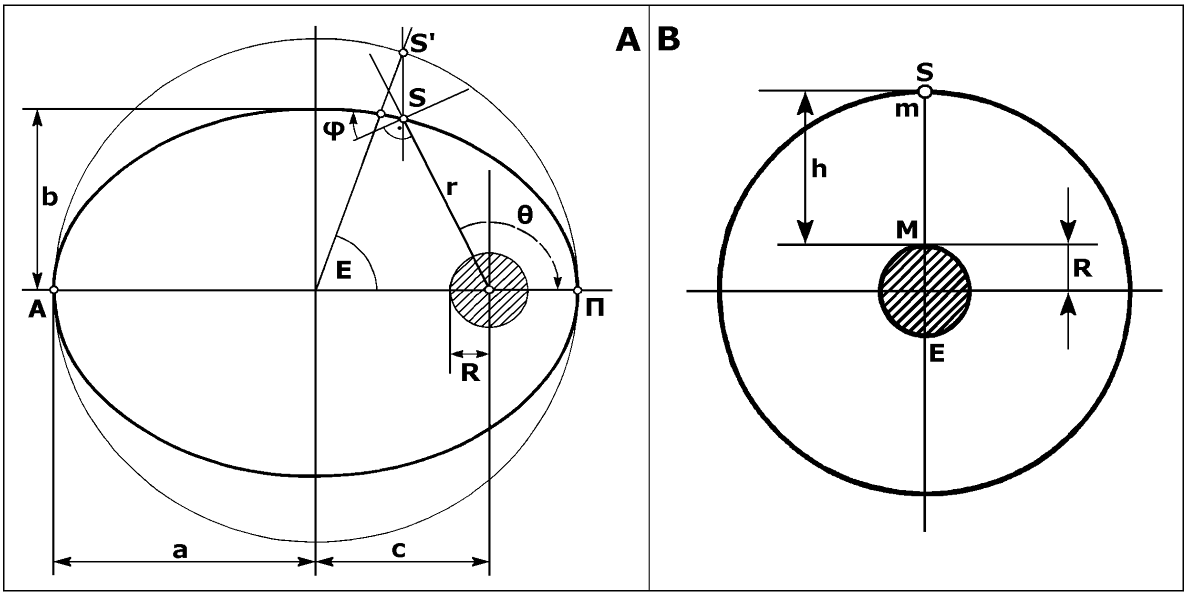

Figure 3.1. Elliptical and Circular Satellite Orbits - Courtesy of Book: by Galic

On the basis of Law II, Newton also formulated the Law of Universal Gravitation, which states that any two bodies attract one another with a force proportional to the products of their masses and inversely proportional to the square of the distance between them. This law may be expressed mathematically for a circular orbit with the relations:

$$F = m\,(2\pi/t)^2\,(R + h) = G\,[M \cdot m/(R + h)^2]; \qquad (3.1)$$

where parameter m = mass of the satellite body; t = time of satellite orbit; R = equatorial radius of the Earth (6.37816×10^6 m); h = altitude of satellite above the Earth's surface; G = Universal gravitational constant (6.67×10^{-11} N m^2/kg^{-2});M = Mass of the Earth body (5.976032×10^{24} kg) and finally, F = force of mass (m) due to mass (M)(Heiser and Pratt 1994; Chobotov 2002).

3.1.2.1. Parameters of Elliptical Orbit

The satellite in circular orbit undergoes its revolution at a fixed altitude and with fixed velocity, while a satellite in an elliptical orbit can drastically vary its altitude and velocity during one revolution. The elliptical orbit is also subject to Kepler's Three Laws of satellite motion.
Thus, the characteristics of elliptical orbit can be determined from the elements of the ellipse of the satellite plane with the perigee (Π) and apogee (A) and its position in relation to the Earth, see **Figure 3.1(A).** The parameters of elliptical orbit are presented as follows:

$e = c/a = \sqrt{[1 - (b/a)^2]}$ or $e = (\sqrt{a^2 - b^2}/a)$;$p = a\,(1 - e^2)$or $p = b^2/a$;(3.2)

$c = \sqrt{(a^2 - b^2)}$;$a = p/1 - e^2$; $b = a\,\sqrt{(1 - e^2)}$;

where: e = eccentricity, which determines the type of conical section; a = large semi-major axis of elliptical orbit; b = small semi-major axis of elliptical orbit; c = axis between centre of the Earth and centre of ellipse and p = focal parameter. The equation of ellipse derived from polar coordinates can be presented with the resulting trajectory equation as follows:

$$r = p/1 + e \cos \Theta \ \ [m] \qquad (3.3)$$

where r = distance of the satellites from the centre of the Earth (r = R+h) or radius of path; Θ = true anomaly and E = eccentric anomaly. In this case, the position of the satellite will be determined by the angle called "the true anomaly", which can be counted positively in the direction of movement of the satellite from 0^o to 360^o, between the direction of the perigee and the direction of the satellite (S). The position of the satellite can also be defined by eccentric anomaly, which is the argument of the image in the mapping, which transforms the elliptical trajectory into its principal circle, an angle counted positively in the direction of movement of the satellite from 0 to 360^o, between the direction of the perigee and the direction of the satellite. The relations for both mentioned anomalies are given by the following equations:

$$\cos \Theta = \cos E - e/1 - e \cos E \text{ or } \cos E = \cos \Theta + e/1 + e\cos \Theta. \quad (3.4)$$

The total mechanical energy of a satellite in elliptical orbit is constant; although there is an interchange between the potential and the kinetic energies. As a result, a satellite slows down when it moves up and gains speed as it loses height. Thus, considering the termed gravitation parameter μ=GM (Kepler's Constant μ=3.99 x 10^5 km^3/sec^2), the velocity of a satellite in an elliptical orbit may be obtained from the following relation:

$$v = \sqrt{}[GM (2/r) - (1/a) = \sqrt{}\mu (2/r) - (1/a)] \quad (3.5)$$

Applying Kepler's Third Law the sidereal time of one revolution of the satellite in elliptical orbit is as follows:

$$t = 2\pi \sqrt{}(a3/GM) = 2\pi \sqrt{}(a3/\mu) \quad (3.6)$$

$$t = 3.147099647 \sqrt{}(26{,}628.16 \cdot 103)3 \cdot 10{-}7 = 43{,}243.64[s]$$

Therefore, the last equation is the calculated period of the sidereal day of the elliptical orbit of Russian-based satellite Molnya with apogee = 40,000 km, perigee = 500 km, revolution time = 719 min and a = 0.5 (40,000 + 500 + 2 x 6,378.16) = 26,628.15 km(Heiser and Pratt 1994; Chobotov 2002).

3.1.2.2. Parameters of Circular Orbit

The circular orbit is a special case of elliptical orbit, which is formed from the relations a = b = r and e = 0, see **Figure 3.1(B).** According to Kepler's Third Law, the solar time (τ) in relation with the right ascension of an ascending node angle (Ω); the sidereal time (t) with the consideration that μ=GM and satellite altitude (h), for a satellite in circular orbit will have the following relations:

$$\tau = t/(1 - \Omega t / 2\pi) \quad (3.7)$$

$$t = 2\pi \sqrt{}(r3/\mu) = 3.147099647 \sqrt{}(r3 \cdot 10{-}7)[s] \quad (3.8)$$

$$h = [3\sqrt{}\ (\mu t2/4\pi 2)] - R = 2.1613562 \cdot 104\ (3\sqrt{}\ t2) - 6.37816106[m] \quad (3.9)$$

The time is measured with reference to the Sun by solar and sidereal day. Thus, a solar day is defined as the time between the successive passages of the Sun over a local meridian. In fact, a solar day is a little bit longer than a sidereal day, because the Earth revolves by more than 360^o for successive passages of the Sun over a point 0.986^o further.

On the other hand, a sidereal day is the time required for the Earth to rotate one circle of 360^o around its axis: t_E = 23 h 56 min 4.09 sec. Therefore, a geostationary satellite must have an orbital period of one sidereal day in order to appear stationary to an observer on Earth. During rotation the duration of sidereal day t= 85,164,091 (s) and is considered in such a way for synchronous orbit that h = 35,786.04x10^3 (m). The speed is conversely proportional to the radius of the path (R+h) and for the satellite in circular orbit it can be calculated from the following relation:

$$v = \sqrt{(MG/R + h)} = \sqrt{(\mu/r)} = 1.996502 \cdot 10–7/\sqrt{r} = 631.65 \sqrt{r}[m/s] \qquad (3.10)$$

From equation (3.8) and using the duration of the sidereal day (t_E) gives the relation for the radius of synchronous or geostationary orbits:

$$r = 3\sqrt{\ } [(\mu t) / 2\pi)2] \qquad (3.11)$$

The satellite trajectory can have any angle of orbital planes in relation to the equatorial plane: in the range from PEO up to GEO plane.
Namely, if the satellite is rotating in the same direction of Earth's motion, where (t_E) is the period of the Earth's orbit, the apparent orbiting time (t_a) is calculated by the following relation:

$$ta= tE\cdot t/tE– t \qquad (3.12)$$

This means, inasmuch as t = $t_E$the satellite is geostationary (t_a = ∞ or τ=0). In **Table 3.1** several values of parameters for times different than synchronous orbital time are presented in certain units.

Table 3.1. The Values of Times Different than the Synchronous Time of Orbit.

Parameter	Values of time					Unit
t	86,164.00	43,082.05	21,541.23	10,770.61	6,052.00	s
h	35,786.00	20,183.62	10,354.71	4,162.89	800.00	km
(R+h)	42,164.00	26,561.78	16,732.87	10,541.05	7,178.00	km
v	3,075.00	3,873.83	4,880.72	5,584.12	7,450.00	km/s^{-1}

According to **Table 3.1** and equation (3.9) it is evident that a satellite does not depend so much on its mass but decreases with higher altitude. In addition, satellites in circular orbits with altitudes of a 1,700, 10,400 and 36,000 km, will have t/ τ values 2/2,18, 6/8 and 24/zero, respectively. In this case, it is evident that only a satellite constellation at altitudes of about 36,000 km can be synchronous or geostationary(Heiser and Pratt 1994; Chobotov 2002).

3.2. Horizon and Geographic Satellite Coordinates

The geographical and horizon coordinates are very important to find out many satellite parameters and equations for better understanding the problems of orbital plane, satellite distance, visibility of the satellite, coverage areas, etc. The coverage areas of a satellite are illustrated in **Figure 3.2(A)** with the following geometrical parameters: actual altitude (h), radius of Earth (R), angle of elevation (ε), angle of azimuth (A), distance between satellite and the Earth's surface (d) and central angle (Ψ) or sub-satellite angle, which is similar to the angle of antenna radiation (δ).

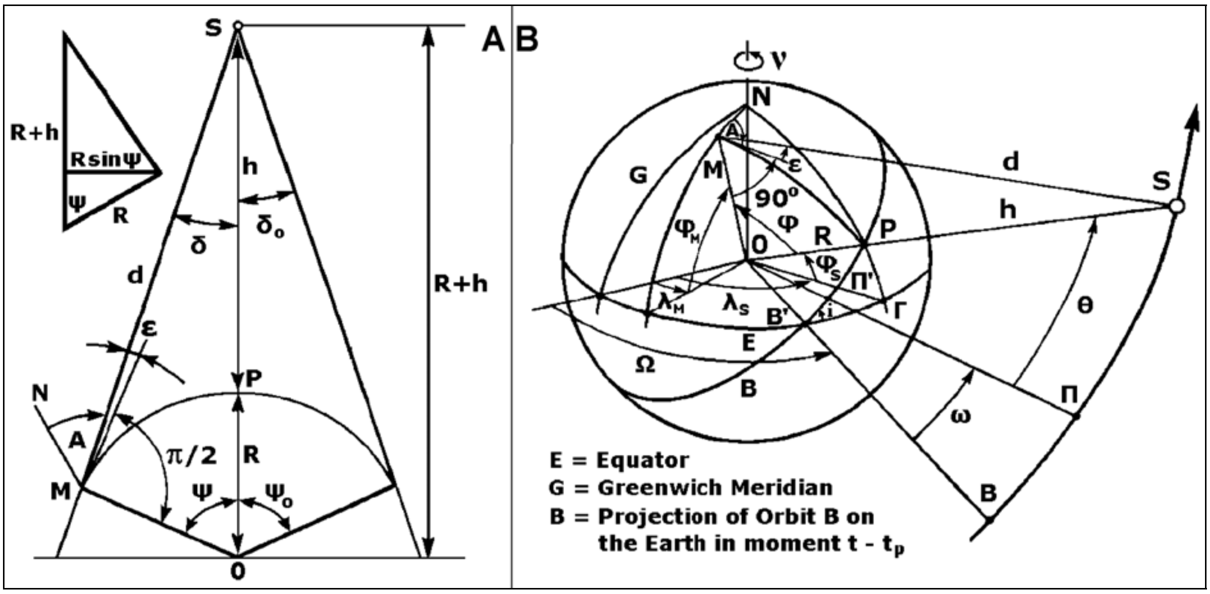

Figure 3.2. Geometric Projection of Satellite Orbits - Courtesy of Books**:** by Zhilin

The geographical and horizon coordinates of a satellite are presented in **Figure 3.2 (B)** with the following, not yet mentioned, main parameters: angular speed of the Earth's rotation (ν), argument of the perigee (ω), moment of satellite pass across any point on the orbit (t_o), which can be perigee (Π), projection of the perigee point on the Earth's surface (Π'), spherical triangle (B'ΓP), satellite (S), the Point of the Observer or Mobile (M), latitudes of observer and satellite ($\varphi_M$and φ_S), longitudes of observer and satellite ($\lambda_M$and λ_S), inclination angle (i) of the orbital plane measured between the equatorial and orbital plane and the right ascension of an ascending node angle in the moment of t_o (Ω_o).
Otherwise, the right ascension of an ascending node angle (Ω) is the angle in the equatorial plane measured counter clockwise from the direction of the vernal equinox to that of the ascending node, while the argument of the perigee (ω) is the angle between the direction of the ascending node and the direction of the perigee(Heiser and Pratt 1994).

3.2.1. Satellite Distance and Coverage Area

The area coverage or angle of view for each type of satellite depends on orbital parameters, its position in relation to the Ground Earth Station (GES) and geographic coordinates. This relation is very simple in the case where the sub-satellite point is in the centre of coverage, while all other samples are more complicated.
Thus, the angle of a GEO satellite inside its range has the following regular reciprocal relation:

$$\delta + \varepsilon + \Psi = 90o. \tag{3.13}$$

The circular sector radius can be determined by the following relation:

$$Rs = R \sin \Psi. \tag{3.14}$$

When the altitude of orbit h is the distance between satellite and sub-satellite point (SP), the relation for the altitude of the circular sector can be written as:

$$hs= R (1 - \cos \Psi). \tag{3.15}$$

From a satellite communications point of view, there are three key parameters associated with an orbiting satellite: **(1)** Coverage area or the portion of the Earth's surface that can receive the satellite's transmissions with an elevation angle larger than a prescribed minimum angle; **(2)** The slant range (actual LOS distance from a fixed point on the Earth to the satellite) and **(3)** The length of time a satellite is visible with a prescribed elevation angle. Elevation angle is an important parameter, since communications can be significantly impaired if the satellite has to be viewed at a low elevation angle, that is, an angle too close to the horizon line. In this case, a satellite close to synchronous orbit covers about 40% of the Earth's surface. Thus, from the diagram in **Figure 3.2(A)** a covered area expressed with central angle (2δ or 2Ψ) or with arc (MP≈RΨ) as a part of Earth's surface can be derived with the following relation:

$$C = \pi (Rs2 + hs2) = 2\pi R2 (1 - \cos \Psi). \qquad (3.16)$$

Since the Earth's total surface area is $4\pi R^2$, it is easy to rewrite C as a fraction of the Earth's total surface:

$$C/4\pi R2 = 0{,}5 (1 - \cos \Psi). \qquad (3.17)$$

The slant range between a point on Earth and a satellite at altitude (h) and elevation angle can be defined in this way:

$$z = [(R \sin \varepsilon)2 + 2Rh + h2]½ - R \sin \varepsilon. \qquad (3.18)$$

This determines the direct propagation length between GES, (h) and (ε) and will also find the total propagation power loss from GES to satellite. In addition, (z) establishes the propagation time (time delay) over the path, which will take an electromagnetic field as:

$$td= (3.33)\, z\ [\mu sec] \qquad (3.19)$$

To propagate over a path of length (z) km, it takes about 100 msec to transmit to GEO. If the location of the satellite is uncertain ± 40 km, a time delay of about ± 133 μsec is always present in the Earth-to-satellite propagation path. When the satellite is in orbit at altitude (h), it will pass over a point on Earth with an elevation angle (ε) for a time period:

$$tp= (2\Psi/360) (t/1 \pm (t/tE). \qquad (3.20)$$

The quotations for right ascension of the ascending node angle (Ω) and argument of the perigee (ω) are as follows:

$$\Omega = 9{,}95 (R/r)3.5 \cos i \quad \text{or} \quad \Omega = \Omega o+ \nu (t - to). \qquad (3.21)$$

$$\omega = 4{,}97 (R/a)3.5 [5 \cos2i - 1/(1 - e2)2]$$

The limit of the coverage area is defined by the elevation angle from GES above the horizon with angle of view ε=0°. In this case, the satellite is visible and its maximal central angle for GEO will be as follows:

$$\Psi = \arccos (R \cos \varepsilon/r) - \varepsilon. \qquad (3.22)$$

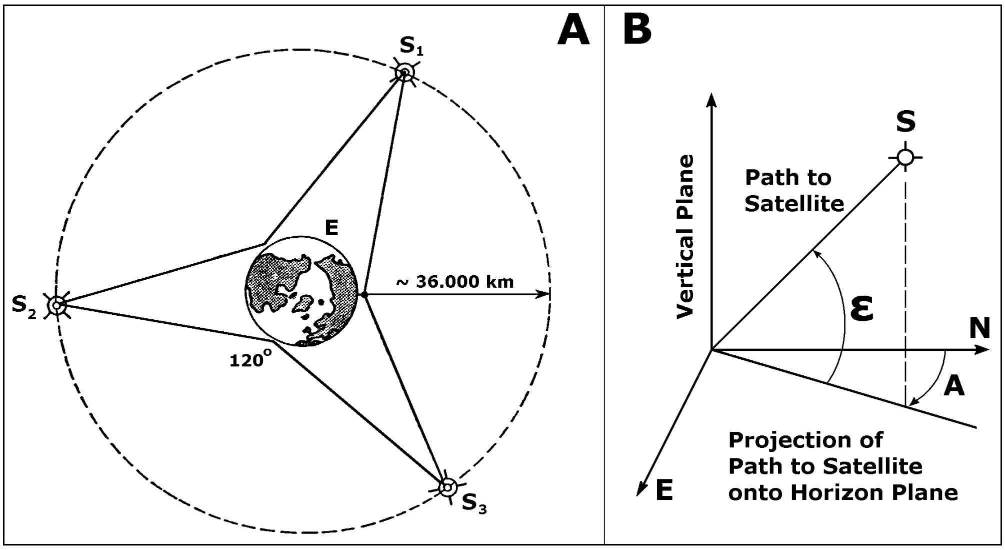

Figure 3.3. GEO Configuration and Look Angle Parameters - Courtesy of Books: by Pratt

$$\Psi = \pi/2 - \text{arc sin } (R/r) = \text{arc cos } (R/r) - \varepsilon = \text{arc cos } k - \varepsilon$$

$$\Psi = \text{arc cos } 6{,}376.16/42{,}164.20 = \text{arc cos } 0.15126956 = 81o\ 17'\ 58.18''$$

$$C_{max} = 255.61 \cdot 106\ (1 - 0.15126956) = 216.94 \cdot 106 \quad (km2)$$

Therefore, all MES and GES with a position above $\Psi = 81^o$ will be not covered by GEO satellites. Since the Earth's square area is 510,100,933.5 km^2 and the extent of the equator is 40,076.6 km, only with three GEO mutually moved apart in the orbit by 120^o it is possible to cover a great area of the Earth's surface, see **Figure 3.3(A).** The zero angles of elevation have to be avoided, even to get maximum coverage, because this increases the noise temperature of the receiving antenna. Owing to this problem, an equation for the central angle with minimum angle of view between 5^o and 30^o will be calculated as follows:

$$\Psi s = \text{arc cos } (k \cos \varepsilon) - \varepsilon. \tag{3.23}$$

The arch length or the maximum distant point in the area of coverage can be determined in the following way:

$$l = 2\pi R\ (2\Psi/360 = 222.64\Psi[\text{km}]. \tag{3.24}$$

The real altitude of satellite over sub-satellite point is as follows:

$$h = r - R = 42{,}162 - 6{,}378 = 35{,}784[\text{km}]. \tag{3.25}$$

The view angle under which a GEO satellite can see GES/MES is called the "sub-satellite angle". More distant points in the coverage area for GEO satellites are limited around $\varphi=70^o$ of North and South geographical latitudes and around $\lambda=70^o$ of East and West geographical longitudes, viewed from the sub-satellite's point. Theoretically, all Earth stations around these positions are able to see satellites by a minimum angle of elevation of $\varepsilon=5^o$. Such access is very easy to calculate, using simple trigonometry relations:

$$\delta\varepsilon=0 = \text{arc sin } k \approx 9o. \tag{3.26}$$

At any rate, the angle (Ψ) is in correlation with angle (δ), which can determine the aperture radiation beam. For example, the aperture radiation beam of satellite antenna for global coverage has a radiation beam of 2δ=17.3°. According to **Figure 3.2 (A)** it will be easy to find out relations for GEO satellites as follows:

$$tg\ \delta = k \sin \Psi/1 - k \cos \Psi = 0.15126956 \sin \Psi/1 - \cos \Psi/1 - 0.15126956 \cos \Psi).(3.27)$$

$$\delta s= 90o - \Psi s= 8o\ 42'\ 1.82''.$$

Differently to say, the width of the beam aperture ($2\delta_s$) is providing the maximum possible coverage for synchronous circular orbit. The distance of GES and MES with regard to the satellite can be calculated using **Figure 3.2 (A)** and equations (3.13) and (3.22) by:

$$d = R \sin \Psi/\sin \delta = r \sin /\cos \varepsilon. \qquad (3.28)$$

The parameter (d) is quite important for transmitter power regulation of GES, which can be calculated by the following equation:

$$d = \sqrt{[(R + r)2 - 2R\ r \cos \Psi]}; \qquad (3.29)$$

$$d = h \sqrt{[1 + 2\ (1/k)\ (R/h)2\ (1 - \cos \varphi \cos \Delta\lambda)]};$$

$$d = r\ [1 - (R \cos \varepsilon/r)2]½\ - R \sin \varepsilon.$$

Accordingly, when the position of any MES is near the equator in sub-satellite point (P) or right under the GEO satellite, then its distance is equal to the satellite altitude and takes out value for d=H of 35,786 km. Thus, every MES will have a further position from (P) when the central angle exceeds Ψ = 81°, when d_{max}=41,643 km(Heiser and Pratt 1994; Chobotov 2002).

3.2.2. Satellite Look Angles (Elevation and Azimuth)

The horizon coordinates are considered to determine satellite position in correlation with an Earth observer, GES and MES terminals. These specific and important horizon coordinates are angles of satellite elevation and azimuth, illustrated in **Figure 3.2 (A** and **B)** and **Figure 3.3 (B),** respectively.

The satellite elevation (ε) is the angle composed upward from the horizon to the vertical satellite direction on the vertical plane at the observation point. From point (M) shown in **Figure3.2 (A)** the look angle of ε value can be calculated by the following relation:

$$tg\ \varepsilon = \cos \Psi - k/\sin \Psi. \qquad (3.30)$$

In **Figure 3.4 (A)** is illustrated the Mercator chart of the 1st Generation Inmarsat space segment, using three ocean coverage areas with a projection of elevation angles and with one example of a plotted position of a hypothetical ship (may also be aircraft or any mobile). Thus, it can be concluded that SES or any type of MES at the designated position (ε=25° for IOR and ε=16° for AOR) has the possibility to use either GEO satellites over IOR or AOR to communicate with any GES inside the coverage areas of both satellites. The satellite azimuth (A) is the angle measured eastward from the geographic North line to the projection of the satellite path on the horizontal plane at the observation point. This angle varies between 0 and 360° as a function of the relative positions of the satellite and the point considered.

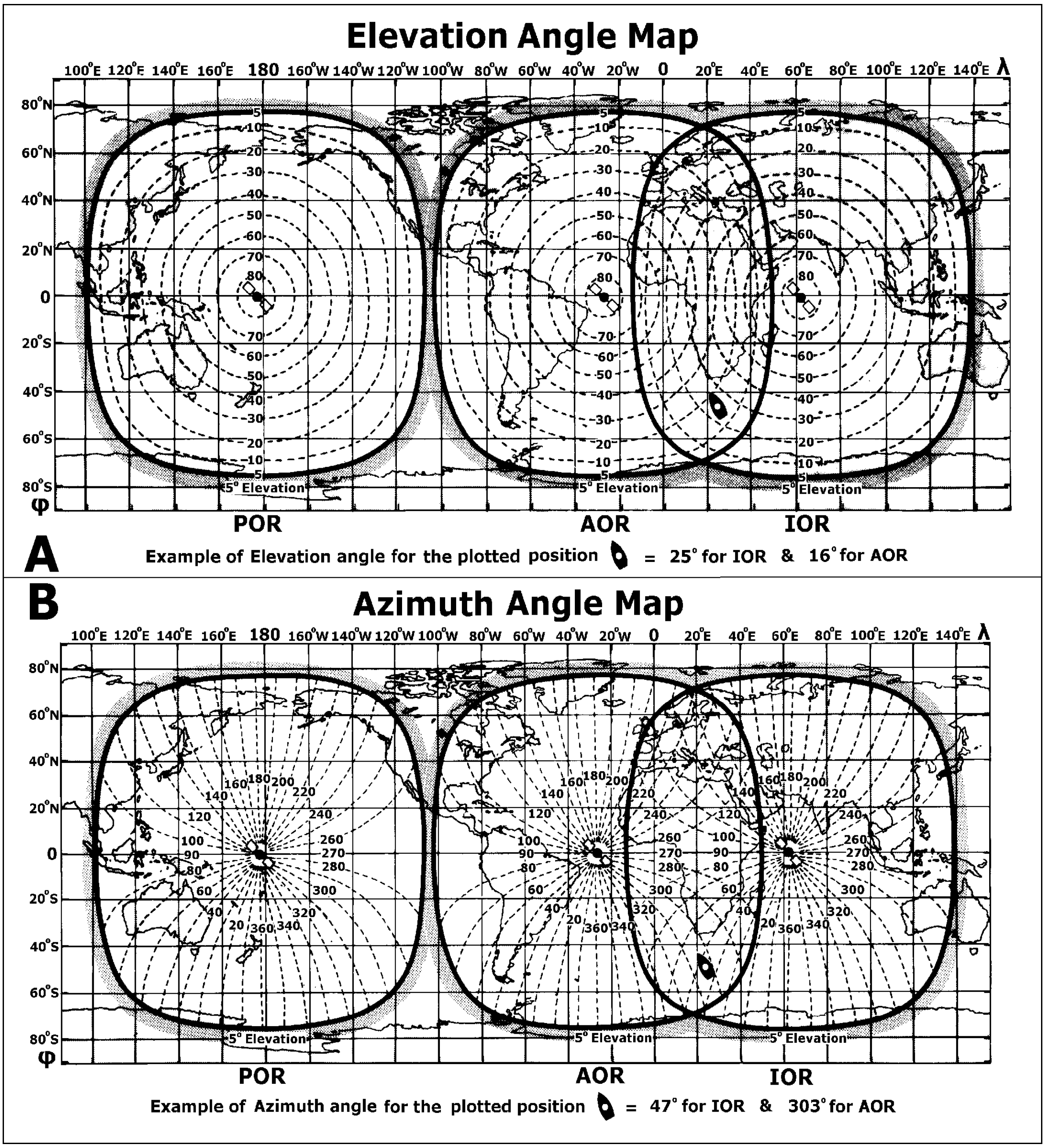

Figure 3.4. Elevation and Azimuth Angle Maps - Courtesy of Book: Ilcev

The azimuth value of the satellite and sub-satellite point looking from the point (M) or the hypothetical position of MES can be calculated as follows:

$$\text{tg } A' = \text{tg } \Delta\lambda M - k/\sin \Psi. \quad (3.31)$$

Otherwise, the azimuth value, looking from sub-satellite point (P), can be calculated as:

$$\text{tg } A = \sin\Delta\lambda/\text{tg } \varphi \quad \text{or} \quad \sin A = \cos \varphi \sin \Delta\lambda \text{ cosec } \Psi. \quad (3.32)$$

In **Figure 3.4 (B)** is illustrated the Mercator chart of 1st Generation Inmarsat 3-satellite or ocean coverage areas with a projection of azimuth angles, with one example for the plotted position of a hypothetical ship (ε=47° for IOR and ε=303° for AOR). Any mobile inside of both satellites' coverage can establish a radio link to the subscribers on shore via any GES.

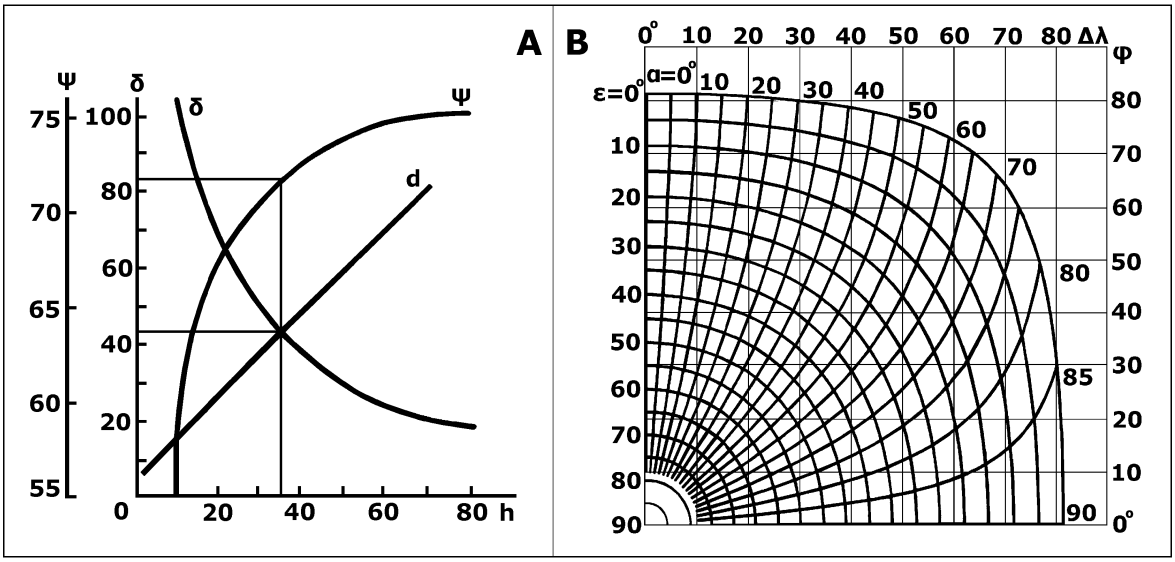

Figure 3.5. Look Angle Parameters and Graphic of Geometric Coordinates – Courtesy of Book: by Zhilin

However, parameter (A') is the angle between the meridian plane of the point (M) and the plane of a big circle crossing this point and sub-satellite point (P), while the parameter (A) is the angle between a big circle and the meridian plane of the point (P). Thus, the elevation and azimuth are respectively vertical or horizontal look angles, or angles of view, in which range the satellite can be seen.

In **Figure 3.5 (A)** is presented a correlation of the look angle for three basic parameters (δ, Ψ, d) in relation to the altitude of the satellite. Inasmuch as the altitude of the satellite is increasing as the values of a central angle (Ψ), distance between satellite and the Earth's surface (d) and duration of communication (t_c) or time length of the signals are increasing, while the value of sub-satellite angle (δ) is indirectly proportional. An important increase of look angle and duration of communication can be realized by increasing the altitude to 30 or 35,000 km, while an increase in look angle is unimportant for altitudes of more than 50,000 km. The duration of communication is affected by the direction's displacement from the center of look angle, which will have maximum value in the case when the direction is passing across the zenith of the GES. The single angle of the satellite in circular orbit depends on the t/2 value, which in the area of satellite look angle, can be found in the duration of the time and is determined as:

$$tc = \Psi\ t/\ \pi. \tag{3.33}$$

Practical determination of the geometric parameters of a satellite is possible by using many kinds of plans, graphs and tables. It is possible to use tables for positions of SES (φ, λ), by the aid of which longitudinal differences can be determined between MES and satellite for four feasible ship's positions: N/W, S/W, N/E and S/E in relation to GEO.

One of the most important practical pieces of information about a communications satellite is whether it can be seen from a particular location on the Earth's surface. In **Figure 3.5 (B)** a graphic design is shown which can approximately determine limited zones of satellite visibility from the Earth (MES) by using elevation and azimuth angles under the condition thatδ = 0. This graphic contains two groups of crossing curves, which are used to compare (φ) and (Δλ,) coordinates of mobile positions. Thus, the first group of parallel concentric curves shows the geometric positions where elevation has the constant value (ε=0), while the second group of fan-shaped curves starting from the center shows the geometric positions where the difference in azimuth has the constant value (a = 0).

This diagram can be used in accordance with **Figure 3.2 (B)** and presented in the following order:

1) First, it is necessary to note the longitude values of satellite (λ_S) and mobile (λ_M) and the latitude of the mobile (φ_M), then calculate the difference in longitude ($\Delta\lambda$) and plot the point into the graphic with both coordinates (φ_M& $\Delta\lambda$).
2) The value of elevation angle (ε) can then be determined by a plotted point from the group of parallel concentric curves.
3) The difference value of the azimuth (a) can be determined by a plotted point from the group of fan-shaped curves starting from the center.
4) Finally, depending on the mobile position, the value of the azimuth (A) can be determined on the basis of the relations presented in **Table 3.2.**

Table 3.2. The Form for Calculation of Azimuth Values

The GEO direction in relation to MES	Calculating of Azimuth Angles
Course of MES towards S & W	$A = a$
Course of MES towards N & W	$A = 180^o – a$
Course of MES towards N & E	$A = 180^o + a$
Course of MES towards S & E	$A = 360^o – a$

Inasmuch as the position of SES is of significant or greater height above sea level (if the bridge or ship's antenna is in a very high position) or according to the flight altitude of AES, then the elevation angle will be compensated by the following parameter:

$$x = \arccos (1 – H/R); \tag{3.34}$$

where: H = height above sea level of observer or MES. Let us say, if the position of GES is a height of H = 1,000 m above sea level, the value of $x \approx 1^o$. This example can be used for the determination of AES compensation parameters, depending on actual aircraft altitude. In such a way, the estimated value of elevation angle has to be subtracted from the value of the compensation parameter (x)(Vinti 1998).

2.2.3. Satellite Track and Geometry (Longitude and Latitude)

The satellite track on the Earth's surface and the presentation of a satellite's position in correlation to the MES results from a spherical coordinate system, whose centre is the middle of Earth, is illustrated in **Figure 3.2 (B)**. In this way, the satellite position in any time can be decided by the geographic coordinates, sub-satellite point and range of radius. At this point, the sub-satellite point is a determined position on the Earth's surface; above it is the satellite at its zenith.
The longitude and latitude of the satellite are the geographic coordinates of the sub-satellite point, which can be calculated from the spherical triangle (B'ΓP) and implementing the following relations:

$$\sin\varphi = \sin (\Theta + \omega) \sin(i); \tag{3.35}$$

$$tg (\lambda S– \Omega) = tg (\Theta + \omega) \cos(i).$$

With the presented equation in previous relation it is possible to calculate the satellite path or trajectory of sub-satellite points on the Earth's surface. The GEO track breaks out at the point of coordinates $\varphi = 0$ and $\lambda = const$.
Furthermore, considering geographic latitude (φ_M) and longitude (λ_M) of the point (M) on the Earth's surface presented in **Figure 3.2 (B)**, what can be the position of the MES, taking into consideration the arc (MP) of the angle illustrated in **Figure 3.2 (A)**, the central angle can be calculated by the following relations:

$$\cos \Psi = \cos \varphi S \cos \Delta\lambda \cos \varphi M + \sin \varphi S \sin \varphi M; \quad (3.36)$$

$$\cos \Psi = \cos \text{arc } MP = \cos \varphi M \cos \Delta\lambda$$

The transition calculation from geographic to spherical coordinates and vice versa can be computed with the following equations:

$$\cos \Psi = \cos \varphi \cos \Delta\lambda \quad \text{and} \quad \text{tg } A = \sin \Delta\lambda / \text{tg } \varphi, \quad (3.37)$$

$$\sin \varphi = \sin \Psi \cos A \quad \text{and} \quad \text{tg } \Delta\lambda = \text{tg } \Psi \sin A.$$

These relations are useful for any point or area of coverage on the Earth's surface, then for a centre of the area if it exists, as well as for spot-beam and global area coverage for MSC systems. The optimum number of GEO satellites for global coverage can be determined by:

$$n = 180o/\Psi. \quad (3.38)$$

For instance, if $\delta = 0$ and $\Psi = 81^{o,}$ it will be necessary to put into orbit only 3 GEO, and to get a global coverage from 70º N to 70º S geographic latitude. Hence, in a similar way the number of satellites can be calculated for other types of satellite orbits.

The trajectory of radio waves on a link between an MES and satellite at distance (d) and the velocity of light ($c = 3 \times 10^8$ m/s) require a propagation time equal to:

$$T = d/c \text{ (s)}. \quad (3.39)$$

The phenomenon of apparent change in frequency of signal waves at the receiver when the signal source moves with respect to the receivers (Earth), was explained and quantified by Johann Doppler (1803–53). The frequency of the satellite transmission received on the ground increases as the satellite is approaching the ground observer and reduces as the satellite is moving away. This change in frequency is called Doppler Effect or shift, which occurs on both the uplink and the downlink. This effect is quite pronounced for LEO and compensating for it requires frequency tracking in a narrowband receiver, while its effect are negligible for GEO satellites. The Doppler shift at a transmitting frequency (f) and radial velocity (v_r) between the observer and the transmitter can be calculated by relation:

$$\Delta fD = f\, vr/c \quad \text{where} \quad vr = dR/dt. \quad (3.40)$$

For an elliptical orbit, assuming that R = r, the radial velocity is given by:

$$vr = dr/dt = (dr/\Theta)\,(d\Theta/dt). \quad (3.41)$$

The sign of the Doppler shift is positive when the satellite is approaching the observer and vice versa. Doppler Effect can also be used to estimate the position of an observer provided that the orbital parameters of the satellite are precisely known. This is very important for development of Doppler satellite tracking and determination systems(Vinti 1998).

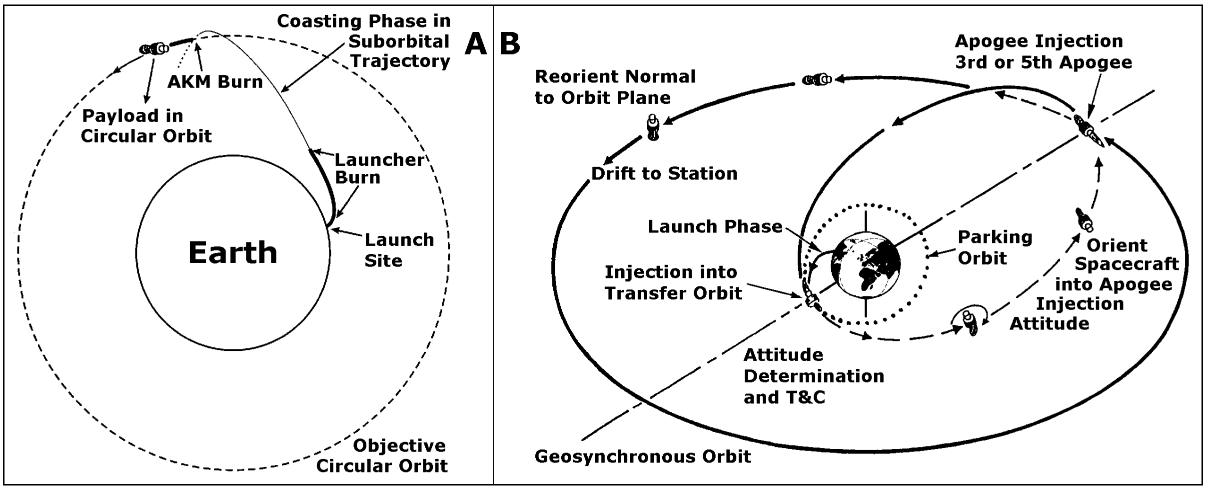

Figure 3.6. Satellite Installation in Circular and Synchronous Orbit - Courtesy of Book: by Pascall

3.3. Spacecraft Launching and Station-Keeping Techniques

The launch of the satellite and controlling support services are a very critical point in the creation of space communications and the most expensive phase of the total system cost. At the same time, the need to make a satellite body capable of surviving the stresses of the launch stages is a major element in their design phase. Satellites are also designed to be compatible with more then one model of launch vehicle and launching type. In a more determined sense, there are multi-stages expendable and manned or unmanned, reusable launchers. Owing to location and type of site there are land-based and sea-based launch systems. Additional rocket motors, such as perigee and apogee kick propulsion systems, may also be required. The process of launching a satellite is based mostly on launching into an equatorial circular orbit and after in GEO, but similar processes or phases are used for all types of orbits. The processes involved in the launching technique depend on the type of satellite launcher, the geographical position of the launching site and constraints associated with the payload. In order to successfully put the satellite into the transfer and drift orbit, the launcher must operate with great precision with regard to the magnitude and orientation of the velocity vector. On the other hand, launching operations necessitate either TT&T facilities at the launching base or at the stations distributed along the trajectory.
Satellites are usually designed to be compatible with more than one prototype of launchers. Launching, putting and controlling satellites into orbit are very expensive operations, so the expenses of launcher and support services can exceed the cost of the satellites themselves.
The basic principle of any launch vehicle is that the rocket is propelled by reaction to the momentum of hot gas ejected through exhaust nozzles. There are two techniques for launching a satellite, namely by direct ascent and by Hohmann transfer ellipse(Shah *et al.* 1998; Vinti 1998).

3.3.1. Direct Ascent Launching

A satellite may be launched into a circular orbit by using the direct ascent method, shown in **Figure 3.6. (A).** The thrust of the launch vehicle is used to place the satellite in a trajectory, the turning point of which is marginally above the altitude of the desired orbit. The initial sequence of the ascent trajectory is the boost phase, which is powered by the various stages of the launch vehicle. This is followed by a coasting phase along the ballistic trajectory, the spacecraft at this point consisting of the last launcher stage and the satellite. As the velocity required to sustain an orbit will not have been attained at this point, the spacecraft falls back from the highest point of the ballistic trajectory.

When the satellite and final stage have fallen to the desired injection altitude, having in the meantime converted some of their potential energy into kinetic energy, the final stage of the launcher, called the Apogee Kick Motor (AKM) is activated to provide the necessary velocity increase for injection into the chosen circular orbit. In effect, the AKM is often incorporated into the satellite itself, where other thrusters are also installed for adjusting the orbit or the altitude of the satellite throughout its operating lifetime in space. The typical launch vehicles for direct ascent satellite launching are US-based Titan IV, Russian-based Proton and Soyuz and Ukrainian-based Zenit(Vinti 1998; Evans 1999).

3.3.2. Indirect Ascent Launching

A satellite may be launched into an elliptical or synchronous orbit by using the successive or indirect ascent sequences, known as the Hohmann transfer ellipse method, shown in **Figure 3.6 (B).** The Hohmann transfer ellipse method enables a satellite to be placed in an orbit at the desired altitude using the trajectory that requires the least energy. At the first sequence the launch vehicle propels the satellite into a low parking orbit by the direct ascent method. The satellite is then injected into an elliptical transfer orbit, the apogee of which is the altitude of the desired circular synchronous orbit. At the apogee, additional thrust is applied by an AKM to provide the velocity increment necessary for the attainment of the required synchronous orbit. In practice it is usual for the direct ascent method to be used to inject a satellite into a LEO and for the Hohmann transfer ellipse to be used for higher types of orbits(Vinti 1998).

3.4. Types of Orbits for Mobile and Other Satellite Systems

An orbit is the circular or elliptical path that the satellite traverses through space. This path appears in the chosen orbital plane in the same or different angle to the equatorial plane. All communication satellites always remain near the Earth and keep going around the same orbit, directed by centrifugal and centripetal forces. Each orbit has certain advantages in terms of launching (getting satellite into position), station keeping (keeping the satellite in place), roaming (providing adequate coverage) and maintaining necessary quality of communication services, such as continuous availability, reliability, power requirements, time delay, propagation loss and network stability. There is a large range of satellite orbits but not all of them are useful for fixed and mobile satellite communication systems. In general, the one most commonly used orbit for satellite communications are GEO and LEO constellations, and after that Highly Elliptical Orbit (HEO) and latterly Geosynchronous Inclined Orbits(GIO), Polar Earth Orbit (PEO) and Medium Earth Orbit (MEO), shown in **Figure 3.7 (A).**

Otherwise, it is essential to consider that satellites can serve all communication, navigation, meteorological and observation systems for which they cannot have an attribute such as fixed or mobile satellites and the only common difference is which type of payload or transponder they carry on board. For example, its name can be satellite specified for fixed communications but in effect it can carry major transponders for fixed communications and others for mobile or other purposes and vice versa.

After many years of research and experiments spent on finding the global standardization for spatial communications, satellites remained the only means of providing near global coverage, even in those parts which other communications systems are not able to reach. There is always doubt about the best orbital constellation that can realize an appropriate global coverage and a reliable communications solution. Unfortunately, there is no perfect system today; all systems have some advantages or disadvantages. The best conclusion is to abridge the story and to say briefly that today the GEO system is the best solution and has only congestion as a more serious problem.

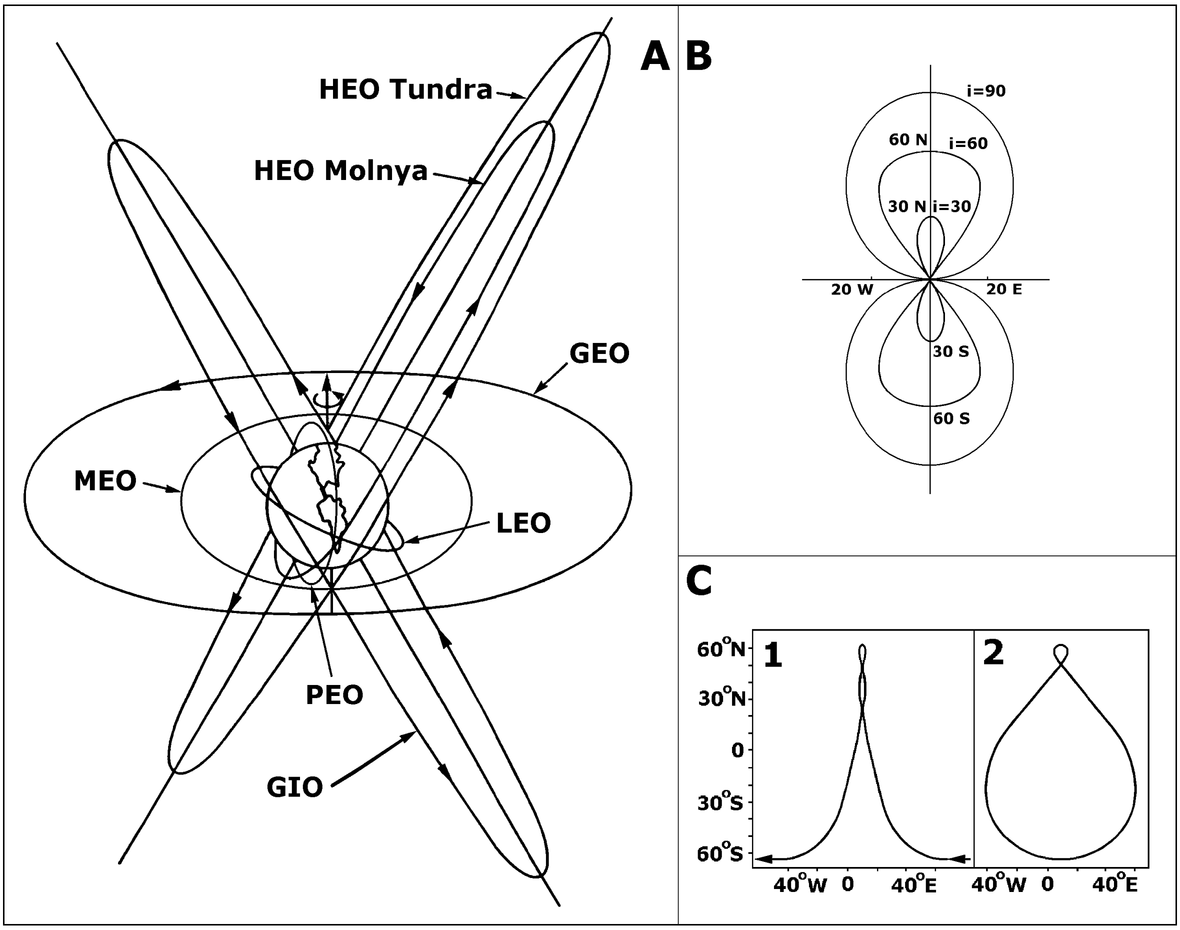

Figure 3.7. Type of Satellite Orbits and Tracks–Courtesy of Book: "Satellite Com. Systems" by Evans

The extensive use of GEO is showing that it provides something good. Inmarsat is the biggest GEO operator whose service and revenue confirm this point of view. The advantages of Inmarsat MSC solutions can be realized if someone uses them such, as operators on board mobiles and finds out how powerful and professional they are. Most of other regional GEO worldwide networks, such as ACeS, Optus and Thuraya are also more successful than other Non-GEO constellations.

The track of the satellite varies from 0to 360°, see **Figure 3.7. (B).** The track of the GEO satellite is at a point in the centre of the coordinate system; two tracks are apparent movements of the GIO satellite with respect to the ascending node of both 30° and 60° inclination angles and the last is the track of the PEO satellite with an inclined orbit plane to the equator of 90°. The tracks of HEO Molniya (part of the track) and Tundra (complete track) orbits are shown in **Figure 3.7 (C-1/C-2)**, respectively. These two tracks pass over the African Continent and almost all of Europe.

This is very important for MSC systems that the orbit used can provide satellite view during 24 hours with less handovers and network difficulties. However, for other types of broadcasting a communication satellite must be visible from the region concerned during the periods when it is desired to provide a communication service, which can vary from a few hours to 24 hours a day. When the service is not continuous, it is desirable that the intervals during which the service is available repeat each day at the same time.

It is sufficient to see **Table 3.3** to understand that the major reasons for LEO problems are enormous satellite cost, complex network and short satellite visibility and lifetime. The LEO/PEO constellations are the same or similar and because of differences in inclination angle of orbital plane and type of coverage they will be considered separately(Evans 1999; Montenbruck and Gill 2000).

Table 3.3. The Properties of Four Major Orbits

Orbital Properties	LEO	MEO	HEO	GEO
Development Period	Long	Short	Medium	Long
Launch & Satellite Cost	Maximum	Maximum	Medium	Medium
Satellite Life (Years)	3–7	10–15	2–4	10–15
Congestion	Low	Low	Low	High
Radiation Damage	Zero	Small	Big	Small
Orbital Period	<100 min	8-12 hours	½ Sidereal Day	1 Sidereal Day
Inclination	90°	45°	63.4°	Zero
Coverage	Global	Global	Near Global	Near Global
AltitudeRange (km^{-3})	0.5–1.5	8–20	40/A – 1/P	40 (i=0)
Satellite Visibility	Short	Medium	Medium	Continuous
Handover	Very Much	Medium	No	No
Elevation Variations	Rapid	Slow	Zero	Zero
Eccentricity	0 to High	High	High	Zero
Handheld Terminal	Possible	Possible	Possible	Possible
Network Complexity	Complex	Medium	Simple	Simple
Tx Power/Antenna	Low	Low	Low/High	Low/High
Gain	Short	Medium	Large	Large
Propagation Delay	Low	Medium	High	High
Propagation Loss	High	Medium	Low	Zero

3.4.1. Low Earth Orbits (LEO)

The LEO systems are either elliptical or more usually circular satellite orbits between 500 and 2,000 km above Earth surface and bellow the Inner Van Allen Belt. The orbit period at these altitudes varies between ninety minutes and two hours. The radius of the footprint of a communications satellite in LEO varies from 3,000 km to 4,000 km.

The maximum time during which a satellite in LEO orbit is above the local horizon for an observer on the Earth is up to 20 minutes. The traffic to a LEO satellite has to be handed over much more frequently than all other types of orbit. When an LEO satellite, which is serving particular users, moves below the local horizon, it needs to be able to quickly handover the service to a succeeding one in the same or adjacent orbit.

Due to the relatively large movement of a satellite in LEO constellation with respect to an observer on the Earth, satellite systems using this type of orbit need to be able to cope with large Doppler shifts. Satellites in LEO are not affected at all by radiation damage but are affected by atmospheric drag, which causes the orbit to gradually deteriorate. Satellites in LEO and MEO constellation are subject to orbital perturbation. For LEO satellites the aerodynamic drag is likely to be significant and in general, some of the other perturbations, such as precession of the argument of the perigee, resolve to zero in the orbit is circular or polar. On the other hand, a perturbation is unlikely to have a serious effect on the operation of a multi-satellite constellation since it will usually affect all satellites of the configuration in equal measure. The major advantages of LEO are as follows:

a) The LEO system may become important in the field of MSC using handheld terminals with global roaming and to be exceedingly useful in areas not covered by cellular systems. The LEO constellations cover almost the entire Earth's surface and some of them provide Polar coverage and show promise in the fields of mobile data and Internet and Fixed Satellite System (FSS) networks for broadband data and communications.

b) High Doppler shift allows the LEO system to be used for satellite positioning, tracking and determination.

c) The relatively small distance between GES and LEO results in much lower power and smaller user terminals. For two-way voice via LEO satellite delay is 13 ms in total for uplink and downlink.

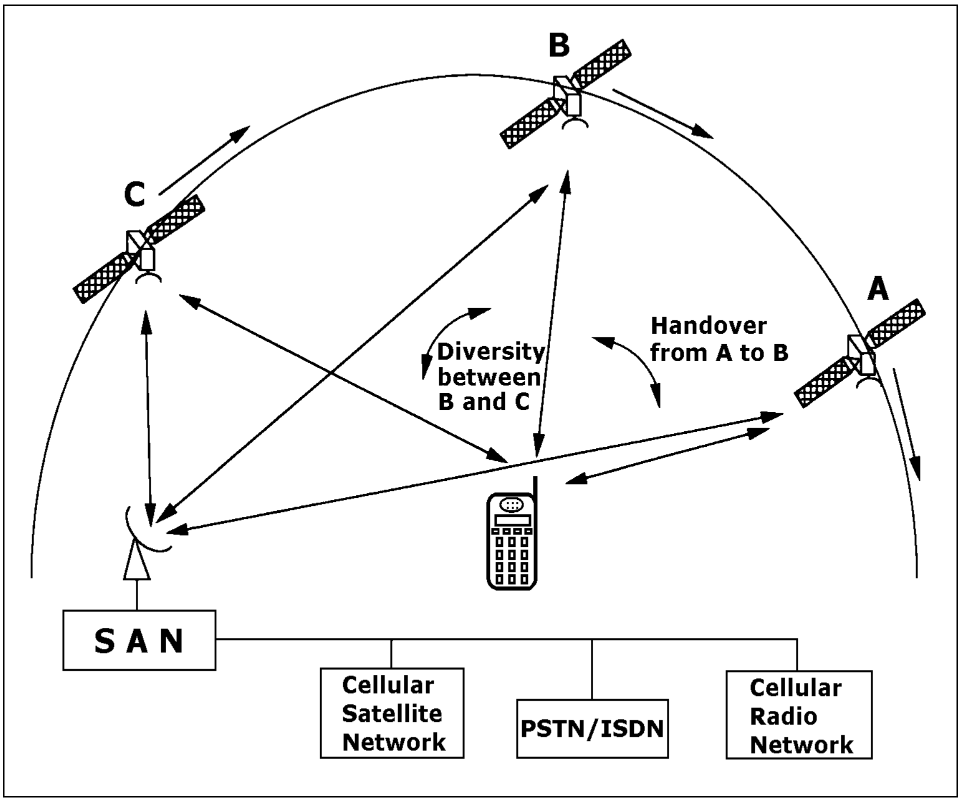

Figure 3.8. LEO MSS Diversity and Handover –Courtesy of Book: by Evans

d) Satellite path diversity eliminates signal interruption due to path obstruction. In **Figure 3.8** handover from satellite A to satellite B is demonstrated and path diversity between satellite B and C. This figure illustrates the LEO MSS space and ground architecture with utilization of handheld personal terminals. However, the Satellite Access Node (SAN) is the GES terminal providing a link between personal or asset tracking terminals through satellites and ground telecommunications infrastructures.

The disadvantages of LEO are as follows:

a) The orbit period at about 1,000 km altitude is in the order of approximately 100 min and the visibility at a point on the Earth is only about 10 min, requiring 40-80 satellites in six to seven planes for global coverage.

b) Frequently handover is necessary for uninterrupted communications. Satellite visibility for Mobile Earth Station (MES) could be improved by using more satellites. Thus, the optimum number of satellites of about 48 inclined in the constellation in a carefully optimized pattern of orbit planes will provide continuous visibility of one or other of the satellites at any location on Earth surface.

c) During times of the year that the orbital plane is in the direction of the Sun, a satellite in LEO is eclipsed for almost one-third of the orbit period. Consequently, there is a significant demand on battery power, with up to 5,000 charge/discharge cycles per year, which with existing NiCd types of batteries, reduces satellite lifetimes to 3–7 years.

d) The launch cost is low, with direct injection into the orbit of several satellites but the total cost is very high, with a minimum of 40 satellites being produced.

Because this orbit configuration is in the initial phase of its exploitation, it is still free of congestion problems.

A LEO constellation for MSS global coverage requires around 10 satellites in two or three orbital planes, each plane inclining 45° to the equator. Their orbit period measures about 6 to 8 hours, providing slightly over 1 hour local visibility above the horizon for an observer on the Earth and handover from one to the next satellite is every 6 hours minimum(Evans 1999; Ilcev, S 2010b).

3.4.1.1. Little LEO

The Little LEO mobile satellite systems are a category of LEO solutions that utilize birds of small size and low mass for low-bit-rate transmission under 1 Kb/s. They are very small Non-GEO satellites, which operate in LEO orbits providing mainly mobile data messaging and tracking services for ships, vehicles and aircraft. The Little LEO systems are using frequency band of 137–138 MHz for the downlink and 148–149.9 MHz for the uplink to Little LEO systems, such as Orbcomm, Falsat, Leo One, VITA Sat, Starnet and other systems. The mass of satellites range from 40 kg in Orbcomm to 150 kg in the Starnet system. These systems prefer a spectrum below 1 GHz, which enables the use of cost-effective equipment for nonvoice two-way messaging and positioning with low cost GPS receivers and satellite transceiver using alphanumerical display.

3.4.1.2. Big LEO

The Big LEO is a larger Non-GEO satellite system, which operates in LEO constellations and provides mainly mobile voice, Fax, data and determination services. Compared to the Little LEO systems, satellites in Big LEO systems are expected to be bigger in body and to have more power and bandwidth to provide a different service to their subscribers. These systems use frequency spectrum available in the L-band of 1610–1626.5 MHz for uplinks and 2483.5–2500 MHz for downlinks are assigned to these MSC systems. It is interesting to note that although the names of these systems include LEO, their frequencies are the ones usually utilized in MEO and GEO satellite systems.
In Big LEO system are systematized Iridium and Globalstar constellations only, which are located at about 700–1,500 km from the Earth's surface. The bigger size of the satellites enables them to carry a transponder on board with more complex data processing facilities than the simple store-and-forward feature of the Little LEO satellite configuration. Hence, an important fact is that these systems are networking with cellular and spreading their roaming and billing capabilities in real global coverage.

3.4.2. Circular Orbits

The GEO satellite constellation has great advantages for MSS communication applications, although they are not providing Polar coverage there are solutions for providing Polar roaming. Satellite orbits in 63.4^{o} inclined high-apogee HEO have some advantages from GEO also providing Polar coverage. The most popular circular equatorial orbit with zero inclination is the GEO satellite constellation. The period of rotation is equal to that of the Earth and has the same direction.
However, both of these satellite orbits exhibit high Line Of Sight (LOS) and long transmission times and delays. Using new technology, these problems can be solved, or as an alternative to these orbits there are LEO and MEO constellations with their good and bad characteristics. The choice of orbit depends on the nature of the MSC mission, the acceptable interference in an adequate environment and the performance of the launchers.

3.4.2.1. Medium Earth Orbits (MEO)

The MEO satellite constellations, known also as Intermediate Circular Orbits (ICO), are circular orbits located at an altitude of around 10,000 to 20,0000 km between the Van Allen Belts. The MEO satellites are operated in a similar way to Big LEO systems providing global coverage.
Thus, compared to a LEO system a MEO constellation can only be in circular orbit. Doppler Effect and handover is less frequent and propagation delay is about 70 ms and free space loss

is greater. These satellites are affected by radiation damages from the Inner Van Allen Belt only during the launching period

Cosmic radiation in this orbit is lower, with subsequently longer life expectancy for the complete MEO configuration, fewer eclipse cycles means that battery lifetime will be more than 7 years, higher average elevation angle from users to satellite minimizes probability of LOS blockage and higher RF output power required for both indoor and handheld MSC terminals. There is in exploitation a special model of the MEO constellation known in practice as Highly Inclined Orbit. This particular orbit is of interest because it has been chosen for existing and proposed GNSS systems such as Navstar (GPS), Navsat, GLONASS and the newly developed Galileo. In all, complete implementation of this orbit configuration would have 24 satellites in 3 orbital planes equidistant from each other, at an altitude of 20,000 km and at an inclination of 55^o. In comparison with existing GNSS the new Galileo system will have 30 satellites in high MEO of about 28,000 km and at a similar inclination of 56^o.

3.4.2.2. Geostationary Earth Orbits (GEO)

A GEO has a circular orbit in the equatorial plane, with orbital period equal to the rotation of the Earth of 1 sidereal day, which is achieved with the orbital radius of 66,107 (Equatorial) Earth Radii, or orbital height of 35,786 km. Otherwise, a satellite in a GEO will appear fixed above the surface of the Earth, and remain in a stationary position relative to the Earth itself. Theoretically, this orbit is with zero inclination and track as a point but in practice, the orbit has a small non-zero values for inclination and eccentricity, causing the satellite to trace out a small figure eight in the sky.

The footprint or service area of a GEO satellite covers almost 1/3 of the Earth's surface or 120^o in longitude direction and up to 75^o–78^o latitude North and South of the Equator but cannot cover the Polar Regions. In this way, near-global coverage can be achieved with a minimum of three satellites in orbit moved apart by 120^o, although the best solution is to employ four GEO satellites for better overlapping. This type of orbit is essentially used for communication services for both FSS and MSS with the following advantages:

a). The satellite remains stationary with respect to one point on the Earth's surface and so the GES antennas can be beamed exactly towards the focus of the GEO satellite without periodical tracking.

b). The Inmarsat GEO space constellation consisting in three or four satellites can cover all three-ocean regions with overlapping longitudes, except for the Polar Regions beyond latitudes of 75^o North and South.

c). The Doppler shift, affecting synchronous digital systems caused by satellites to drift in orbit (affected by the gravitation of the Moon and to a lesser extent of the Sun) is small for GES/MES within satellite coverage.

The disadvantages of GEO compared with LEO and MEO operation are as follows:

a). The long signal delay is due to the large distance of about 35,800 km if the satellite is in zenith for MES and about 41,000 km at the minimum elevation angle of about 5^o. For the EM waves traveling at the speed of light this causes a round-trip signal delay of 240-270 ms and full duplex delay of 480-540 ms. Namely, the voice used via satellite can experience some disturbance but echo cancellation devices developed in the 1980s can reduce the problem. For data transmission equipment, especially when using error-correction protocols that require retransmission of blocks with detected errors and complex circuitry with special high-capacity buffer devices is required to overcome delay problems.

Practical experience has shown that given good control of the echo, a telephone connection which includes one hop in each direction via GEO satellite is acceptable to public users.

b). The required higher RF output power and the use of directional antennas system aggravate GEO operation slightly for use with handheld terminals, although it is not critical, because some GEO operators provide this service, such as Inmarsat, Thuraya and ACeS.
c). The launch procedure to put a satellite in GEO is expensive but the total cost of 4 satellites is less than the cost of a minimum of 12 or 40 for MEO and LEO, respectively.
As stated earlier, the major disadvantage of a GEO satellite in a voice transmission is the round-trip delay between satellite and GES of approximately 2.5 sec, which can be successfully solved with current and newly advertised echo cancellation circuits. Because of the enormous use of the GEO constellation for many space applications, some parts of the GEO are becoming congested, owing to only one radius and latitude. This orbit is geostationary and so its track is one point called the sub-satellite point and obviously, handover and Doppler Effect does not apply to GEO.
An GEO satellite is at essentially fixed latitude and longitude, so even a narrow-beam Earth antenna can remain fixed. Satellites in GEO can use high and recently low-gain antennas, which helps to overcome the great distances in achieving the required Effective Radiated Isotropic Power (EIRP) at ground level. Using satellite spot beam antennas GEO coverage can be confined to smaller spot areas with bigger power and higher speed of transmission. The GEO satellites pass through both Van Allen Belts only on launch, so their effect is insignificant. After reaching the end of operational life a satellite has to be removed from its orbital slots into a graveyard orbit some 200 km above the GEO plane. The GEO satellite constellation seems likely to continue to dominate in the satellite communications world, especially in MSS, providing near global coverage with low and high-power transmission(Kechichian 1997; Vinti 1998).

3.4.2.3. Geosynchronous Inclined Orbits (GIO)

This system would consist in four satellites at six-hour intervals around the Earth orbit at an inclination of 45^o to the equatorial plane. The satellites provide Polar coverage for six hours either side of their most northerly and southerly movement. Special GES with full tracking antennas are needed, therefore this system in general must be considered complex and expensive for a polar communication system.
The GIO satellite has a period of orbit equal to or very little different from a sidereal day (23h 56 min and 4.1 sec), which is time for one complete revolution of the Earth. The satellite movement speed has only very little difference from the angular velocity of the Earth, so this movement also has constant angular velocity. The projection of this movement on the equatorial plane is not at a constant velocity. There is an apparent movement of the satellite with respect to the reference meridian on the surface of the Earth and that of the satellite on passing through the nodes.
The orbit may be inclined at any angle, which produces a repeating ground track. In **Figure 3.7(B)** are presented tracks of 30^o and 60^o inclined orbits. The coupled N–S and E–W motion of GIO satellites is illustrated as a figure eight pattern, while the patterns could also be distorted circles. Depending on the inclination angle, the GIO satellite shows points on the equator at various longitudes.
This satellite may operate in GIO for several reasons. Firstly, there is no need to control inclination, but GES and MES require tracking antennas. Secondly, the GIO constellation with non-zero inclination can be chosen because of easy launching and placing of the satellite into orbit. This satellite must move with an angular velocity equal to the Earth and be in a prograde orbit, that is, revolving eastward in the same direction as the Earth rotates. The only requirements for a GIO constellation are the right period and direction of rotation(Evans 1999; Ilcev, S 2010d).

3.4.3. Highly Elliptical Orbits (HEO)

Using inclined HEO satellite configuration both Polar areas can be effectively covered with four satellites only and with two satellites in each polar orbit. The elevation angle to the HEO satellites remains high for most of the 12-hour period of visibility, which is especially required for continuous Euro-Asian regional coverage providing land MSC service. Blocking of the beam due to occlusion of the satellite by buildings, mountains, hills and trees is minimized. Multiple trajectories caused by successive reflection of various obstacles are also reduced.

Minimum two special GES in both Northern and Southern Polar Regions are required to serve MES terminals and GES tracking can be reached by the fixed antenna. Tracking of the satellite is facilitated on account of the small apparent movement and the long visibility duration, so it is possible to use a low gain antenna of the 3 dB bandwidth and also high gain antenna to overcome the great distances in achieving the required EIRP values.

The noise captured by the GES antenna, from the ground or due to interference from other radio systems and atmosphere, is also minimized due to the high elevation angles. These advantages have led the former USSR to use these orbits for a long time in order to provide coverage of their high latitude territories.

The HEO satellite two-way voice transmission has a similar delay as a GEO at the apogee of about 0.25 sec. At this point, free space loss and propagation delay for HEO is comparable to that of the GEO constellation.

Compared with GEO, the launch and satellite cost of the HEO satellite constellation is reasonably low; this constellation is free of congestion because of only a few current and projected new HEO systems providing high elevation angles for GES terminals, which reduces atmospheric losses.

Due to the relatively large movement of a satellite in HEO constellation with respect to an observer on Earth, satellite systems using this model of orbit need to be able to cope with large Doppler Shifts, 14 kHz for Molnya and 6 kHz for Tundra satellite orbits in L-band 1.6 GHz. However, as the former USSR's experience has shown, satellites in this orbit tend to have rather a short lifetime due to the repetitive crossing of both Van Allen Belts. The rest of the disadvantages are the necessity of constant satellite tracking at the MES terminals, compensation of signal loss variation, very long eclipse periods and complex control system of MES and spacecraft.

The HEO satellite typically has a perigee at about 500 km above the Earth's surface and an apogee as high as 50,000 km. The orbits are inclined at 63.4^{o} in order to provide services to locations at high northern latitudes. The particular inclination value is selected in order to avoid rotation of the apses, i.e., the intersection of a line from the Earth's centre to the apogee and the Earth's surface will always occur at latitude of 63.4^{o}N. Orbit period varies from eight to 24 hours.

Owing to the high eccentricity of the orbit, a satellite will spend about two thirds of the orbital period near apogee and during that time it appears to be almost stationary for an observer on Earth (this is referred to as apogee dwell). After this period, the switchover needs to occur to another satellite in the same orbit in order to avoid loss of communications. There have to be at least three HEO satellites in orbit, with traffic being handed over from one to the next every eight hours at a minimum.

Examples of HEO systems are Molnya, Tundra, Loopus, Borealis of the Ellipso system and Archimedes. The ESA proposed Archimedes system employs a so-called "M-HEO" 8-hour orbit. This produces three apogees spaced at 120^{o}. In effect, each apogee corresponds to a service area, which could cover a major population centre, for example the whole European continent, the Far East and North America(Solari and Viola 1992; Evans 1999).

3.4.3.1. Molnya Orbit

The first HEO-Molnya satellite was launched in 1964 and after more than 150 has been deployed, primarily produced by the Applied Mechanics NPO in Krasnoyarsk, former USSR. These satellites weigh approximately 1.6 tons at launch and stand 4.4 m tall and with a base diameter of 1.4 m. Electrical energy is provided by 6 windmill-type solar panels, producing up to 1 kW of power. A liquid propellant attitude control and orbital correction performs orbital maneuvers. Sun and Earth sensors are used to determine proper spacecraft attitude and antenna pointing. The first Molniya 3 spacecraft launched in 1974 carried communications payload of three 6/4 GHz transponders with power outputs of 40/80 W. The second stratum of the Russian space-based system consists of 16 Molniya-class spacecraft in highly inclined 63° semi-synchronous orbit planes. With initial perigees between 450 and 600 km fixed deep in the Southern Hemisphere and apogees near 40,000 km in the Northern Hemisphere.
The hypothetical Russian Molniya network can employ minimum 3 HEO satellites in three 12-hour orbits separated by 120° around the Earth, with apogee distance at 39,354 km and perigee at 1,000 km. This orbit takes the name from the system installed by the former USSR, whose territories are situated in the Northern Hemisphere at high latitudes. The orbital period (t) is equal to ($t_E/2$), or about 12 hours, which details are given in **Table 3.4.**

Table 3.4. Molnya and Tundra Orbit Parameters

Characteristics	Molnya Orbit	Tundra Orbit
Orbital Period (t)	12 h	24 h
Sidereal Period	11 h 58 min 2 s (half day)	23 h 56 m 4 s (full day)
Semi-major Axis (a)	26,556 km	42,164 km
Inclination (i)	63.4°	63.4°
Eccentricity (e)	0.6 to 0.75	0.25 to 0.4
Perigee Altitude (h_p)	$a(1 - e) - R$	$a(1 - e) - R$
(e.g.: e=0.71)	1,250 km	25,231 km
Apogee Altitude (h_a)	$a(1 + e) - R$	$a(1 + e) - R$
(e.g.: e=0.71)	39,105 km	46,340 km

The only one-track cycles of a total of two satellite tracks on the surface of the Earth is illustrated in **Figure 3.7 (C-1)** for a perigee argument equal to 270°. The shape of this track is cycles of one orbit only near Greenwich Meridian, so the centre, of the next identical track is around 180° Westward. Therefore, the satellite at apogee passes successively on each orbit above two points separated by 180° in longitude. The apogee is situated above regions of 63° latitude, the altitude of the vertex is equal to the value of the inclination and the apogee coincides with the vertex of the track when the argument of the perigee is equal to 270°
It is evident that the Molnya HEO orbit has the advantage of high-elevation-angle coverage of the Northern Hemisphere, because of a need to completely cover a great part of the Russian territory. With three satellites, each satellite is used (or handover is) 8 hours per day, while with four satellites handover is every 6 hours. The GES must use tracking antenna systems, so a terminal with only one antenna will have an outage during handover (switching) from one satellite to another. The disadvantages of the Molnya orbit include the need for multiple satellites (which the system does not need), the poor, virtually useless coverage of the Southern Hemisphere and the need for tracking antennas at each GES. Since the distance from the terminal to the satellite is continually changing, the received power and frequency vary (Doppler Effect). The former may require automatic uplink power control and scheduling is needed to allow GES to switch satellites simultaneously. As the satellite altitude varies, the beam also coverage changes, so the satellite carries a tracking antenna that must be kept continuously pointed at operating GES(Evans 1999; Turner 2001).

3.4.3.2. Tundra Orbit

The Russian Tundra HEO system employs 2 satellites in two 24-hour orbits separated by 180° around the Earth, with apogee distance at 53,622 km and perigee at 17,951 km, which provides visibility duration of more than 12 hours with high elevation angles. The Tundra orbit can be useful for regional coverage for both FSS and MSS applications. Similar to the Molniya orbit, this orbit is particularly useful for land MSS where the masking effects caused by surrounding obstacles and multiple path are pronounced at low elevation angles, (> 30°). The period (t) of the orbit is equal to t_E, which is around 24 hours. The characteristics of an example orbit of this type are given in **Table 3.4.**

This orbit has only one track on the Earth's surface, as shown in **Figure 3.7 (C-2),** for a perigee argument equal to 270°, inclination i = 63.4° and eccentricity e = 0.35. The latter parameter can have three values of eccentricity e = 15, e = 25 and e = 45. According to the value of orbital eccentricity, the loop above the Northern Hemisphere is accentuated to a greater or lesser extent. For eccentricity equal to zero, the track has a form of a figure 8, with loops of the same size and symmetrical with respect to the equator. When the eccentricity increases, the upper loop decreases, while the lower loop increases and the crossover point of the track is displaced towards the North. This loop disappears for a value of eccentricity of the order of e = 0.37 and the lower loop becomes its maximum size. The transit time of the loop represents a substantial part of the orbital period and varies with the eccentricity. The position of the loop can be displaced towards the East or West, with respect to the point of maximum latitude, by changing the value of the argument of the perigee (ω) and the eccentricity(Evans 1999; Turner 2001).

3.4.3.3. Loopus Orbit

The proposed Loopus system, which employs 3 satellites in three 8-hour orbits separated by 120° around the Earth, has an apogee distance at 39,117 km and perigee at 1,238 km. This orbit has similar advantages and disadvantages as for the Molnya orbit. One of the problems encountered by the GES is that of repointing the antenna during the handover (changeover) from one satellite to another. With orbits whose track contains a loop, it is possible to use only the loop as the useful part of the track in the trajectory. Handover between two satellites is performed at the crossover point of the track. At this instant the two satellites are seen from the GES in exactly the same direction and it is not necessary to repoint the antenna. To achieve continuous coverage of the region situated under the loop, the transmit time of the loop must be a sub-multiple of the orbit period and the number of satellites. Hence, the coverage can be extended to one part of the hemisphere by increasing the number of satellites in orbit regularly spaced about the globe(Dondl 1984).

3.5. Polar Earth Orbits (PEO)

The PEO constellation is today a synonym for providing coverage of both Polar Regions for different types of meteorological observation and satellite determination services. Namely, a satellite in this orbit travels its course over the geographical North and South Poles and will effectively follow a line of longitude. Certainly, this orbit may be virtually circular or elliptical depending upon requirements of the program and is inclined at about 90° to the equatorial plane, covering both poles. The orbit is fixed in space while the Earth rotates underneath and consequently, the satellite, over a number of orbits determined by its specific orbit line, will pass over any given point on the Earth's surface. Therefore, a single satellite in a PEO provides in principle coverage to the entire globe, although there are long periods during which the satellite is out of view of a particular ground station.

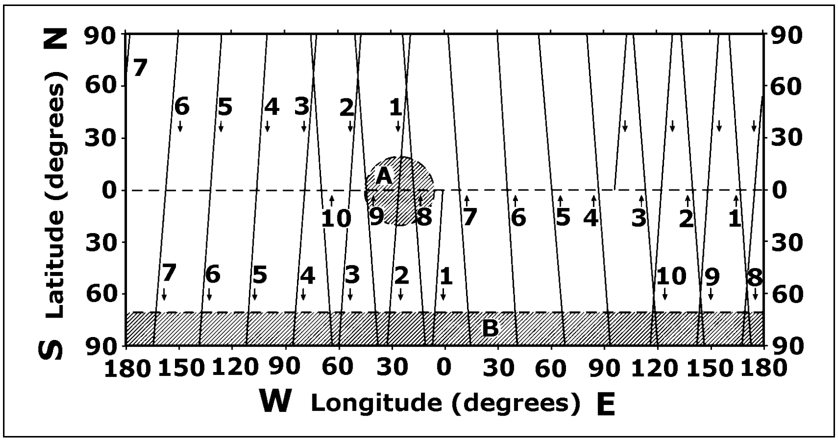

Figure 3.9. LEO Satellite Orbits and Tracks – Courtesy of Book: by Pascall

Accessibility can of course be improved by deploying more than one satellite in different orbital planes. If, for instance, two such satellite orbits are spaced at 90^o to each other, the time between satellites passes over any given point will be halved.

The PEO system is rarely used for communication purposes because the satellite is in view of a specific point on the Earth's surface for only a short period of time. Any complex steerable antenna systems would also need to follow the satellite as it passes overhead. At any rate, this satellite orbit may well be acceptable for a processing store-and-forward type of communications system and for satellite determination and navigation.

There are four primary requirements for PEO systems as follows:

1) To provide total global satellite visibility for LEOSAR Cospas-Sarsat distress beacons;

2) To provide global continuous coverage for current or forthcoming GSNN systems;

3) To provide at L-band or any convenient spectrum the communication requirements of ships and aircraft in the Polar Regions not covered by the Inmarsat GEO system; and

4) To provide global coverage for meteorological and synoptic observation stations.

The Inmarsat team has studied two broad ranges of orbit altitude of PEO for both distress and communication purposes, first, low altitudes up to 1,400 km and second, high altitudes above 11,000 km. In reality, these two orbit ranges are separated by the Inner Van Allen radiation belt. In the regions of the radiation belt the radiation level increases roughly exponentially with height at around 1,000 Km, reaching a peak at about 5,000 Km altitude. Thus, a critical requirement to reduce high-energy proton damage to the solar cell arrays of the satellite system constrains the PEO to low and high altitudes. As is evident, another Outer Van Allen Belt has not negative influence on these two PEO constellations because it lays far away between MEO and GEO planes. For both the Low and High PEO the number of operational satellites required to provide adequate Earth coverage needs to be minimized system costs and no time delays in distress alerting of Cospas-Sarsat mission anywhere in the globe(Vinti 1998; Ilcev, S 2010e).

3.5.1. Low PEO

The Low PEO satellite constellation similar to the LEO mostly employs both polar and near-polar orbits for communications or navigation utilities such as Cospas-Sarsat SAR system for maritime, land and aeronautical applications. In **Figure 3.9** is illustrated the Earth track of ten successive orbits of satellite in Low PEO with an altitude of 1,000 km. The MES in shaded area A (4,200 km in diameter) would see the satellite, in the absence of environmental screening, at an angle of elevation not less than 10^o, while the satellite was passing through the equatorial plane. The coverage area has the same size and shape wherever the satellite is in the orbit but its apparent size and shape would change with latitude, being distorted by the map projection used in the figure.

The Low PEO system uses 8 satellites in 4 near-polar orbits: four US-based Sarsat satellite constellations at 860 km orbits, inclined at 99°, which makes them sun-synchronous and four Cospas satellite configurations at 1,000 km orbits, inclined at 82°. However, this orbit was also suitable for the first satellite navigation systems Transit and Cicada, developed by the USA and the former USSR, respectively.
The South Pole coverage area at a single pass of the satellite is shown by shaded area B. The same figure shows that a single PEO satellite in a polar orbit will have a brief sighting of every part of the Earth's surface every day. There will be 2 or 3 of these glimpses per day near the equator, the number increasing as the Poles approach. The period of visibility as seen from the MES range from about 10 min, then the satellite passing overhead, down to a few seconds when the satellite appears briefly above the horizon. If the orbital plane of the satellite is given an angle of inclination differing from 90° of the PEO, a similar Earth track is obtained but the geographical distribution of the satellite visibility changes.
The short visibility period during a transit and the uneconomic need for large numbers of satellites for continuous coverage makes a Low PEO unattractive for modern communications considerations. If this orbit configured well as an economic way for distress coverage in Polar Regions to be used for communications purposes, users would have to operate with the following restrictions: **(1)** Only burst mode, non-simultaneous data communication would be possible; **(2)** Transmission time and/or bit rate would be limited by satellite message storage capability; **(3)** Replies to the message would require an interrogation or pulling system from the MES expecting a reply; **(4)** Depending on the PEO constellation and MES position, a reply could take some hours(Vinti 1998).

3.5.2. High PEO

The High PEO constellation would consist of three satellites separated by 120° in the same circular orbit of 12,000 km altitude, geometrically similar to the GEO and as orbit similar to MEO configuration. This orbit provides continuous coverage to both Polar Regions above 59° latitude. Six satellites (in two orbital planes of three satellites each) would provide continuous and real global coverage if that was required, which GEO cannot obtain. By comparison with Low PEO satellites transmission path losses of this orbit are higher, distress beacons need to be high powered to transmit successfully alert signals, Doppler shift is lower (about 10 kHz at 1.6 GHz), single high latitude GES in both Arctic and Antarctic Polar Regions allows reception with no delay of all distress messages transmitted from above 59°, and with two GES positioned at high latitude with continuous visibility can offer near continuous communication services to the Polar Regions.

3.6. Hybrid Satellite Orbits (HSO)

The Hybrid satellite constellation can be configured by several types of combinations between existing orbital solutions today. Namely, any of these combinations can provide better global coverage for both hemispheres, including both Polar Regions. In this context will be introduced shortly five hybrid constellation systems, which are currently using or developing MSC and navigation systems as follows:
1. Combination of GEO and HEO Constellations – The development of a MSS which would provide reliable communications with MES terminals, which include vessels, road vehicles, trains and aircraft, rural areas and remote terminals. This MSC system, called Marathon, includes five GEO Arcos-type satellites and four Mayak-type satellites in a HEO, as well as a ground segment that is composed of base stations and terminals installed at fixed premises or mobile users.

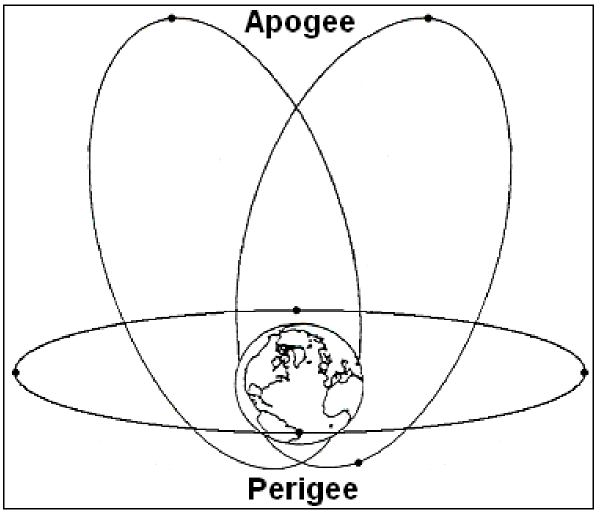

Figure 3.10. LEO Combination of GEO and HEO Constellations –Courtesy of Book: by Ilcev

The combination of GEO and Non-GEO, such as HEO constellations makes it possible to render MSC services, including those at high latitudes and in the both Polar areas, this is especially important for Russia, with its vast northern Eurasian territories and to provide the most reliable satellite communication between the territories of the western and Eastern Hemispheres, which is shown in **Figure 3.10.** This hybrid constellation can be useful as well as for the Alaska, Greenland and northern Canada. The similar hybrid constellation with 2 HEO satellites can be configured for complete coverage of Southern Hemisphere with apogees on opposite side as shown in the same figure. This HSO configuration is the best solution for providing complete global coverage for aeronautical applications.

2. Combination of GEO and PEO/MEO Constellations – This current combination of orbits has been developed by the efforts of the Cospas-Sarsat organization, with the assistance of International Maritime Organization (IMO), Inmarsat and other international and regional contributors. The Cospas-Sarsat space segment is a combination of three GEO operational satellites of the subsystem called GEOSAR and four PEO operational satellites of the subsystem called LEOSAR, with spare spacecraft for all participants. Thus, recently Cospas-Sarsat included MEO satellites as MEOSAR. The GEOSAR employs one satellite type of INSAT-2A and two GOES type GOES-E and GOES-W, while the LEOSAR configuration provides two Cospas and two Sarsat spacecraft. The GEOSAR project in the future has to include the European MSC and two Russian Luch-M spacecraft. This system is responsible for providing distress alert and to help SAR forces on-scene determinations for maritime, land and aeronautical applications, shown in **Figure 3.11. (A).**

3. Combination of GEO and LEO Constellations – Celestri is the Motorola trademark name for a proposed GEO and LEO satellite hybrid communication network, illustrated in **Figure 3.11. (B).**

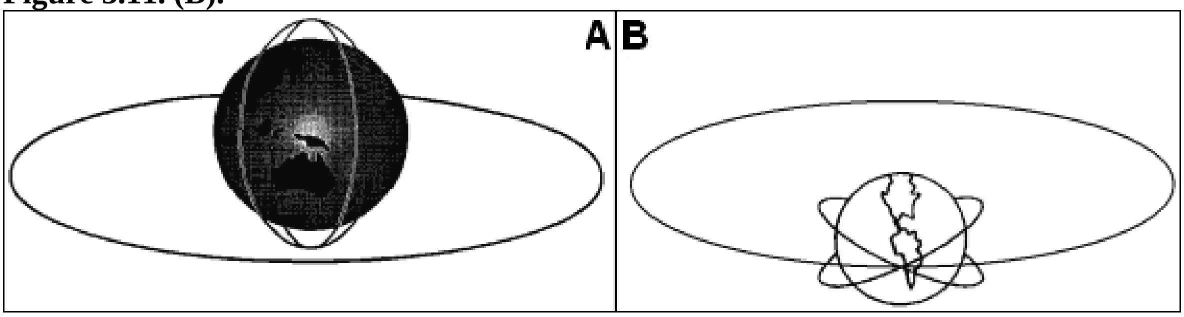

Figure 3.11. Combination of GEO and PEO and GEO and LEO Constellations – Courtesy of Book: by Ilcev

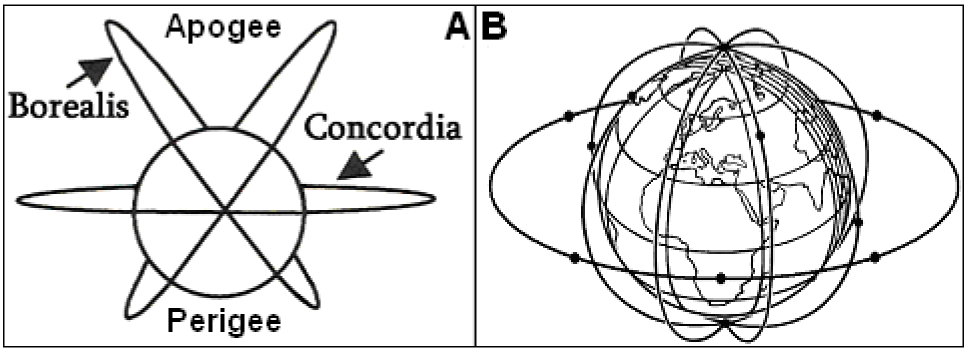

Figure 3.12. Combination of MEO and HEO and MEO and LEO Constellations – Courtesy of Book: by Ilcev

The network will combine 9 GEO and 63 LEO satellites in 7 planes with Earth-based control equipment and will provide interfaces to existing telecommunication infrastructures, the Internet and corporate and personal networks. The system will offer a 64 Kb/s voice circuit from anywhere in the world. The architecture is not limited to fixed sized channels but permits dynamic bandwidth assignment based on application demand. Business users will benefit by Celestri's to provide remote access to LAN infrastructures.

4. Combination of MEO and HEO Constellations – The new proposed MSS Ellipso is developing in combination with an initial complement of seven Concordia satellites deployed in a circular equatorial MEO at an altitude of 8,050 km and ten Borealis satellites in two HEO planes inclined at 116.6^{o}. They have apogees of 7,605 km and perigees of 633 km and a three-hour orbital period. This combination of two constellations, shown in **Figure 3.12 (A)** would provide coverage of the entire Northern Hemisphere including North Pole areas and part of the Southern Hemisphere up to 50^{o} latitude South. The HEO satellites can spend a greater proportion of their orbital periods over the Northern latitudes. Together with the MEO constellation Ellipso hybrid system will provide voice, data and Fax communication and navigation services to areas with large landmasses, enormous populations with a large density of users and potentially widespread markets. This system is also planned to cooperate with the terrestrial PSTN and other services.

5.Combination of MEO and LEO Constellations – The Kompomash consortium for space systems in Russia prepared the Gostelesat satellite system for MSS, shown in **Figure 3.12 (B),** using 24 satellites in MEO and 91 in LEO constellation. This project is provided for future global MSC with possibility to cover both Polar Regions(Ilcev, S 2010a).

4. Chapter 4

RADIO TRACKING AND DETECTING SYSTEMS

This chapter introduces the main technical characteristics and possible applications of Radio Tracking and Detecting systems for maritime applications. The GMDSS radio and satellite integrated networks are already developed and implemented for the ship's safety, distress alert and SAR communications. This system is not effective enough to provide a real tracking and detecting system of ships for everyday navigation aids.
The GMDSS radio and satellite networks need additional integration with new CNS systems as a proposal that has to be developed to provide seafarers with global communications and tracking networks introduced in this thesis. The GMDSS has to integrate CNS systems that use radio and satellite technologies for automated alerting, rapid tracking and detecting of ships in distress and to prevent emergency situations employing more sophisticated techniques for collision avoidance and enhanced safety and security.
The modern maritime Radio Tracking and Detecting systems and onboard equipment are listed below and usually using traditional frequencies at MF, HF, VHF, UHF and SHF-band integrated or autonomous CNS networks and equipment onboard ships, vehicles and aircraft.

4.1. Shipborne S and X-band Surveillance Radars

The navigational radars onboard ship are special electronic units designed for surveillance, detecting and search using very short waves that reflect from Earth in general and from sea, coast and moving objects in particular. They are common on both ships and aircraft. Marine radars are in service many decades by vessels for collision avoidance, navigation, safety purposes and search of radar or Automatic Identification System (AIS) transponders. However, ship radar can be used for searching captured ships by pirates as well.
The frequency band of radars used on most ships is an X-band (9 GHz/3 cm) and also S-band radar (3 GHz/10 cm). The S-band radar can be installed on most ocean going ships to provide better detecting of coast, other objects at sea and ships in rough sea and heavy rain condition. However, sometimes during extremely heavy weather conditions accompanied by very deep clouds up to the sea surface, very rough sea and strong winds is very difficult to get any targets on the radar screen. Sometimes in this critical situation during insufficient propagation conditions is very difficult to get positions of adjacent vessels in certain sailing areas and to avoid collision. For Vessel Traffic Service (VTS) is used special marine radars X or S-band, known today as an Automatic Radar Plotting Aid (ARPA)for providing tracking and collision avoidance or traffic regulation facilities of ships in the surveillance areas(Grajal *et al.* 2004).
General purpose radars are increasingly being substituted for pure navigational radars. These generally use navigational radar frequencies and modulate the pulse so the radar receiver can determine the type of surface of the reflector. The best general-purpose radars distinguish the rain of heavy storms, as well as land and vehicles. Some can superimpose sonar and map data from GPS position. Radar determines distance to an object by measuring the time required for a radio signal to travel from a transmitter to the object and return. So, such measurements can be converted into Lines of Position (LOP) comprised of circles with radius equal to the distance to the object. Since marine radars use directional antennae, they can also determine an object bearing. However, due to its design, radar's bearing measurement is less accurate than its distance measurement. Understanding this concept is crucial to ensuring the optimal employment of the radar for safe navigation(Skolnik, Merrill Ivan 1970).

Figure 4.1. Radar Antenna (Left) and Display (Right) – Courtesy of Brochure: by Sea-Hawk Radars

4.1.1. Radar Signal Characteristics and Display

In most marine navigation applications, the radar signal is pulse modulated and generated by a timing circuit so that energy leaves the antenna in very short pulses. When transmitting, the antenna is connected to the transmitter but not the receiver, see the radar antenna in **Figure 4.1 (Left).** As soon as the pulse leaves, an electronic switch disconnects the antenna from the transmitter and connects it to the receiver. Thus, another pulse is not transmitted until after the preceding one has had time to travel to the most distant target within range and return. Since the interval between pulses is long compared with the length of a pulse, strong signals can be provided with low average power. The duration or length of a single pulse is called pulse length, pulse duration or pulse width, which emission sequence repeats a great many times, perhaps 1,000 p/s. This rate defines the Pulse Repetition Rate (PRR). The returned pulses are displayed on an indicator screen.

The radar display is often referred to as the Plan Position Indicator (PPI), shown in **Figure 4.1 (Right)**. On a PPI, the sweep appears as a radial line, centered at the center of the scope and rotating in synchronization with the antenna. Any returned echo causes a brightening of the display screen at the bearing and range of the object. Because of a luminescent coating on the inside of the tube, the glow continues after the trace rotates past the target. On a PPI, a target's actual range is proportional to its distance from the center of the scope. A moveable cursor helps to measure ranges and bearings. In the "heading upward" presentation, which indicates relative bearings, the top of the scope represents the direction of the ship's head. In this unstabilized presentation, the orientation changes as the ship changes heading. In the stabilized" north-upward" presentation, gyro north is always at the top of the scope(Navigation).

4.1.2. Radar Components

4.1.2.1. Power Supply and Modulator

Power supply is important component serving for distribution to all radar units, which is represented as a single block by functionality. However, it is unlikely that any one supply source could meet all the power requirements of a radar set. The distribution of the physical components of a system may be such as to make it impractical to group the power-supply circuits into a single physical unit. Thus, different supplies are needed to meet the varying requirements of a system and must be designed accordingly. The power supply function is performed by various types of power supplies distributed among the circuit components of a radar set.

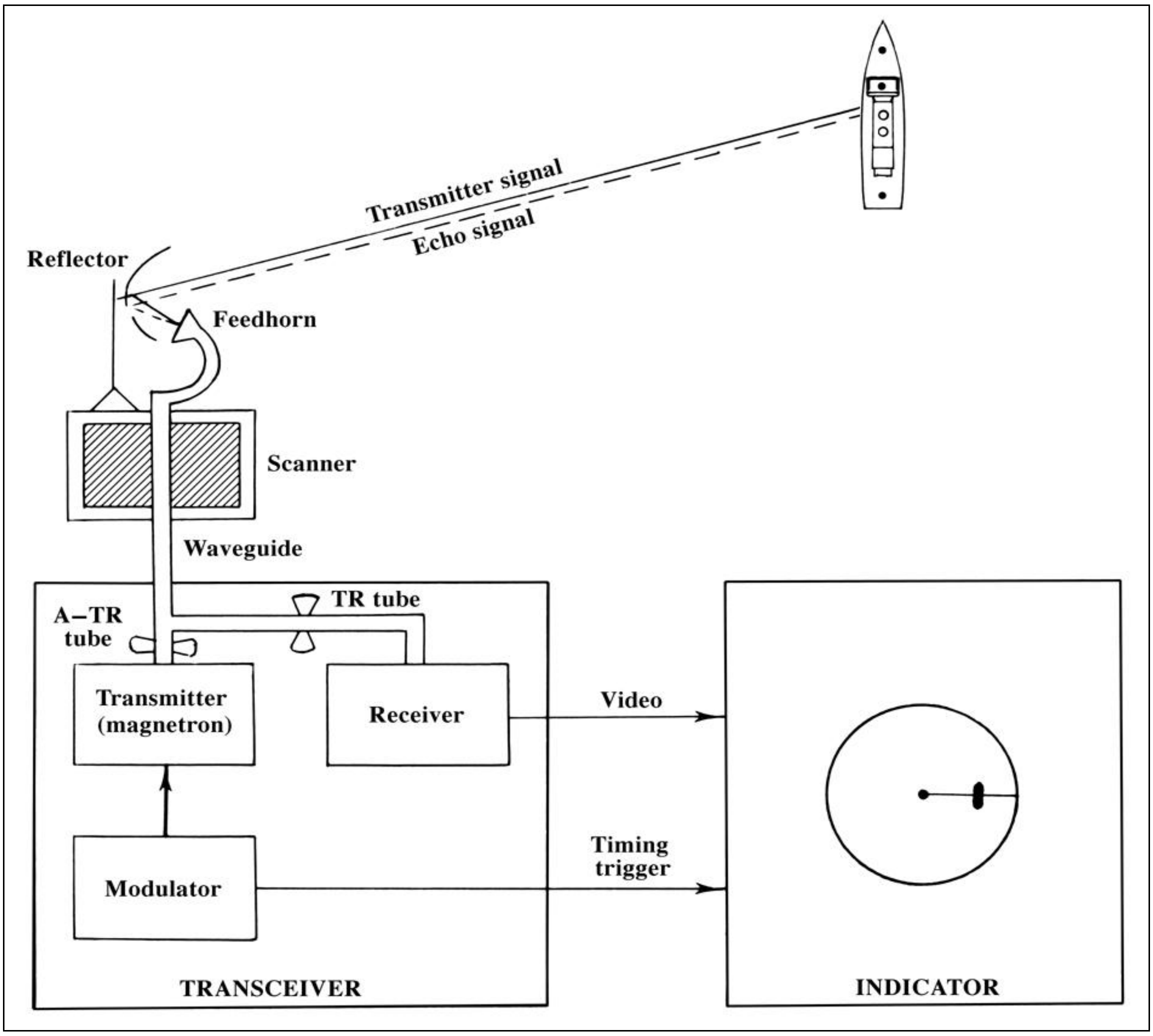

Figure 4.2. Block Diagram of Basic Radar System – Courtesy of Paper: by Radar Navigation

The function of the modulator is to insure that all circuits connected with the radar system operate in a definite time relationship with each other and that the time interval between pulses is of the proper length. The modulator simultaneously sends a synchronizing signal to trigger the transmitter and the indicator sweep. This establishes a control for the PRR mode and provides a reference to the timing of the travel of a transmitted pulse to a target and its return as an echo (Sonnenberg 1988).

4.1.2.2. Transceiver, Antenna System and Indicator

In **Figure 4.2** are illustrated antenna system and indicator as separate components, while the modulator, transmitter and receiver are contained in the same chassis. In this arrangement, however, the group of components containing receiver (Rx) and transmitter (Rx) called a transceiver.

The transmitter is basically an oscillator which generates Radio Frequency (RF) energy in the form of short powerful pulses as a result of being turned on and off by the triggering signals from the modulator. Because of the frequencies and power outputs required, the transmitter oscillator is a special type known as a magnetron.

The function of transmitting and receiving radar antenna system is to take the RF from the transmitter, radiate this energy in a highly directional beam, receive any echoes or reflections of transmitted pulses from targets and pass the see chose to the receiver and display.

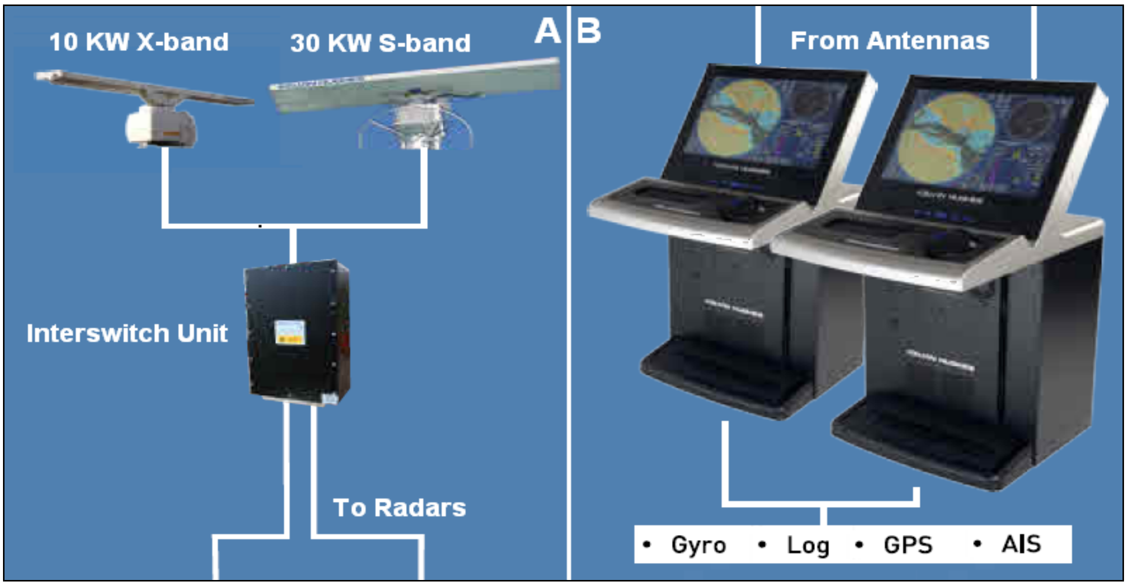

Figure 4.3. Block Diagram of Basic Radar System – Courtesy of Brochure: by Kelvin Hughes Radars

There are two types of shipborne transceiving radar antennas, minimum 10 KW of X-band and up to 50 KW of S-band radar antenna systems, shown in **Figure 4.3 (A).** The signals from both antennas are passing throughout Interswitch Unit towards both X-band and S-band radars, shown in **Figure 4.3 (B).** Both ships radars are interfaced to Gyro, Log, GPS and AIS onboard facilities(HUGHES 2014).

In carrying out this function the RF pulses generated in the transmitter are conducted to a feed horn at the focal point of a directional reflector, from which the energy is radiated in a highly directional pattern. The transmitted and reflected energy (returned by the same dual purpose reflector) are conducted by a common path. This common path is an electrical conductor known as a waveguide. A waveguide is hollow copper tubing, usually rectangular in cross section, having dimensions according to the wavelength or the carrier frequency, i.e., the frequency of the oscillations within the transmitted pulse or echo.

Because of this use of a common waveguide, an electronic switch, a Transmit-Receive (TR) tube capable of rapidly switching from transmit to receive functions, and vice versa, must be utilized to protect the radar receiver from damage by the potent energy generated by the transmitter. The TR tube, as illustrated in **Figure 4.2** blocks the transmitter pulses from the receiver. During the relatively long periods when the transmitter is inactive, the TR tube permits the returning echoes to pass to the receiver. To prevent any of the very weak echoes from being absorbed by the transmitter, another device known as an Anti-TR (A-TR) tube is used to block the passage of these echoes to the transmitter.

The feed horn at the upper extremity of the waveguide directs the transmitted energy towards the radar reflector, which focuses this energy into a narrow beam. Any returning echoes are focused by the reflector and directed toward the feed horn. The echoes pass through both the feed horn and waveguide enroute to the receiver.

The function of the radar receiver is to amplify or increase the strength of the very weak RF echoes and reproduce them as video signals to be passed to the indicator or display. Thus, the receiver contains a crystal mixer and intermediate frequency amplification stages required for producing video signals used by the indicator (Cook 2012).

The primary function of the indicator is to provide a visual display of the ranges and bearings of radar targets from which echoes are received. However, in this basic radar system, the type of radar display used is PPI, which is essentially a polar diagram, with the transmitting ship's position at the center. At this point, images of target echoes are received and displayed at either their relative or true bearings, and at their distances from the PPI center.

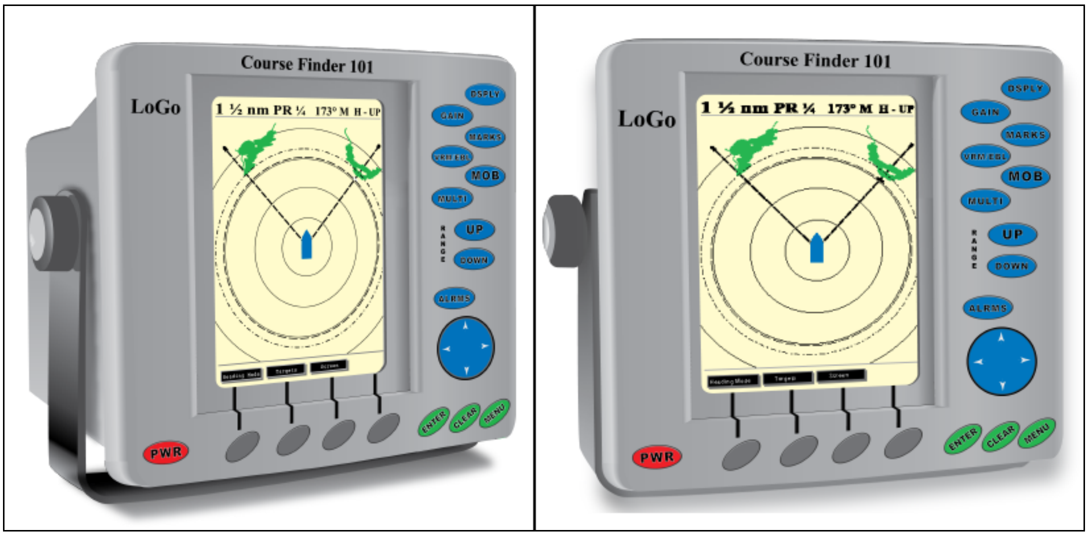

Figure 4.4. CRT and LCD Radar Displays – Courtesy of Manual: by Navigation Using Radar

With a continuous display of the images of the targets, the motion of the target relative to the motion of the transmitting ship is also displayed. The secondary function of the indicator is to provide the means for operating various controls of the radar system.

All of the readily available radar sets that fall into the small marine category use raster scan technology to present the radar picture. Thus, early radar sets used mechanically driven PPI Cathode Ray Tube (CRT) s to match the scan of the antenna and thus draw the actual picture. Modern displays apply digital processing to transform the ”rotating” analogue data from the receiver into a TV-like format. Each row of information is drawn across the display surface from left to right and, from top to bottom. This is called a raster scan. To do this, the face of the display is divided into a series of rows and columns, made up of individually addressable locations in the display memory of the unit, like a computer monitor. The display is usually rotated into a vertical "portrait" orientation. These individually addressable locations are called pixels, which is short for addressable picture [pix] elements [els]. They determine the overall definition and clarity of the displayed data. A "640 deep x 480 wide" display has 640 rows, each with 480 pixels, for a total amount of 307 200 individually addressable locations in the display memory, and thus, on the display surface(Bole *et al.* 2013).

The two currently available types of display faces are the CRT unit illustrated in **Figure 4.4 (Left)** and Liquid Crystal Display (LCD) unit illustrated in **Figure 4.4 (Right)**. The CRT unit has the advantages of having a much higher definition, and a more easily read, clearer picture. The LCD unit has the distinct advantages of low power consumption and better moisture resistance, but it has limited readability in direct sunlight or other bright lighting conditions. The definite disadvantages of a CRT unit are its heat generation and its hunger for higher power supply. These two illustrations show graphically the differences in the detail available with a higher definition screen. In this case the CRT has four times the detail of the LCD, and has superior contrast with its green-on-black picture versus the gray-on-white of the LCD.

Some models of recreational radar use color CRT displays. However, production costs for high contrast, high definition color LCD panels are steadily decreasing to meet the growing demand for digital personal computer monitors and TV sets. This is allowing color LCD panels to steadily displace the monotone CRT and lower definition LCD displays. Color display has a distinct advantage in the presentation of the radar picture. The receiver can easily pass an indication of the signal strength of the received echo to the display processor. This would allow a color value to be assigned to each pixel indicating this to the operator. Imagine how much easier it would be to read the display if echoes were displayed from very weak to very strong using, perhaps, red, yellow, blue and green(Imagery and Agency 1994).

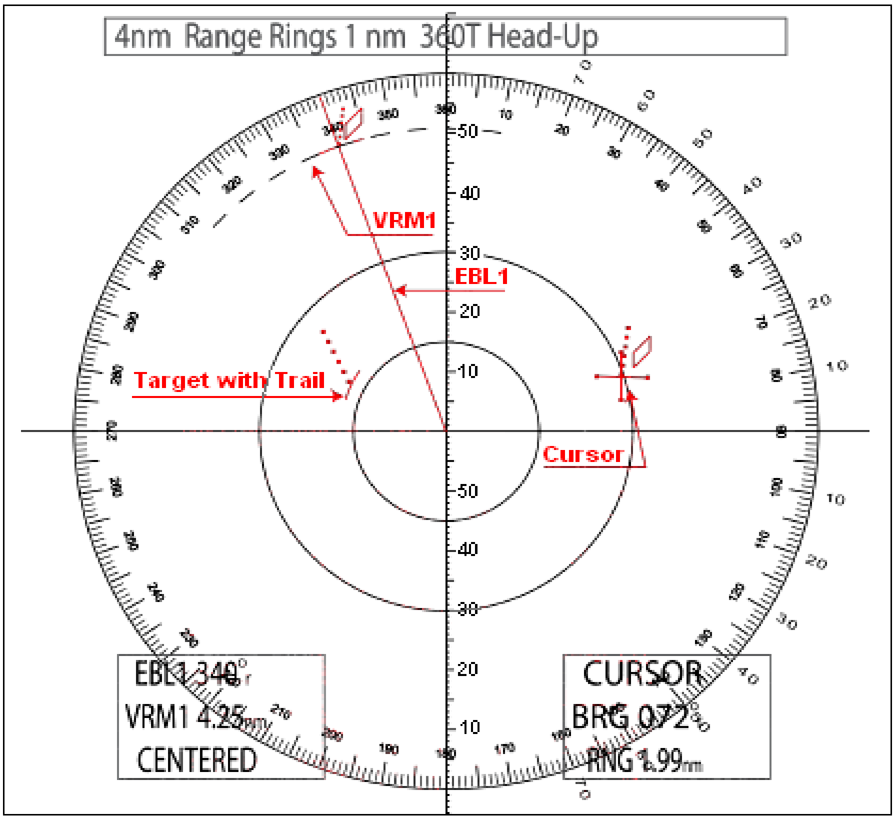

Figure 4.5. EBL, VRM and Radar Target Trails – Courtesy of Manual: by Navigation Using Radar

4.1.3. Digital Display Processing and External Inputs

Thanks to digital processing, the basic radar picture can be enhanced without losing the integrity of the received data. So not only can the various range changes be rapidly displayed, with suitable range marks, but the relative location of the vessel itself, shown on the display, can also be offset to allow the operator to look towards a particular area of interest.

4.1.3.1.MovableRange Markers and Bearing Lines

The real advantage of the digital flexibility of shipborne radar is its ability to superimpose an operator's controllable azimuth indicator called the Electronic Bearing Line (EBL) and its complementary Variable Range Marker (VRM). These lines or rings can be moved across the screen using either a directional rocker switch or a trackball. The azimuth drawn by the EBL and the range of the VRM ring are displayed, with great accuracy, in one of the text areas of the display, illustrated in **Figure 4.5.** Some models combine both of these functions into a trackball-controlled cursor. The cross–shaped cursor icon can be "rolled" into place over the point of interest. The azimuth and range from origin to the cursor position is then shown in a text window on the display screen. These features are much more precise than the trusty old grease pencil that we once used.
As technology sprints ahead, more standard features are appearing with each generation of manufacturer's displays. Two EBL indicators are now offered on many models, and the origin of one, or both, can be moved to any location on the radar display to obtain accurate bearings between any two points in the display area. The VRM associated with the EBL can then be moved along the offset bearing line and an accurate range between these two offset points can be immediately measured. This feature is a great benefit to the navigator (Skolnik, Merrill I 1962; Organization and Internacional 1999; Monahan 2003).

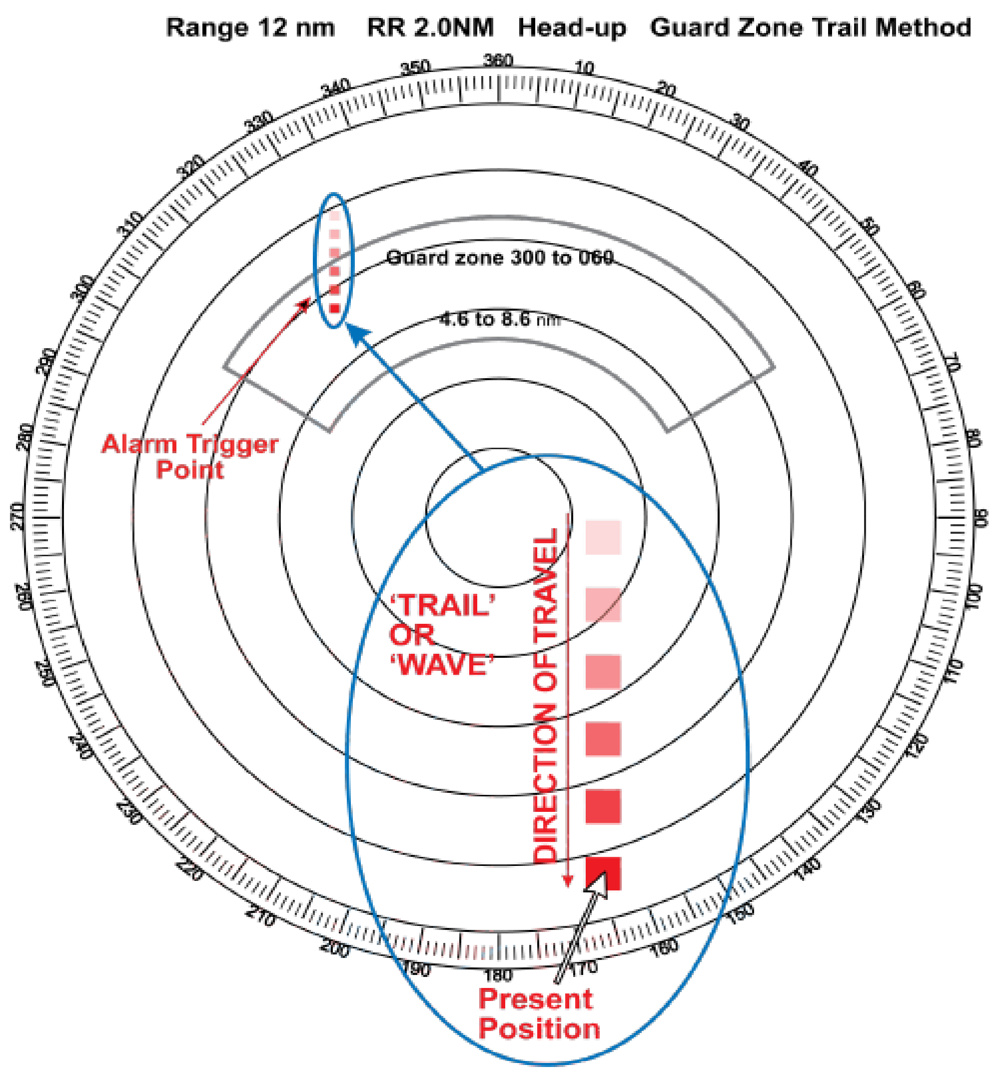

Figure 4.6. Guard Zones – Courtesy of Manual: by Navigation Using Radar

4.1.3.2. Target Trails and Guard Zones

The classic attribute of a target moving across the screen, leaving a slowly fading trail behind it, disappeared with the demise of the mechanical PPI CRT and its long persistence phosphor coating. This feature is now provided electronically and can be selected, with the displayed trail lengthened or shortened, at the operator's pleasure, as illustrated in **Figure 4.5.** These trails or wakes provide key information at a glance: relative movement, direction of travel, and opening or closing speed. This feature should never be switched off. Two other common features to aid the watchkeeper are the Guard Zone and the Intermittent or Sleep modes of operation. Thus, a Guard Zone can be set up using the EBL control to indicate the desired arc, by start and stop azimuths, with the desired depth of zone inserted, using the VRM to set the start and stop ranges.

When activated, any consistent targets entering the zone of observations will trigger an audible alarm, hopefully bringing the radar watchkeeper's attention to the display, shown in **Figure 4.6.** Depending upon the radar system manufacturer, these zones can be activated for targets inbound to or outbound from, the zone. Thus, this is a good safety feature as it allows the guard zone to be set in such a way that large fast targets will trigger the alarm on the outer edge of the zone, while smaller weaker targets trip the closer, inner boundary. Guard zones can be extended to 360º around the vessel, if so desired.

This feature can be tricky to set up and monitor in heavy seas, due to sea clutter causing false alarms. The Guard Zone feature will not work effectively if the outer perimeters of the zone are set up beyond the reasonable pickup range of desired targets(Organization and Internacional 1999; Monahan 2003).

4.1.3.3. Intermittent and Night Operations

The Intermittent, Timed Transmit or Sleep mode is intended to allow the ship radar to automatically go into standby operation for user-selected periods of time, and then reactivate the transmitter for selected periods of time. Manufacturers have slightly different methods of controlling this feature, by time, or by sweeps of the antenna, but they all have the same end result. As well, this feature can extend precious battery power.
A useful feature for night use on LCD displays is their ability to invert the display colors or shades. The screen background becomes dark and the radar returns show light. This is more like a traditional radar display. A dim, red backlight on some models reduces the brilliance of the light from the display surface, thus helping the retention of the watchkeeper's night vision while still providing good radar intelligence. Text displays across the top and/or the bottom of the display area provide the operator with pertinent information, for example, the relative bearing and range at which the VRM and EBL lines have been set. Radar sets now come with the ability to accept inputs from external devices(Sonnenberg 1988; Monahan 2003).

4.1.3.4. Gyrocompass, Log, GPS and AIS Inputs

The most popular extra inputs are Gyrocompass, Log, GPS and recently AIS inputs. For instance, when both Gyrocompass and GPS devices are properly interfaced, the geographic location of the GPS antenna is displayed in the text area on the radar display. Adding an input from a compatible fluxgate compass allows the display of the ship's heading, as well as allowing the operator to change the radar picture display from the classic " Heading up" to " Course up", " North up - True", or " North up -Magnetic". Once compass information is also available, the next GPS waypoint, or series of waypoints in a GPS route, can be overlaid with accuracy, onto the radar display. Therefore, this representation known as the "lollipop" on most displays because of its appearance. A line is displayed on the screen from the last waypoint to the next, with the next waypoint location shown in a circle, the lollipop.
With the desired GPS course line between waypoints overlaid on the ship radar display, the captain or deck officer has a visual reference as to whether or not the ship is on its projected course, of course to port or starboard, and by how much, i.e. Cross Track Error (XTE).
Modern radars today have as additional inputs on the radar display such as the Log speed and AIS device. With the connection of external AIS receiver up to 100 AIS may also be tracked. A variety of navigational information such as vessel name, speed, Rate of Turn (ROT), draft, and the destination of the selected targets can be included in real time. Unlike ARPA targets, AIS targets are visible on-screen even if they are obscured by large ships or islands, since AIS works with the VHF transceiver system and does not require line-of-sight. Both ARPA and AIS require heading input(Sonnenberg 1988; Monahan 2003).

4.1.3.5. Chart Information Display

Lastly, for our purposes, a highly integrated system can display chart information. Some systems are able to overlay the radar returns onto a graphic display on the chart. Thus, this capability is not available on models which show the radar picture in a separate window on the same display screen. The composite display feature is becoming more common and is now available on computer displays that accept inputs from the radar control/display unit.

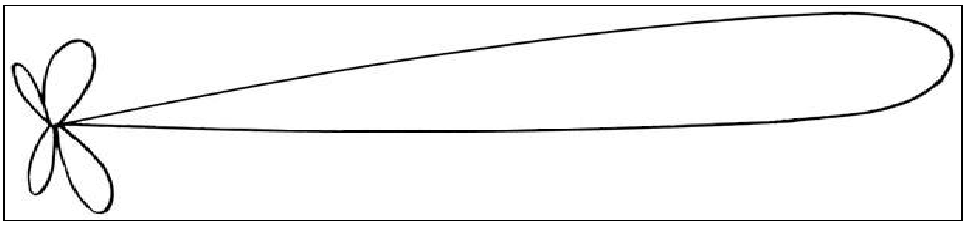

Figure 4.7. Free space Radiation Pattern– Courtesy of Manual: by Radio Navigation

4.1.4. Radar Radiation Beam

The pulses of RF energy emitted from the feed horn at the focal point of a reflector or emitted and radiated directly from the slots of a slotted waveguide antenna and comprising the radar beam would form a single lobe-shaped pattern of radiation if emitted in free space. **Figure 4.7** illustrated this free space radiation pattern, including the undesirable minor lobes or side lobes associated with practical antenna design. Because of the large differences in the various dimensions of the radiation pattern shown in **Figure 4.7** is necessarily distorted. Although the radiated energy is concentrated or focused into a relatively narrow main beam by the antenna, similar to a beam of light from a flashlight, there is no clearly defined envelope of the energy radiated. While the energy is concentrated along the axis of the beam, its strength decreases with distance along the axis. With the rapid decrease in the amount of radiated energy in directions away from this axis, practical power limits may be used to define the dimensions of the radar beam(Knott 2006).

A radar beam's horizontal and vertical beam widths are referenced to arbitrarily selected power limits. The most common convention defines the beam width as the angular width between half power points. The half power point corresponds to a drop in 3 decibels from the maximum beam strength. The definition of the decibel shows this halving of power at a decrease in 3 dB from maximum power. A decibel is simply the logarithm of the ratio of a final power level to a reference power level:

$$dB = 10 \log [P_1/P_0] \tag{4.1}$$

where: P_1 is the final power level and P_0 is a reference power level. When calculating the dB drop for a 50% reduction in power level, the equation becomes:

$$dB = 10 \log (0.5) = -3 \text{ dB} \tag{4.2}$$

The radiation diagram illustrated in **Figure 4.8**depictsrelative values of power in the same plane existing at the same distances from the antenna or the origin of the radar beam. Maximum power is in the direction of the axis of the beam.

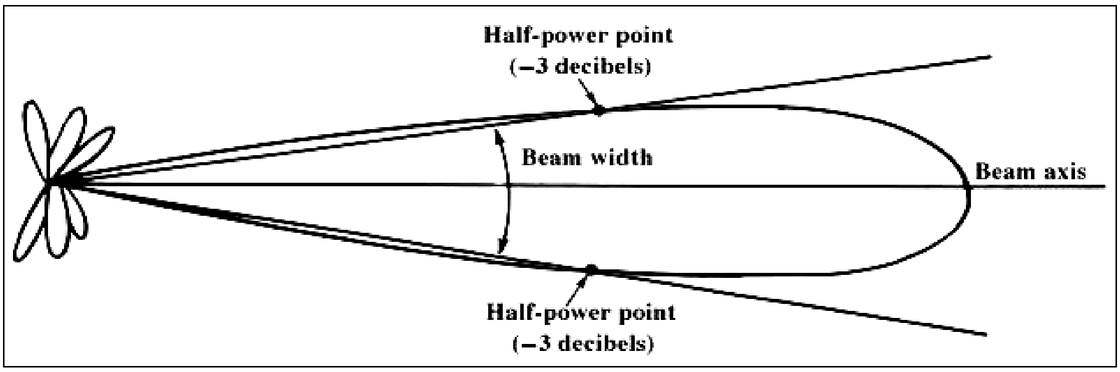

Figure 4.8. Radiation Diagram – Courtesy of Manual: by Radio Navigation

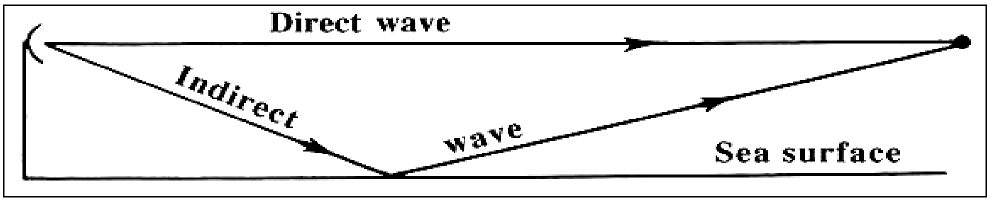

Figure 4.9. Radiation Diagram – Courtesy of Manual: by Radio Navigation

Power values diminish rapidly in directions away from the axis. The beam width is taken as the angle between the half-power points. The beam width depends upon the frequency or wavelength of the transmitted energy, antenna design, and the dimensions of the antenna.
For a given antenna size(antenna aperture) narrower beam widths result from using shorter wavelengths. Thus, for a given wavelength, narrower beam widths result from using larger antennas. With radar waves being propagated in the vicinity of the surface of the sea, the main lobe of the radar beam is composed of a number of separate lobes, as opposed to the single lobe-shaped pattern of radiation as emitted in frees pace. This phenomenon is the result of interference between radar waves directly transmitted, and those waves which are reflected from the surface of the sea. The vertical beam widths of navigational radars are such that during normal transmission, radar waves will strike the surface of the sea at points from near the antenna (depending upon antenna height and vertical beam width) to the radar horizon. The indirect waves reflected from the surface of the sea may, on rejoining the direct waves, either reinforce or cancel the direct waves depending upon whether they are in phase or out of phase with the direct waves, respectively, shown in **Figure 4.9.**Thesereflected waves either constructively or destructively interfere with the direct waves depending upon the waves' phase relationship. Where the direct and indirect waves are exactly in phase, i.e., the crests and troughs of the waves coincide, hyperbolic lines of maximum radiation known as Lines of Maxima are produced. Where the direct and indirect waves are exactly of opposite phase, i.e., the trough of one wave coincides with the crest of the other wave, hyperbolic lines of minimum radiation known as Lines of Minima are produced. Along directions away from the antenna, the direct and indirect waves will gradually come into and pass out of phase, producing lobes of useful radiation separated by regions within which, for practical purposes, there is no useful radiation(Sonnenberg 1988; Monahan 2003).

4.1.5. Atmospheric and Weather Effects on Radar Display

The real usefulness of a radar set is its ability to provide navigators with information about hidden objects and obstacles around the ship. Obviously, this is not as useful when watchmen are looking at a clear horizon around the ship. It becomes a different story in the pitch dark with zero visibility and compounded by foul weather. In these conditions the weather can also affect the radar, reducing its sensitivity and ability to see clearly. In the next stage will be discussed these weather and atmospheric phenomena.
The Anomalous Propagation (AP) or ducting can noticeably increase the range of the pickup and tracking of targets on radar, apparently over-the-horizon. This usually happens in calm weather conditions with cool surface temperatures and warmer air aloft.
Rain, shower, sleet or snow paints well on marine radar. Heavy areas of precipitation can mask a legitimate target echo and cast a radar shadow over the area beyond them. Radar can clearly show less dangerous passages through a line squall or around the thunderstorms.
Sitting and mounting a ship radar antenna requires consideration of the desired range of surveillance. The higher placement will give the better range of coverage. Self-leveling mounts will significantly improve the radar efficiency on a sailboat, when heeled, and on all boats, in rolling seas.
The danger of the continuous exposure to microwave radiation from marine radar cannot be overemphasized. This should be taken into consideration when installing the antenna.

In same delicate and extreme weather situation, it is important that deck officers onboard ship equipped with navigation radar know the capability of their own radar to detect other vessels in order to avoid collisions. However, it is critical for navigation of all vessels to know if radar on another vessel can detect their own vessel. This is especially important as weather deteriorates and visibility decreases. The range at which a vessel can be detected by radar depends on many variables such as the radar power, antenna, the vessel's radar cross section (how strongly it reflects radar), and the environmental conditions (weather, waves, rain, fog) etc. The radar system has the following problems in detecting other ships:
– Detecting a vessel in perfectly calm water when is flat sea is more difficult than detecting it in moderately rough seas.
– Fog attenuates the ship's radar signal and reduces detecting range. How much the fog reduces detecting range depends on the visibility distance, scanner power, and the extent of fog between scanner and target. Here we assume that fog extends over the entire distance between the scanner and target vessel.
– Sea clutter limits detecting at short range, because summarizing the effect of sea clutter on detecting range is difficult because of the dependence on ship antenna height and wave height. Generally, the larger radar systems are generally on larger ships and are higher, so the clutter ring is larger.
– Sea waves can shadow a vessel at all ranges, because the vessel can be detected only when it is on the crest of a wave and it will be masked and undetectable when in a trough.
– Heavy clouds up to sea surface known as super cells, rainfall and other precipitation such as snow, etc. reduce detecting range in two ways. First, rain attenuates the radar pulses just as fog does. Second, rain produces clutter like waves, although the details are different. When rain surrounds the target, clutter is invariably the dominant factor rather than attenuation. Thus, since the clutter return is proportional to the amount of rain and the rainfall rate in the volume of space covered by the beam, and the beam fans out with range, there is always a rain-clutter-limited-detecting-range that depends only on the rainfall rate and target of Radar Cross Section (RCS). Beyond this limit, the target will not be detected. Closer than this limit target may be detected if range and attenuation don't prohibit it. Therefore, the key concept is that detecting is possible only at ranges shorter than the rain-clutter limited detecting range, which depends only on the rate of rainfall.
As a conclusion it can be said that rain surrounding a vessel establishes a rain-clutter ring that depends only on rainfall rate and target radar cross section. Detecting is not possible outside the rain-clutter limit ring. Inside the ring detecting depends on attenuation due to fog or rain and on scanner power. At this point, in heavier rain surrounding the targeted ship possibly it will be detected with difficulties or will probably preclude detecting.
In the following context and in the next chapters of this thesis will be introduced how new proposed radio and satellite tracking systems can provide more reliable detecting of ships sailing in extremely bad and various weather conditions including pirated ships(Sonnenberg 1988; Imagery and Agency 1994; Monahan 2003).

4.1.6. Anti Piracy Radar Detecting

To prevent attach of merchant ship by pirates in the area of their operation is necessary to detect their small boats and avoid their attack. This stage will be explained possibility to employ very sensitive surveillance radars onboard ships that can be attacked.
The Sea-Hawk radar is very sensitive to display even a small echo coming from boats at speed of about 14 knots suspected as pirates. In this case, the captain of the ship has to alter his course steering towards this target.

Figure 4.10. Pirates in Action– Courtesy of Brochure: by Anti Piracy Radar

While closing in on the unidentified vessel towards ship observer, the ship captain realizes that the echo keeps changing its course, seemingly trying to approach his ship from astern. Immediately after, captain of the ship has to alter course and to keep steering towards this target. If captain consider this as a suspicious approach he has to pick up binoculars when is coming closer and see an approaching boat containing 6armed persons, see **Figure 4.10.**
Using the Sea Hawk radar captain of ship can detect much easier and earlier the pirates boat and alert a helicopter from a nearby military vessel. The possible threat turns away as they notice the approaching helicopter. In the scenario described above, the Sea-Hawk radar detected these hostile targets at a much longer distance and in greater detail than any other ordinary surveillance radar. In addition, the Sea Hawk radar can have more superior surface detecting for ships employing a polarimetric radar antenna onboard as the best choice. The suspected pirate boat approaching behind of the ship observer is shown in **Figure 4.10**.
Most radar transmits and receives radio waves with a single, horizontal polarization. That is, the direction of the electric field wave crest is aligned along the horizontal axis. Polarimetric radars, on the other hand, transmit and receive both horizontal and vertical polarizations.
Sea-Hawk polarimetric radars are multi polarized, resulting in far more detailed detecting ability than traditional radar systems. Sea-Hawk can detect very small, fast moving objects and would therefore increase anti-piracy capabilities. Anti-piracy detecting is important also in windy conditions. In sea-state 4 or higher, small targets become even more difficult to detect for standard marine radar. Unlike this type of radar, Sea-Hawk still provides detailed and reliable data during wind, storm and rain. It has been verified that polarimetric Sea-Hawk radar is able to detect any thing on the surface at a much longer distance than any standard navigation radar. In fact, the reason for polarimetric radar's superior detecting ability is the combined utilization of different polarizations (horizontal, vertical and circular), while standard navigation radars only utilize horizontal polarization.

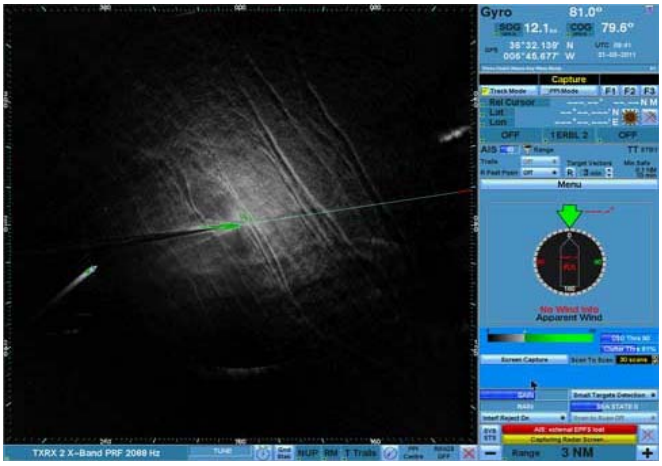

Figure 4.11. Detected Pirates Boat– Courtesy of Brochure: by Anti Piracy Radar

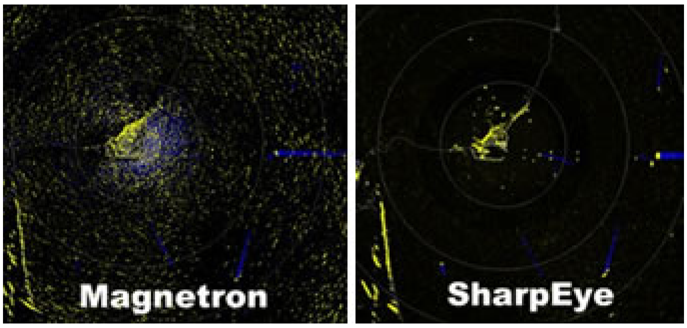

Figure 4.12. Sharp Eye– Courtesy of Brochure: by Eunavfor

Furthermore, this radar is able to process the background clutter from the antenna, and the turbulence and fluctuations naturally produced by the sea. A small target of two square meters is big enough to be visible in the sea. In calm weather a vertical polarized antenna is superior for surface detecting. The surface echoes are significantly stronger in the vertical plane than in the horizontal plane utilized in ordinary X-band radars. Thus, “combo” polarimetric radar is therefore favorable for your anti-piracy system in all weather conditions, from calm to storm.

On the other hand, the BAE British Company has designed special surface radar that can detect even the smallest skiffs on the water’s surface. For instance, this could turn the tide against Somali pirates off the coast of East Africa, Gulf of Aden and off the coast of West Africa. There were 111 reported attacks in 2008 and 42 ships were hijacked. The ships were then held to ransom, so between $30 million and $50 million was paid out. The UK-based Times newspaper said that defense experts believe the number of attacks already be doubled. Ship owners have been seeking ways to protect their vessels, which often carry cargo worth up to $100 million. But until now the existing technology on ships is not advanced enough to detect the small, fast boats favored by pirates. The BAE Company said this month that it had developed surface wave radar that can spot even the smallest skiffs beyond the horizon. The radar has a range of up to 25 Km and a 360-degree arc around the ship. Atmospheric conditions and target shape, material and aspect slightly affect radar range. However, radar range or distance (D) from the antenna scanner to the target horizon in Nautical Miles (NM) is calculated as follows:

$$D = 1.22\ (\sqrt{ha} + ht)[NM]; \tag{4.3}$$

where: h_a = high of radar antenna (scanner) in feet and h_t = high of scanned target in feet. Under normal atmospheric conditions, this distance is 6% greater than the optical horizon. This is because radio waves bend or refract slightly by atmospheric change.

Two years ago Kelvin Hughes Company developed special radar named SharpEye as Radar Performance Improves Pirate Threat Detecting. The value of this radar is being able to detect small vessels approaching in any weather conditions, and automatically identify potentially hostile behavior. SharpEye radar can detect small pirate craft much better than conventional marine radar, shown in **Figure 4.12.** Thick low clouds and rain may provide a hiding place for pirate craft. The careful radar watch should be kept on areas of thick low clouds and rain, adjusting range and rain clutter accordingly. To improve results for detecting of pirated ships would be necessary to use radars with improved detecting characteristics such as previous mentioned radars and SharpEye radar. Thus, such kind of radars as solid state technology is exceptionally effective in detecting small targets, especially in high levels of rain including sea clutter and so can prove a valuable tool in the early detecting of pirates. Furthermore, SharpEye radar can help to take the strain off radar watch keepers by automatically alerting them to craft displaying hostile behavior patterns.

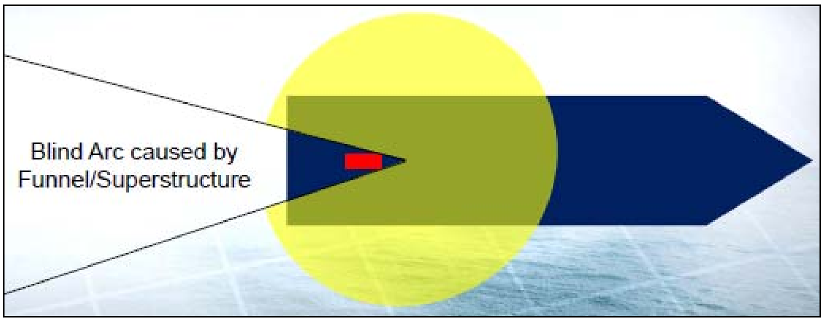

Figure 4.13. Solid State Radar– Courtesy of Brochure: by Piracy Detecting

Pirates typically use boats with very small radar cross-sections and approach their intended victims on a direct track, most often from astern and frequently at night. SharpEye's optional Doppler processing means it can extract targets showing certain velocity characteristics. The detecting process is completely autonomous of the display system and can be used to drive a Manta Digital display's second PPI. All targets meeting the velocity filter characteristics will be displayed, with a warning and alarm if required. SharpEye™ provides better detecting of smaller targets than conventional magnetron radar both because of its improved performance in clutter and by using Doppler processing. These two factors combine to provide SharpEye™ with the best possible threat detecting, approaching that of multi-million-dollar military systems, and give a ship time to take appropriate countermeasures.

Existing radars usually face forward and have a range of only a few kilometers. The problem is that radar has a blind spot because cannot "see" behind, shown in **Figure 4.13.** Otherwise, radar can be linked to software developed for the military, which is capable of analyzing a target behavior to determine whether it is a threat. There is necessary to be developed the system that will prevent attacks if the pirates get close. A number of options are being developed, including a laser that dazzles attackers. The big question is logical, namely, what is going to be when pirates have their hands over the railing and capture ship, putting seamen's lives in danger? To this question will be given replies in the next chapters(Bahar 2007; HUGHES 2014).

4.1.7. Modern Shipborne Surveillance Radars

The revolutionary FAR-28x7 series of X and S-band ship radars are the result of Furuno's 50 years experience in marine electronics and advanced computer technology. This series of equipment is designed to meet the exacting standards of the IMO regulations for ships of 10,000 GT and above.

The display unit employs several sizes of monitors, but the most common is a 23.1" LCD and provides an effective picture diameter of larger than 340 mm. The SXGA Digital Video Interface (DVI) monitor provides crisp radar echoes, which are presented in a selected color with a day or night background color for easy observation in all lighting conditions. Different colors are assigned for marks, symbols and texts for user-friendly operations.

The detecting of targets is enhanced by sophisticated signal processing techniques featuring a superb short range detecting and such as Multi-Level Quantization (MLQ), echo stretch, echo average and radar interference rejecter. Two guard zones can be set at required ranges in any sector. Other ship's movements are assessed by advanced target tracking software and alerted by CPA/TCPA data readouts. This radar provides ARPA and AIS (transponder is required) function as a standard, thereby further enhancing situation awareness of the operators.

A variety of radar antenna is selectable, from 4', 6.5' or 8' radiator. The rotation speed is selectable from 24 rpm for standard radars or 42 rpm for High Speed Craft (HSC). Thus the S-band radar FAR-2837S is also available, which assures target detecting in adverse weather where X-band radars are heavily affected by sea or rain clutter.

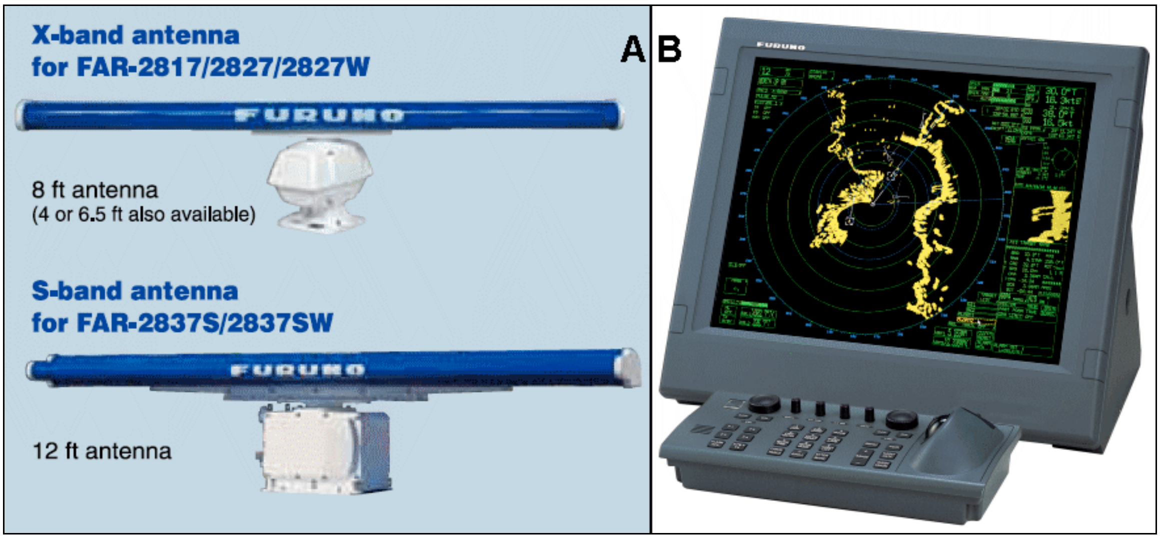

Figure 4.14. FAR-28x7 Series of X and S-band Shipborne Radar – Courtesy of Brochure: by Furuno

The characteristics of two types of radar antennas for Furuno radar FAR-28x7 series of X and S-band are shown in **Figure 4.14 (A),** while the view of LCD display with Full-keyboard Control Unit are shown **Figure 4.14 (B)**.

The radars can be connected to an Ethernet network for a variety of user requirements. Each of X and S-band radars can be interswitched without using an extra option. Up to four radars can be interchanged in the network. The essential navigational information including the electronic chart, Latitude/Longitude L/L, Course Over Ground (COG), Speed Over Ground (SOG), Speed Through the Water (STW) or Log, etc. can be shared in the same network.

Data display is showing a variety of navigational information, such as own ship status, radar plotting data, wind, water temperature and information from other shipborne sensors, which are displayed on the cells. These selected targets are marked with a square symbol on the radar display. Magnify is a special feature of the FAR-28x7 radar series. This looks like a delayed-sweep zoom that the IMO strictly prohibits, but where the Administration accepts, the Magnify feature enlarges part of radar display for some special maritime activity.

The radar Full-keyboard Control Unit is very important part illustrated in **Figure 4.15 (Left).** The control head has logically arranged controls in a combination of push keys and trackball. Well organized menu ensures that all operations can be done by trackball. Palm Control Unit is an alternative to the Full-keyboard Control Unit or additional as a remote operation, shown in **Figure 4.15 (Right).**

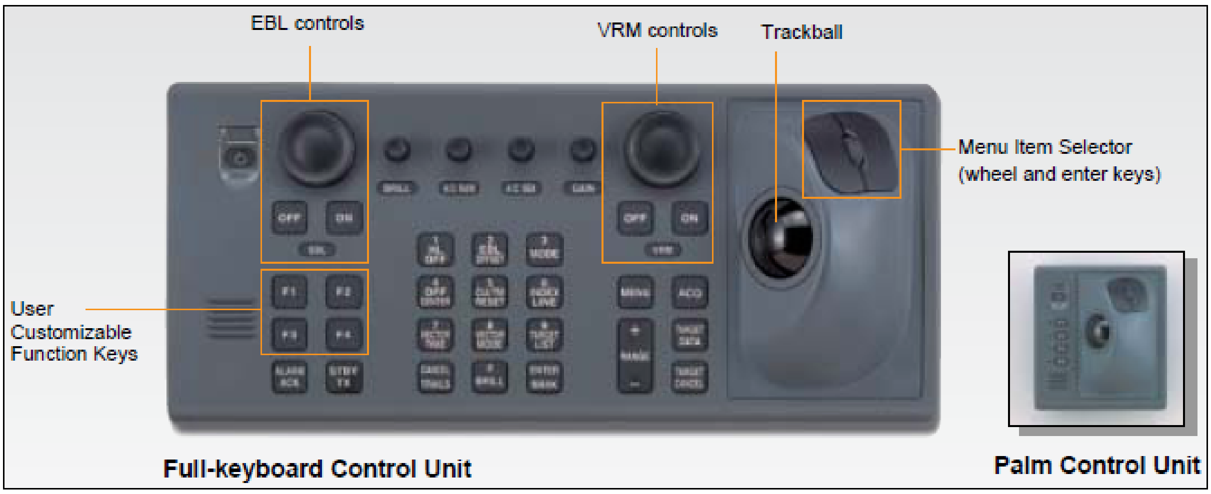

Figure 4.15. Keyboard and Palm Control Unit of Furuno FAR-28x7 Radar – Courtesy of Brochure: by Furuno

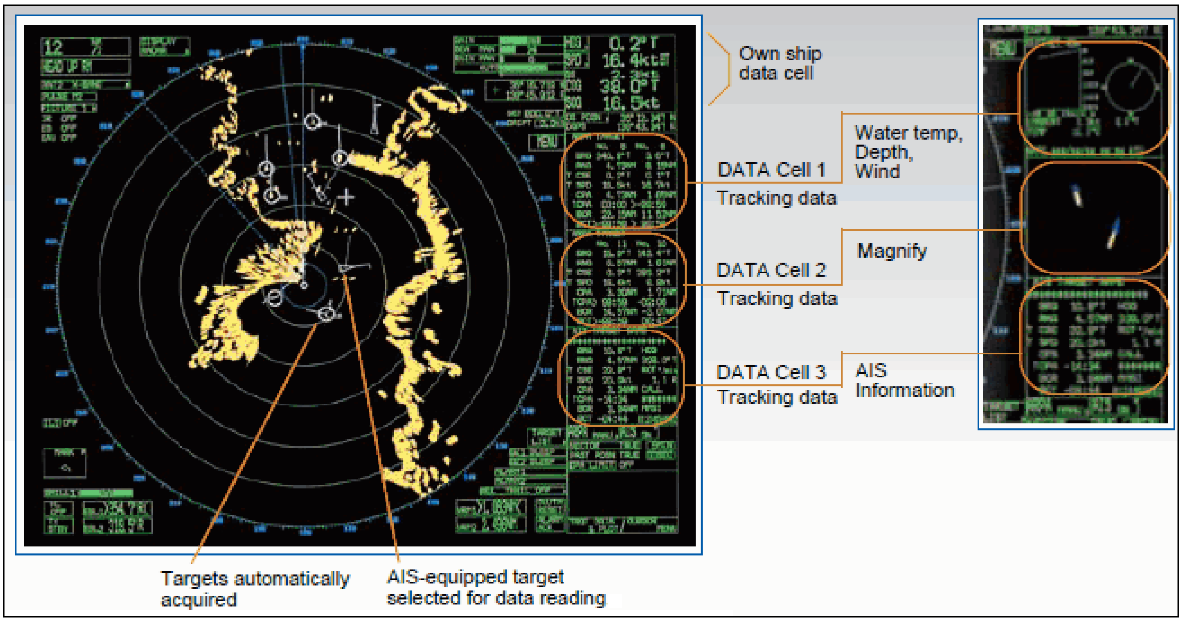

Figure 4.16. ARPA/AIS Target Display of Furuno FAR-28x7 Radar – Courtesy of Brochure: by Furuno

Target association (fusion) is important that an AIS-equipped ship may be displayed by both AIS and ARPA symbols, shown in **Figure 4.16.** This is because the AIS position is measured by GPSin L/L, while the ARPA target blip and data are measured by range and bearing from own ship and located on the radar PPI. When the symbols are within operator-set criteria, the ARPA symbol is merged in the AIS symbol. The criteria are determined by the differences in range, bearing, course, speed, etc. The AIS information can be Static data about important ship particulars of ship, Voyage related data, Dynamic data (ship course, speed, heading and etc) and Short safety-related messages.

Two automatic acquisition zones may be set in a sector or any form on the radar display. They also act as suppression zones, avoiding unnecessary overloading to the processor and clutter by disabling the automatic acquisition and tracking outside them. Targets in an automatic acquisition zone appear as inverse triangle. The operator can manually acquire important targets without restriction. Target tracking symbol changes to a triangle when its predicted course (vector) violates the operator set Closest Point of Approach (CPA) and Time CPA (TCPA) Alarm Zones. The operator can readily change the vector lengths to evaluate target movement trend. Guard Zones generate visual and audible alarms when targets enter the operator set zones. One of Guard Zones may be used as an anchor watch to alert the operator when own ship or targets drift away from the set zone.

The target trails feature generates monotone or gradual shading afterglow on all objects on the display. The shading afterglow paints the radar display just like on an analog PPI. The monotone trails are useful to show own ship movement and other ship tracks in a specific fishing operation. The trail time is adjustable from 15, 30 s, 1, 3, 6, 15, 30 min or continuous. The target trails are indicated with a different color from background. The unique feature in this radar is a choice of True or Relative mode in Relative Motion (only True in TM).

Up to 200 waypoints and up to 30 routes can be stored. Each route may contain up to 30 waypoints. Thus, a radar map is a combination of map lines and marks whereby the user can define and input the navigation area, route planning and monitoring data. The radar map has the capacity of 3,000 points for map lines and marks. The map data can be memorized to facilitate repeated use of a routine navigation area(COMPASS and First 1991; Monahan 2003; Juszkiewicz *et al.* 2013).

This radar incorporates a Video Plotter that allows displaying electronic charts, plot own and other ship's track, enabling entry of waypoints/routes and making a radar map. Radar chart is displayed in combination of radar images (for non-SOLAS ships only).

4.2. Coastal or Ground HF Surveillance Radars

Over the years there have been many systems developed to serve coastal HF surveillance radars, but more known are High Frequency Surface Wave Radars (HFSWR) and Over the Horizon Radars (OTHR). It uses the frequency band of 3-30 MHz to provide a large coverage that could extend to 200NM in range. The primary benefits of the HF band for coastal radar systems are over the horizon capability, sky-wave and ground wave propagation modes and simplified signal generation and processing requirements. A traditional system design for coastal surveillance radar systems include large bistatic HF transmit and receive arrays with a substantial geographic footprint since a wide aperture array is used to provide the resolution needed for detecting surface targets while reducing clutter. Although proven to be effective, the infrastructure requirements of these systems generally render them large, costly and not environmentally friendly and immobile, creating major limitations for wide deployment. On the other hand, the increased emphasis on homeland security applications such as maritime surveillance for enhanced safety at sea, national security and enforcement continues to drive the need for efficient mobile and low cost HFSWR and OTHR systems. In order to meet the demands of homeland security applications while keeping the costs, environmental impact and infrastructure requirements at a minimum, novel integrated HF radar system designs are required(Trizna 2008; ISR 2014).

4.2.1. Coastal ISR HFSWR System

The costal HFSWR and OTHR radars are highly cost-effective remote sensing technology for measuring waves, swell direction and for monitoring the movements and detecting of ships and aircraft at over the horizon ranges including pirate boats. The US Imaging Sciences Research (ISR) company is currently developing a low cost, compact HF Phase Array Radar to measure directional wave spectra along a single radial line offshore, without requiring beam steering. The project of ISR is being funded for this work as a Bureau of Ocean Energy Management by NOAA National Oceanographic Partnership Program (NOPP) participant.
However, bistatic HF radar has been developed for application to ocean current mapping and especially for ship vector tracking. The radar can operate in a multi-frequency mode, so that it can map ocean current vertical shear and can provide more robust ship tracks than single frequency HF radars. This tracking robustness is achieved by avoiding target fading due to echo nulls from frequency and azimuth variations in ship radar cross section that occur using a single radar frequency. The radar is fully digital in frequency generation and reception and has no RF receiver components because the received antenna signals are digitized at the HF frequency directly. The system uses Analogue-to-Digital (A/D) conversion rates sufficiently high to maintain the 2 to 1 frequency ratio required for the highest radar frequency of interest to avoid frequency aliasing. The newly developed radar acquisition code provides real-time range compression, so that data files that are stored in processor are In-phase and Quadrature (I/Q) samples, at a much less dense rate than the original digitized signal time series. Thus, the bistatic capability is based on accurate system timing and radar frequency. These are provided at each of two or more radar sites by rubidium clocks and GPS timing, accurate for the first pulse to 50-ns to initiate data acquisition in the bistatic mode. Once acquisition is initiated, the rubidium clocks at each site maintain much more accurate frequency and time stability to allow Doppler velocity measurements accurate to 2 μHz at 25 MHz operating frequency. The primary site requires an 8 or 16-elementreceives array, and both primary and satellite bistatic-illuminator sites have a modest 2 or 4-element monopole transmit antenna pair. This bistatic approach reduces the coastal space requirements because of the need for just one receive-antenna array per radar system.

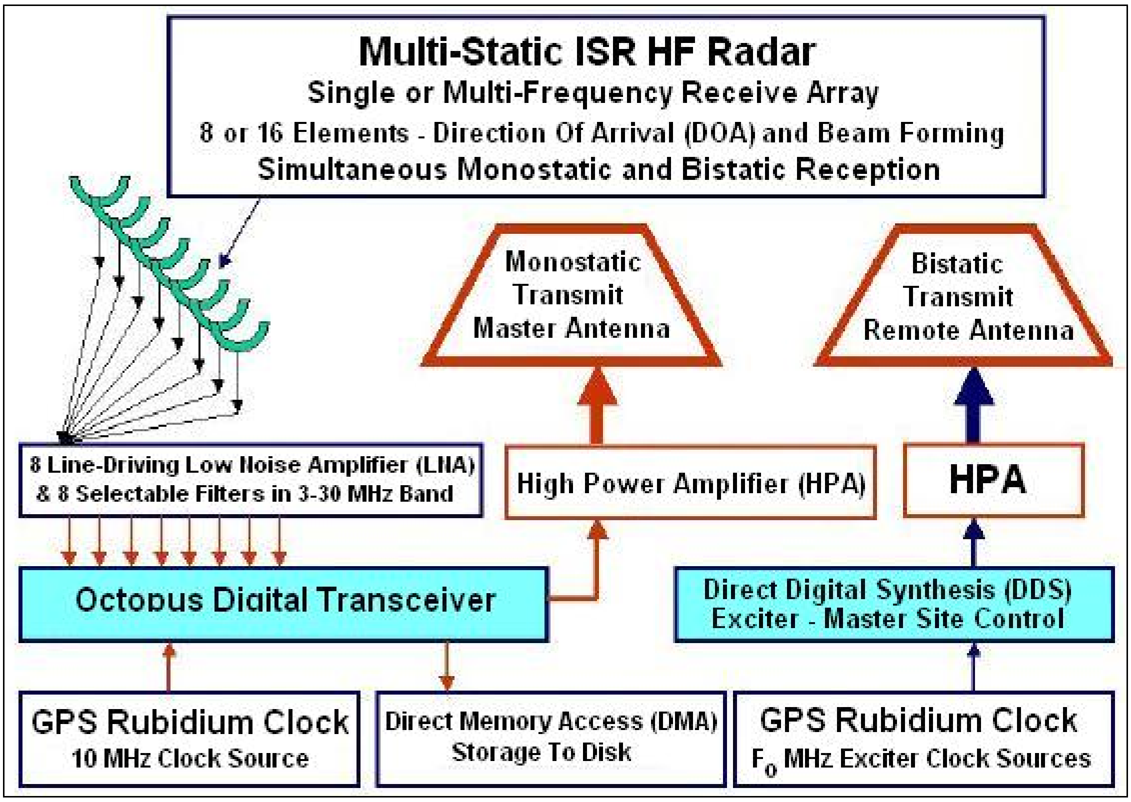

Figure 4.17. System Layout of Typical Bistatic Two-site HF Radar – Courtesy of Brochure: by ISR

These systems can be operated by a pair of bistatic transmitters, either side of the receive site, to expand the spatial coverage. Using such an approach, these units could be staggered to create a system of few radars, providing continuous coverage along a coastline, alternating transmits and receives sites. This type of arrangement could be used to provide robust ship tracking along a country’s coastline, and a modest estimate of the type and tonnage of all vessel traffic based on target echo strength. Due to its digital approach, the cost of these radars is substantially less than that of existing single coastal HF radars, none of which has a multi-frequency capability(ISR 2014).

4.2.1.1.Multi-static ISR HF Radar

The ISR Company has developed a bistatic HF radar for robust ship tracking in coastal seas and ocean current mapping based on purely digital receiver and transmission technology. The bistatic capability represents an upgrade from the previous system, requires the use of accurate system clocks and absolute time referencing in order to operate in a bistatic mode. These are provided by GPS timing and rubidium clocks. Initially, the system was comprehensively tested in the VHF-band and presented some of those results here. The VHF-band allows for shorter range and wider bandwidth usage than can be achieved at HF frequency. The technology transfers directly to HF frequencies, with slower A/D conversion rates required due to lower radar frequencies and corresponding lower Nyquist frequencies, named after engineer Harry Nyquist, as ½ of the sampling rate of a discrete signal processing system.
A layout of the bistatic radar is shown in **Figure 4.17** for a 2-site system, with the master site on the left and a bistatic transmitter shown in the right. The heart of the radar is the Octopus transceiver card, which has both a programmable pulsing capability and 8-receivechannels per card. For a 16-element array, a second Octopus Receiver card provides eight additional channels of receives capability. At the bistatic transmit-only site, an Exciter card is used to generate the pulsed waveforms.

Figure 4.18. Multi Frequency Radar Transmit LPA and Receive LRA– Courtesy of Brochure: by ISR

Typically, the radar is operated with up to a 20% duty cycle pulse compressed waveform, fully programmable by the operator. For long range operation, for example, a 100μs pulse is transmitted (forcing a 15 Km blind area around the area), which is compressed to 10μs, achieving a 20dB pulse compression gain. Thus, this allows a 250 W peak power pulse to be compressed to the equivalent of a 5 KW pulse using frequency-modulated pulse waveforms.
The receive array at the master site receives both monostatic echoes from pulses transmitted at the master site, as well as bistatic echoes from pulses transmitted at the slave site. The pulses can either be interleaved on ping-pong like time sequence, or can be transmitted simultaneously at two different radar frequencies with non-overlapping frequency content. Additionally, one array could use orthogonal phase modulated waveforms simultaneously for optimal use of frequency-time bandwidth. In the case of multi-frequency operation, more complicated antennas at both, transmit and receive end, which must be used to accommodate the desired bandwidth. It is developing a low-cost single frequency system that will use off the shelf antenna components to minimize cost and space requirements.
A multi-frequency system covering the full 3-30 MHz HF band requires wide band antennas and switchable narrow band filters to assure good signal to noise ratios for reliable ship tracking. The long-periodic array is most suitable for such a wide operating bandwidth. Operation over a smaller fraction of the HF band, as might be required for long range application in order to minimize radar propagation losses in the surface wave mode, might require only a 3-10 MHz bandwidth, for example. One can achieve this by using transmit antennas in a short two or four elements transmit array, with trap antennas or multi-mode elements with several resonances that have low reflection and good standing wave ratios at several frequencies in the desired band. For receiving antennas for multi-frequency radar, loop antennas provide good bandwidth and some directivity to minimize reception of the transmitted pulse.
A new transmit radar antenna was designed for broad band operation over the entire 3-30 MHz band, a modified Log Periodic Antenna (LPA), many of which are shown in **Figure 4.18.**However, more compact designs are feasible for operation at pre-specified selected frequencies of four or eight in number, say for operational current shear maps. The LPA antenna provides full tunability to any frequency in the HF band, and is suggested for target classification applications, such as small and large ships or current shear experiments.
The receive Loop Receive Array (LRA) antenna is based on a loop design, three of which are shown in **Figure 4.18.** The ISR internal broad preamplifiers provide impedance matching to the loop over the 3-30 MHz filtered output. These elements can be arranged for Direction-of-Arrival (DOA) processing. A small 4-element loop array requires less space than long linear arrays, and is useful for current mapping and ship classification, but could not be used for measurement of directional wave spectra. For this latter application, long arrays of between 8 and 32 elements, in groups of 8, can be built using an Octopus transceiver, supported by up to three OctRec cards, all of which are time-locked to the master clock on the Octopus card(Anderson, SJ 2013; ISR 2014).

4.2.1.2.Components of HF Radar

The DOA processing is a monostatic model, which typically has 4-elements designed for space-limited applications where large receive arrays could not be deployed. This system contains transmit antenna 4-element monopole array with side lobe control and landward null, receive antenna beam forming array of 4-elements, receive element single frequency system (resonant monopole), radar receiver Quadrapus, radar Pre-Amplifier Filter (PAF) box with 4–channel pre-amplifier (configurable with up to 8 narrow bandor broad band filters for each channel if multi-frequency option is desired), multi-frequency option wideband transmit antenna and loop receive antennas for 3-30 MHz range.
The Phased Array of Multi-static HF Radar contains transmit antenna 2-element monopole array, receive antenna beam formed by 8-elements array of, receive element with single frequency system (reduced-size loop), radar receiver Octopus and 8-channel radar PAF box.
Bistatic DOA model is 2 or 3 site bistatic radar where all signal reception and processing is done at the master site, with remote sites used for transmission only. Unambiguous target tracks and vector velocities are determined at the master site, using echoes received, the master monostatic transmission and one or two bistatic signal echoes from the radar remote sites. Control of the remote sites is achieved by radionetworking protocol and remote PC control. It contains transmit antenna 4-element monopole array with side lobe control and landward null, receive antenna beam forming array of 4 elements, receive element single frequency system (resonant monopole), radar receiver ISR Quadrapus, 4–channel PAF box with configurable up to 8 narrow bands or broad band filters for each channel of multi-frequency optionwide band transmit antenna (loop receive antennas for 3-30 MHz range)(Anderson, SJ 2013).

4.2.1.3.Networksof HF Radar

Each of the above models can be configured to operate as part of a multi-static network of radars, as each card has access to Universal Time (UT) on board using a GPS receiver as part of the basic system. Both Differential GPS and RSAS capabilities are available as added options, primarily for other mobile radar applications. Under this networked approach, each radar operates within its own time slot. Thus, two-sited phased array radar would operate using alternate pulse time slots, so as to allow interleaved operation using the same radar frequency. Planned options include using such a pair to receive each other bistatic signal echoes as well, thus mixing monostatic and bistatic operations at both sites. This is useful for target classification and current shear measure, as is described elsewhere on this web site.
Each model also can be configured with a multi-frequency option, requiring loop receive and multi-frequency transmit antenna or also as desired to be configured a system to additional requirements. The system also offers a Rubidium clock option, which provides extremely low phase noise, important for high dynamic range applications, such as sea state monitoring using 2nd-order Doppler echoes or for target (ship) detecting, classification and tracking (Anderson, SJ 2013).

4.2.1.4.Types of HF Radar Transceivers

The Octopus transceiver card family presents a state of the art digital radar capability that forms basis of the system. It utilizes the miniaturization of RF components in the design of new radar capabilities and provides transmit and receive capability on one PCI card. It offers programmable pulse generation capability with 1 to 100 MHz bandwidth programmability, and eight digital receiver channels using 8-bit A/D converters for the receiver section for the first step of acquisition, followed by additional on-board processing that increases the dynamic range of the recorded signal.

The single Octopus transceiver supports an 8-element receive array and can be used with up to three additional OctalRec receiver cards to increase the receive aperture to as many as 32 elements. Receiver output data are two byte words, achieved by either repetitive pulse averaging or digital down conversion I/Q data generation. In the case of averaging, up to 256 consecutive echoes can be averaged, providing 2-byte output real data. For Digital Down Converter (DDC) processing, the gain is the ratio of 95 MHz divided by the desired output rate (~ pulse bandwidth). For an 8-ms pulse, 125 KHz bandwidth, a gain of 95/.125=760 is achieved, with I/Q pairs generated and stored at 4-bytes output format. On-board averaging is also available to more fully utilize the 4- byte output word size.
The waveform generation capability ranges from a few KHz to 100 MHz, with user-defined programmable pulse envelope control, in addition to ISR provided cosine-squared, square wave, and triangle envelopes. The signals are generated using Direct Digital Synthesizer chips with a square waveform, fed to a mixer with a user-defined pulse envelope, resulting in a pulse waveform with RF spectrum characteristics that will satisfy HF-band requirements.
Software graphical-user-interface is provided that allows the user to program the transceiver according to the desired specifications for the application at hand, stores the parameter file for future use, and then executes the acquisition. The program can be run on a periodic basis using a task scheduler for continuous data collection.
The Octopus card currently operates under Microsoft Windows and Linux platforms and the Octopus transceiver fits in standard full-sized Peripheral Component Interconnect (PCI) slot (full height and length card) utilizing components of PLX Technology with a PCI9054 chip to communicate with PCI bus.
The Quadrapus transceiver is 4-channel version of the Octopus, designed for use with DOA Radar or four (fewer) receive antennas with other identical characteristics to the Octopus.
The OctRec receiver card is basically the same design as the Octopus without the transmitter capability. It is designed for use in larger phased array radars where 16 to 32 elements. One or more OctRec receiver cards are then used in tandem with an Octopus transceiver, which generates master A/D timing for the OctalRec cards. In the future, it will be offering other passive sensing systems based on the OctalRec digital receiver. The QuadRec receiver card is basically a Quadrapus card without the transmitter capabilities.

4.2.2. Ship Classification using Multi-Frequency HF Radar

The ability to operate multi-frequency HF radar allows one to classify ships and small boats. One makes use of the radar frequency dependence of the echo strength or Radar Cross Section (RCS) of individual ships. This occurs because for vertical polarization at HF frequencies, the echo strength is typically dominated by vertical structures of the order of a quarter radar wavelength, such as masts, antennas and stowed fishing lines, so in the case of large ships, the bow and stern vertical rise from the water. Use of the 3-30 MHz range encompasses quarter wavelength ranges between 2.5 to 25 meters in height.
The additional use of bistatic illumination, where a second (or more) transmitter is placed a few tens of miles from the receiver site, either on land or on an offshore platform and ship at sea, allows and additional dimension to the RCS dependence. When two or more vertical structures are illuminated using a bistatic geometry, they can produce RCS maxima and minima that vary with bistatic aspect angle, as well as ship aspect or heading, relative to the receive site. The first figure below shows the radar cross section frequency dependence of an ungrounded vertical mast7.5 meters high. The shape of the region around the maximum is based on a mast width of about 10-cm,and will narrow/broaden with smaller/larger diameter masts. The solid line intersecting the Y-axis at ~37dBm2 represents the locus along which this curve is slid for taller or shorter masts of length one quarter of the radar wavelength.

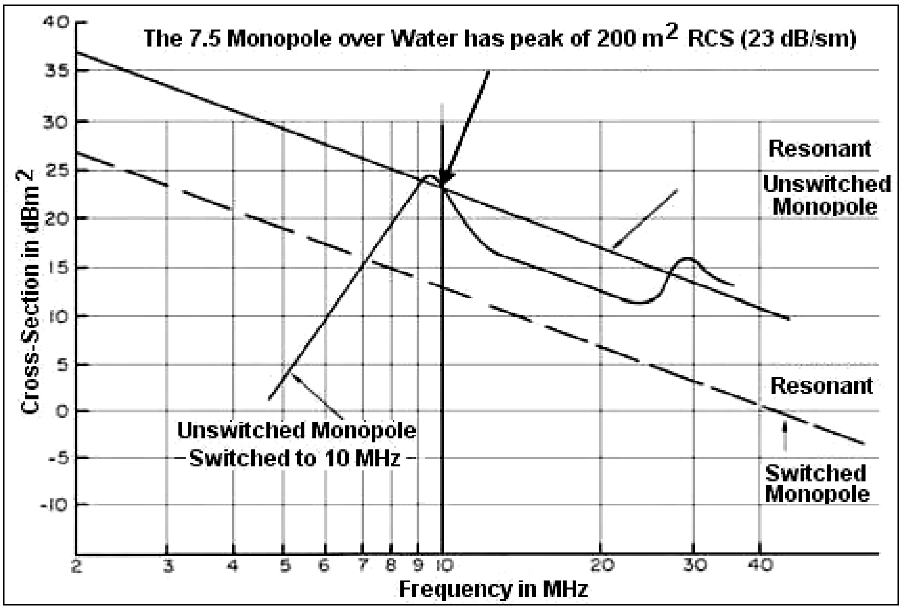

Figure 4.19. Radar Measurements of Small Boats – Courtesy of Brochure: by ISR

More than one mast, or a tall radio antenna and a mast, can be considered as a pair of monopoles of corresponding lengths, and the RCS of the combination is a function of their spacing and aspect relative to the radar transmitter and receiver.

Radar Measurements are using the radar cross section of a small boat, illustrated in **Figure 4.19**and is seen to be well represented by a monopole resonant at 16.6 meters length, plus some additional monopole elements that are responsible for the other peaks.

Radar Modeling is a design in which two masts resonant at 8 and 12 MHz, separated by 7.5 meters was used to calculate the RCS as a function of bistatic angle for a second transmitter. The ships heading is toward the receive antenna. The effects of the changing illumination angle for coherent addition of the scatter from the two monopoles is rather complex, but can be used to classify targets using such models(INTERTANKO 2009; ISR 2014).

4.2.3. Coastal HF Radar Surveillance of Pirate Boats

The deployment of a network of HFSWR systems is a complex task with many factors to be considered, particularly when the radars are expected to perform multiple roles. Failure to treat the sitting problem with appropriate care could seriously degrade performance in one or more radar missions. Here is described a practical technique for HFSWR network design, based to the multi-objective optimization, which has to demonstrate its efficacy in the context of a hypothetical two-radar system deployed in the Strait of Malacca and off Somalia Coast, a major waterway along which many critical surveillance requirements for tracking of pirate boats have been identified. The results confirm that quite disparate criteria can be taken into account with this research approach and that this methodology can be extended to higher and successful dimensions.

4.2.3.1. System Architecture for Anti-Piracy Mission in Strait of Malacca

The HFSWR surveillance network is a highly cost-effective remote sensing technology for measuring waves and currents including monitoring the movements of ships and aircraft, at over-the-horizon ranges. To place this in a specific context, the nominal performance of two representative HFSWR systems, such as Low Cost Civilian Radar and more sophisticated Military Radar are summarized in **Table 4.1.**

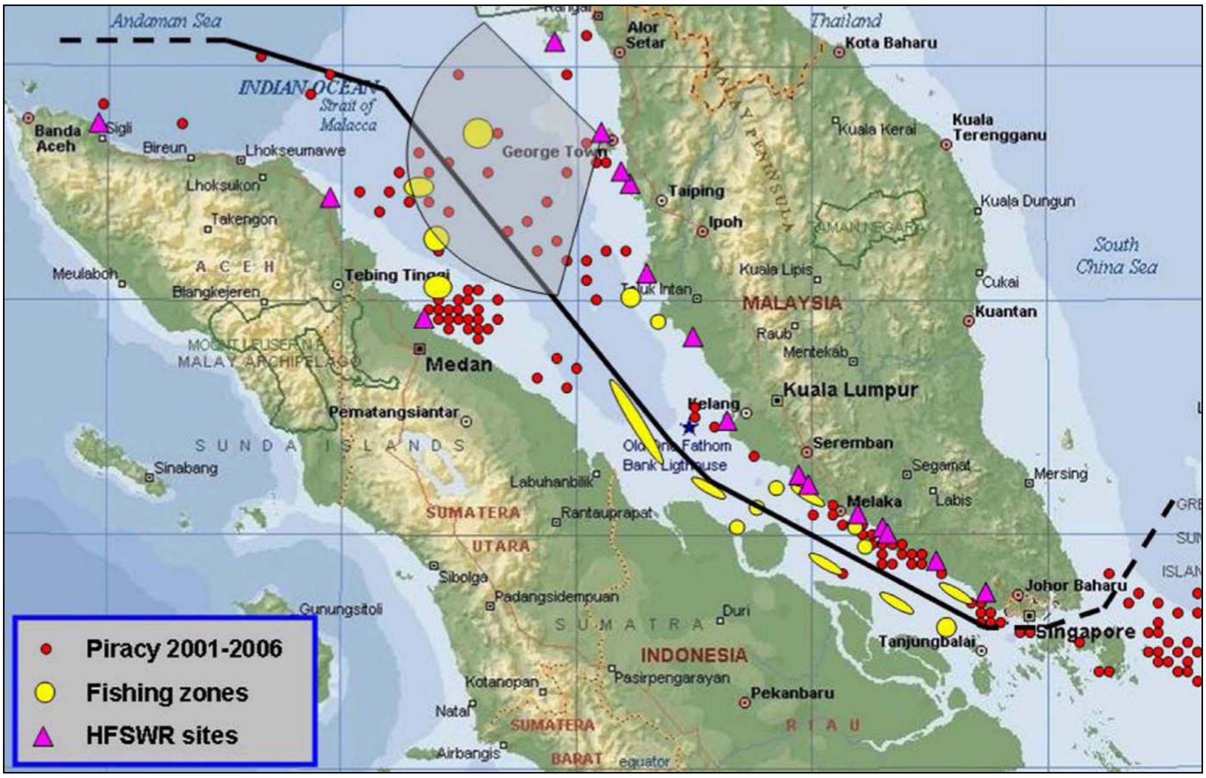

Figure 4.20. Radar HF Surveillance and Remote Sensing of Pirate Ships – Courtesy of Paper: by S.J. Anderson

Table 4.1. Performances of Civilian and Military Systems

Observable	Typical Performance			
	Low-cost Civilian Radar		Military Radar	
	Max, Range (Km)	± Accuracy	Max, Range (Km)	± Accuracy
Surface Current	60 - 200	0.02 - 0.20 m/s	350 - 450	0.02 - 0.10 m/s
Wave Height	30 - 100	10 - 25%	150 - 259	10 - 20%
Wind Direction	50 - 150	30^0 - 60^0	320 - 400	20^0 - 60^0
Wind Speed	30 - 100	20%	200 - 250	20%
Large Ships	50 - 180	0.5 - 3 Km	300 - 450	0.5 - 3 Km
Fishing Boats	20 - 65	0.5 - 2 Km	120 - 280	0.5 - 2 Km
Small Ships	10 - 25	0.5 - 1 Km	70 - 150	0.5 - 1 Km

In above table is presented normal performance of representative HFSWR systems against generic mission. It is noted that coverage and accuracy are dependent on sea conditions, target behavior and other factors, consideration that is indicated here by citing the range within, which each parameter usually lays. In **Figure 4.20** shown the primary shipping channel in the Strait of Malacca, along with the locations of the main fishing zones and the areas with the highest incidence of piracy.
To understand better how is work the system, the prospective coverage of a representative HFSWR system is shown in **Figure 4.20** for hypothetical radar located in George Town on Pulau Pinang Island in the Strait of Malacca. No other sensor technology possesses the same combination of over-the-horizon radar coverage, day–night operation with ability to detect non-cooperating targets, remote sensing of sea conditions, ships and low cost per unit are under surveillance. While some HFSWR systems have been designed and deployed with a single mission in mind, it is increasingly recognized that the versatility of this technology supports a variety of applications.

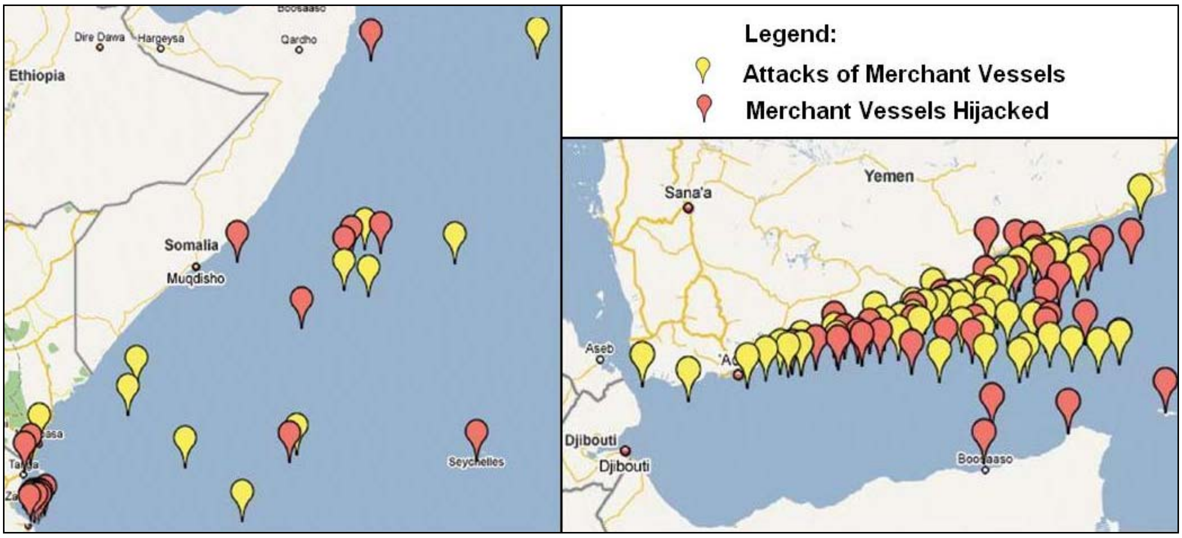

Figure 4.21. Reported Piracy Incidents at Somalia Coast and Gulf of Aden – Courtesy of Booklet: by OCIMF

For instance, one might wish to detect and track shipping and pirate boats in the Strait of Malacca but also to measure surface currents so that risks of collision or grounding can be minimized and any transport of pollution predicted. The most important task of anti piracy mission in the future will be to prevent the piracy activities by deploying additional HFSWR systems in Strait of Malacca and insure more security and safety of ships and crews onboard. Accordingly, one must resort to numerical optimization techniques in a multidimensional parameter space if one is to deploy radar to best advantage. Moreover, single surveillance radar can measure only one component of the instantaneous velocity vector of a moving target. For detecting and tracking of ships and aircraft, observing target motion over time removes this limitation and the full velocity vector can be estimated(INTERTANKO 2009; Mukherjee and Brownrigg 2013; ISR 2014).

4.2.3.2. Deployment of HFSWR for Anti-Piracy Mission of the Somali and Aden Coasts

The navigational dangers of collision and grounding in the area of Somalia and Gulf of Aden are serious problems for a long time. Armed attacks on merchant vessels transiting this area have increased in frequency over the past years. There were 140 approaches and at least 39vessels actually detained by pirates in 2008 by source of The UK Maritime Trade Operations (UKMTO).Such acts have usually been conducted with the use or threat of violence, which can be particularly traumatic for those directly involved, as well as their families.

The Oil Companies International Marine Forum (OCIMF)is a voluntary association of oil companies having an interest in the shipment and terminalling of crude oil and oil products, which mission is to organize with its membership on matters relating to the safe shipment of crude oil and oil products, including marine pollution and safety. The Terminal Operators (SIGTTO) have initiated with the aim of providing practical information to assist seafarers faced with potential or actual acts of piracy operating in Somalia and Aden waters.

In **Figure 21 (Left)** is shown a diagram of the area to the South of the Horn of Africa, which is associated with Somali piracy in 2008 with the events of 9**a**ttacks on merchant vessels, of which 8 were fired at and 10 merchant vessels hijacked.

In **Figure 21 (Right)** is shown diagram in the area Gulf of Aden with the total number of reported 92 incidents by pirate boats. During 2008 in this area pirates organized 60 attacks on merchant vessels, 31 vessels were fired at and 32 merchant vessels hijacked.

This High Risk Area covers the ocean waters where attacks are frequently during past years, so to prevent the actions of pirates in this area have to be deployed minimum two HFSWR installations, one at Somalian coast and another in Gulf of Aden(Mukherjee and Brownrigg 2013).

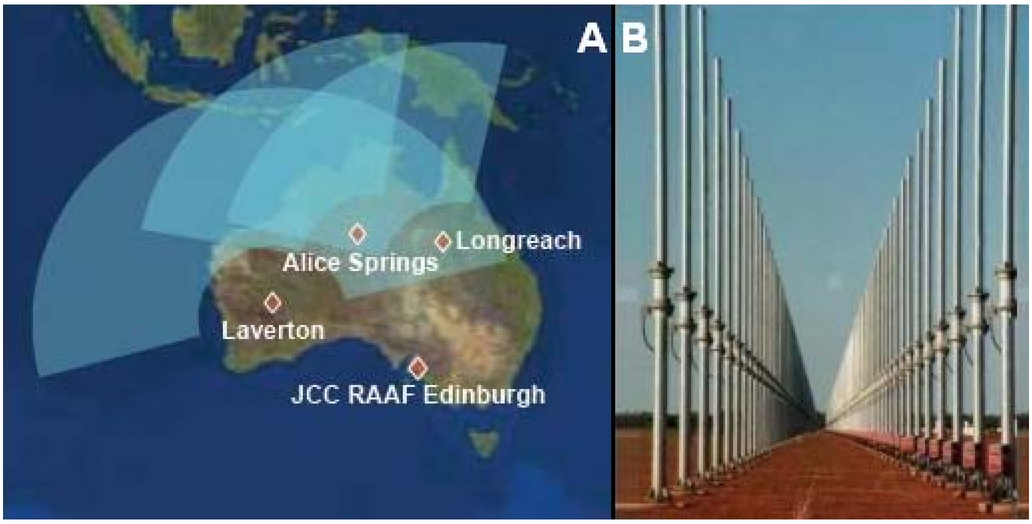

Figure 4.22. Coverage Areas and Receiving Antenna of JORN – Courtesy of Paper: by JORN

4.2.4. Coastal HF Jindalee Operational Radar Network (JORN)

Jindalee was the first such project taken up in the 1960s as bistatic OTHR system controlled from the Jindalee Facility at Alice Spring (JFAS) in central Australia, where two separate transmitter and receiver sites were deployed. The main OTHR transmitter was located at Harts Range and the receiver was located at Mount Everard. However, the other system is an ionospheric sounder known as the Frequency Management System (FMS).

The JORN HF Radar is the OTHR network that can monitor mobile movements at sea and in the air across 37,000 Km^2 and it has an official range of 3,000 Km. It is used in the defense of Australia and can also monitor maritime operations, wave heights and wind directions. On 2 April 2003, Jindalee was joined with two other OTHR systems and formed what is today known as JORN system. These three radars are dispersed across Australia, at Long reach in Queensland, Laverton in Western Australia and Alice Springs in the Northern Territory, to provide surveillance coverage of Australia's Northern approaches, as shown in **Figure 4.22(A).**This figure depicts the locations of the three OTHR systems and the JCC, and highlights the coverage of all three surveillance radars. Of note, the Alice Springs and Long reach radars cover an arc of 90° each, whereas the Laverton OTHR coverage area extends through 180.

Radar data from these three sensors is conveyed to the JORN Coordination Centre (JCC) within the Air Force's No 1 Radar Surveillance Unit (1RSU) at Royal Australian Air Force's(RAAF) Base Edinburgh in South Australia. The 1RSU site is tasked by higher headquarters to operate the JORN capability on a daily basis(Anderson, S 1986).

The OTHR systems operate on the Doppler principle, where an object can be detected if its motion toward or away from the radar is different from the movement of its surroundings. They are typically made up of very large fixed transmitter and receiver antennas called arrays, whish receiving antenna is illustrated in **Figure 4.22(Right).**The location and orientation of these arrays determines the lateral limits or arc of radar's coverage. The extent of OTHR coverage in range within this arc is variable and principally dependent on the state of the ionosphere. The OTHR systems do not continually "sweep" an area like conventional radars but rather "dwell" by focusing the radar's energy on a particular area, referred to as a "tile" within the total area of coverage. The transmitted HF energy can be electronically steered to illuminate other "tiles" within the OTHR networks coverage as required to satisfy operational tasking or in response to intelligence cuing. Disadvantage of this system is that can detect metal vessels, while it is improbable that an OTHR will detect wooden boats. In such a way, the JORN system cannot be used for tracking small wooden boats of pirates.

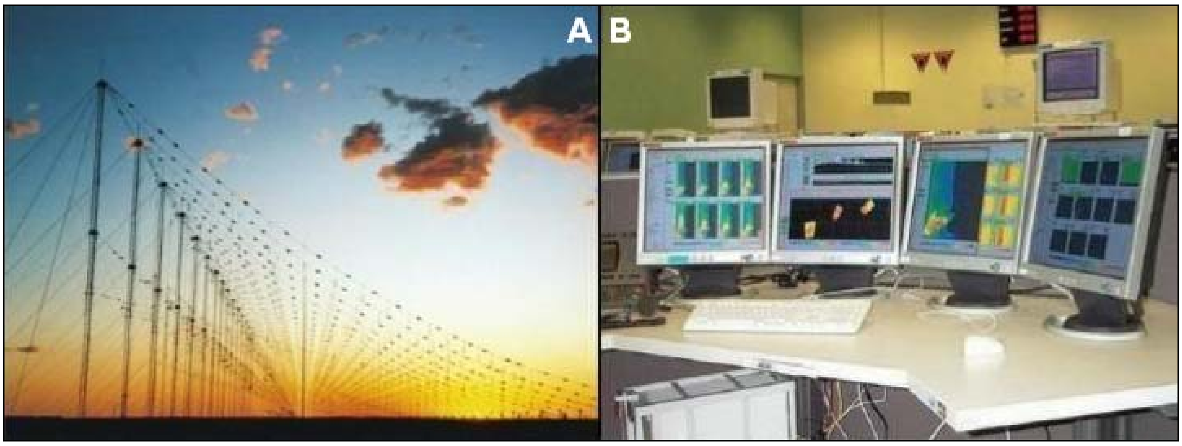

Figure 4.23. JORN Transmit Antenna and Coordination Centre – Courtesy of Paper: by JORN

The combination of these three systems, JORN, can detect all sea and air Doppler moving targets in the area between 1,000 and 3,000 Km North of the radar sites. It is also the key component of the sea-air gap surveillance system in Australia by ensuring a surveillance area with an arc of almost 180° wide and out to 2,000 Km from the Australian coastline. The detailed characteristics of JORN transmit antenna can be found in **Figures 4.23 (A),** which shows the transmission antenna array of JORN near Long reach, in Queensland. **Figure 4.23 (B)** demonstrates an interior view of the JORN Co-ordination center at RAAF Edinburgh, South Australia.

All radar surveillance systems normally have a problem with the bend of the Earth surface. The maximum range of the detecting radars is limited by the radio horizon, which is slightly far away than the optical horizon. The early HF communication systems have made use of ionospheric refraction to obtain spectacularly long ranges for most of the twentieth century. The idea of actually radiating via the ionosphere and detecting the backscatter returning by the same path did not seem credible until coherent processing became practical in the early 1960s. In **Figure 4.24** is presented the key JORN operating principles to transmit signals on HF frequency via ionosphere towards radar coverage and to receive reflected signals(Cameron 1995; JOURN 2010).

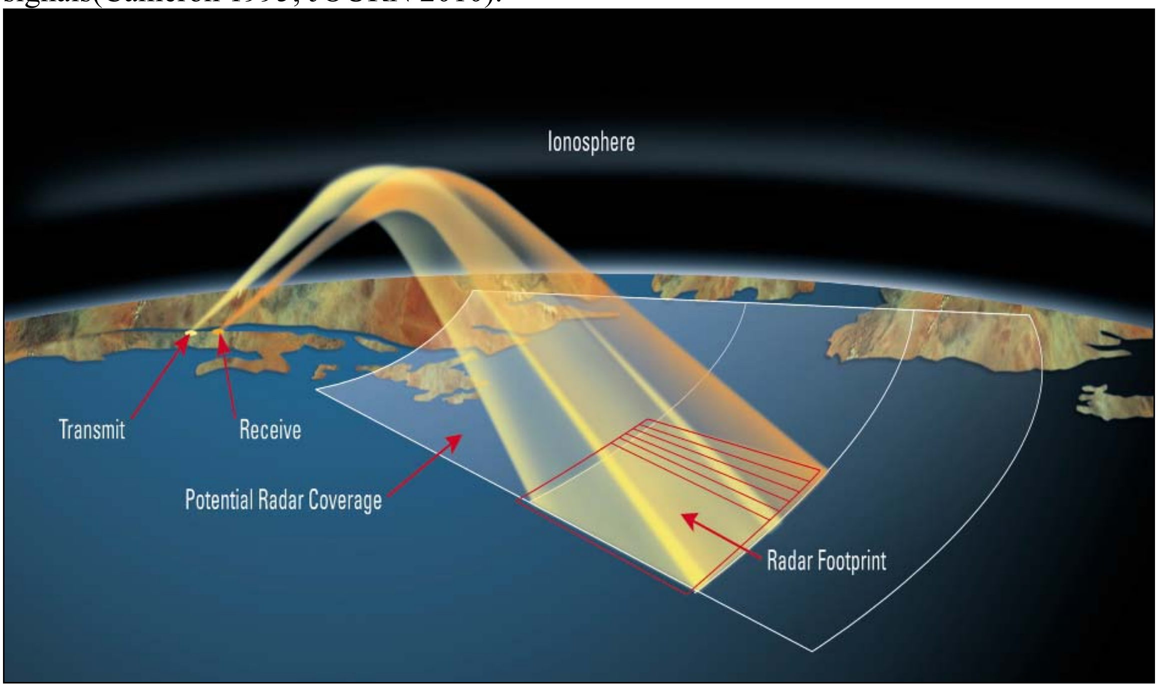

Figure 4.24. Key JORN Operating Principles – Courtesy of Paper: by JORN

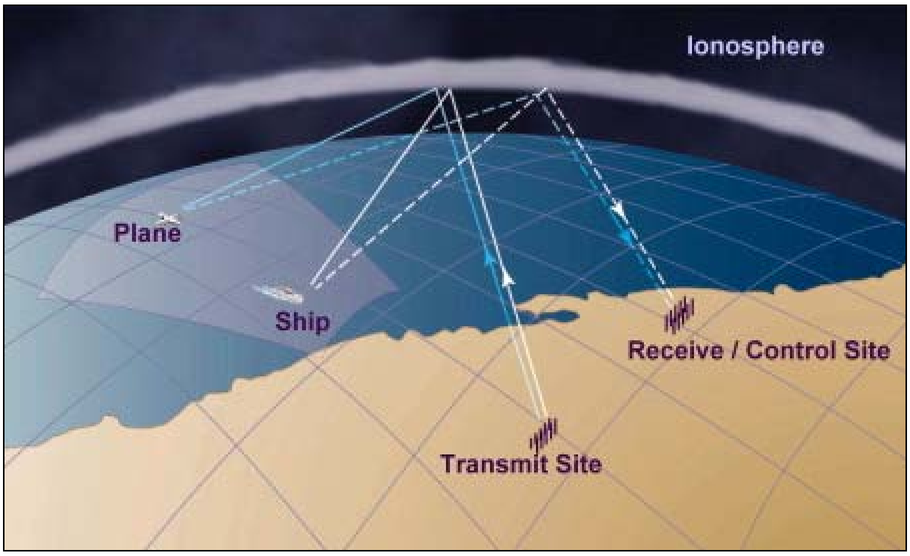

Figure 4.25. Transceiver/Control Sites of HF Radar – Courtesy of Paper: by IARU

The ionosphere is the upper part of the atmosphere extending from 75 to 450 Km above the Earth's surface that consists of particles that have been ionized by solar radiation emitted by the Sun. Thus, the state of the ionosphere depends on the level of solar activity. Other more localized phenomena also affect the stability and/or structure of the ionosphere, which are combination of these phenomena and solar events which determines the quality of ionosphere support for HFSWR or OTHR operations.
Therefore, the ability of JORN remote sensing HF radar is to see beyond the horizon with a range that dwarfed conventional radar made it an invaluable tool for detecting of seagoing ships. The HF Radar is able to send signals via ionosphere towards its radar footprint or to potential radar coverage and receive reflected signals from targets at footprint and from ionosphere. In **Figure 4.25** is illustrated diagram of the International Amateur Radio Union (IARU) that Transmit Site sends the HF signal to the ionosphere and after reflected signal from ionosphere goes to the targets, such as ships and aircraft. In opposite direction HF radar detects signals in Receive Site reflected from both targets via ionosphere, which finally have to be processed in Control Site(Wheadon *et al.* 1994; COUNCIL 2010).

4.2.5. Different Projects of Coastal HF Radars for Vessels Detecting

The HF surface wave radars have been identified to be a gap-filling technology for maritime domain awareness as a key factor in coastal activities for detecting and tracking of vessels in deep sea and coastal navigation, for enhanced safety and security, improved national security (terrorism, drug smuggling, etc.) and environmental sea protection (marine protected areas, fishery monitoring and regulation, oil spills, etc.). Therefore, the HF surveillance radar is a strong candidate to become a component of any large sea area for vessel-monitoring network. This research realized several design options for an HF radar and ship monitoring system, such as multiple or a single frequency, multiple or single sites or method of target bearing determination, such as Multiple Signal Classification (MUSIC) or real aperture antenna. Also, it presents a model of the SNR for ship detecting by HF radar and as well as observational examples of ship detecting with single and multifrequency HF radars. Finally, it suggests future experiments about tracking of pirate ships and draws conclusions. The further discussion has to estimate the primary metrics for assessing performance for ship tracking radars with Probabilities of detecting (Pd) and false alarm (Pfa) including their variation with parameters such as range, azimuth and frequency, and number of observing modes.

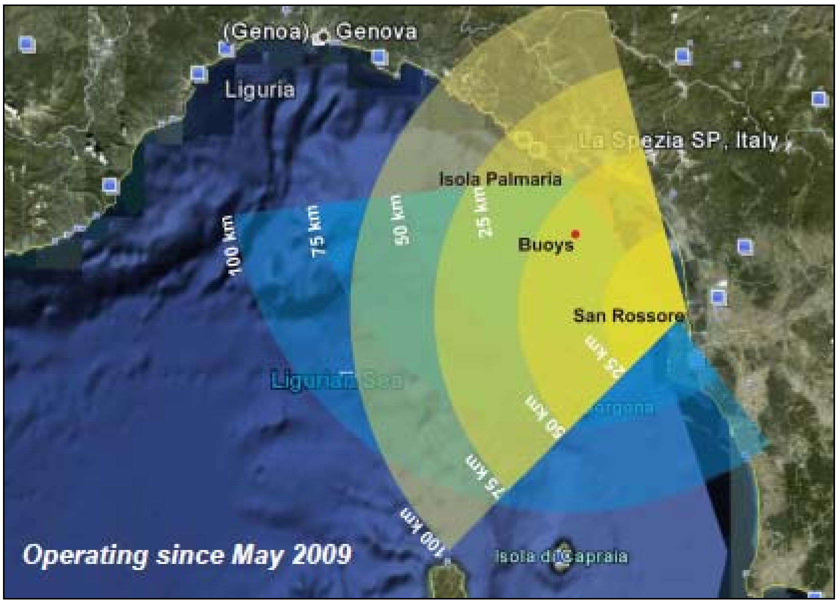

Figure 4.26. Wellen Radar in Ligurian Sea – Courtesy of Paper: by NURC

There are many different projects of Coastal HF Radars for detecting and tracking seagoing ships such, but here will be introduced the network coverages of the German Wellen Radar (WERA) and the US Sea Sonde.

1. WERA HF Radar – This type of HF coastal surveillance radar is employed in May 2009 in international project known as "NURC BP09 Experiment" by the NATO Research Centre(NURC) of La Spezia, Italy, Department of Information Engineering, University of Pisa, Italy and Institute of Oceanography, University of Hamburg, Germany. The NURC effective

maritime situational awareness project deployed a Maritime Surveillance System (MSS) that includes vessel ground truth and contact simulation, sensor processing, data fusion, anomaly detecting, sensor management and performance evaluation. Two WERA systems operating at 12.5 MHz have been installed at the Italian coast for experimental and evaluation purpose.

In **Figure 4.26** is illustrated map depicting the HF setup in the Ligurian Sea near La Spezia town in Italy. The red dot shows the location of a Meteo and a wave rider buoy, which were deployed for validation purposes. The Ligurian Sea setup is depicted showing the overlap area in which the current and wave retrieval is performed as well as the range(Essen *et al.* 2000). The WERA HF radar system transmits an average power of 30 W but it achieves detecting ranges up to 200 Km, which are far beyond the conventional microwave radar coverage. Due to external noise, radio frequency interference and different kinds of clutter, special techniques of target detecting such as ships using the WERA system have to be applied. For a 12-hour period HF radar data have been recorded and processed. Thus, the target locations detected by the HF radar using the proposed adaptive technique are passed to a tracking filter to track the ship position. In order to estimate the performance of the radar detecting and tracking techniques, these ship locations are compared with the ship positions recorded by the VHF AIS. The WERA network was developed at the German University of Hamburgin 1996 to allow a wide range of working frequencies, spatial resolution and antenna configurations in order too pirate as low power oceanographic radar providing simultaneous wide area measurements of surface currents, ocean waves, wind parameters and detecting of ships. Otherwise, this HF Radar system is based on a modular design that can be easily adopted to the requirements of an actual application(Gurgel *et al.* 2001; Horstmann *et al.* 2010).

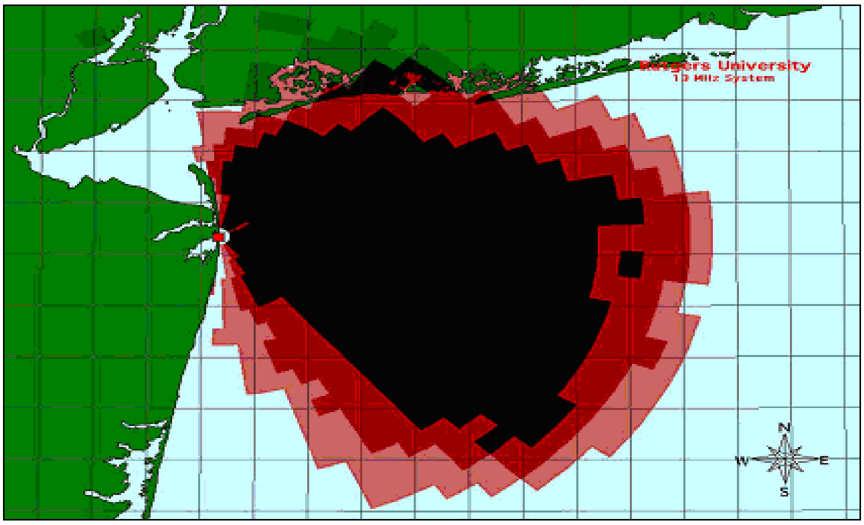

Figure 4.27. Sea Sonde Radial Coverage Map – Courtesy of Paper: by CODAR

2. Sea Sonde HF Radar – Present Sea Sonde HF radars have been designed to map surface currents, but are able to track surface vessels in a dual-use mode(Hodgins 1994). The US Rutgers University in New Jersey and CODAR Ocean Sensors from Mountain in California, have collaborated on the development of vessel detecting and tracking capabilities from the compact HF radars, demonstrating that ships can be detected and tracked by multistatic HF radar in a multiship environment while simultaneously mapping ocean currents. Furthermore, the same vessel is seen simultaneously by the radar based on different processing parameters, mitigating the need to preselect a fixed set and thereby improving detecting performance. The radar was deployed in Sea Bright, New Jersey, 40Km south of the Battery in New York City. It was a direction-finding type radar, Sea Sonde Remote Unit code SSRS-100, manufactured by CODAR Ocean Sensors and was installed in October2008. The radar's primary function was the measurement of surface currents, which are provided in real time to the NOAA National HF Radar Network. The radar also has the dual-use capability to detect the location of ships at sea. In **Figure 4.27**isshows the spatial and temporal radial vector coverage for ocean currents of the radar over a 1-weekperiod, which coincided with the ship detecting exercise. Thus, radial coverage map is presented in an area of the Sea Sonde at Sea Bright, New Jersey, over a 1-week period. The color map illustrates the temporal coverage along the radial grid (black = 75%, red = 50% and pink = 25%). The radar collected range data, which are a time series of the complex echo signal voltages before Doppler processing. These range files are the result of the first Fast Fourier Transform (FFT) of the frequency-modulated continuous wave received signal. The range data were collected using an FFT length of 512 points. With a2-Hz sweep of the radar, each range file encompasses 256 sec of coherent integration time. There were a total of15 range files over the hour-long period. However, the time on the computer and all the subsequent files it generates are synchronized to atomic time via GPS by the Macintosh operating system. The Sea Sonde HF radar consists of a compact receive antenna with three elements, such as two directional crossed loops and an omnidirectional monopole, a monopole transmit antenna and a hardware housed within a climate-controlled enclosure. The radar transmits a radio wave with a center frequency of 13.46 MHz and a bandwidth of50 kHz. The bandwidth of the radar sets the spatial range resolution of the system, which was about 3 Km for this particular bandwidth. Separate transmit and receive radar antennas were used for this study spaced at least one a wavelength apart, which is approximately23 m at the 13MHz radio band. A ship with a vertical structure of a quarter wavelengths (6 m) is the minimum-sized optimal reflector(Whitehouse and Hutt 2003; Roarty *et al.* 2011).

4.3. Radio Multiband and Multifunctional Radio Direction Finders (RDF)

A Radio Direction Finder (RDF) is a navigation device for finding the direction to a fixed or recently mobile radio source known as bearings including personal detecting. Due to low frequency propagation characteristic to travel very long distances and “over the horizon”, it makes a particularly good navigation system for ships, small boats and aircraft that might be some distance from their destination. The operating procedure for determining the bearing of radio signals at a receiving point of the source can be realized by observing the direction of arrival of the wave front.

The RDF unit consists of an antenna-feeder system, which is used to receive the radio waves propagating from the object on which a bearing is being taken and detected on a receiving indicator. Thus, the Direction Finding (DF) refers to the establishment of the direction from which received signal was transmitted. This can refer to radio or other forms of wireless communication. By combining the direction information from two or more suitably spaced receivers (or a single mobile receiver), the source of a transmission may be located in space via triangulation. Radio direction finding is used in the navigation of ships and aircraft, to locate emergency transmitters for search and rescue, for tracking wild life, and to locate illegal or interfering transmitters.

Alternating electromotive forces are induced in the antenna-feeder system by the received waves, and depending on the method employed, the amplitudes of the induced signals may become pared or the phase differences may be measured. This provides information regarding the angles between the direction to the object and given reference planes. In the universal (two-coordinate) RDF systems, both angles that determine the bearing are measured. In the azimuthal RDF type, only one of the angles (the azimuth) is obtained, and in such a way this method is employed in maritime navigation.

Depending on the extent to which the measurements are or not automated and the method of indicating the bearing, the following types of RDF are recognized:

1. Nonautomatic (aural) type, with indications for the minimum or maximum audibility of the signals from the object;
2. Semiautomatic (visual) type, with a pointer indicator or an oscilloscope display; and
3. Automatic type as a modern method, with a digital readout of the measured parameters.

The radio DF system with two direction finders separated by a sufficiently great distance (such that the radio bearings to the radio source differ by no less than 30°) is capable of determining the position of an object from the intersection of the two bearings. However, it may also employ two or more sources of radio waves, for which bearings may be computed simultaneously or with short intervals between. This makes it possible to determine the position of the object from which the measurements are being made.

The phenomenon of directivity in radio reception, which is a characteristic of most antenna types and which is the basis of the amplitude method of radio direction finding, was noted by Professor A. S. Popov. The invention of the loop antenna led to the development of the first radio direction finders. Later many world scientists have made important contributions to the theoretical and practical development of radio direction finding. The technique is employed extensively in maritime, air, space navigation, in electronic reconnaissance, radio astronomy and meteorology.

In this section will be explained shortly the RDF equipment and systems for ship navigation using the fixed bearings at shore. On the other hand, to achieve a context in correlation with thesis structure, here will be detailed introduced the RDF for detecting of ships, lifeboats, persons, SAR forces in distress or any emergency situation, for tracking wildlife and to locate illegal or interfering transmitters, including captured ships by pirates if some kind of radio beacon is discretely installed onboard.

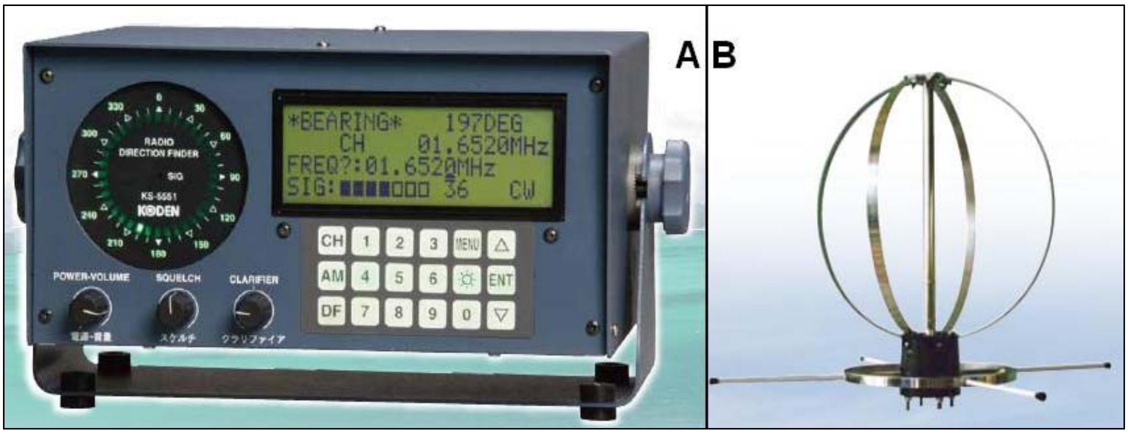

Figure 4.28. Radio MF/HF/VHF DF KS-5551 – Courtesy of Brochure: by Koden

4.3.1. Koden Shipborne Multib and MF/HF/VHF KS-5551 RDF

The Koden KS-5551 RDF is an omni-directional automatic DF with intermediate wave 1 to 8 band and frequencies of 1 to 54 MHz band providing high accuracy coverage from 50 miles for MF/VHF and minimum 150 miles for HF-band. It provides digital and analogue bearings to a radio transmission and loudspeaker is also included, shown in **Figure 4.28 (A).**Up to 100 channels memory for spot reception are helpful and users are free from repeating input operation of spot channels. Thus, measuring receiving frequency range is the same as stated receiving band. It consists of a 600mm diameter light weight loop antenna with 15m of cable and power rectifier, shown in **Figure 4.28 (B).** Its bearing display panel uses brilliant Light Emitting Diode (LED) for high visibility. The 3 digit numerical unit display on the liquid crystal panel indicates bearing by one degree step. The LED lamps arranged in a circular pattern by 10 degree step provide visual indication of bearing. This equipment has comfortable operability with rotary knobs for fine adjustment, numerical keypad for number input and dedicated keys for functional setting. True heading can be input via National Marine Electronics Association (NMEA) to allow the KS-5551 device to display true bearings to transmissions, so at this point the heading data can also be output on NMEA(ELECTRONICS 2014).

4.3.2. Taiyo Shipborne VHF TD-L1630RDF

When, in 2002, the International Conference on Maritime Security concluded and decided with the implementation of AIS, it seemed as though the combination of GPS and AIS would offer total reliability for the assignment of a ship's position in Vessel Traffic Service (VTS) area. However, this is frequently turning out not to be the case. Therefore, AIS is certainly an appropriate means of conveying a large and varied amount of information about shipping movements to all users onshore, but during navigation master mariners need very precisely aids in determining the ship's location at a certain point in time. This study reports on a solution to this that involves the aid of a radio direction finder and other radio and satellite systems to provide some more reliable solutions for ships collision avoidance and tracking systems.

The VHF shipborne RDF is of inestimable value for making shipping lanes safer, especially when monitoring vessels representing a particularly high risk. It provides precise directional information about the origin of the VHF transmission at the time of the enquiry. The RDF unit offers additional assistance when putting pilots aboard via helicopter. In this case the helicopter can be guided with the aid of a land-based VHF direction finder to the ship lying in the roads, which is of great assistance particularly in poor visibility.

Figure 4.29. Radio VHF DF TD-L1630– Courtesy of Brochure: by Taiyo

The VHF automatic digital RDF TD-L1630 has a user convenient operation panel with single purpose switches that are applied for function keys, illustrated in **Figure 4.29 (A).** It has a frequency range of 110 to 170 MHz in 5 kHz step with one-touch reception of 121.5 MHz distress frequency and CH16 (156.8 MHz) by individual push button and it also provides output port for NMEA 0183 bearing data. This unit is provided with computer-controlled synthesizer with a triple super-heterodyne circuit provides high sensitivity, accuracy and stability. The unit is suitable for stand-by reception and a new tracking technique is adopted to give a high stability, even receiving a weak signal with low S/N ratio. The holding function is provided to maintain the last bearing data while receiving no signal. The bearing data is updated when receiving new signal regardless the holding function is on or off.

This is an automatic RDF, designed for reception and direction measurement of radio waves in International VHF-band and the US weather channels or Scandinavian fishing channels including SAR distress frequency 121.5 MHz and it has the following major features:

- Manual, spot and scan reception are selectable and all operations are commanded by the keyboard layout on its front panel;
- The channel number with the type of station, ship and coast or weather can be stored in 100addresses with two digit number, named Address No, from 00 to 99;
- The direction of incoming radio signal with respect to bow direction of own ship is simply indicated with 2 types, a linear indicator for quick recognition and a numeric display;
- H type Adcock antenna allows precise direction measurement with high sensitivity; and
- As a power source, 10V - 16V DC is provided and a suitable adapter is available for AC power source on option.

When finding a radio transmitter for location purposes, it is important to use an antenna that permits good all-round reception. The 4-element AdcockA6243H4 antenna for civil aviation and maritime VHF radio was designed with special attention given to lightning protection and to installation on light masts in an environment that has a high salt content, which shape is shown in **Figure4.29 (B)**.The choice of the location of the antennas is also extraordinarily important, which has to be installed at the highest point on the mast, away from reflected fields, so that only the signal that spreads out on the direct path between the transmitter and the receiving antenna is tracked. Any residual errors are to be kept stable, so that they can be easily compensated for by computer at the receiver. The shape of the coastline and the topography of the hinterland play a role here, as does the presence of conducting obstacles e.g. antennas, bridges or silos etc. For the direction finding or location of vessels under way, the location of one or more radio direction finding stations in relation to one another and to the primary direction of shipping movements also plays a crucial role. The RDF antenna has been examined that have never suffered a failure, despite years of use in exposed locations and traces of lightning strikes(Gething 1991; TAIYO 2014).

Figure 4.30. Radio VHF DF TD-L1630– Courtesy of Brochure: by Plath

4.3.3. Plath Shipborne VHF/UHF DFP 2400 and DFP 2055RDF

The Plath DFP 2400 is an RDF finder with a large coherent bandwidth of 20 MHz including large dynamic range and high scan-speed and for the frequency range 20 - 3000 MHz, which is shown in **Figure 4.30 (A).**The unit provides 7-channel correlative interferometer principle and parallel processing of all channels and it permits the interception of frequency-stationary and frequency-agile emissions. Due to the correlative interferometer principle this RDF unit is characterized by high bearing accuracy and immunity to interference. The true parallel processing of all channels performs the bearing of short time signals even with very small signal duration below the Fast Fourier Transform(FFT) time resolution. Thanks to large dynamic range, high scan-speed as well as small noise figures the probability of signal detecting is very high. Thus, the selectable FFT resolution from 500 Hz to 32 kHz features the optimal adjustment of the sensor system to the intelligence scenario. Thus, both narrow-band and short time signals can be intercepted.
The Plath DFP 2055 is a consistently high-precision and sensitive digital RDF suitable for the frequency range from 20 MHz to 3 GHz, shown in **Figure 4.30 (B).**Thus, it is designed to bear uplinks data of Inmarsat ground terminals in the L-Band and to be utilized in mobile Inmarsat intelligence systems. The evaluation of the detecting Inmarsat signals will be done on a PC or Laptop, so it can be also traced the suspected ship doing smuggling of narcotics or captured by pirates. Except of bearing of Inmarsat up-link signals this unit is providing high RDF sensitivity and is optimized for mobile applications, especially for ships.
The Plath DFA 2405 VHF/UHF RDF 6-element H-Adcock antenna performs the bearing of short time signals even with very small signal duration below the FFT time resolution, which shape is illustrated in **Figure 4.30 (C).**Thanks to large dynamic range, reliability and high scan-speed as well as small noise figure the probability of signal detecting is very high. This, it has the selectable FFT resolution from 500 Hz to 32 kHz features the optimal adjustment of the sensor system to the intelligence scenario. Thus, both narrow-band and short time signals can be intercepted with very high bearing accuracy and sensitivity(PLATH 2014).

4.3.4. Rhotheta Shipborne and Coastal SAR VHF/UHF 4-band RT-500-M RDF

The RT-500-M is a complete direction finding solution for professional SAR applications at sea. This universal 4-band RDF operates and automatically monitors not only civilian bands at 121.5 MHz andCH16 (156.8 MHz), but also military emergency frequencies at 243 MHz. It can also receive Cospas-Sarsat signals at 406 MHz of maritime Emergency Position Indicating Radio Beacons (EPIRB), land or personal Emergency Personal Locator (PLB) and aeronautical Emergency Locator Transmitter (ELT), provide the bearing of the source and display the content. However, this unit and RhothetaRT-202 Crew Finder can serve as emergency receivers for SAR as Man Over Board (MOB), which monitor international emergency frequency 121.500 MHz and trigger an alarm of distress signals.

Figure 4.31. Radio SAR VHF/UHF 4-band RT-500-M RDF– Courtesy of Brochure: by Rhotheta

The RT-500 is a most professional direction finder for the VHF-marine band, VHF-air band and 406 MHz Cospas-Sarsat emergency beacons for all mobile and personal applications, which Display Control Unit(DCU) is shown in **Figure 4.31 (A).** It is best suits on seagoing rescue, coastguard, guard and other vessels. Thus, a ship gyro or GPS-compass can be NMEA coupled to maintain a true-heading radio bearing all times and an NMEA data radio bearing output is foreseen for presentation in Electronic Chart Display and Information System (ECDIS). It has a dual or tri-watch over all bands fully remote controlled by Ethernet. The bright TFT unit display guarantee a visible reading in sunlight, a display-sleep function avoids dazzling at the bridge at night and clear overview of all direction finder information and operating parameters.
The bearing aerial is a dipole antenna with housing containing all bearing electronics, which Antenna Unit (AU) is shown in **Figure 4.31 (B).**The short bearing signal paths with low loss and also high insensitiveness to external disturbing fields are achieved. The bearing system is working with the Doppler principle by the high scanning frequency of 3 kHz and clockwise and counterclockwise rotation of the antenna to compensate running time errors highest precision of the system is achieved. Various interfaces (LAN, NMEA RS-422, and RS-232 etc) facilitate integration of the direction finder system in legacy or planned system environments. Although the RT-500-M unit was optimized for use in high sea states, same as RT-500 RDF, it is also suitable for stationary Vessel Traffic Service (VTS) applications at shore. In **Table4.2** are presented all frequencies nominated for RT-500-M RDF(Kemmelpark 2011; RHOTHETA 2014).

Table 4.2. Frequency Bands for RT-500-M RDF

Frequency Ranges:		Emergency Frequency:	
VHF air band	118.000 MHz	121.500 MHz	123.975 MHz
VHF marine band	155.000 MHz Channel 00 Ship	156.800 MHz Channel 16	162.995 MHz Channel 88 Coast
UHF militari air band	240.000 MHz	243.000 MHz	245.975 MHz
Cospas-Sarsat	400.000 MHz	406.022 – 406.076 MHz	409.975 MHz

4.3.5. Rhotheta Coastal VHF/UHF 4-band RT-800 RDF

The RT-800 is a radio direction finder for stationary coast surveillance and identification of ships that are transmitting on the VHF radio band. The bearing information from transmitters can be correlated with the corresponding radar target and AIS-position information at an VTS centre. Two or more RT-800 RDF systems on different locations can be used to locate a ship’s exact position by triangulation, which can easily be integrated in a VTS environment.

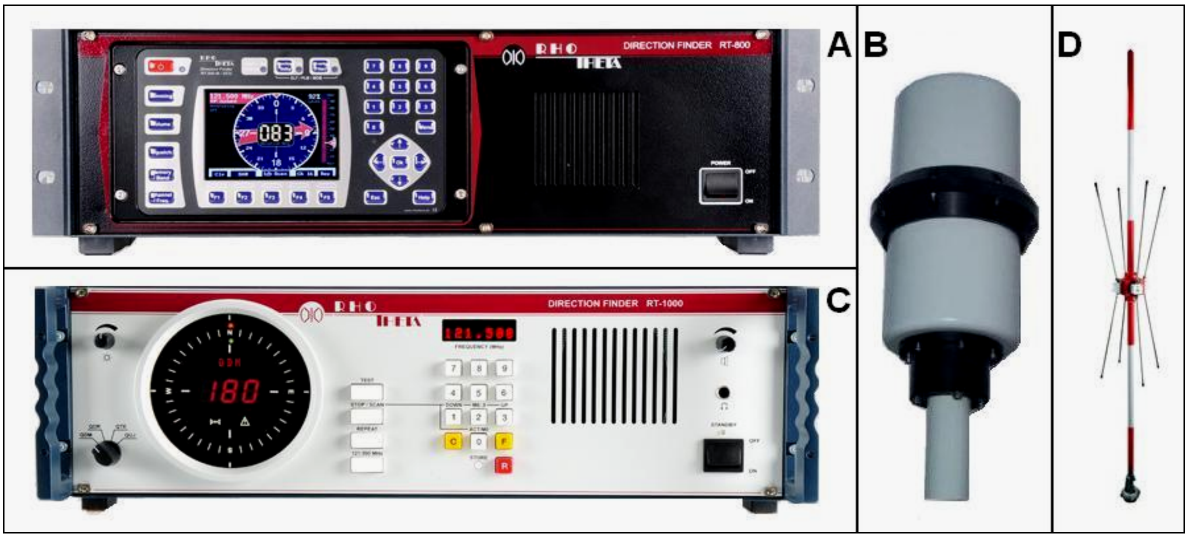

Figure 4.32. Coastal Radio SAR RT-800 and RT-1000 Equipment – Courtesy of Brochure: by Rhotheta

The DF-system RT-800 combines a communication of Radio and an SAR direction finder, thus allowing to bear all coastal and maritime radio stations. In such a way, equipped persons or vessels with EPIRB or PLB may be found quickly and safely.
The RT-800 RDF is shown in **Figure 4.32 (A),** which operates on different four frequency bands presented in **Table 4.2.** It provides decoding of transmissions on all 19 Cospas-Sarsat channels, fast frequency monitoring by scanning of up to 8 frequencies, effective remote operation via RS-232, Ethernet and LAN interfaces. This unit is using and extreme compact, rugged and light-weight DF antenna for easy installation and use in harsh maritime weather conditions, which is illustrated in **Figure 4.32 (B).**
The bearing array is a dipole antenna, which housing contains all bearing electronics. It is watertight (protection IP 67) and may be used under extreme and rough conditions. Thus short bearing signal paths with low loss, but also high insensitiveness to external disturbing fields are achieved. The RDF-system is working with the Doppler principle, and by the high rotation frequency of 3 kHz and clockwise and counterclockwise rotation of the antenna to compensate running time errors, highest precision of the system is achieved. The indicating and operating system represents bearing signals and allows operating and controlling of the bearing antenna. Additionally external devices can be connected(speaker, audio, line out, PTT push to talk and so on). Also data in and export is possible by various interfaces including remote control over IP and IP-based audio transmission. This system is suitable for stationary surveillance of coastal ship traffic as well as for mobile use on big vessels(RHOTHETA 2014).

4.3.5. Rhotheta Coastal VHF 2-band RT-1000 RDF

The RT-1000 RDF system is designed specifically for aeronautical and maritime applications and complies with ICAO and DFS (Deutsche Flugsicherung) requirements, shown in **Figure 4.32 (C).**The separate large and compact antenna system for simple installation is presented in **Figure 4.32 (D),** which location independent of controller workstation. More than 100 systems are currently in use worldwide for Air (ATC) and Ship Traffic Control (STC). The VTS network contributes to the safety of shipping traffic by monitoring ships from information shore-based facilities. When a vessel enters the waters of a port or harbor, the responsible VTS station is informed accordingly by radio telephony (VHF). The traffic control station then uses its radio direction finder to determine the position of the vessel. The VHF coastal RDF therefore contributes significantly to the safety of shipping traffic since the possibility of accidents caused by confusion is eliminated.

Figure 4.33. Network Configuration of Coastal VTS – Courtesy of Brochure: by Rhotheta

The RT-1000 is used as a navigation aid that allows controllers at shore to transmit magnetic bearing to the navigation bridge or verify position reports received from ships. The radio bearing information can be also integrated into a radar screen, which makes it possible to immediately assign radio messages to the right vessel on the radar display. The system is using the following frequency range: Aviation band from 118.000 to 136.975 MHz and Marine band from 156.000 to 174.000 MHz

This unit is high-precision Doppler direction finder with extremely high rotation frequency for fast signal processing and doesn't require an infrastructure for remote operation, which integrated modular construction is illustrated in **Figure 4.33.** The VTS network operates in "remote mode" and integrates the following components:

- Massive direction finding antenna system RTA 1300 installed remotely from the controller and connected to the receiver RTR 1200 by means of an RF cable; and
- One remote RDF RTC 1100 unit located up to 10 Km distance can be connected to the RTR receiver via 6-wire telephone cable. Two RTC 1000 units can be connected in parallel.

Therefore, receiver, demodulator and antenna control module are integrated in the receiver unit located at the antenna position(RHOTHETA 2014).

4.3.6. ELTA System for Air/Vessel Traffic Control RDF EL/K-7029

All known radio direction finding methods are based on the utilization of the electromagnetic wave field generated by the transmitter to be found. Thus, good results are only possible if this wave field at the direction finding position is largely undisturbed. Regrettably, incoming wave fields are distorted significantly in the tower area due to reflections and shadows from surrounding buildings. Even large and costly antenna systems can only solve these problems, resulting from physical facts, unsatisfactorily.

Employing "remote operation" any professional ground RDF configuration for airports and seaports have to realize a concept permitting an antenna position to be chosen, which is almost totally independent from the tower system display at controller position. Hence, the antenna with its weatherproof receiver unit may be installed at a location within the airport or seaport areas that may be optimal for direction finding. The connection to the controller is made through a wire line. Expensive equipment and costly infrastructures are eliminated in contrast to usual direction finding systems.

The aeronautical or maritime RDF ground systems may realize an equipment family that can be utilized in a flexible manner. Apart from the advantage of being service-friendly to mobile customers, the consequent modular design makes it possible to implement several system components variously equipped and in such a way the optimum system configuration will be available with a minimum of equipment, depending on the application.

The EL/K-7029 RDF of ELTA company is a compact cost-effective VHF/UHF infrastructure interferometer-based and accurate RDF to support airport and harbor traffic management for collision avoidance.

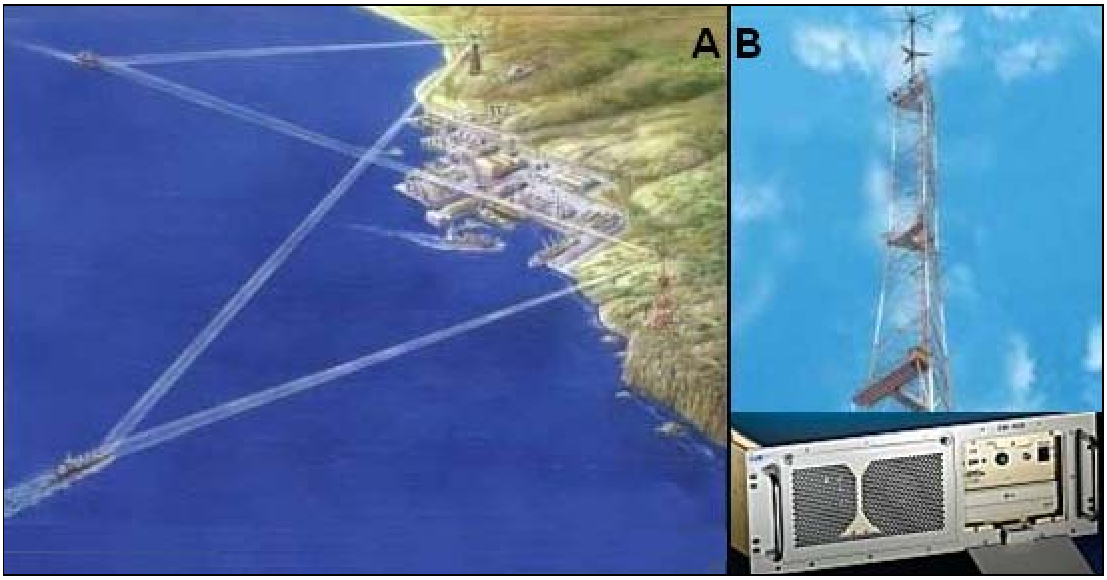

Figure 4.34. Coastal RDF Service and Antenna for VTS Network – Courtesy of Brochure: by ELTA

In **Figure 4.34 (A)** is illustrated the VTS employing two coastal RDF stations for location of ship transmissions on VHF/UHF-bands. By implementing several synchronized RDF coastal infrastructures, the system performs automatic triangulation and provides accurate location of ships transmission source. The EL/K-7029 DF system comprises a single broadband (100 MHz – 400MHz) 3 m in diameter antenna stack, shown in **Figure 4.34(Above)** and an RDF with the Commercial Off-The-Shelf(COTS) PC, embedding wideband in-house receivers and advanced Digital Signal Processors (DSP), shown in **Figure 4.34 (Below).**
The EL/K-7029 DF system incorporates advanced algorithms based on ELTA's and system of Communication Intelligence (COMINT) in RDF networks. The technical features of this high precision RDF are compact and modern design, cost-effective broadband and High Probability Of Interception (HPOI). It is employing advanced DF algorithms that overcome multi-path interference and providing interoperability with other traffic management systems using the COTS hardware and software. The display of signal bearing is integrated with on top of geographical map and multi–DF systems with time synchronization by GPS.
The antenna stack is covering frequency range from 100 to 400MHz for VHF airborne at 116– 138MHz, VHF naval at 156 – 162MHz and UHF airborne at 225 – 400MHz.A new direction-finding system is capable of tracking, from coastal stations, the drift of drogues more than 100 km from the shoreline(IAI 2014).

4.3.7. Rohde & Schwarz (R&S) Determination of Vessel Bearings in Coastal Waters

The R&S VTS is designed for identification and location of vessels communicating via radio communication equipment at VHF or UHF-band. As the name suggests, this component of VTS helps in obtaining maritime information that will help to locate direction from which radio frequencies are coming. This device particularly helps in acting like a vessel finder. Vessel traffic services are used for the sole purpose of making all ship routes safer and more efficient. With trained personnel, this take becomes easier and makes marine routes safer.
The VHF RDF stations are used in the VTS system to support operators in identifying all vessels in the RDF coverage for normal sailing operations or even to detect some secrete or hiding actions, such as pirates, drug smugglers, saboteurs and other initiatives that threaten the Homeland Security System (HSS). Therefore, RDF is providing bearing information on VHF/UHF-band transmissions from all vessels in radio coverage, which is presented on the traffic display at the VTS Control Centre.

Figure 4.35. Coastal DDF 100M RDF and Antenna ADD 090M for VTS – Courtesy of Brochure: by R&S

In **Figure 4.35 (Left)** is illustrated new digital RDF R&S DDF 100M, which consist of the DF Processor R&S EBD 100M and a modified VHF/UHF Monitoring Receiver R&S ESMB. In **Figure 4.35 (Right)** as an example is shown an RDF antenna model R&S ADD 090M for installation around a mast. It has a frequency range of 118 to250 MHz and consists of nine dipole elements arranged in a circle two meters in diameter.

This unit is an RDF serves for stationary coastal surveillance and identification of ships that transmit on the VHF/UHF radio bands. In such a way, the coastal RDF stations are equipped with apparatus for determining the direction of radio signals transmitted by ships and other stations. Thus, all known radio direction finding methods are based on the utilization of the electromagnetic wave field generated by the transmitter to be found.

In coastal areas, vessels and land-based stations communicate on defined radio channels in the VHF range of 156 to 163 MHz. Communications are carried out both in duplex and simplex modes and on a channel spacing of 25 KHz and RDF often play an important role. Most vessels today have GPS receivers, enabling them to transmit their location via radio if they are in distress. However, many cases still require using land-based RDF to determine a vessel's position, so only then can SAR efforts be initiated and coordinated. Otherwise, RDF can be used to provide the location of illegal, secret or hostile transmitters, including to detect vessels captured by pirates if they transmit on the VHF-band in coastal waters up to 50 miles coverage. In addition, RDF is critical not only for coastal vessels, they can also detect the distress alert on aircraft landed at sea.

The RDF Processor has anRS-232-C system interface via which an operator can control the entire direction finder, even at great distances. By design, this RDF constantly is switching between two frequencies and dwells on each frequency for 300 ms. So, this concept ensures that even signals with transmission duration of only 1 s are reliably detected. In most cases, channel 1carries maritime distress CH16(156.8 MHz), and channel 2 is set to any other frequency based on the range of the RDF antenna. The operator can also assign the frequency for channel 1 via remote control. In special situations, operators can manage the direction finder at only one frequency and optimize it either for very short signals or high sensitivity. In some cases, antennas for transmitting signals in the useful range of the direction finder are also attached to the DF antenna mast. They can cause significant intermodulation or even block the direction finder. To solve this problem, it is possible to employ an adaptive interference canceller device as an option and perform RDF without much interference.

The RDF stations are usually unattended and operated remotely. Information from the RDF stations is received at the ground control centre via the RS-232-C interface and directed to a computer, which processes the data for the individual operator positions. The RDF is also using a special software package that enables service technicians to operate the direction finder on-site via a laptop and check the DF results(SCHWARZ 2014).

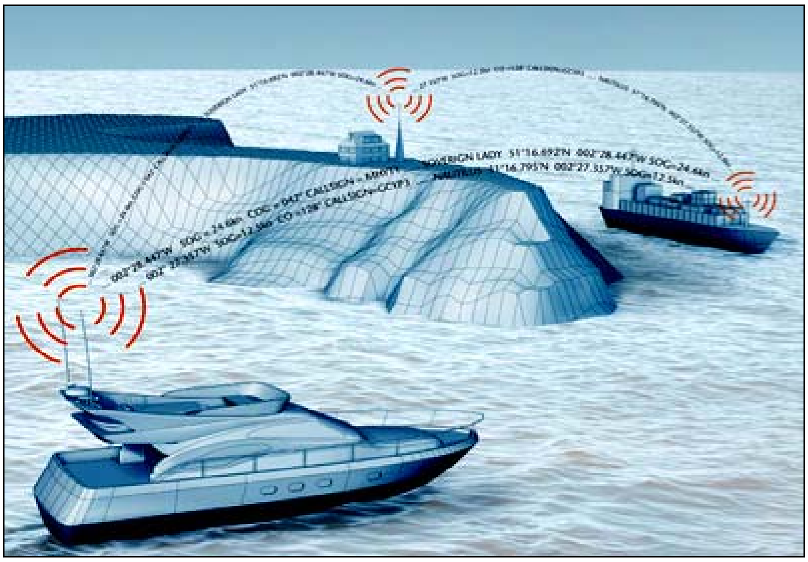

Figure 4.36. Maritime AIS Network – Courtesy of Brochure: by IMO

4.4. Radio VHF Automatic Identification System (R-AIS)

The Radio VHF AIS or Radio VHF Data Link (R-VDL) is a most attractive system at present for tracking and detecting of ships for short range in coastal navigation. Thus, more adequate designation for AIS will be Radio AIS (R-AIS), because recently is developed Satellite AIS (S-AIS) with a similar service for ships and aircraft.

Regulation 19 of SOLAS Chapter V provided requirements for shipborne navigational systems and equipment and sets out navigational equipment to be carried on board ships, according to ship type. In 2000, IMO adopted a new requirement, as part of a revised new chapter V, for all ships to carry AIS transponders capable of providing information about the ship to other ships and to coastal authorities automatically(Harati-Mokhtari *et al.* 2007).

The R-AIS is a maritime surveillance system using the VHF band to exchange information between ships and shore stations, including positions, identification, course and speed, which network is shown in **Figure 4.36**. It mainly aims at avoiding collisions between ships. The link budgets allow receiving transmitted AIS signals from space, and consequently a global maritime surveillance can be considered. However, some challenges arise, especially message collisions due to the use of a Self Organized Time Division Multiple Access (SOTDMA) protocol (not designed for satellite detecting). Thus, advanced signal processing for separation of received signals is needed.

According to IMO regulations by 31 December 2004each oceangoing vessel has to install AIS transponders onboard, which automatically broadcast regularly to the coast station ships name, call sign and navigation data. This data is programmed when the equipment is installing onboard and also all this information is transmitted regularly. The signals are received by R-AIS transponders fitted on other ships or on land based systems, such as VMS systems. The received information can be displayed on a screen or chart plotter, showing the other vessel's positions in much the same manner as a radar display(Tetreault 2005).

Ships fitted with R-AIS equipment onboard shall maintain AIS in operation at all times except where international agreements, rules or standards provide for the protection of navigational information. Thus, the R-AIS standard comprises several substandard called as "types" that specify individual for each product type. The specification for each product's type provides a detailed technical specification, which ensures the overall integrity of the global R-AIS system, within which the entire product types which must operate. Namely there are two types of R-AIS Transceivers (transmit and receive) "Class A" and "Class B".

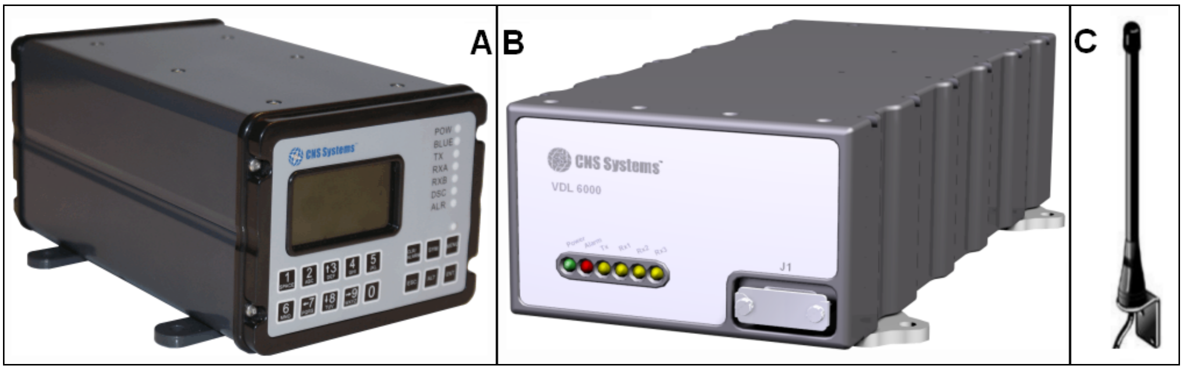

Figure 4.37. Maritime VDL Classs A R-AIS Stations – Courtesy of Brochure: by CNS Systems

The IMO regulation requires that AIS shall provide information by transmitter including the ship’s identity, navigational status and other safety-related information automatically to the appropriately equipped shore stations, other ships and aircraft, and to receive automatically such information from similarly fitted ships, monitor and track ships and exchange data with shore-based facilities.
At its79th session in December 2004, the Maritime Safety Committee (MSC) agreed that, in relation to the issue of freely available AIS-generated ship data on the worldwide Web, the publication on the worldwide Web or elsewhere of AIS data transmitted by ships could be detrimental to the safety and security of ships and port facilities and was undermining the efforts of the IMO expertise and its Member States to enhance the safety of navigation and security in the international maritime transport sector. In addition, the Committee condemned those who irresponsibly publish AIS data transmitted by ships on the world-wide Web, or elsewhere, particularly if they offer services to the shipping and port industries(System 2012).

4.4.1. CNS Systems R-AIS Class A Station

The VDL 6000 AIS Class A ship R-AIS transponder station of the Swedish Company CNS Systems provides IMO SOLAS compliance and also Bundesamtfür Seeschiffahrt und Hydrographie (BSH) certification for installation onboard oceangoing vessels, shown in **Figure 4.37 (A).** The screen presentation of this transponder is indicating the call signs of other ships enables a user to make direct contact by text or voice communication.
Another model of CNS Systems is VDL 6000 Secure Class A shipborne R-AIS transponder that operates on Standard, Silent and Secure Mode, shown in **Figure 4.37 (B).**This R-AIS is also serving for naval operation can be configured in ”receive only” mode or both ”receive and transmit” mode for positive identification and positioning of all ships in the vicinity. The R-AIS unit secure system is designed on existing technology and supports a user to receive, schedule and transmit encrypted messages to other users. This can include transmission of secure text messaging and to receive encrypted range and bearing. The secure R-AIS can also support simulated targets for naval operations.
Both AIS transmitters generates output power (adjustable) 1 and 12.5 W and 50 Ohm load. The unit bandwidth is 25 kHz employing TDMA (AIS) protocol with baud rate 9600 b/s (AIS)/1200 b/s Digital Selective Call (DSC) and GMSK (AIS)/FSK (DSC) modulation. Both transceivers are using frequency bands from156.025 to 162.025 MHz with default channels 87B (161.975 MHz) and 88B (162.025 MHz), 70 (156.525 MHz). Both AIS units of Secure Class A system have 3 (2 AIS TDMA, 1 DSC) number of receiver sand Minimum Keyboard and Display (MKD) unit. The R-AIS Class A transponder is easy to install onboard any ship by connecting it to GPS and VHF antenna or to the own antenna, illustrated in **Figure 4.37 (C)**, and is complete after connecting it to the onboard sensors.

Figure 4.38. Maritime Classs B R-AIS – Courtesy of Brochure: by ICOM

To maximize the benefit of the investment, the R-AIS Class A transponder is delivered with an interface to the electronic chart system and/or ARPA radar. Moreover, the system is designed to support long-range reporting via satellite, which will be introduced in the next chapter. To maximize the benefit of the functionality, both R-AIS Class A systems are delivered with an interface to the chart system and/or ARPA radar.

The data link communication covers identity, position, destination and other required static, voyage-related and dynamic data, which gives all vessels in an area increased situational awareness and improves safety at sea of the individual ship. Positive identification and positioning of all ships in the vicinity reduces the unnecessary “ship on my port bow” calls.

Less information overload greatly enhances safety at sea.

The SOTDMA technology is used in the R-AIS transponder, which transmits and receives information on all vessels within VHF coverage. This information includes position, identity, course over ground, heading and rate of turn as well as navigational status and the destination of the ship. The information received from, and provided to, the ships are easily plotted on any ARPA radar or electronic chart system. This gives the Officer of the watch a situational awareness that could never be achieved prior to AIS. Thus, information on draught, type of cargo and destination could also be used to make decisions related to maneuvering. In such a way is accomplished the maximum awareness.

Targeted at large commercial vessels, SOTDMA mode requires a transceiver to maintain a constantly updated slot map in its memory such that it has prior knowledge of slots, which are available for it to transmit. The SOTDMA transceivers will then pre-announce their transmission, effectively reserving theirs transmit slot. This is achieved through two receivers in continuous operation. Class A unit has an integrated display, transmit at 12 W, interface capability with multiple ship systems, and offer a sophisticated selection of features and functions. In default transmit rate it sends information every few seconds providing tracking control of the vessel. Described system is transmitting all necessary tracking information with help of the VHF transmitter to other nearby ships and to a coastal base station (Mathapo 2007; System 2012).

4.4.2. IcomMA-500TR Class B AIS Transponder

The MA-500TR is a Class B R-AIS transponder for Non-SOLAS vessels such as pleasure craft, workboat, fishing and small vessels. Transmitter power of this unit is 2 W and not required to have an integrated display. Class B R-AIS can be connected to most display systems, which the received messages will be displayed in, lists or overlaid on charts. In **Figure 4.38** is presented interface of Icom MA-500TR Class B AIS transponder with antenna, which can be installed on small vessels(System 2012).

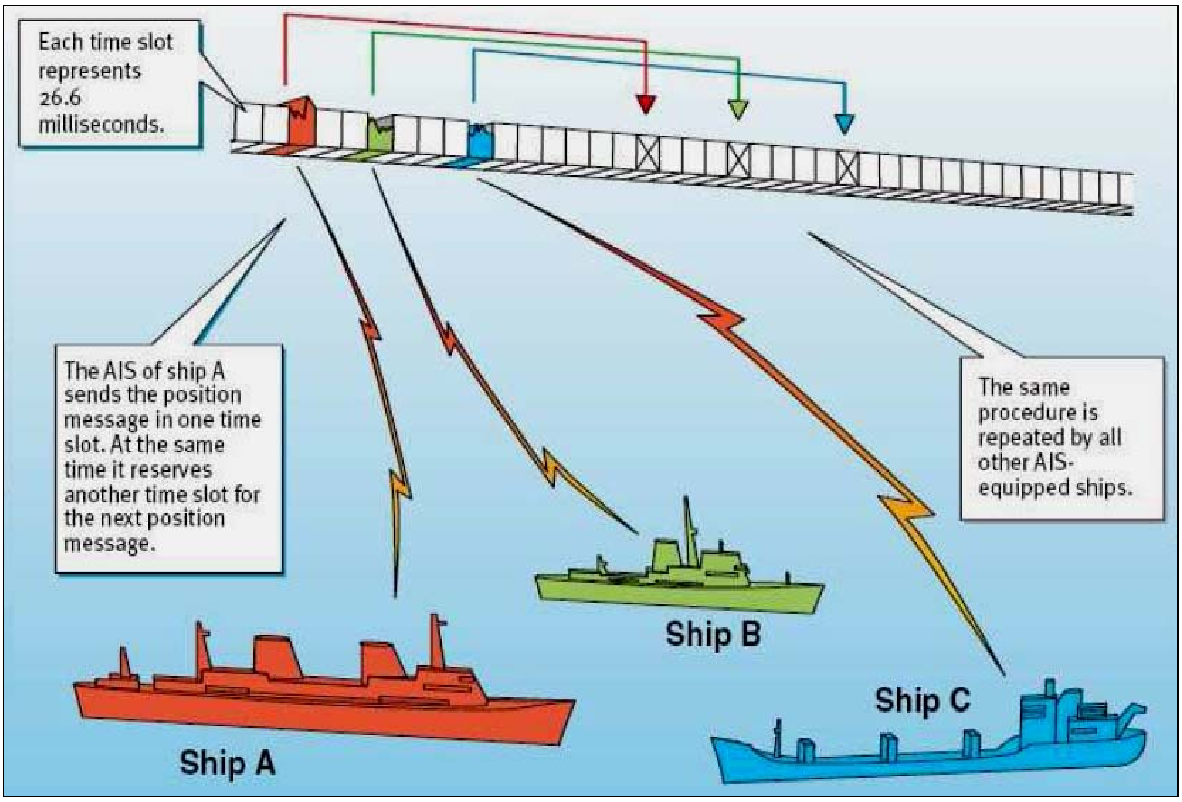

Figure 4.39. Maritime SOTDMA AIS Transmissions– Courtesy of Brochure: by NavSoftware

4.4.3. Basic Technical Details of AIS Transponder

Vessel mounted both R-AIS type Class A and B transceivers employ Carrier Sense TDMA (SCTDMA) or self organizing TDMA (SOTDMA), which network is shown in **Figure 4.39.** The system is automatically sending and receiving via the standard vessel's radio units. They use two VHF channels simultaneously, such as 87B at 161.975 MHz and channel 88B at 162.025 MHz. To order a lot of vessels sending out their data, the AIS transmission protocol works with 2250 slots per minute which can be used by different senders to transmit their information. The SOTDMA mode is used to autonomously divide the available timeslots between different senders(Lee, H *et al.* 2007). Due to the limited range of VHF and the different transmission intervals of senders the number of slots is sufficient and collisions hardly occur. An AIS system sends out via Base Station different types of information in varying time intervals. In total, AIS is able to communicate 27 different message types. Message #1 e.g. is the position of the vessel. Thus, transmitted information by this unit is: Maritime Mobile Service Identity (MMSI) code, Vessel name, Call sign, Type of ship, GPS antenna position, Ship's position, SOG (Speed Over Ground), COG (Course Over Ground), UTC date and time, GPS antenna type, PA (Position Accuracy) and Simple operation. Not all messages are regularly used.

The Plotter display looks like a marine radar display. North-up, course-up and range zoom from 0.125 to 24 NM (miles) are supported. The Target list display shows all detected AIS equipped vessels and targets. The Danger list display shows a list of vessels that are within 6 NM of Closest Point of Approach (CPA) and 60 minutes of Time to CPA (TCPA) from own vessel. Therefore, the Danger list can be sorted by CPA or TCPA order. In addition to these display types, the Detail screen shows various information about the selected R-AIS targets, such as CPA and TCPA for collision-risk management. When a vessel comes into the CPA and TCPA range, the unit icon blinks on the Plotter display and emits a beep sound. When connected to external audio equipment installed on the deck tower, the collision alarm function will alert operator even when you are away from the AIS transponder(System 2012).

Figure 4.40. Maritime AIS Base Stations – Courtesy of Brochure: by CNS Systems

4.4.4. CNS Systems AIS Base Station (BS)

Maritime R-AIS Shore Stations are used for surveillance and management of vessel traffic along coastlines, on inland waterways and in ports. These stations are providing all the features required for surveillance and management of vessel traffic at R-AIS VTS. They are easily configured to the specific needs of necessary service and solutions, from a basic unit to a fully redundant system with an embedded controller providing extensive processing and logging functionality. These R-AIS base stations fulfill the requirements of international AIS standards, provide service for national maritime authority implementing an R-AIS network and are also suitable for stand-alone operation at the VTS or seaport. The Swedish Company CNS Systems have two designs of Maritime R-AIS Base Stations: VDL 6000/FASS, shown in **Figure 4.40 (Left)** and VDL 6000/FASS Advanced, shown in **Figure 4.40 (Right).**
All AIS stations automatically broadcast information on dedicated VHF maritime channels. The AIS broadcasting system consists of static (geostationary), dynamic (non-geostationary) and navigation information, shown in **Figure 4.41.** All this information is originating from ships sensors connected to the R-AIS transponder. R-AIS Station sends position reports every 2 seconds to 3 minutes, depending on type of R-AIS transponder, speed and turn rate. Thus, the received R-AIS information at Base Station can be shown on a VTS Operator's screen or an ECDIS display(System 2012).

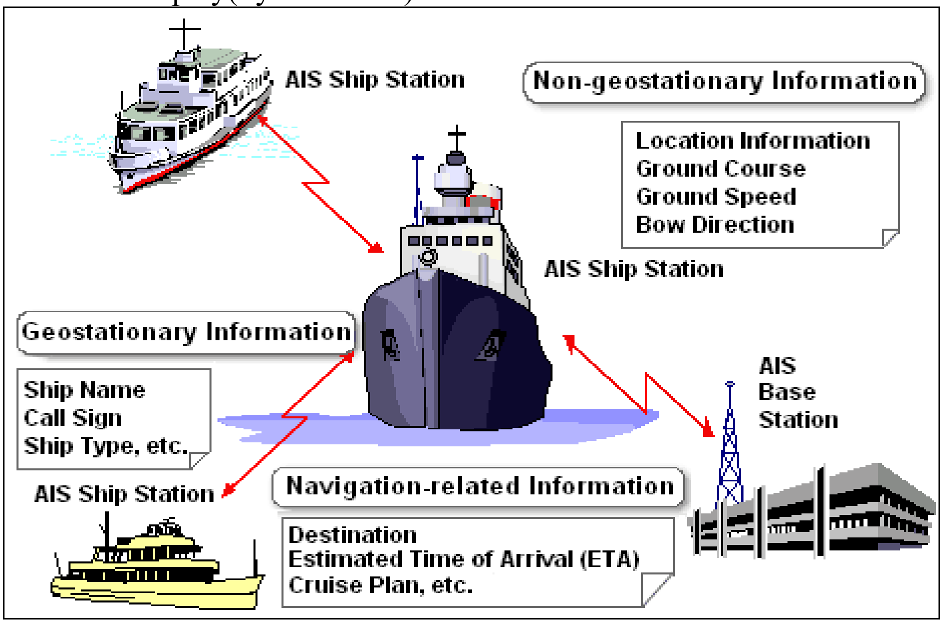

Figure 4.41. Maritime AIS Base Stations – Courtesy of Brochure: by Trans Maris

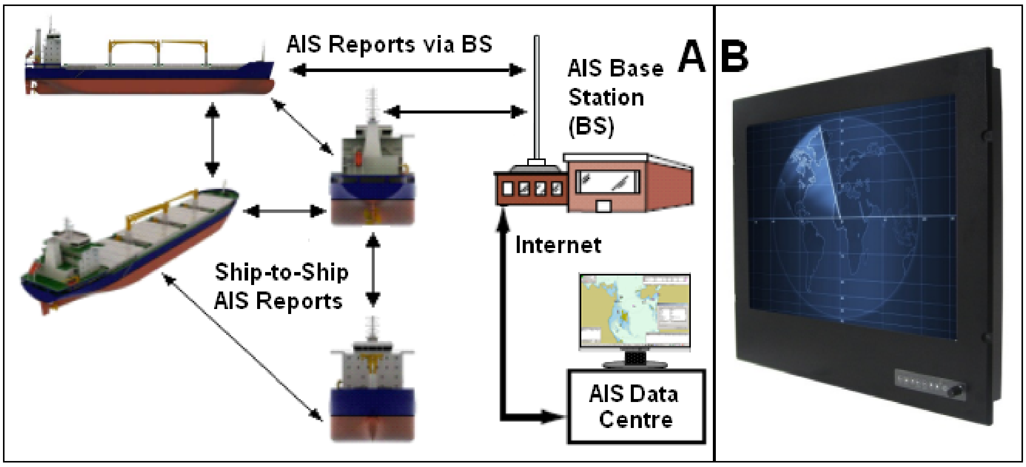

Figure 4.42. Maritime AIS Network and Display – Courtesy of Brochure: by AIS

4.4.4.1.CNS Systems AIS Base Station VDL 6000/FASS

The VDL 6000/FASS is configured as an AIS BS is presented in **Figure 4.40 (Left)**, which includes two VDL 6000/FASS (Fixed AIS Station System), one base station transponder and controller in each FASS unit and one Power and Antenna Distribution (PAD) unit. The AIS network with AIS internship reports and reports between ships and AIS BS are presented in **Figure 4.42 (A).**In **Figure4.42 (B)** is illustrated the Multifunction Displays for Marine's Integrated Platform Management System (IPMS) for AIS VTS infrastructure, which also can be used as an Integrated Bridge System (IBS) display for installation onboard ships.

This AIS BS configuration is across redundant AIS shore station with high reliability and full redundancy of all electronic components. It exceeds all the requirements of international AIS BS standards and provides all the features required for surveillance and management of vessel traffic. The AIS BS will automatically switch over to the stand-by FASS unit if the active one goes down (hot stand-by). It can also use the controller and BS transponders crosswise in case of dual failures of hardware. Thus, this solution gives extremely high Mean Time Between Failure (MTBF) and availability and a very low mean time to repair, reducing the need for unscheduled maintenance. The calculated MTBF of the AIS BS is more than 3 million hours, provided faulty units are replaced within 72 hours. The PAD unit contains the VHF antenna switch which can be used when only one VHF antenna is required. If dual VHF antennas are used at the installation site, the VHF switch can be bypassed by connecting directly to the two VDL 6000/FASS units VHF antenna ports.

The AIS BS provides a number of remote functionalities, including configuration, software updates, virtual targets and more. Other functions are local storage of AIS messages, local target filtering and Simple Network Management Protocol (SNMP). Power management is also integrated in the PAD unit. This feature makes it possible for the user to remotely switch the FASS units power on and off, what is giving the operator full control. Therefore, the AIS BS is designed for operation in secure mode by handling encrypted AIS data. The secure mode enables secure communication between ship-to-shore station and the control centre. Thus, by adding the secure modules to the network software, encryption and decryption can be managed between the users in a secure AIS network. The AIS BS can be supplied with a third AIS channel as well as increased receiver sensitivity.

The AIS BS is employing Power IP relay IF TCP/IP and RJ45 Ethernet with transmitter and receiver tuning range of156.025 –162.025 MHz and with channel spacing of 12.5 and 25 KHz. Modulation scheme is 25 KHz GMSK (AIS TDMA), 2.5 KHz GFSK (AIS TDMA) and 25 KHz FSK (DSC). The AIS BS station comprises GNSS Receiver as well with GPS L1, 16 parallel channels and DGNSS support(System 2012).

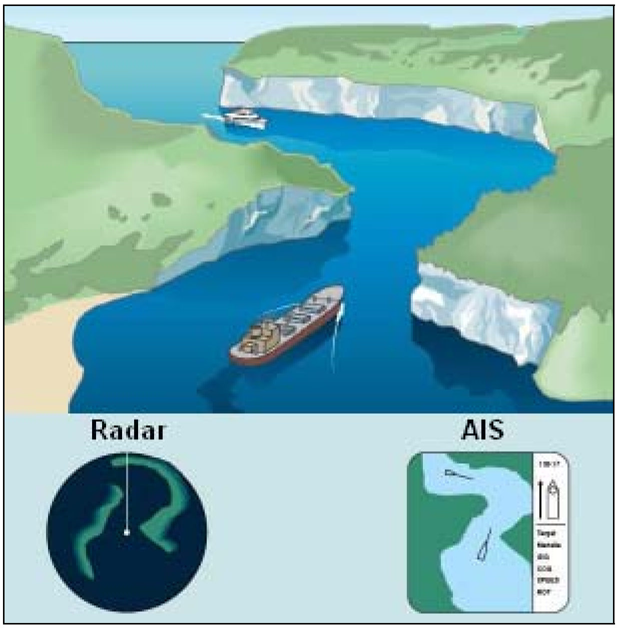

Figure 4.43. Radar vs AIS – Courtesy of Photo: by AIS

4.4.4.2.CNS Systems AIS Base Station VDL 6000/FASS Advanced

The Advanced configuration has one transponder and embedded controller hardware running unique software from CNS Systems, shown in **Figure 4.40 (Right).**This BS can be installed as a single unit providing AIS message logging, remote configuration and software update, virtual and synthetic targets, SNMP, local target filtering, remote power on/off and more. Otherwise, two shore stations can be locally connected to form a fully redundant installation, where hot-standby operation including cross-wise redundancy transponder and controller between the units provides very high availability.

This AIS BS is delivered with the Monitor and Control Tool (MCT) and the Power Supply Management Tool (PSMT).The MCT is a graphical interface that provides monitoring and control capabilities such as; change of status of the base station and its subunits, change of operational mode, enabling and disabling of services, configuration of the base station and its subunits, display of number of transmitted and received messages as well as a software update.

The PSMT allows a user to control the power supply to the base station and its subsystems. It can be factory configured for the following base station types: AIS BS, Limited AIS BS, Repeater BS and Aids to Navigation (AtoN) only transmitting Base Station.

With the Repeater station this BS is the perfect choice when implementing an AIS network where extended coverage at remote locations is required. This AIS BS is equipped with dual VHF antennas provides a number of functions, including filtering of AIS targets by selection of MSG type and/or filtering of a defined area. The dual antenna configuration allows the Repeater station to receive and transmit on directional antennas. This greatly improves coverage and distance in an AIS network, so for example in **Figure4.43** is shown the advantage of AIS vs Radar. Both ships do not have radar contact due to the difficult terrain, but can see each other by AIS. However, sometimes in more mountainous shore line there is not LOS between ships or between ships and base station, so can be used Satellite AIS instead.

In order to simplify the functionality of AIS network it is necessary to construct the network model basing on a LAN. The system can use two ways to construct such a network. The first way is based on computing node, which communicate and exchange data or message each other via computer. The second is based on switching node, which contains data switches and equipment for controlling, formatting, transmitting, routing and receiving data packets(Gustavsson 1996; System 2012).

4.4.5.CNS Systems AIS Base and Ship Station Software

The CNS Systems company is also a supplier of important software for use by the AIS base and ship stations. There are two CNS Systems software for supporting onboard AIS stations, such as Aldebaran II and Sentinel. However, there are four software solutions used at Base stations, such as Horizon, Data Store, Data Switch and Maestro.

1. Aldebaran II– This is Electronic Charting System (ECS) software for use onboard ships. It is designed with advanced navigation and communication features and is used by AIS operators worldwide. ECS solutions improve efficiency and safety in today's fast paced computer-aided navigation and situational awareness environments. It offers complete AIS integration with the ability to display static, dynamic and voyage related information in real time on a multitude of electronic chart formats.

2. Sentinel– This is an AIS surveillance and secure information system built on proven AIS display technology for use by operators in the need for secure communication. It offers AIS standard and private communications capabilities to deliver a common operating picture to all users. It permits the simultaneous cover tracking of standard AIS participants, allowing operators to monitor the network without being detected.

3. Horizon – This is a shore-based vessel monitoring solution which designed for vessel traffic and monitoring centres. The horizon is ideal for vessel traffic monitoring in national waters, and has been proven to increase safety, security and efficiency. It provides a complete AIS interface that includes the ability to view and track all vessels, display specific vessel information and send and receive safety related and text messages. Horizon's interface and display of AIS related information offers a substantial leap forward in the ability to communicate and interact with vessels. Since Horizon is fully configurable, operators can adjust the display of information panels; customize color patterns for AIS targets and set entry and exit alarms**.**

4. Data Store – This is a real-time data logging and playback software solution for NMEA and NMEA-formatted data, specifically AIS data. The "back-end" of the solution is a service that interfaces with a database, and the "front-end" interfaces with an application that allows a user to control logging and playback of data. Data Store can be configured to store all data or a user defined subset of data. Data stored in the AIS database can be queried and played back in the ECS system or an external application.

5. Data Switch – This is a data routing and management software application that provides a reliable flow of data to your environment. Data Switch supports the functionality defined in International Association of Lighthouse Authorities (IALA) Recommendation A-124,LSS Layer and Part IV. It is ideal for the collection, filtering, logging and sharing of AIS data over networks. For shore-based networks, Data Switch enables the flow of information from one or more AIS base stations and/or receivers to a Vessel Traffic Service (VTS) centre. Similarly, a VTS center can send vital information to a regional headquarters, and then on to a national entity via another Data Switch. For a vessel-based network, Data Switch can send information from attached NMEA devices (sensors)to a number of stations on the vessel. The distribution of both standard and proprietary data messages from one central location to shared locations makes Data Switch essential in many diverse environments.

6. Maestro – This software provides top layer control for the AIS network, supporting the functionality defined in IALARecommendation A-124, Functionality of the AIS Service Management (ASM) and Part V. It is a graphical display interface and a configuration utility for the AIS network. Maestro monitors all AIS network components including status and failure of all components, warnings about failover and backup systems, user account status, and all other relevant events. From the single interface accessed via a web browser, Maestro users can monitor, maintain, and manage all elements of the AIS network. Maestro is an independent process that runs without affecting the other AIS services (Eriksson and Lundmark 2002; System 2012).

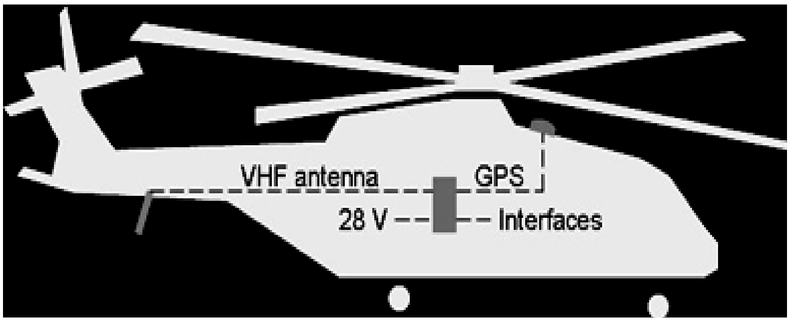

Figure 4.44. Aircraft R-AIS – Courtesy of Brochure: by Avionetics

4.5. Radio AIS (R-AIS) Airborne VDL System

The Airborne R-AIS or VDL equipment is dedicated for installation onboard airplanes and helicopters for use in SAR and coastal surveillance mission of ships and aircraft in distress. As stated earlier maritime R-AIS became a standard under the International Convention for the SOLAS purposes in December 2001.For the similar reason developed aeronautical VDL system as and R-AIS aircraft-borne transponder devices for aeronautical safety and collision avoidance of aircraft. However, the airborne R-AIS transponders can be also used to provide greatly enhance surveillance of large areas for SAR of ships in distress and alerts of aircraft landed at sea. The localization and identification of all AIS equipped aircraft greatly increases national security, environmental protection, and the possibility of rescuing aircraft in distress. R-AIS-equipped aircraft, with their high speed and extreme VHF coverage, are well suited to be used in Radio SAR (R-SAR) operations.

The received information is easily plotted on an electronic chart display system. This gives a surveillance capability that was not possible prior to R-AIS. The airborne R-AIS unit is the result of the extensive experience of avionics, and is designed and produced to the same high demands as VDL avionic transponders. In fact, the airborne R-AIS transponder, with its internal GPS Rx, connects to power supply, VHF and GPS antennas and to a laptop with adequate software. The same laptop or a CDTI can also be running an electronic chart system to display targets received by the airborne AIS transponder.

All maritime aircraft interacting with ships or with other maritime aircraft will benefit from having an airborne R-AIS transponder onboard, shown in **Figure 4.44.** The ships R-AIS data VHF transmissions from maritime surface traffic and airborne R-AIS equipped aircraft are broadcasted and utilized in the air by maritime airborne operators. In such a way, most frequent airborne R-AIS users include: SAR Aircraft (SARA), Maritime Patrol Aircraft (MPA) and Offshore Helicopter Traffic. The R-AIS Class A products are for ships over 300 tones under SOLAS Convention, and R-AIS Class B products are for non-SOLAS vessels.

Airborne R-AIS has become an obligatory for well equipped SARA and MPA aircraft. Thus, a dedicated SAR message including altitude is implemented in the R-AIS standard. The Silent Mode is an optional feature with receive/no transmits operation. For offshore and other airborne maritime aircraft, the R-AIS service brings significant safety improvements and a number of useful applications. The R-AIS network is also a new tool for National coastal surveillance and security monitoring. In addition, the system is very useful and cost effective for fleet tracking and management. Standard airborne R-AIS transponder installation include: GPS and VHF antennas and provide optional interfacing with a display system (cockpit or cabin display). The AIS network is an ideal tool for SAR at sea and other marine avionics operations. The AIS base stations, helicopters equipped with special airborne AIS and in such a way ships and aircraft landed at sea can coordinate their efforts more efficiently with AIS equipment. The automatic update of all AIS information provides an excellent tool for situation awareness in the aircraft or helicopter(Gunawardena and Rankin 2001; System 2012).

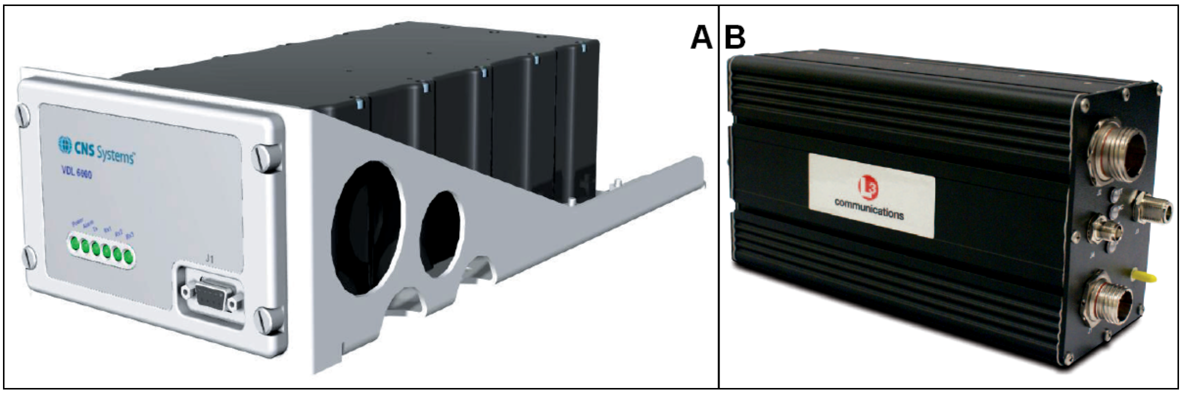

Figure 4.45. Aircraft R-AIS Transponders – Courtesy of Brochure: by CNS Systems and L3

4.5.1.CNS Systems VDL 6000 Airborne R-AIS Transponder

The VDL 6000 R-AIS transponder is developed for aircraft installation for use in SAR sea and costal surveillance missions that greatly enhances surveillance of large areas, which is illustrated in **Figure 4.45 (A).** The localization and identification of all R-AIS equipped vessels greatly increases national security, environmental protection, and the possibility of rescuing vessels in distress. R-AIS-equipped aircraft, with their high speed and extreme VHF coverage, are well suited to be used in SAR operations.
The technique of SOTDMA technology used in the R-AIS transponder broadcasts/receives information about all R-AIS equipped vessels within VHF coverage. This information can include position, identity, course and speed over ground, heading and rate of turn as well as navigational status and the destination of the ship. The information received is easily plotted on an electronic chart display system. This gives a surveillance capability that was not possible prior to R-AIS. It gives information on draught, type of cargo and destination is also useful in rescue operations. However, AIS information is also useful in rescue operations of ships in distress or aircraft landed at sea with the increased situational awareness.
The airborne R-AIS transponder, with its internal GPS, connects to power supply, VHF and GPS antennas and to a laptop with our configuration software. In fact, the same laptop or a CDTI can also be running an electronic chart system to display targets received by the airborne R-AIS transponder. Power requirements of R-AIS is 21.6-31.2 V DC, Number of transmitters 1, Tuning range 156.025 –162.025 MHz, Channel spacing 12.5 and 25 kHz, Baud rate 9600 b/s and Number of receivers 3 (2 R-AIS TDMA, 1 DSC)(System 2012).

4.5.2.F3 Protec-A Airborne R-AIS Transponder

The L-3 Protec-A Airborne R-AIS transponder provides commercial and civil aircraft the ability to track and identify AIS-equipped vessels and also report aircraft position over a dedicated VHF data link, shown in **Figure 4.45 (B).** It is a fully compliant R-AIS transceiver and has been designed in accordance with DO-160Eenvironmental test standards.
This device meets applicable performance and protocol standards for maritime R-AIS, which with increased receiver sensitivity improves performance and coverage. Therefore, advanced RF filtering reduces interference risk and open protocol simplifies integration with R-AIS and onboard surveillance radar display systems. It also supports Receive-Only and also VHF Transmit and Receive R-AIS operations' including is providing optional Aeronautical Radio Incorporated (ARINC) interface.
The transmitter and receiver frequency range is from 156.025 to 162.025 MHz and its antenna type is 5V active or passive. Transmitter power control is 1 – 12.5W and this R-AIS unit is including two receivers, one GPS and optional DSC receiver.

Figure 4.46. Aircraft R-AIS Transponders – Courtesy of Brochure: by SAAB and Avionetics

4.5.3.SAAB R4A Airborne R-AIS Transponder

The R4 Class AR-AIS product from SAAB is specifically designed to support the mariners in mission-critical decision making during SAR operations of ships and aircraft in distress. Sometimes aircraft landed at sea has to act as ships in distress. This transponder satisfies all carriage requirements, but more importantly it will provide better situation awareness to the ship officer on watch. In the any kind of vessel, the unique simplicity and versatility of the man-machine interface will allow the operator to carry out all-important tasks required to operate the R-AIS system, using the multipurpose display unit only. In **Figure 4.46 (A)** are illustrated SAAB R4 R-AIS transponder and its multipurpose display. Thus, in the integrated bridge system, the R4 will feed reliable data to virtually any electronic chart system and/or radar, and thus vastly improve the quality of the information presented. However, predefined safety-related text messages will assist in quickly notifying other ships or aircraft and VTS stations in distress situations. Furthermore, the R4 vessel transponder offers unprecedented VHF radio coverage, thus allowing the mariner to see further ahead.
This transponder is the second generation of Search and Rescue (SAR) solution using the latest technology to achieve the highest performance and reliability. It is the first R-AIS transponder developed specifically for airborne use, meeting the relevant requirements and standards for airworthiness. It can be installed in a variety of aircraft, both aero planes and helicopters. The installations vary from temporary installations for a specific trial or mission to full integration into the glass-cockpit. The operational use varies from monitoring and SAR missions to encrypted tactical directives between coast guards, using the Secure R-AIS solution. It supports technique based on the SOTDMA technology and is also available for ship borne R-AIS, BS infrastructures and infrastructure as well as for Aids to Navigation(SAAB 2014).

4.5.4.Avionetics TX-20 Airborne R-AIS Transponder

The Avionetics TX-20 Airborne R-AIS transponder is certified for installation in fixed wing and rotorcraft (harsh environment) aircraft, which compliant with maritime R-AIS standards, shown in **Figure 4.46 (A).** The R-AIS message exchange with R-AIS vessels, aircraft and ground BS. It transmits and receives SAR and aircraft R-AIS messages and autonomously monitors all R-AIS equipped vessels from aircraft. It is fully provisioned for interfacing with R-AIS cockpit or cabin display system. It provides link for receiving and transmitting data as customer configurable messages. Three R-AIS receiver units and one transmitter are using RF range of 156 –162.5 MHz and channel spacing at 25/12.5 KHz connected to VHF antenna via type N antenna connector. This unit provides data ports3 I/O RS 422/NMEA 0183, 38400/4800 b/s and is integrated with 12 channels GPS receiver (DGPS prepared), which antenna is connected via TNC antenna connection(SAAB 2014).

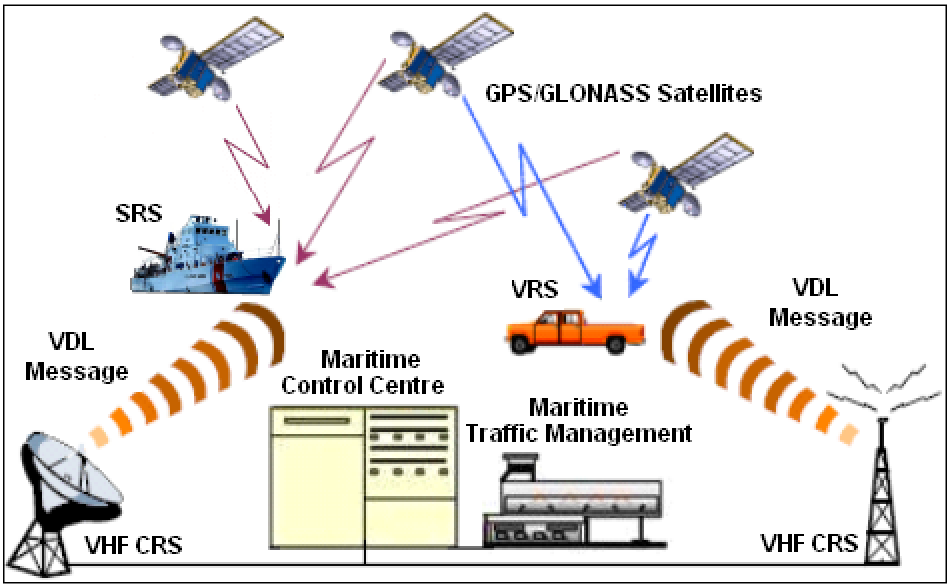

Figure 4.47. Maritime R-LST Network – Courtesy of Manual: by Ilcev

4.6. Radio Local Ship Tracking (R-LST) for Anchorage Areas and Seaport Networks

The new proposed maritime Radio Local Tracking System (R-LTS) or Radio VHF Data Link (VDL) networks and equipment are modern CNS solution suitable to support navigation and surveillance functions of ships in coastal navigation and approaching to anchorages including for traffic control and management of ships and vehicles in seaport areas. In **Figure 4.47** is presented the Radio VDL network in hypothetical seaport, which can serve for approachings to anchorages and coastal navigation as well in VHF range of the VHF Coast Radio Stations (CRS). The Ship Radio Station (SRS) and Vehicle Radio Stations (VRS) are caring onboard special VHF Radio transceivers integrated with GPS receivers and transceiving and GPS antennas. Both SRS and VRS devices are receiving GPS signals to determine own position, and after that CRS are sending ships and vehicles positions as VDL message via any CRS terminals in the VHF-band coverage to the Maritime Control Centre (MCC) and Maritime Traffic Management (MTM). In the MCC site there is computer system that processes all received CNS data from ships and vehicles and indicates all positions at the display look like radar screen. The MTM site situated in control tower can send navigation instructions via CRS to any ship and vehicle in this area with proposed course and further movements plan.

The R-LST or Radio Data Link (RDL) is a maritime surveillance system using the VHF band onboard ships and vehicle equipment to exchange information between ships or vehicles and shore stations, including positions, identification, course and speed. In fact, it mainly aims at avoiding collisions between ships and better management of all movements in seaports. This solution is working on the similar way as R-AIS, that ships and vehicle R-VDL terminals receiving GPS or GLONASS positioning signals and automatically sending this data to the MCC and MTM within VHF coverage. The difference is that VHF Ground Stations (GS) are interfacing transponders in mobiles and MCC, while in vice versa direction MCC can send instructions to ships how can move more safely at sea and seaports and to vehicles in seaports only.

Every waterway presents unique safety challenges, because coastal area and seaports can be subject to many threats, such as smuggling, sea pirating, different trafficking, immigration, ecological disasters and maritime accidents. These events are just a few of the challenges that arise to create the need for maritime surveillance. However, increased vessel traffic in coastal and inland waters, approaching to anchorages and seaports can drastically complicate traffic management of waterways as well.

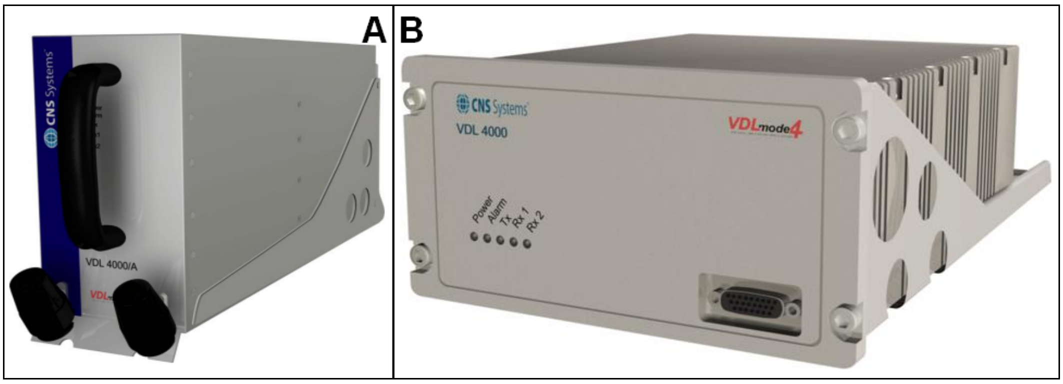

Figure 4.48. Aircraft VDL-4 Equipment – Courtesy of Brochure: by CNS Systems

Additionally, ship in distress and emergency alert in coastal waters need to be quickly found and assisted. There is a strong necessity in the maritime world for CNS solutions that help manage vessel traffic, tracking and monitor the waterway environment. To provide this kind of service can be employed VDL 6000 R-AIS Class A ship transponder station as convenient for R-LST solutions, shown in **Figure 4.37 (A).** Another convenient model of CNS Systems is VDL 6000 Secure Class A shipborne R-AIS transponder that operates in Standard, Silent and Secure Mode, shown in **Figure 4.37 (B).**

The aeronautical VHF Data Link Mode 4 (VDL4) solution is currently using as a broadcast link to support CNS functions of aircraft. Namely it provides digital communication between mobile stations and between mobile units and fixed ground stations for Surface Movement Guidance and Control (SMGC) of the following aircraft and airport surface vehicles:

1. Airborne Transponder VDL 4000/A – This is a multi-purpose data link unit developed by company CNS Systems for advanced CNS and Air Traffic Control (ATM) applications. It is used onboard aircraft for non-safety-critical application, shown in **Figure 4.48 (A).**

2. Airborne Transponder VDL 4000/GA – This transponder is used onboard aircraft and helicopters for non-safety-critical applications, shown in **Figure 4.48 (B).**

3. Vehicle Transponder VDL 4000/VTE – This transponder has been developed to meet the stringent demands of safe surface vehicle movement operations and more efficient utilization of airport resources, shown in **Figure 4.49 (A).**

4. Vehicle Transponder VDL 4000/GSI – This mobile transponder is designed for a wide range of CNS/ATM applications, tailored to fit many different areas of operation such as helicopter operation and airport vehicle fleet management, shown in **Figure 4.49 (B).**

All above radio transponder can be adopted by frequency band and functionality for maritime CNS and Ship Traffic Control (STC) and used for Coastal Movement Guidance and Control (CMGC) of sailing ships in coastal waters, approaching to the anchorages and inside of seaports, and can monitor all vehicle movements in seaports. In addition, R-VDL system can be used as a media for new proposed Radio Automatic Dependent Surveillance - Broadcast (RADS-B) and provide maritime CNS and CMGC service(System 2012).

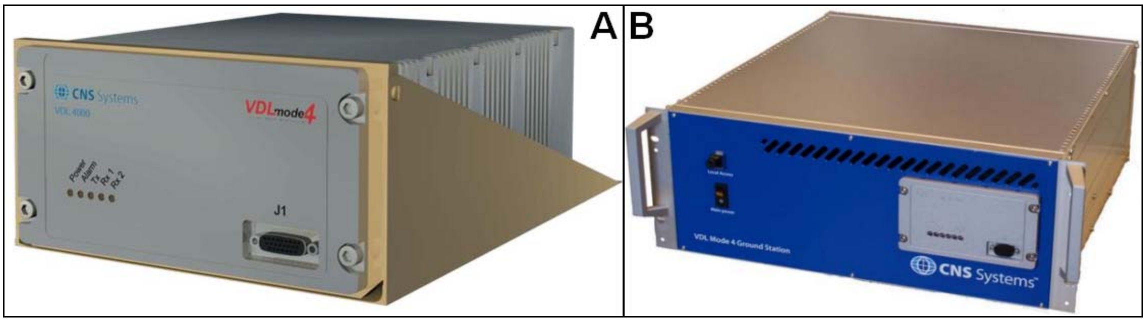

Figure 4.49. Vehicle and Helicopters VDL-4 Equipment – Courtesy of Brochure: by CNS Systems

4.7. Radio Automatic Dependent Surveillance - Broadcast (RADS-B)

The RADS-B network is developed for aeronautical applications, but also can be adopted and proposed for maritime purposes.

4.7.1. Overview of Aeronautical RADS-B

The surveillance systems presently in use can be divided into two main types: dependent surveillance and independent surveillance. In dependent surveillance systems, the aircraft position is determined on board and then transmitted to ATC. However, as far independent surveillance such as primary radar is a system that measures aircraft position from the ground. The current surveillance is based on both voice and data position reporting or radar service, which measures range and azimuth of aircraft from the ground station. The Second Surveillance Radar (SSR) augmented with Mode-S transponder when traffic conditions so warrant will continue to be used, especially in high traffic density airspaces. In other places, where coverage of SSR is not possible, such as large oceanic airspaces and remote areas over the Earth surface, surveillance will be provided by RADS, RADS-A (Addressed), RADS-C (Contract) and RADS-B**.**

Therefore, the RADS-B is a system that aircraft broadcasts the continuously updated data stream at short intervals, approximately once a second, such as identity, position, heading, velocity, ground track and speed, altitude and other information at a high rate, which anyone can receive and display the information. Thus, ground stations receive aircraft RADS-B transmissions and forward them for display on ATC consoles. Typically, ATC uses RADS-B information in the same way as radar. The RADS-B provides two primary functions, ADS-B OUT and ADS-B IN. The RADS-B OUT is the transmission of RADS-B information out from an aircraft to other aircraft in the coverage area, to the ground vehicles and ground stations. The ADS-B IN is transmission of RDAS-B ATC information from ground stations or other aircraft to the on-board device for reception of RADS-B OUT transmissions to allow a cockpit display of nearby aircraft to the pilot of the RADS-B IN equipped aircraft.

The RADS-B mode is a system that uses radio transmissions from aircraft to provide all flight data that have been detected and computed by onboard aircraft sensors and sends them via either 1090 MHz Extended Squitter (ES) or 978MHz Universal Access Transceiver (UAT) receiver/transmitters gathers Typically, the airborne onboard position sensors are a GNSS receiver, or the GNSS output of a Multi-Mode Receiver (MMR) terminal.

An RADS-B ground station uses a non-rotating omni-directional antenna to receive messages transmitted by the aircraft. The RADS-B network is designed as a multiple use surveillance technique for aerodrome surface, terminals, en-route airspace and is applicable to both ATC and aircraft-to-aircraft surveillance. It is LOS based surveillance and requires ground station to receive RADS-B data and retransmit to the Air Traffic Management (ATM) and ATC. A single ground station can provide coverage out to approximately 250 miles(AIRBUS 2014).

4.7.2. Overview of New-proposed Maritime RADS-B

The maritime RADS-B is a new-proposed VHF/UHF radio surveillance concept by virtue of which the ship transmits automatically in very short intervals its identity, position, heading, speed, ETA and other relevant information through data link. This information is received by near-by ships in the coverage area, which enables all users to be informed about their own position and the position of all other nearby traffic. Thus, the position information may be indicated on the ships bridge display to allow for new possibility of detecting traffic. Ground vehicle and facilities in seaports can also be equipped to receive and transmit position data.

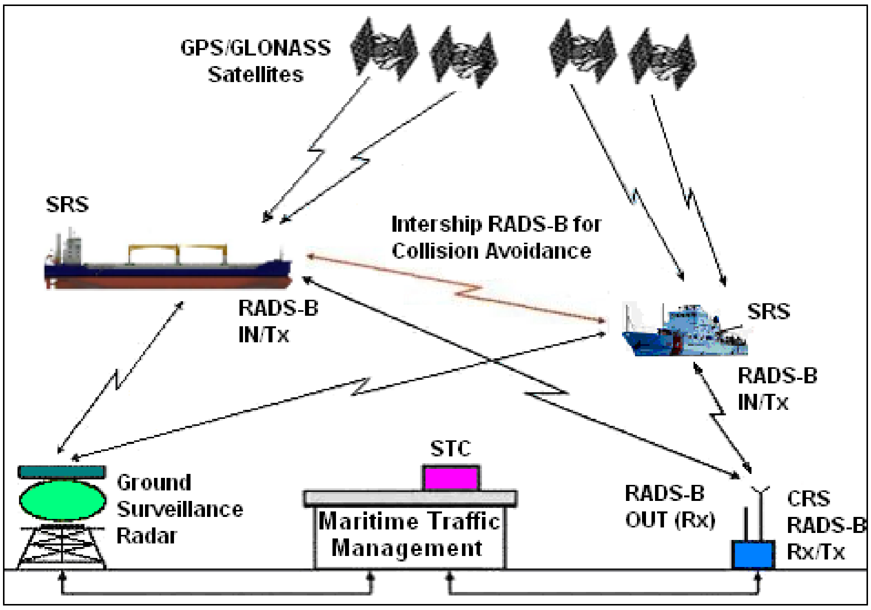

Figure 4.50. Maritime RADS-B Network – Courtesy of Manual: by Ilcev

Therefore, the maritime RADS-B is making possible to monitor all types of ships traffic in coastal waters, anchorages and inside of ports through two-way data links. This solution will play important role in the bridge environment and it will keep the duty officers informed about all the traffic vicinity of the coast and inside of seaports. The bridge display can be used to show the position and intentions of all ships within a 200 miles (NM) radius. On the ground, the RADS-B will offer Ship Traffic Control (STC) employing new more reliable surveillance and tracking capabilities. The RADS-B application offers benefits in:
a) Extending radio tracking coverage of ships in coastal areas, approachings to anchorages and inside of seaports, including ground vehicles, not covered by other shore feasibilities;
b). Providing redundancy to existing surveillance systems for collision avoidance;
c). Increasing surveillance accuracy and consistency in tracking;
d). Facilitating a reduction in capital and maintenance costs for surveillance infrastructure;
e) Providing a starting point for shipborne separation procedures; and
f) Increase safety and security in navigation for all equipped sea space users.
The maritime RADS-B system is a surveillance technique that relies on the ship deriving its own position from the GNSS and periodically broadcast a data packet consisting of all other information along with vessel identification and intention to near-by RADS-B receivers installed on other ships, on fixed Coast Radio Stations (CRS) or on ground vehicles. Once the data packet is received by the CRS site, it is for warded to an STC and a Maritime Traffic Management (MTM) central processing facility via a conventional data network where a traffic picture is generated then sent for display on the STC screen, shown in **Figure 4.50.**The result is that master mariners and controllers share the same accurate picture of the sea traffic in a given radio coverage. The maritime RADS-B can be broken into two primary functions, RADS-B OUT and ADS-B IN. Ship Radio Stations (SRS) equipped with RADS-B OUT works by sending GNSS-derived position and other data from the ship systems, through an RADS-B VHF/UHF powerful transponders to other ships, vehicles inside seaports and CRS, which receive this data and send it to STC displays for the purpose of enhanced collision avoidance and coordination. The RADS-B IN is transmission of STC information from CRS or from other ships onboard devices and their reception by RADS-B OUT onboard equipment. This allows a bridge display data of nearby ships to the ship officer of the ADS-B IN equipped ship. The RADS-B information can be used to augment existing ground surveillance radar or used in lieu of those radar technologies.

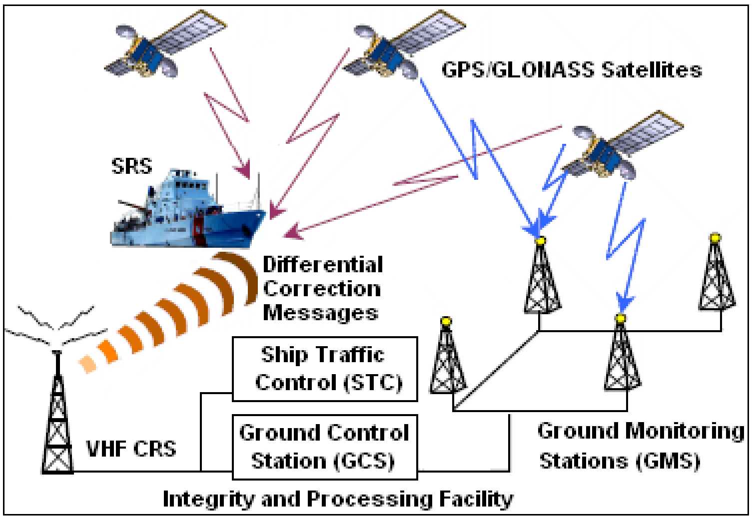

Figure 4.51. Local VHF Augmentation System (LVAS) – Courtesy of Manual: by Ilcev

4.8. Radio GNSS Augmentation VDL-Broadcast (GAVDL-B)

The Radio GAVDL-B network is also modern Local VHF Augmentation System (LVAS) system able to transmit and receive augmentation GNSS signals for maritime CNS solutions and enhanced collision avoidance system, more effective CMGC network, improved tracking and detecting of ships in VHF sea coverage including enhanced safety and security at sea.
Navigation is evolving from terrestrial navigation aids to satellite navigation systems called GNSS. GNSS provides standardized positioning information via R-VDL to the ships for precise navigation globally, shown in **Figure 4.51**. The new R-VDL system in the core GPS constellations broadcast a timing signal and a data messages for differential correction of GPS or GLONASS signals. Ships GNSS receivers use these signals to calculate their range from each GPS or GLONASS satellite in view and also calculate 3-D position and precise time. Mariners are urging states to move from the current terrestrial navigation systems to GNSS solution that is capable of being used in all sea space during all phases of sailing.
The procedure of maritime LVAS network is as follows:
1. Ships and Ground Monitoring Stations (GMS) or Reference Stations are getting GNSS-1 signals from existing GPS and GLONASS satellites. In the near future can be used GNSS-2 signals of European Galileo and Chinese Compass satellites. In such a way all ships can use both not-augmented and augmented GNSS signals.
2. The GMS sites of integrity monitoring network, operated by governmental agencies within some hypothetical country or port, are sending the monitored data to the local Integrity and Processing Facility of Master Station or Ground Control Station (GCS), where the data is processed to form the integrity and Local Area Differential GNSS (LADGNSS) correction messages, which are then forwarded to the VHF CRS facilities.
3. The VHF CRS terminals sends augmented GNSS-1 signals to the GNSS receivers onboard ships (GPS or GLONASS) and getting more precise navigation data to plot on the chart.
4. Ships captain can include this integrity and processed data in GNSS message of onboard VDL equipment and send to the VHF CRS and STC service of MTM, where data from all adjacent ships will be indicated on augmented GNSS displays.
5. On certain ship demand STC can send position of all near by ships for improved traffic control and collision avoidance. This solution is essential in extremely bed weather situations with zero visibility and when ship radar is not able to function normally or is out of order. In addition, there is also the possibility that CRS terminals can send LVAS signals to all ships in the certain VHF coverage area.
As of 2008, the United States NAVSTAR Global Positioning System (GPS) became fully operational GNSS used by ships. However, the Russian GLONASS is being restored to full

operation (20 satellites by 2009) and the European Galileo global navigation system is scheduled to be operational in 2013. Thus, other future GNSS candidates include China's COMPASS navigation system (potential of 35 satellites) and India's Regional Navigational Satellite System (IRNSS). GNSS is the ideal radio navigation aid to allow full exploitation of the global benefits to be gained from port-to-port sailing operations via R-VDL.
Therefore, to meet required performance for the more stringent navigational applications such as collision avoidance and enhanced traffic control, the following augmentation of the GNSS signal is required in order to improve accuracy and monitor data integrity:
1. Ship Local Augmentation System (SLAS) used onboard ships (SRS);
2. Local VHF Augmentation System (LVAS) using VHF CRS and VDL equipment to send GNSS augmented signals to the onboard ships GNSS Receiver; and
3. Regional Satellite Augmentation System (RSAS) using satellite Ground Earth Station (GES) terminal and Satellite Data Link (SDL) to send GNSS augmented signals to the ships.
In the other words, the LVAS solution will augment the GPS or GLONASS signals to improve ships safety and security and sailing awareness including collision avoidance in coastal navigation, during approaching to anchorages and maneuvering in seaports. The LVAS will yield the extremely high precision and meet the present maritime civilian requirements for high-operating Integrity, Continuity, Accuracy and Availability**(**ICAA) necessary for all stages of ship navigation. At this point, it is expected that the end-state configuration will pinpoint the ship's position to within one meter or less with a significant improvement in service flexibility and user operating costs.
The LVAS is comprised of ground and ships equipment. The ground augmentation equipment includes 4 or more reference receivers (GMS), a LVAS ground facility and a VHF data broadcast transmitter or VHF CRS. However, this ground equipment is complemented by LVAS VHF transceiver installed onboard ships. Signals from GPS satellites are received by the LVAS GPS Reference Receivers (4 receivers for each LVAS) at the LVAS-equipped seaport. The GMS terminal calculates their position using GPS signals. The GPS reference receivers and LVAS Ground Facility known as master stations (GCS) work together to measure errors in GPS-provided position. The GBAS Ground Facility produces a LVAS correction message based on the difference between actual and GPS-calculated position. Included in this message is suitable integrity parameters and approach path information.
This LVAS correction message is then sent to an VHF CRS, which broadcasts the LVAS signals within VHF coverage area to the LVAS equipped ships. It provides its service to local area coverage approximately up to 100 mile radius. The signal coverage is designed support the ship's transition from approachings to the anchorages in coastal water areas into and throughout the seaport terminals areas. The receiving LVAS equipment onboard ships uses the corrections provided on Position, Velocity, and Time (PVT) to guide the ship safely. In fact, the LVAS signals provide more safety sailing in coastal waters and maneuvering on the anchorages and in seaports.
In addition, the GAVDL-B solutions are an uplink service intended to support a range of applications such as seaport surface surveillance for managing all ships movements and vehicle traffic operations. Thus, each CRS terminal provides uplink broadcast of GAVDL-B messages generated by the STC and GCS infrastructures. It provides increased position accuracy complying with new CMGC concept generated locally by the CRS terminals, and supports increased position accuracy of RADS-B reports.
Note: In this thesis the use of the current nomenclatures: Ground Based Augmentation Systems (GBAS) and Satellite Based Augmentation Systems (SBAS), which appears in the classification of acronyms, will be replaced by LVAS and RSAS terminology(Prasad and Ruggieri 2005).

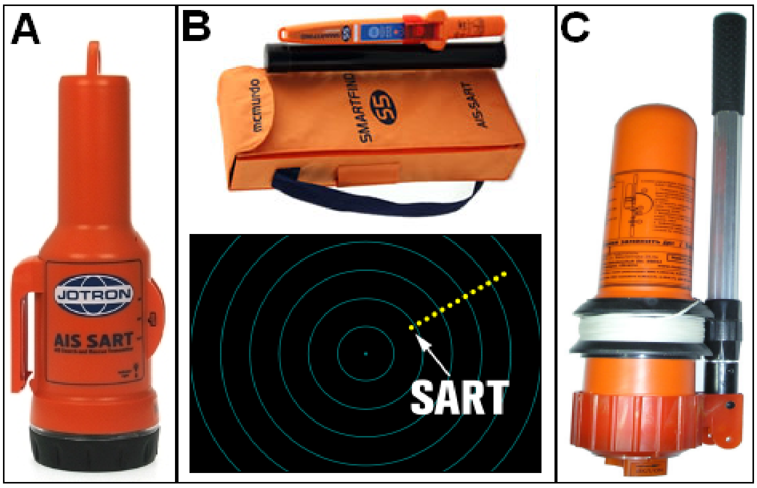

Figure 4.52. Radio SART– Courtesy of Manual: by Ilcev

4.9. Radio Search and Rescue Transponder (SART)

The SART system is for identification of lifeboat, survival craft and Man over Board (MOB) equipped with SART units by the marine surveillance radar onboard ships and aircraft or helicopters during emergency and distress alert. This system can also serve in the special situation when aircraft landing at sea and in this case aircraft will act as vessel to transmit the alert messages on the designated aeronautical air to ground route frequency and maritime distress frequencies as well. In this situation will also help already mentioned EPIRB for ships distress and ELT for aircraft alert and emergency situations.

In this context will be presented maritime emergency equipment known as SART that can be used for ship distress and aircraft landed at sea. According to IMO SOLAS requirements SART unit has to be installed on every ship since 2011. In addition, some mini SART units can be discreetly installed onboard ships and powered by long life batteries or by ships supply, so if some pirates capture certain ship, it can be found easily on SART radar display(Kopacz *et al.* 2001).

1. Jotron R-AIS Search and Rescue Transponder (SART) – This unit is waterproof and a self contained, waterproof radar transponder intended for emergency use at sea, shown in **Figure 4.52 (A).** The radar-SART is used to locate a survival craft or distressed vessel by creating a series of dots onboard a rescuing ship's or helicopter radar display, shown in **Figure 4.52 (B Below).** A SART will only respond to a 9 GHz X-band (3 cm wavelength) radar within a range of approximately 8 nautical miles (15 kilometers). The SART unit will not be seen on S-band (10 cm) or other radar. Unique AIS technology contribute to a more effective and less time consuming SAR operation, due to superior position accuracy and can detects on both R-AIS Class A and B (JORTON 2014).

2. McMurdo Portable R-AIS SART – The new Smart find S5 AIS SART is a new manual deployment survivor location device intended for use on life rafts or survival craft. It meets IMO SOLAS requirements and is an alternative to a Radar SART, shown in **Figure 4.52 (B Above).**Thus, this SART is very suited to be used onboard ships, aircraft and helicopters(MCMURDO 2014).

3. Musson 505 R-AIS SART – This Ukrainian product is AIS SART device illustrated in **Figure 4.52 (C).** This SART operates on A and B VHF channels of R-AIS inspire of standard SAR radar transponder operating in 9.2-9.5GHz. This new SART model fully corresponds to IMO, SOLAS and GMDSS requirements. The Musson R-AIS SART 505 uses the built-in GPS Rx module to send messages with coordinates of distress to near R-AIS installed onboard aircraft or ship(Marine 2014).

5. Chapter 5

SPACE TRACKING AND DETECTING SYSTEMS

This chapter introduces the main technical characteristics and possible solutions of Space Tracking and Detecting systems for maritime applications. As stated earlier the GMDSS network is designed by integrating radio and satellite systems for the ship's safety, distress alert and SAR communications. This system is not effective enough to provide a real tracking and detecting system of ships for everyday navigation aids, for enhanced safety and security and for the more effective collision avoidance of ships in very critical weather conditions.
Modern Space Tracking and Detecting Systems and Equipment are usually using VHF, UHF and SHF-band integrated or autonomous onboard mobiles space CNS equipment that is introduced in the following sections.

5.1. Overview of the Satellite Long Distance Identification and Tracking (LRIT) System

The LRIT system is providing positioning data for detecting and monitoring of seagoing ships sent from onboard satellite transceiver equipment via GEO Inmarsat or Non-GEO satellite network represented by Big LEO Iridium satellite constellation. In 1972, IMO experts with the assistance of Consultative Committee on International Radio (CCIR), commenced a study of new distress and safety systems for maritime applications, and after many efforts IMO and its member governments developed the new Global Mobile Distress and Safety System (GMDSS) as an integration of Radio and Satellite Communications in coordination with CCIR, ITU, WMO, IHO, Inmarsat and Cospas-Sarsat. The GMDSS was incorporated into Chapter 4 of the SOLAS Convention and began implementing the GMDSS in 1992 and full complying took place on 1 February 1999. The carriage of communication equipment for GMDSS and SAR operations is mandatory for SOLAS Convention vessels (cargo ships of 3,000 GRT and over and passenger ships making international voyages). Other ships will fit equipment to the GMDSS standard on a voluntary basis or as required by their national administrations. Most ships, whether SOLAS or not, will find it desirable and convenient to install Inmarsat-type approved onboard ship equipment which will provide advantages for commercial communications and the added benefit of acceptance for GMDSS operation(Cairns 2005).
To improve GMDSS facilities of Standard-A and B in 1991 Inmarsat was developed third Standard-C device initially for maritime and later for land and aeronautical applications. This standard was the first Ship Earth Station (SES) transceiver with integrated GPS receiver and both tracking and communication antennas(Krajewski 2008). However, in 2001 Inmarsat introduced smallest Standard mini-C tracking and communication device allowing producers to develop more compact and less power consuming tracking equipment. The Inmarsat-C and mini-C are the smallest Inmarsat terminals suitable for all mobile, transportable and semi fixed applications. Both are used for transmission of two-way store-and-forward text or data messaging (telex) at a rate of about 600 b/sec on L-band, while facsimile and E-mail messages are transmitted only in ship-to-shore direction. The typical Inmarsat-C and mini-C have a small and compact omnidirectional antenna, which because of its lightweight and simplicity can be easily mounted on all types of ships, yachts, fishing boats and offshore platforms. Both antennas can be produced as a single Inmarsat or combined Inmarsat-C/GPS omnidirectional antenna, what depend whether GPS is integrated or not in equipment. The Inmarsat-C and mini-C devices have been designed to meet highly reliable maritime communication and tracking capabilities and are platform for development of new solutions of LRIT and satellite AIS (Skoryk, I and Ilcev 2013).

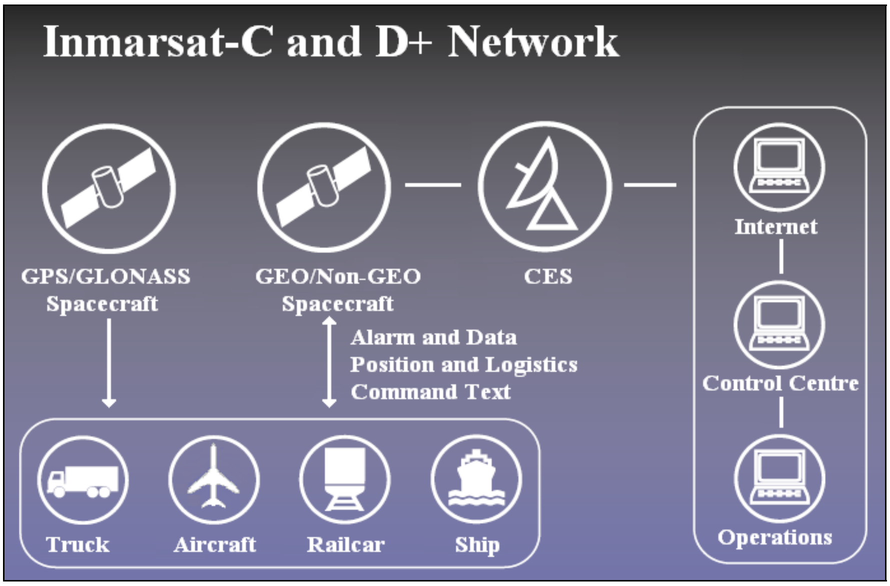

Figure 5.1. Configuration of SAT System– Courtesy of Paper: by Ilcev/Skoryk

5.1.1.Development of Satellite Asset Tracking (SAT) Networks and Equipment

A major goal of IMO is the near-universal use of GNSS of the GPS and GLONAS solutions integrated with Radio and Satellite Mobile Communication Systems. ICAO proposes and supports augmenting GNSS to provide and enhance ATC for civil aviation safety and security. As a result of these efforts, new LRIT and Radio AIS networks have been projected and developed to utilize CNS solutions and services at STC for improved safety and security in maritime transportation.

In order to meet the requirements for improved CNS and SAT in ocean navigation except LRIT it was also proposed establishment of Global Satellite Tracking (GST), Satellite AIS (S-AIS), Satellite Data Link (SDL) and other solutions. Thus, these current and new SAT applications will be used as a modern maritime CNS for ocean and sea crossings, coastal navigation, travel through channels and passages, approaching to anchorages and harbors, inland waters and inside of seaports. The new infrastructures will provide global and even local coverages for enhanced STC and SAT. Using these facilities can be enhanced tracking of pirates and fishing vessels as well. The new SAT technique will upgrade the basic GPS and GLONASS facilities in integration with radio and satellite transceivers as a primary means of tracking of sea going vessels and all land vehicle movements in the seaports.

The scenario of SAT network is an integration employing the GNSS subsystem of the US GPS and Russian GLONASS to provide free of charge Position, Time and Velocity (PTV) data to different users at sea, on the ground (road and rail) and in the air. Thus, this PTV data can be received by ships, land vehicles and aircrafts via onboard GPS/GLONASS Receivers (Rx) and used in navigation purpose, illustrated in **Figure 5.1.** If GPS/GLONASS Rx is integrated with Satellite Transceiver (Rx/Tx) in a unit with both antennas known as SAT, it will be possible to provide frequent transmission of PTV data via GEO and Non-GEO spacecraft through CES and Internet to the Control and Operations Centres.

Therefore, tracking systems mainly are necessary for tracking and detecting of ships and what is very important for collision avoidance of a vessel especially in areas with heavy traffic movements such as harbor or close cost areas. Using standalone GPS or GLONASS data these systems can provide speed and position of vessels only. Integrated with special units and sensors, these systems are also capable to control main parameters of ships such as continuous position, mileage, consumption of fuel, different electrical and mechanical indicators, residual level in petrol and water tanks, temperatures of engine and etc.

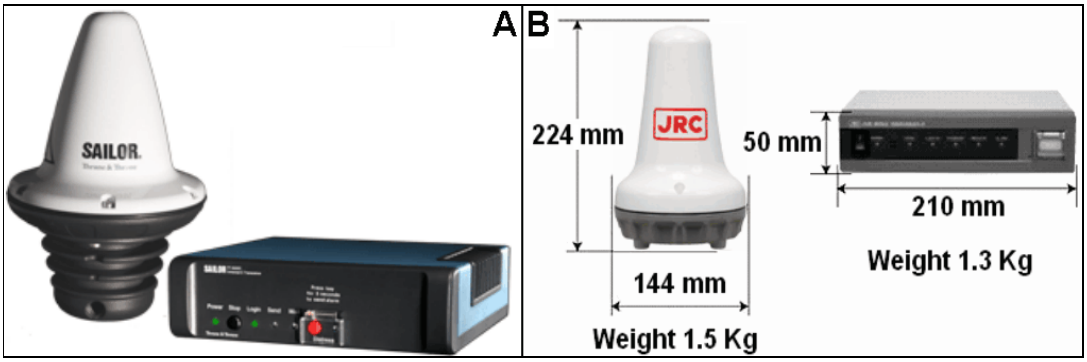

Figure 5.2. Inmarsat Standard-C and mini-C Equipment– Courtesy of Paper: by Ilcev/Skoryk

The main goal of the SAT network is to provide integrated communication facilities to the GPS or GLONASS receivers for sending PTV data to the Control and Operations Centres and get back tracking data of adjacent ships. In such a way, appearance of these SAT systems will make a very important contribution for collision avoidance, for enhanced safety and security according to the SOLAS Convention and improved SAR operations at sea, because these systems are working without man intervention in order to prevent human errors. Thus, continuous increasing of maritime transport by the sea going ships is augmenting the necessity for exploration the emerging safety and security solutions for vessels CNS and especially for tracking, detecting and messaging facilities. These new techniques consider the consequences of a communication framework supporting asynchronous messaging that can be used to enhance the basic LRIT and R-AIS capability. The analyzed modern SAT options can be pursued within the standardization process or independently developed with attention to compatibility with existing radio systems (Skoryk, I and Ilcev 2013).

5.1.2. Inmarsat Standard-C and mini-C GEO Solutions

Inmarsat-C SES is a digital satellite transceiver whereby data can be encoded into digital format, whether text, numeric data from instruments or other information derived from GPS receiver in digital format and sent over the Inmarsat GEO constellation or the system can allow polling of this data. In vice versa direction, this unit can receive from the shore all necessary data for collision avoidance from shore. A simple user interface allows sending and receiving messages by data and telex system. This is a highly reliable mobile satellite message communication system, having the ability to handle ships commercial, operational, tracking and personal messages just as easily as distress and safety communications.

The Sailor Inmarsat-C terminal is consisting satellite communication modem or transceiver with omnidirectional antenna(Teller *et al.* 1988), shown in **Figure 5.2 (A).** This unit is usually integrated with GPS or GLONASS receiver, while some models can be without GNSS facilities for SCADA or M2M system. The JRC mini-C unit has the same characteristics, functions and peripheral equipment as Standard-C, with only a difference that is smaller and more compact, shown in **Figure 5.2 (B).** Both standards SES terminals are designed as Message and Determination Terminals (MDT) for global maritime messaging, distress and tracking service that has become a mainstay of maritime safety and security as part of the GMDSS network.

For non-safety use the system offers a 600 b/s text message and short packet system. On the terrestrial side the Inmarsat-C system connects to Internet, PSDN, Telex, Fax and PSTN. The system consist of Network Coordination Stations (NCS) to control spectrum and access to the Inmarsat satellites and to announce calls, and to connect all SES terminals to a number of Inmarsat-C CES (C-CES) terminals for transferring of data in both directions (ship-to-shore and vice versa). The NCS terminals are owned and operated by Inmarsat while the C-CES stations are owned and operated by Tele Operators and placed locally in these countries.

Figure 5.3. Message Display, Keyboard and Emergency Devices – Courtesy of Paper: by Ilcev/Skoryk

The NCS stations also provide mobility management to the C-CES terminals, i.e. keeping track of registered mobiles and to which satellite a particular mobile terminal is logged in to. On top of this the NCS transmits a common channel with distress and security information. The NCS terminals are monitored and operated from the Inmarsat Network Operation Center (NOC) in London, while the NCS stations are placed in Norway, Italy, Japan and Singapore and offer both internal redundancy as well as site redundancy to ensure high availability. The C-CES stations are store-and-forward terminals for text messages and short data packets. The CES terminals hold user registrations and generate billing information. The technology utilized includes: TDM/TDMA, BPSK, TCP/IP, E-mail, Telex, X.25, FAX and so on.

However, to perform communication and tracking facilities Standard-C and mini-C can use display or messenger terminal with installed communication software and keyboard, shown in **Figure 5.3.** Additionally both standard can use normal PC or laptop configuration with adequate software and peripherals like printer and extra memory unit, while on small vessels and yacht can be installed small keyboard and printer of producers Sailor/Thrane & Thrane (TT) small keyboard and Capsat printer, shown in **Figure 5.4 (A and B),** respectively(Skoryk, I and Ilcev 2013).

The Inmarsat-C/mini-C networks and onboard ships equipment provide the following functions and services: EGC (Safety NET and Fleet NET) maritime safety and emergency transmissions, alert and distress message handling, two-way digital store-and-forward data messaging including polling, E-mail, data reporting, distress and security alert transmissions at the threat of terrorism or piracy information, etc. However, both Inmarsat C-system and functions are completely conforming to the IMO SOLAS XI-2/6 Convention and IMO MMSC Resolution 136(76)/147(77).The feathered functions of C-system are as follows:

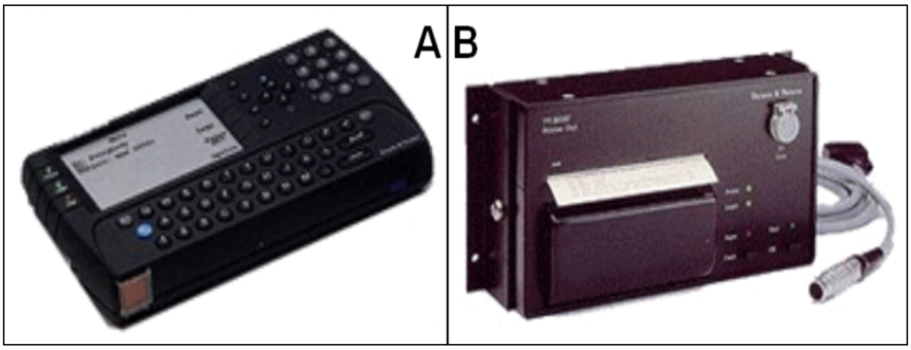

Figure 5.4. Message Terminal and Capsat Printer – Courtesy of Brochure: by Sailor

1. Store and Forward Message Transfer Terminal – Data messages can be transmitted and received by simple operation using satellite transceiver or modem. Store and forward message transfer by ARQ ensures reliable message transmission between the SES and telex or data subscribers via CES and through a satellite channel.
2. External Buzzer Box – When an incoming message is received, the external buzzer box generates an audible alarm to advice message reception to the bridge or other places, shown in **Figure 5.3 (Left).**
3. Distress Button – In case of emergency onboard ship or income distress message, shown in **Figure 5.3 (Middle),** the operator has to press this button and provide communication procedure according to the GMDSS regulations.
4. Ship Security Alert System (SSAS) Button – The multiple address functionality of modem enables additional messages to be sent directly to the vessel owner, operator or crew family, in addition to the required flag state and ship owner message in relation to the ISPS code, shown in **Figure 5.3 (Right).**
5. Messenger Terminal (Display), External Memory (USB) Device and Printer – These units fully meet the latest IMO regulations for GMDSS as main unit for Distress alerting Safety and Security (SAS), Search and Rescue (SAR) operations.
6. Distress Alert – The distress alert message sent by Inmarsat-C SES (C-SES)station has to contain own vessels ID, date/time and the present position, course and speed is acquired manually or automatically from an integrated GNSS receiver, such as GPS or GLONASS, or the vessel's navigational interface, allowing you to send a distress alert simply by pressing and holding the dedicated built-in distress button or sending distress messages to CES and SAR forces.
7. Enhanced Group Calling (EGC) – The C-system can transmit special group messages in determined sea area, which enables authorized maritime information providers to broadcast international safety and commercial service messages to selected groups of ships or fleet. The EGC solution is available as a standard on C-SES providing two EGC services: a) EGC Safety NET is the international safety service, which broadcasts Maritime Safety Information (MSI), such as meteorological and hydrographic messages to all ships in certain geographical areas, and b) EGC Fleet NET is the international commercial service, it is a subscription service, and allows shipping companies or governments to broadcast messages to selected groups of vessels.
8. Polling – The C-SES is programmed to automatically respond to a polling command from any landline subscriber, such as shippers, chatterers, agents, port operations etc, and send out pre-edited messages and various onboard data to them.
9. Data Reporting – The C terminal automatically transmits ship's position data and various onboard data by presetting the file name, send-out time and address number, and input of an automatic transmission command.
10. Self-Testing Facilities – The C-SES incorporates various self-diagnostic programs to facilitate maintenance and troubleshooting. The self-testing results are displayed on data terminal equipment. In addition, automatic testing for performance verification and commissioning via satellite channel is also available.
11. AC/DC Switching Power Supply – In case occurs failure of the ship's mains AC sources, the power supply is automatically switched over to an emergency DC source of ship batteries, what is main GMDSS requirement.
12. GPS Data – The C-SES optionally can incorporate high-performance GPS or GLONASS receiver in the Externally Mounted Equipment (EME) for position polling and reporting. Otherwise, the C-SES units dedicated for ships tracking and detecting solutions should by obligation integrate GPS or GLONASS receivers in the onboard Inmarsat-C, mini-C and Inmarsat-D+ or Isat Datadevices (Prosch 2007; Skoryk, I and Ilcev 2013; Skoryk, Ilcev 2014).

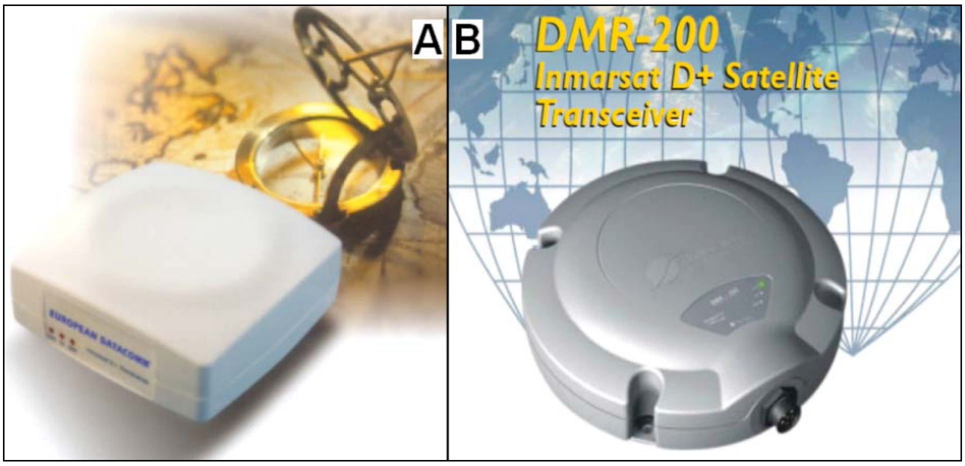

Figure 5.5. Standard-D+ Units – Courtesy of Brochure: by SkyWave

5.1.3. Inmarsat-D+ and IsatData Pro/IsatM2M Solutions

The Inmarsat-D+ system and network is developed as a first generation of D+ standard on the basis of Inmarsat-C system as the best and very cost effective solution for SAT and GST applications. This unit is able to transmit and receive data anywhere via Inmarsat satellite constellation and it is ideal for ship tracking, security and fleet management. The unit is convenient for M2M or SCADA solutions as well, for what is not necessary to be integrated with GNSS receivers. It is low powered by onboard main sources and batteries supply with possibility to work even if the ship is grounded somewhere without main engine power. This unit is the integration of GPS Rx and small Satellite Transceiver, which is de facto Receiver and Transmitter (Rx/Tx) with GPS/Satellite antennas fixed in the compact and rugged fiberglass or plastic enclosure. In **Figure 5.5 (A)** shown the first and in **5.5 (B)** second generation of SkyWave Inmarsat-D+(Wilson 2008).

Features of these units are two-way messaging service of about 25-byte message data size from terminal or in ship-to-shore direction and up to 100-byte message size to terminal in shore-to-ship direction. Fast message delivery in 1 minute to terminal and rapid response in 10 seconds from terminal. Both units can be integrated with GPS or GLONASS receivers providing speed and position data. With external additional sensors it monitors consumption of fuel, mileage, temperatures and etc.

Recently Inmarsat has developed IsatData as third generation of D+ standard for two-way burst messaging service that enables a wide range of SAT, SCADA or M2M applications for tracking and monitoring remote fixed or mobile assets on a global basis, whether at sea, on the land or in the air. The new generations of IsatData Pro for mobiles and IsatM2M for SCADA are satellite telematic equipment based on Inmarsat-D+ standard, which offer faster data forwarding rates, quicker responses to polling requests and shorter time to first transmission. The GST system may use satellite services of the Inmarsat Isat Data constellation, which is a fully funded, launched and operational satellite network with a commercial life beyond 2023.

Therefore, both IsatM2M and IsatData Pro Inmarsat solutions were developed from initial Inmarsat-D+ system and they can be used for all mobile and fixed SAT applications. The global IsatM2M satellite network is able to offer better service than Inmarsat-D+ system, which examples for maritime applications include: tracks geographic location of fleets, finds a deviation from pre-defined geo fenced areas, monitors ship's locations worldwide, sends PTV data to the special shore Air TCC and enables polling by request from shore to be obtained data of any ship in certain sailing area. Depending on the requirements of GST solution Inmarsat has a communication service that can meet those needs presented in **Table 5.1.**

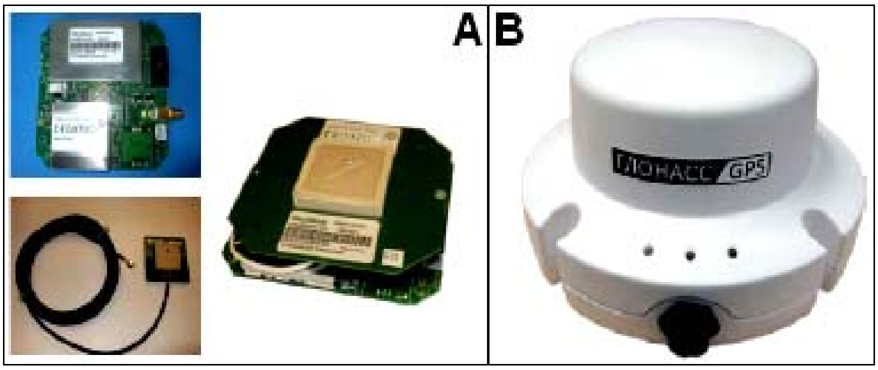

Figure 5.6. IsatData/IsatM2MUnits – Courtesy of Brochure: by SkyWave

Table 5.1. Comparison of Third Generation of Inmarsat SAT Solutions

Particulars	IsatM2M	IsatData Pro
Communication Capability	Two-way satellite	Two-way satellite
Service Type	Global	Global
Asset Types	Fixed & Mobile Assets	Fixed & Mobile Assets
Maximum From-Mobile Message Size	>192 bytes	6,400 bytes
Maximum To-Mobile Message Size	100 bytes	10,000 bytes
Typical Monthly Usage	< 10 kBytes	10 kBytes - 1 MBytes
Typical Response Time (Latency)	<30 seconds for typical messages	< 15 seconds for typical messages

Otherwise, Inmarsat system is providing coverage up to 75^0 North and South Hemisphere, so Inmarsat is not covering both poles. Because seagoing ships are not sailing so frequently in polar areas, coverage in these areas will be provided by Radio MF/HF/VHF system.
Inmarsat offers many models of unpackaged satellite SAT of SkyWave producer such as:
1. DMR-800 D/S OEM Terminal – This unit provides a flexible, unpackaged assembly with integrated GPS receiver and satellite transceiver, in-unit or separate satellite/GPS antenna and discrete input/output feeds, shown in **Figure 5.6 (A).** A built-in processor/controller board allows the unit to work as a simple modem and to interface a set of onboard sensors and actuators. This terminal is able to support GST and can be easily packaged with batteries to provide communications when grounded aircraft has not power supply.
2. DMR-800L Terminal – This unit has GLONASS/GPS receiver and satellite data transceiver dedicated for many SAT solutions including to provide GST service via both GPS and GLONASS navigation signals, shown in **Figure 5.6 (B)**(Prosch 2007; Skoryk, I and Ilcev 2013)**.**

5.1.4. Iridium and Globalstar Non-GEO (Big LEO) Solutions

Iridium as a real global operator provides voice and data service including SAT for all mobile applications via uplink/downlink at 1621.35-1626.5 MHz, feeder links at 29.129.3 GHz of Ka-band (uplink) and at: 19.4-19.6 GHz of K-band (downlink) and cross-link or intersatellite link at 23.1823.38 GHz of Ka-band.
Reliable everywhere on the planet, the Big LEO Iridium low-latency SAT solutions are dedicated, cost-effective and free from equipment interference. Because that Inmarsat system cannot provide polar coverage, for communication and tracking operations in Sea Area A4, Iridium solutions are the only compliant option available today. Thanks to intersatellite links, Iridium network is covering both poles, what is very important for aeronautical applications.

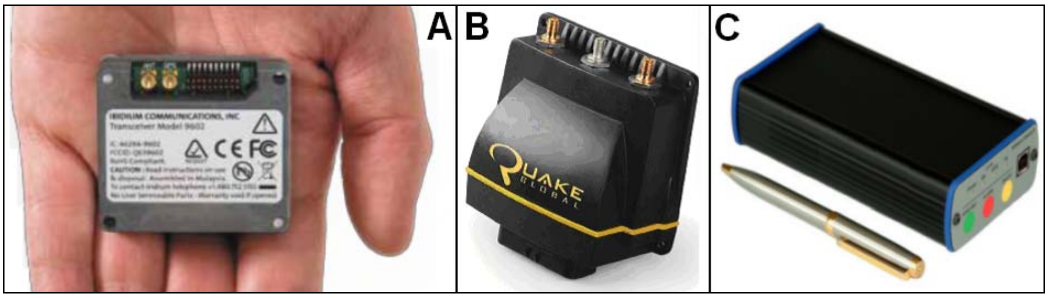

Figure 5.7. Iridium SAT Trackers – Courtesy of Brochure: by Quake and E-Track/NSE Systems

Iridium can provide an automatic vessel tracking service that uses special onboard equipment to transmit location reports from ship-to-shore. This vessel tracking system provides data such as GPS time, latitude and longitude, course and speed, and selected weather parameters. The information can be embedded ships messages and/or reported to a central database with each email session. In addition, automatic tracking reports also can be delivered according to a predetermined schedule. Four expedition cruise ships, multiple passenger vessels and other ships operating in the Arctic and Antarctic waters can use Iridium SAT system(Del Re *et al.* 2002).

On the other hand, the Globalstar system is also Big LEO, but because has not intersatellite links is not able to provide coverage of both pole areas and South Africa are not covered. This system is providing very cost effective onboard equipment and bandwidth than and other mobile satellite system, especially for African continent and coastal waters. Globalstar is providing service for users via satellite at 1.610-1.621 GHz (uplink) and at 2.483-2.500 GHz (downlink) and from satellite to GES at 5.091-7.055 GHz (feeder link).

The Iridium and Globalstar global mobile and personal satellite systems are providing the following tracking devices:

1. Quake 9602 Mini Tracker – The 9602 is a short-burst data transceiver with antennas designed for use as basic unit for many trackers using the Iridium Network, illustrated in **Figure 5.7 (A).** This very tiny, 41x45x13 mm and 27.22 grams, two-way transceiver is perfect for use in different applications including for LRIT and GST solutions. This unit has built-in GPS input/output ports, which will permit system integrators to interface with an external GPS receiver and antenna. In integration with GPS receiver, this satellite transceiver will be able to use a single dual-mode L-Band antenna for GPS and Iridium SBD, saving the cost of an antenna in applications.

2. Quake Q-Pro Multipurpose Tracker – This Iridium unit is a small (119.2x119.4x57.6 mm and 390.6 grams), rugged and environmentally-sealed universal tracking unit. Namely, it is transceiver for Iridium and GSM networks integrated with GPS receiver, shown **Figure 5.7 (B).** The same unit can be integration of Orbcomm/GSM/GPS modems as well designed as self-contained flexible solution for multiple applications ideal for any developer of mobile and SCADA (M2M) fixed applications. Mobile assets such as ships and containers, trucks, trains and aircraft can also be more safely tracked, monitored and managed.

3. E-Track/NSE Alpha Tracker – This unit is satellite tracking device of NSE/ex-E-Tracks Systems, whish provides real time and global coverage via Iridium and GSM networks, shown in **Figure 5.7 (C).** Features of this integrated 116x64x 46 mm and 239 gr very small unit are automatic transmission of the GPS position together with speed, date and time. It also has buttons for sending parameterizable alarm and alert messages by satellite E-mail or GSM messages. The integrated time programmer is enabling the E-Track device to send regularly messages during the same intervals, namely it has ability to send SBD on two-state input trigger for special alarms and start-up of the unit when movement starts. Therefore, in accordance with the set programmable interval this unit is providing transmission of short messages from external applications, recording position and automatic sending of a message on passing through a pre-defined geographical position (500 configurable waypoints).

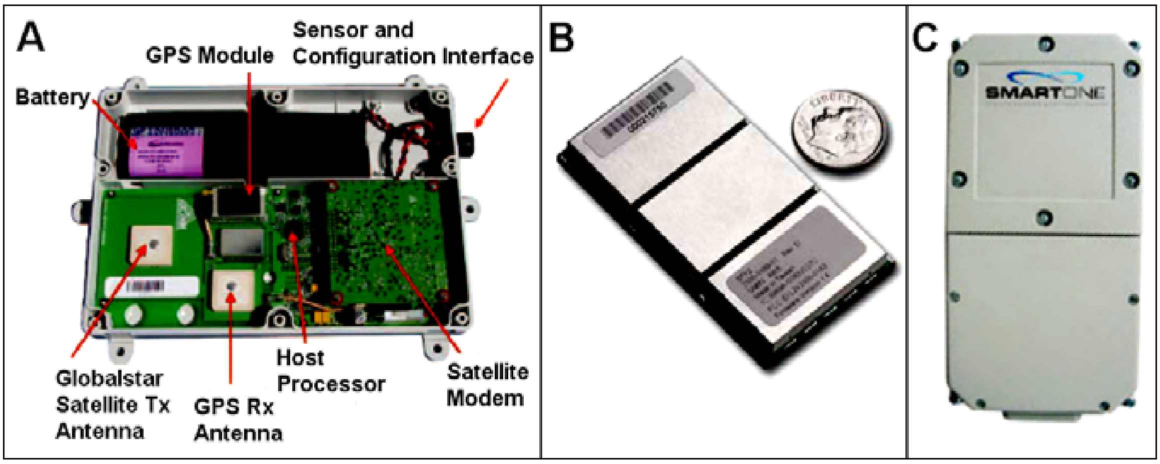

Figure 5.8. Globalstar SAT Trackers – Courtesy of Brochure: by Axonn

Globalstar tracking units are usually simple and one-way satellite trackers containing GPS receivers and satellite transmitters. The US Qualcomm company is manufacturer of the special Globalstar GPS receiver and satellite transceiver for duplex voice and data global tracking and communications systems for mobile applications. The Axonn producer of satellite tracking equipment using Globalstar network are designated for asset tracking of road vehicles, trains, containers and ships, but with simply modification of GPS receiver it can be used for aircraft as well. Here will be introduced the following simplex Globalstar tracking devices:

1. Simplex AxTracker – This unit provides a battery-operated, self-contained telemetry device, delivered complete and ready-to-go with no need for an external antenna or power source, shown in **Figure 5.8 (A).** It is 9.25x6.25x1" in size unit ideal for hazardous operating environments and is ideal for mobiles onboard installation and tracking because can work independently of power source and any inspection. The units can be pre-programmed by to requirements and to send GPS location and other information on pre-defined intervals. Messages are transmitted over the Globalstar simplex service through a message routing infrastructure and then sent to host application or can be integrated with a hosted mapping application. However, options for implementation range from configuring the AxTracker units to send a GPS location once or several time a day or when mobiles move, enter/exit Geo-fencing zones or integrating the units to capture and report other information such as speed, position, engine run-time and so on. Unit is using battery up to 7 years of life.

2. Simplex Axonn STX2 Tracker – At a mere three square inches, this unit is the world's smallest 3 Sq inches satellite transmitter available for use by product developers, shown in **Figure 5.8 (B).** This Axonn product also operates over the Globalstar simplex data network to enable data collection from remote sites globally using low current and long battery life. As the lowest cost method for collecting data over satellite network, seaman should consider the STX2 as an integral, low-power component for the development of ships asset tracking, monitoring and management systems.

3. Simplex Axonn SMARTONE Tracker – This GPS receiver and Globalstar transmitter is designed for the intelligent tracking and management of powered and non-powered fixed and movable assets, and is a practical solution to improve operating efficiency and security, shown in **Figure 5.8 (C).** The design of this unit allows it to be easily installed and field managed without the need for harnesses, antennas and external power. The advantages of independent power supply, this unit can work and send position data even if vessel is without any power sources. The SMARTONE is powered by 1.5 V adapter or by 4 AA 1.5 V lithium batteries providing 3+ years of battery life and removes the need to purchase expensive proprietary batteries for replacement(Skoryk, I and Ilcev 2013).

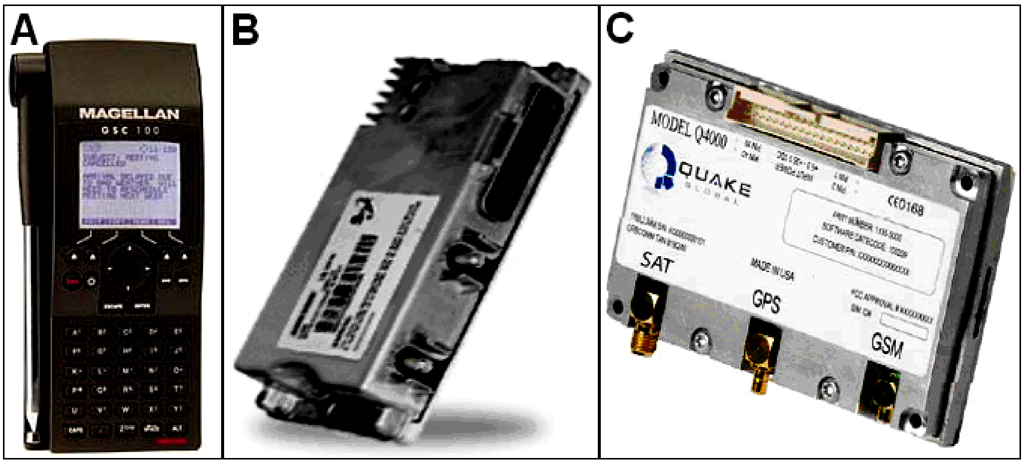

Figure 5.9. Orbcomm SAT Trackers – Courtesy of Brochure: by Magellan, Stellar and Quake

3.1.5. Orbcomm Non-GEO (Little LEO) Solutions

Orbcomm satellite constellation works without inter-satellite links, therefore communication with the network is possible if satellite is covering subscribers and ground gateway at the same time. In such way Orbcomm satellite constellation covers all Earth surface, but communication is possible only if mobiles are in a particular area where ground gateways are operational, hence this satellite system cannot provide global coverage service. The Orbcomm satellite system receives at 148 to 149.9 MHz by 2400 b/s and transmits at 137 to 138 MHz and 400.05 to 400.15 MHz by 4800 b/s. The system uses X.400 (CCITT 1988) addressing and message size is typically 6 to 250 bytes (no maximum). This Little LEO mobile satellite system covers South Africa and offers the following tracking devices for GST and AIS:

1. Magellan GSC 100 Terminal – This unit is the world's first handheld satellite terminal that allows sending and receiving text and E-mail messages to and from anywhere in the coverage area, illustrated in **Figure5.9(A)**. This unit offers communication and navigation using the Orbcomm network and GPS satellite system. Messaging features allow worldwide data transmissions via Orbcomm satellites, send and receive brief, global E-mail messages called Global Grams to any E-mail address via the Internet, use menu-driven interface, storing up to 100 messages and 150 E-mail addresses, sending and receiving messages at pre-selected time intervals and automatic wake-up. This unit is equipped with telescopic whip antenna, rechargeable NiCad battery package and universal AC converter.

2. Stellar DS300 Terminal – This device is a two-way satellite communicator for use with the Orbcomm network, illustrated in **Figure5.9(B)**. The DS300 terminal is a complete hardware solution for companies using a wide variety of applications to track, monitor and communicate with fixed and mobile assets around the globe. It features a satellite modem, user-programmable application processor with adequate software, GPS receiver and battery charger packaged in a rugged and automotive-grade enclosure. In such a way, the world-class design, and stable performance make the DS300 an exceptional device for transportation, heavy equipment, marine, aeronautical and many other markets. This satellite modem is configurable with 8 input or output digital channels, 4 input analog channels and 8 GPS receiving channels. Its user programmable application processor can facilitate Value-added customers for different applications.

3. Quake Q4000 Terminal – This universal Orbcomm communication and navigation unit is cost effective and fully programmable satellite and GSM data modem with 22 channel GPS global tracking capability, illustrated in **Figure5.9(C)**. It is serving for SCADA (M2) and business-to-business Internet communications with land, marine or aviation based assets and equipment anywhere in the world(Skoryk, I and Ilcev 2013; Skoryk, Ilcev 2014).

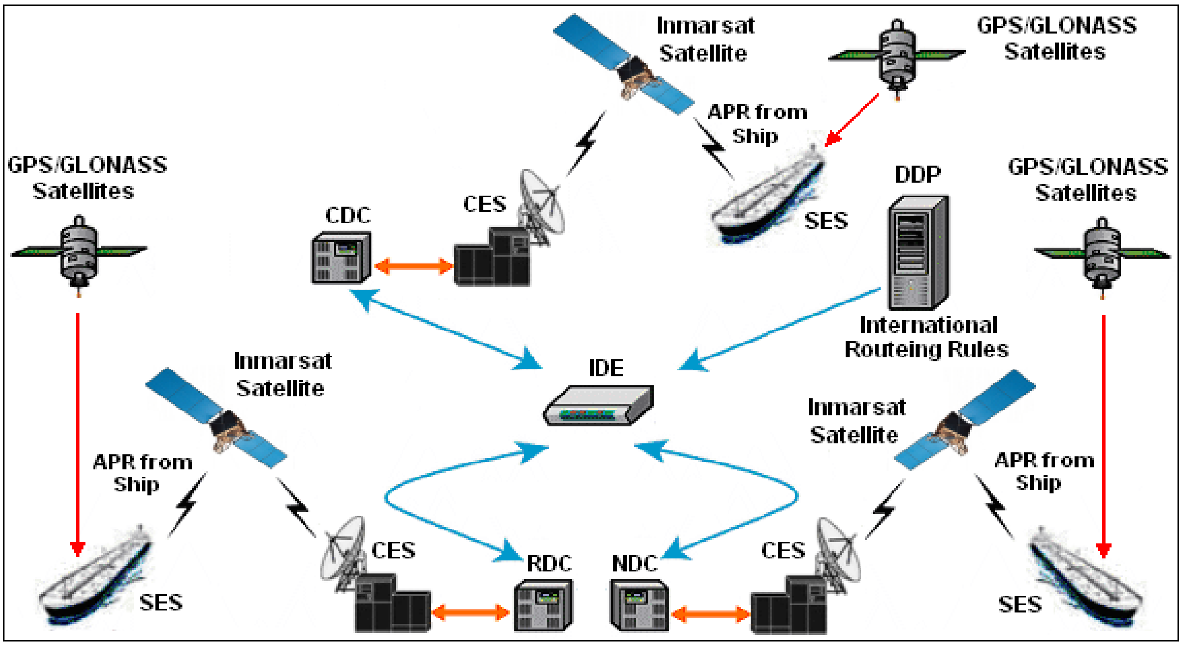

Figure 5.10. LRIT Guide to Requirement and Implementation – Courtesy of Manual: by AMSA

5.1.6. Development and Improvements of LRIT

The concept of LRIT was borne out of the desire to increase maritime domain awareness and terrorist attacks worldwide. The IMO specialists introduced the International Ship and Port Security (ISPS) code in 2003 and began a dialog about a maritime security system to receive daily position reports from ships engaged in international voyages. The concept of a global tracking system with high security and performance was conceived in 2006 under the name "Long Range Identification and Tracking" system of vessels or as abbreviation "LRIT"(Claramunt *et al.* 2006; Shuang and Junzhong 2007). The LRIT acronym and system is experiencing two problems:
1. Since 2001 the Low Rate Information Transmission (LRIT) is an international standard in use for data transmission that was developed by the Coordination Group for Meteorological Satellites (CGMS) in response to a digital meteorological satellite broadcast. Therefore, the same abbreviation of LRIT for the ship tracking system is not appropriate and in the future will have to be substituted by adequate nomination.
2. The second problem of maritime LRIT is that is usually system for commercial data and information without possibility to be used as system for reliable ship collision avoidance and improved safety and security at sea.
In fact, the LRIT system is providing tracking and detecting data to control centers only for commercial purposes, although can be upgraded with possibility for collision avoidance. Both above problems can be solved by the development of proposed Global Ship Tracking (GST) system as a complete maritime commercial and CNS system, which will be introduced in the following section of this chapter(Skoryk, Ilcev 2014).

5.1.6.1. Operational Concept of LRIT Network Architecture

The Inmarsat-C and mini-C standards were a main platform for deployment of the LRIT system as compulsory by IMO and SOLAS Regulation adopted by the 2002 SOLAS Conference, which simplified overview data flow is illustrated in **Figure 5.10.** This shows the process for linking the data collection to ground centers operated by the Contracting Government to an exchange system known as the International Data Exchange (IDE).
A simplified overview of the LRIT global data flow is shown in **Figure 5.10**.Namely, all ships sailing around the globe are sending Automatic Position Reporting (APR) data derived

from GPS/GLONASS satellites via Inmarsat spacecraft and CES terminals to the Regional (RDC), Cooperative (CDC) and National Data Centers (NDC), respectively. All centres are connected via Data Distribution Plan (DDP) of International Routeing Rules (IRR). The LRIT network is providing positioning information sending by all ships globally for a commercial and SAR purposes and not for collision avoidance and enhanced safety.
The IMO office has appointed the International Mobile Satellite Organization (IMSO) as an LRIT Coordinator, who will undertake the audit and oversight functions for LRIT. Long time before that, the IMO office has adopted an amendment to Chapter V of the 1974 International SOLAS Convention that introduces new mandatory position reporting obligations for all SOLAS ships. At this point, the SOLAS Chapter V, Regulation 19-1, on LRIT refers to the requirement for specified Convention vessels to automatically transmit their identity, position and date/time of the position at 6-hourly intervals, with ability to increase the rate to intervals of up to once every 15 minutes when requested. In addition, the equipment must be able to respond to poll requests. The LRIT system was designed in such a way as to limit the direct cost to ship or SAR services, with IMO Member States bear the cost of the system. The SOLAS amendment came into effect 1 January 2008 with compliance originally mandated from 31 December 2008. On December 2008, at the 85th meeting of the IMO Maritime Safety Committee (MSC), transitional arrangements were agreed to cover the period between 31 December 2008 and 30 June 2009(POPA ; SOLAS).
Both Inmarsat ships C-terminals come standard with LRIT facilities provide Maritime Domain Awareness (MDA) initiative to enhance maritime safety, security and protect the marine environment according to the IMO requirements for the global monitoring system of the ship’s movement. In fact, the LRIT network allows Member States to receive position reports from vessels operating under their flag, vessels seeking entry to seaport within their territory or vessels operating in proximity to the State’s coastline. There are two aspects to LRIT:
1. The “reporting” aspect where vessels to which LRIT system applies report their identity and position, with a date/time stamp, every six hours (four times per day).
2. The “receiving” aspect where coastal States can purchase reports when vessels are within 1,000 nautical miles, or where port States can purchase reports when vessels seek entry to a port at a pre-determined distance or time from that port(up to 96 hours pre-entry).
Therefore, LRIT is not designed to provide position of all ships sailing in certain sea area for the purpose of collision avoidance and enhanced safety and security. Put in simple terms, LRIT is a collection and distribution system for basic information on vessels, which applies to the following ships engaged on international voyages: all passenger ships including high speed craft; cargo ships, including high speed craft of 300 gross tonnages and above; and mobile offshore drilling units. Ships operating exclusively in GMDSS Sea Area A1 and fitted with R-AIS are exempt from LRIT requirements, while ships operating in Sea Areas A2, A3 and A4are required to be fitted with a system to automatically transmit LRIT information in the accordance with SOLAS Regulations. Therefore, vessels limited to domestic voyages, for example coastal trading vessels that only travel between any national ports, do not reflect the definition of “International Voyage” and are not required to report to LRIT. However, if a vessel that normally does coastal trading proceeds to an international port for any reason, including dry dock, they will need to either fully comply with the LRIT requirements or apply for an exemption for the duration of the international voyage.
The LRIT vessel system involves a request and response process, with various components linked together. Ship LRIT network architecture must be capable of being configured to transmit information as an Automatic Position Report (APR). The APR includes the identity of the ship, the position of the ship and the date and time of the position report.

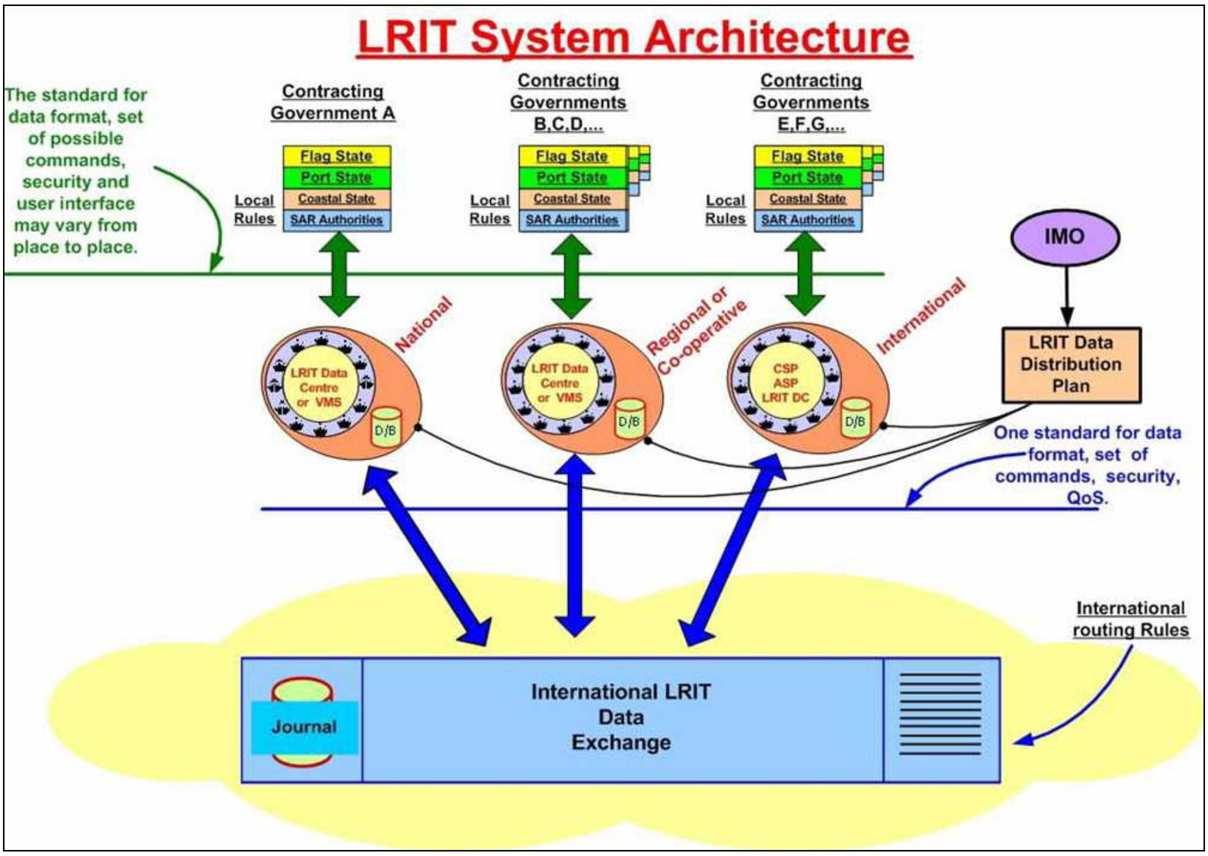

Figure 5.11. LRIT System Architecture – Courtesy of Manual: by AMSA

Thus, the LRIT system architecture, as provided in the IMO Performance Standards for LRIT (MSC.263(84) is illustrated in **Figure 5.11,** which offers governments choices ranging from:
1. Creation of a National LRIT Data Centre (NDC) to service own flagged vessels only;
2.Participation in a Regional or Cooperative Data Centre (RDC) or Cooperative LRIT Data Centre (CDC) that services two or more Member State's flagged vessels; through to
3. Reliance on an International Data Centre(IDC) site that would provide services to those Member States not using an NDC, CDC or RDC.
At the IMO Maritime Safety Committee session in October 2007 (MSC83) it was determined that the LRIT system could initiate implementation without the formation of an IDC although efforts continue to identify options to provide an IDC. Data flows from a vessel through the communications and Application Service Provider (ASP) to the IDE, and then back out to the requesting contracting government. Figure 1 depicts the model. The LRIT system design is based on a multi-tiered receiving system of ground data centres comprising of distributed data centres that report to a central IDE. Receiving systems are referred to as LRIT data centres and can be as simple as a small database connected to a satellite service provider and the IDE enabling the receipt and transmission of position reports(WAWRUCH 2008; Skoryk, Ilcev 2014).

5.1.6.2. Operational Requirements of LRIT Ground and Onboard Equipment

The LRIT equipment must be able to respond to poll requests for an on-demand position report and be able to immediately respond to instructions to modify the APR interval to a frequency of a maximum of one report every 15 minutes. The equipment requirement may be met through existing GMDSS Inmarsat equipment or it may be necessary to install devices designed to be LRIT compliant and testing has been designed to ensure whatever equipment is used will work within the overall LRIT system.

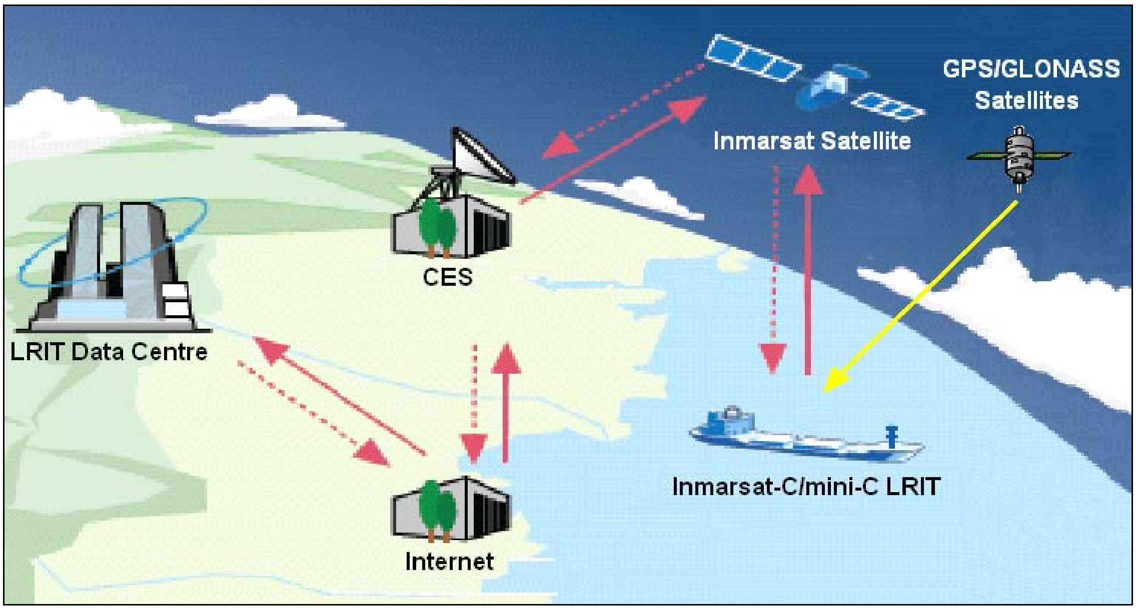

Figure 5.12. Inmarsat LRIT Network – Courtesy of Brochure: by Furuno

Ship owners or ships managers should be aware of the Application Service Provider (ASP) that their flag has recognized or authorized to undertake testing. The Terminal Control Unit (TCU) is the key connection point to the system and brings new functionality to ease operation to support day-to-day operation whilst ensuring compliance. It has a range of LED indicators so operators may quickly determine status such as power, Inmarsat login to adequate spacecraft and GPS fix and program status. This information can determine operational status of the system towards the flag Application Service Provider (ASP) or other physical inspections. Thus, they are all useful features if the C-SES SSAS and is also used for LRIT solutions.

According to the IRR system information transmitted by ships through automatic position reporting is available to the vessel's FlagState at all times. For another FlagState to access the information, they will send a request to the IDE. Thus, linked to the IDE is the DDP scheme that will have the "routeing rules" and this will verify that the "requestor" can access the information. In such a way, each Contracting Government will provide these routeing rules to the IMO, which has developed the DDP system. Data is entered into the DDP using the LRIT module of the Global Integrated Shipping Information System (GISIS). The DDP ensures that LRIT data flows according to the wishes of Contracting Government, i.e. providing information on vessels within 1,000 NM for coastal state or up to 96 hours out for port state. If the DDP verifies that the information request is valid, the IDE will then act as a link to the Data Centre (DC) requesting the information and DC will provide the information. The link between the satellite and an DC will require the use of an CSP and ASP. To ensure effective operation of the end-to-end system, the IMO rules have identified a rigorous series of development and integration tests that include Data Centres, ASP, CSP, IDE and DDP.

In **Figure 5.12**is presented the General Overview of the Inmarsat LRIT System, which provides transmission of GNSS tracking data between vessels and LRITDC via CES. The LRIT information should be acquired by data users within 30 minutes after the request is lodged and LRIT information should be acquired by data user within 15 minutes after it is transmitted from the ship. As stated earlier, according to implementation schedule of LRIT installations all ships after 31st of December 2008 have to be fitted with LRIT equipment for A2, A3 and A4 sea areas. Ships fitted with R-AIS are not required to comply with the LRIT regulation for A1 sea area, but in extremely bad weather situation can happen that sometimes R-AIS cannot be reliable, LRIT devices have to be compulsory for A1 sea area as well.

Figure 5.13. Inmarsat-C SAS Onboard Equipment for LRIT Solutions – Courtesy of Brochure: by JRC

The more convenient LRIT equipment for SSAS is an Inmarsat-C solution that contributes to the IMO's efforts to strengthen maritime security and suppress acts of terrorism and piracy against shipping, shown in **Figure 5.13.** In case of attempted piracy or terrorism, the vessel's SSAS function can be activated and appropriate law-enforcement or military forces can be alerted. The SSAS Inmarsat-C LRIT consists of ADE and BDE as main units with PSU and peripheral configuration of DTE and Printer. According to the SSAS Regulation C-SES has fully to meet and exceed the requirements listed in IMO MSC 136 (76) and MSC 144 (77) under SOLAS resolution XI-2/6. However, this stipulates that all vessels over 500 GT are required to be fitted with an SSAS to be used under pirate attacks to notify the flag state administration. Alarms are silent, meaning that there is no audio or visual indication on the vessel that an alarm has been activated.

The Inmarsat SatMail-C service allows inexpensive E-mail communication between land and through the light and compact Inmarsat-C equipment. It allows to ship operators and master mariners to send and receive E-mail as normally provided by the Internet, making it remarkably useful for LRIT or GST tracking facility globally, shown in **Figure 5.14**. In fact, the onboard navigation officer can send E-mail via Inmarsat-C SES via Inmarsat Satellite and CES to the SatMail-C Server. Then the server is distributing E-mail messages via the Internet to the users computers. In the vice versa direction users at shore are sending E-mail messages via Server, CES and Inmarsat Satellite to onboard SES terminal. The receiver can choose their own time to read the email, whether on land or at sea. Therefore, the users can send E-mail messages between Inmarsat-C equipments and the terrestrial Internet, as well as between Inmarsat-C equipments themselves. The operator can apply any combination of "TO", "CC" and "BCC" to send to multiple addresses. Delivery or non-delivery notices are sent to all ship's communications. The maximum size of each message, including addresses, is 32 KB (some Inmarsat-C equipments may limit this size to 8KB). Users can also use the polling feature to get information about the location of the ship from land, but cannot be sent positions of any ships in certain sea area for collision avoidance.

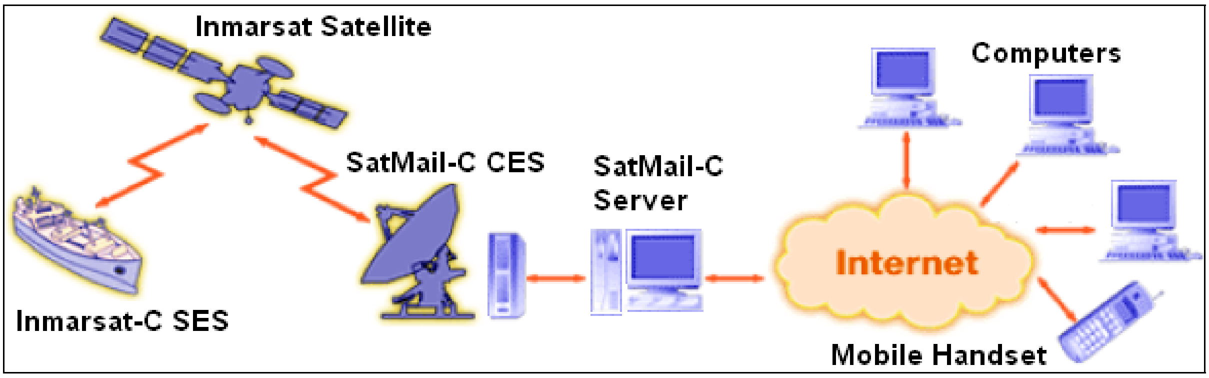

Figure 5.14. Inmarsat SatMail-C Service – Courtesy of Brochure: by KDDI

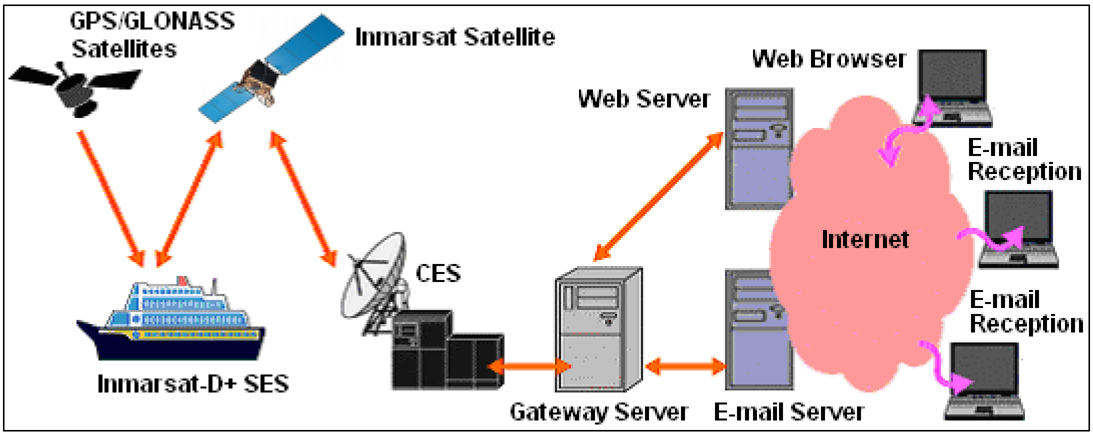

Figure 5.15. Inmarsat-D+ Network and Service – Courtesy of Brochure: by KDDI

As stated before, except Inmarsat-C and mini-C, the Inmarsat-D+ terminals and network are suitable for LRIT and GST solutions. The Inmarsat-D+ unit will be able to transmit position information derived from integral GPS as short burst messages globally. The Inmarsat D+ service and network are shown in **Figure 5.15,** where Inmarsat-D+SES is getting GNSS data and sends PTV in ship-to-shore and vice versa direction via Inmarsat satellite, CES, D+ Gateway Server and E-mail Servers to the Internet network subscribers. Inshore-to-ship direction users at the shore can use the polling feature to get data about the location of the desired ship, but this system cannot provide positions of any ships in certain sea area for collision avoidance. Therefore, the Inmarsat-D+ equipment is a bi-directional packet communications system (up to 80-bit transmission and 256-bit receiving) using the stored packet exchange method and it takes approximately 2 minutes for a reception after transmission(KDDI 2014).

Reliable everywhere on the Earth, Iridium low-latency LRIT network is dedicated and free from equipment interference, shown in **Figure 5.16**. Because Iridium covers both poles its LRIT system is able to operate in Sea Area A4. For maritime application this feature is not very important because Inmarsat is providing coverage up to 75^0 N and S Hemisphere, but for over North Pole flights Iridium coverage is the best solution. The LRIT terminal is getting signals from GNSS and transmitting identity, position, date and time in an APR. The ship equipment responds to polling of data from the shore station for on-demand position reports and instructions. The APR interval is about every 15 minutes ARP data are transmitted a minimum of 4 times per day to an NDC), CDC or RDC nominated by a flag(Skoryk, I and Ilcev 2013; Skoryk, Ilcev 2014).

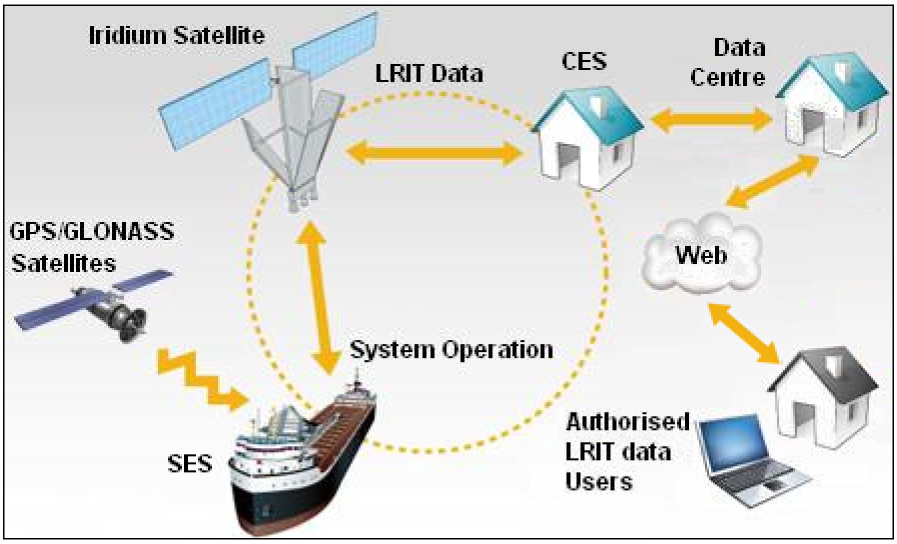

Figure 5.16. Iridium LRIT Solutions – Courtesy of Brochure: by Iridium

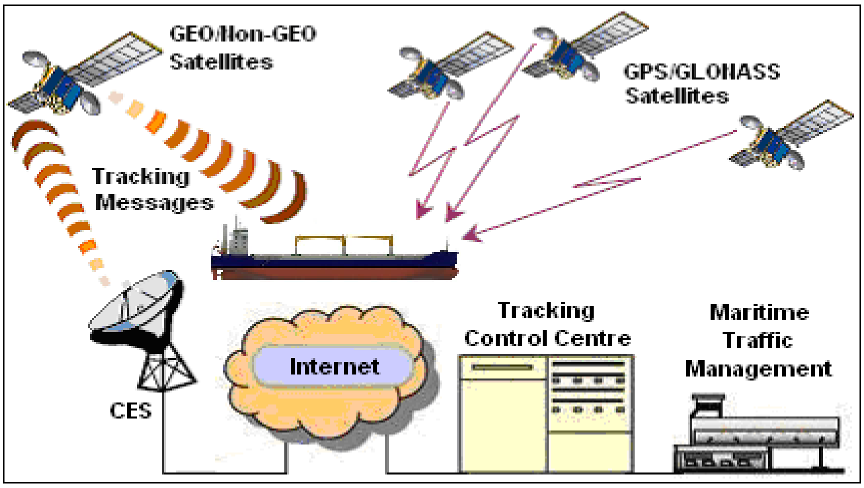

Figure 5.17. GST Network for Maritime CNS – Courtesy of Manual: by Ilcev

5.2. Global Ship Tracking (GST) Network and Equipment

New developed Global Satellite Asset Tracking (SAT) of seagoing vessels via Inmarsat, Iridium, Globalstar, Orbcomm and other satellite constellations is a basis for proposed Global Ship Tracking (GST) as the best global ship tracking and detecting systems, which space and ground segment is illustrated in **Figure 5.17.**The ship GST transponder consists of a GPS receiver and GEO or Non-GEO transceiver. The GST unit is receiving GPS or GLONASS signals and transmitting derived position via GEO/Non-GEO satellites, Coast Radio Station (CES) and Internet to the Tracking Control Centre (TCC) and Maritime Traffic Management (MTM).
In the TCC station processes all received tracking data and indicating on likewise radar display. In the vice versa direction TCC can send via the Internet, CES and GEO or Non-GEO to ship GST terminal position of all ships adjacent to the ship requesting tracking data for collision avoidance purposes.
The GST operational diagram is shown in **Figure 5.18**, which is designed to provide global tracking and detecting all types of ships. The GST receives GNSS data from GPS/GLONASS spacecraft (1) and sends PTV tracking messages of position (2) via GEO satellite to CES (3) of Satellite Communication and Internet to the TCC processor and display (4). Thus, all lines highlighted in red are indicating GST receiving process and black transmitting links.

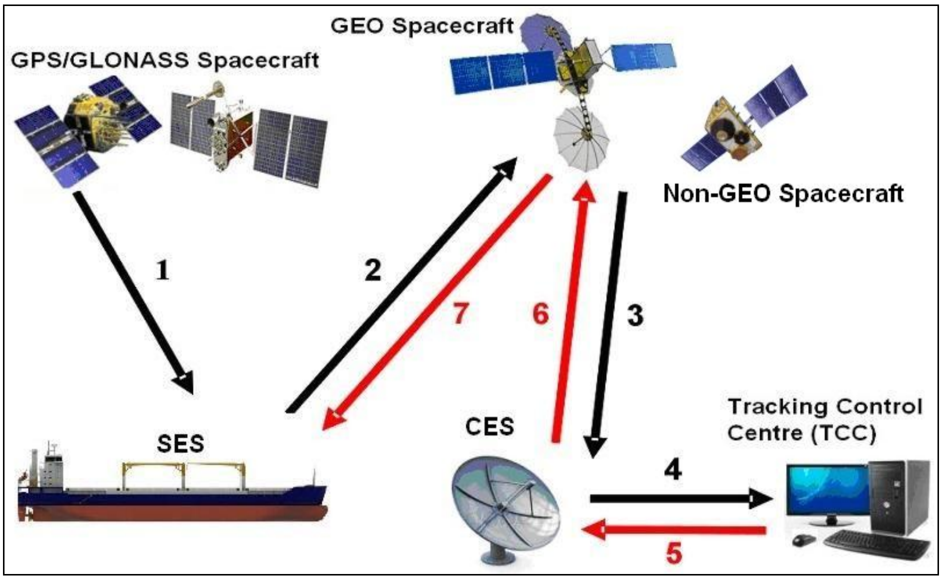

Figure 5.18. GST Operational Diagram – Courtesy of Paper: by Ilcev/Skoryk

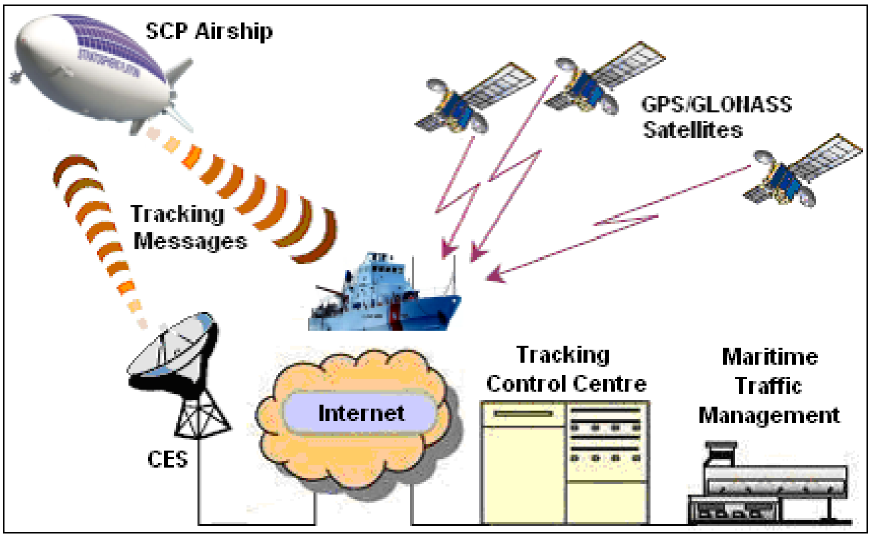

Figure 5.19. RST Network for Maritime CNS – Courtesy of Manual: by Ilcev

In vice versa direction the TCC terminal drives and sends via CES position and other PTV particulars of all ships in vicinity area of ship requesting this data (5) and then CES is proceeding all data via GEO or Non-GEO satellite (6) to the ships GST onboard device (7). In such a way master mariner can determine PTV data of all ships in his vicinity and provide better management of enhanced safety in navigation and improve collision avoidance.
As stated earlier, the LRIT network is a new compulsory system onboard ships established by IMO for vessel tracking worldwide. Thus, the system consists of the shipborne transmitting equipment, Communication Service Provider(s), Application Service Provider(s), LRIT Data Centre(s) including any related Vessel Monitoring System(s), LRIT Data Distribution Plan and International LRIT Data Exchange. The new proposed GST also can use the Inmarsat-C, mini-C and Inmarsat-D+ onboard ship equipment integrated with GPS/GLONASS receivers or Iridium, Globalstar and Orbcomm tracking devices as integration of satellite modems and GPS/GLONASS receivers. The GST proposal needs additional study, research and project for development GST network worldwide.
In comparison with LRIT new proposed GST can provide the same automatic positioning data for the Ship Traffic Control (STC) and is designed to provide vice versa positioning data of adjacent ships in a sailing area of any ship that is requesting these critical data for collision avoidance, what LRIT cannot. This unit is also very suitable for SAR detecting of ships in distress polling of PTV data from ship in emergency and for tracking of pirated ships, what will be explained in the next chapter. The GST device can be also integrated with 5 years battery power supply and send minimum 2 times position message to the TCC terminal. Thus, if this device is secretly installed onboard any ship can be very easily used for tracking and detecting of captured ships by pirates(Skoryk, I and Ilcev 2013; Skoryk, Ilcev 2014).

5.3. Regional Ship Tracking (RST) via Stratospheric Communication Platforms (SCP)

The RST system via SCP or Unmanned Aerial Vehicles (UAV) will provide transmission of automatic positioning data, tracking and detecting of all ships sailing in this region covered by single or more SCP airships. In the vice versa direction each ship in this region will be able to receive positioning data for all adjacent ships for improved collision avoidance.
New developed SAT and GST of seagoing vessels via GEO and Non-GEO satellite systems is a basis for proposed Regional Ship Tracking (RST) as the solutions of ship tracking and detecting systems inside of SCP coverage, which space and ground segment is illustrated in **Figure 5.19.**The ship RST transponder also consist GPS receiver and SCP transceiver.

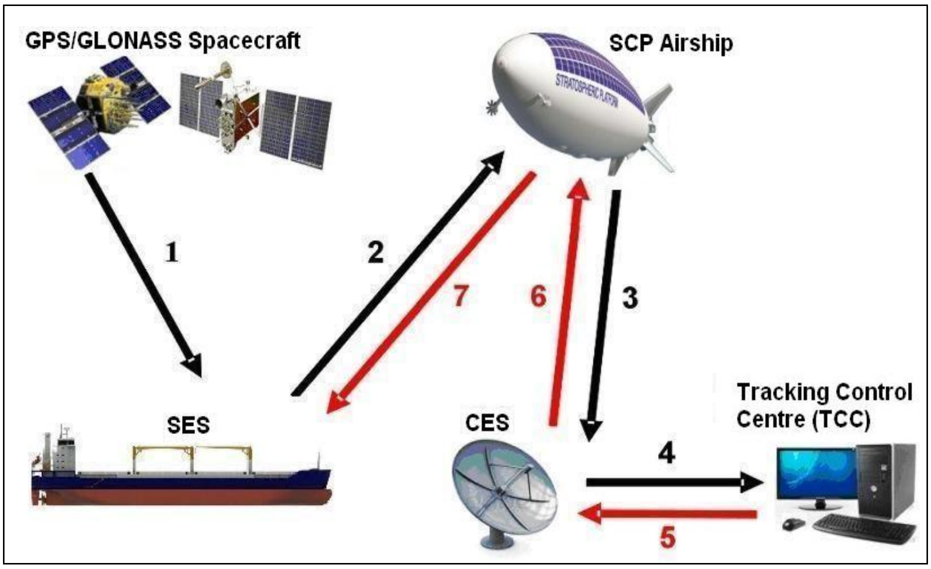

Figure 5.20. RST Operational Diagram – Courtesy of Paper: by Ilcev/Skoryk

The RST unit is receiving GPS or GLONASS signals and transmitting derived position via SCP airship or UAV aircraft, Coast Radio Station (CES) and Internet to the Tracking Control Centre (TCC) and Maritime Traffic Management (MTM). In the TCC station processes all received tracking data and indicating on likewise radar display. And the vice versa direction TCC can send via Internet, CES and SCP airship to ship GST terminal position of all ships adjacent to the ship requesting tracking data for collision avoidance purposes.
The RST operational diagram is shown in **Figure 5.20**, which is designed to provide local or regional tracking and detecting all types of ships. Same as GST, the RST receives GNSS data from GPS/GLONASS spacecraft (1) and sends PTV tracking messages of position (2) via GEO satellite to CES (3) of Satellite Communication and Internet to the TCC processor and display (4). Thus, all lines highlighted in red indicate GST receiving and black transmitting links.
In vice versa direction the TCC terminal drives and sending via CES position and other PTV particulars of all ships in vicinity area of ship requesting this data (5) and then CES forwards all data via SCP airship UAV aircraft (6) to the ships RST onboard device (7). In such a way master mariner can determine PTV data of all ships in his vicinity and provide better management of enhanced safety in navigation and improve collision avoidance(Skoryk, I and Ilcev 2013; Skoryk, Ilcev 2014).

5.4. Space Automatic Identification Systems(Space-AIS)

The Space Automatic Identification Systems (Space-AIS) uses new proposed satellite and SCP solutions that will serve all ships sailing across oceans out of the VHF R-AIS range.

5.4.1. Satellite Automatic Identification Systems(S-AIS) Network

The recently developed VHF Radio - Automatic Identification System (R-AIS)network, being an RF-based communications system was never designed for reception of signals from space, however Satellite AIS (S-AIS) greatly extends the range of the original system and creates new application possibilities for competent maritime and aeronautical authorities. Visibility scope is significantly enhanced using S-AIS and in such a way this solution provides global coverage and creates increased CNS situational awareness well beyond the 50 NM range from shore. Similar to the VHF R-AIS, the VHF S-AIS equipment is easy to install onboard any ship by connecting it to GPS receiver, gyro and the Pilot Plug interface.

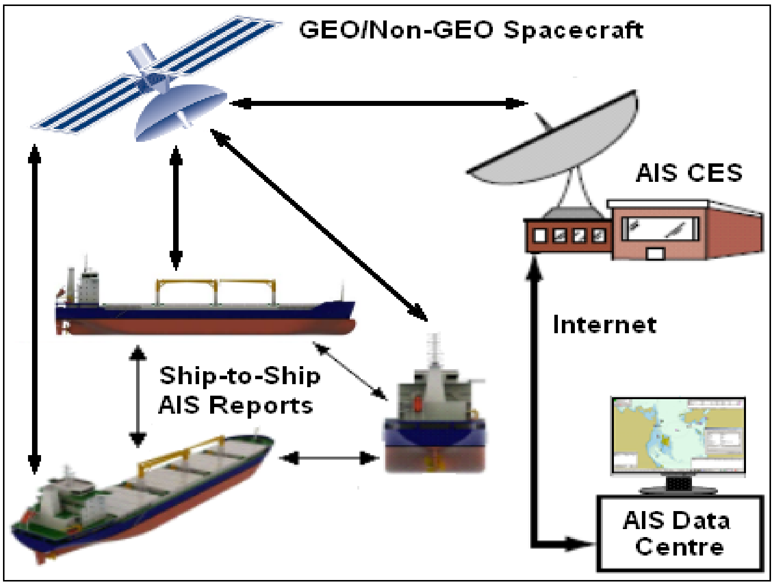

Figure 5.21. Satellite AIS Network – Courtesy of Manual: by Ilcev

Therefore, most terrestrial-based R-AIS networks provide only limited shore-based coverage via VHF-band to track and monitor vessels, and thus are not able to provide global, open ocean coverage. The Orbcomm and other LEO satellite network including Nano (CubeSat) satellites overcomes many of these challenges with unique S-AIS data service that can monitor a vessel's location and daily status well beyond coastal waters and ports to assist in navigation and improve maritime safety and security. More importantly, the Orbcomm and other LEO networks can do this cost-effectively and in near-real-time transmissions. The Orbcomm system was the first commercial satellite network providing S-AIS data services. At this point, Orbcomm has licensed S-AIS service to over 100 different customers in a variety of government and commercial organizations(Cervera *et al.* 2011).

Except Orbcomm satellite system, to establish S-AIS system can be used existing GEO and Non-GEO satellite networks on L or UHF-band, shown in **Figure 5.21.** In fact, it will be necessary to provide an adequate satellite constellation, CES terminals, mission operation, data processing centre, operation centers and customer delivery of S-AIS service. Onboard ships S-AIS equipment can send two types of messages, the first type is inter ship communication of ship-to-ship AIS reports, and the second type is direct transmission of AIS messages via SES, Internet or terrestrial communication line to the AIS Data Centre. The AIS Data centre is providing processing of all receiving information and is forwarding S-AIS messages instantly to the customer facilities via Internet.

The Orbcomm S-AIS network and service offers valuable data for applications that maximize global maritime safety and security, enabling the maritime industry to know where nearly every vessel is located, where it is going and when it will arrive at its destination. Orbcomm has already provided access to tracking and detecting information from well over 120,000 unique vessels daily by leveraging proven expertise and existing worldwide ground infrastructure. In addition, by partnering with some of the most trusted maritime information providers in the world, the Orbcomm system offers the most complete situational picture of global vessel activity(Holsten 2009).

In May 2004, the US Coast Guard awarded Orbcomm a contract to develop and supply new S-AIS service to meet their national security requirements. By utilizing Orbcomm S-AIS service, security and intelligence departments around the world can know where nearly every vessel is located, where it is going and when it will get there. These valuable data can be used to quickly react to anomalies at sea such as piracy and suspicious movements, contraband and route deviation, SAR, fishery and environmental monitoring and other unusual behavior(Skoryk, Ilcev 2014).

5.4.1.1. Enhancements of Surveillance and Security

The proposed S-AIS system is improving surveillance and security in navigation of ships at sea. Namely, the S-AIS system maximizes maritime safety and security, which service is thought to be the most significant development in maritime navigation safety and security since the introduction of radar. This system is a shipboard broadcast system that transmits a vessel identification, position and other critical information to provide the most complete and timely situational picture of vessel activity worldwide. The benefits of S-AIS in helping maritime authorities are to enhance maritime domain awareness and surveillance through detecting and identifying of all ship's route deviation and suspicious movements. In fact, by utilizing S-AIS service, security and intelligence departments around the world can know where nearly every vessel is located, where it is going and when it will get there. These agencies can use this valuable data to quickly react to anomalies at sea such as suspicious movements, route deviation and other unusual behavior of pirate and contraband boats.

The use of data fusion by merging S-AIS data with sensors such as electro optical imaging and Satellite Synthetic Aperture Radar (SSAR) enables the rapid and reliable identification of S-AIS-emitting vessels and highlights non-S-AIS-emitting vessels. This data has proven to be beneficial for government authorities responsible for security, fisheries, exclusive economic zones and environmental monitoring in improving security and safety efforts. From more efficient management of port traffic, to support of national surveillance initiatives, to collision avoidance and other benefits, S-AIS service is helping to keep global waterways more safe and secure. Received data from these agencies can be used just for commercial purposes, however, for collision avoidance new S-AIS system cannot work without establishment of special ground tracking centres, which have to provide positions of all adjacent ships to the certain ship requesting these data. In such a way ships captain getting this electronic data with positions of all surrounded ships can easily and safe navigate even in the extremely bad weather conditions.

5.4.1.2. Improvement of Counter Piracy and Suspicious Movement

Piracy in high-risk areas has become a major threat to regional trade and maritime security in recent years. As the frequency and aggressiveness of pirate attacks have increased, the need for S-AIS service in mitigating the risk of piracy is more important than ever before. It can be used to locate the approach of pirate boats, suspicious movements and identify ships of interest, such as terrorist attacks, contraband and so on. Namely, the S-AIS can help alert vessels to a potential threat, so fleet operators can avoid, deter or delay piracy attacks and greatly reduce risks to the vessel and crew. This system reduces the escalating threat and dangerous impacts of piracy and improves vessel safety and security is more important than ever before.

The S-AIS system enhances detecting of a ship's movement at sea, identifies vessels of interest and filter out "friendly" ships, especially in high-danger areas. If there is a data anomaly with regard to ID, location or speed, maritime authorities can use S-AIS data to determine the variance in reported versus actual status and take immediate action. This system can also be used to reduce the need for routine patrol missions at sea and help dispatch the appropriate authorities quickly when security incidents occur and in such a way significantly to improve the efficiency of all maritime operations. In addition, by providing proven and reliable global coverage, S-AIS delivers uninterrupted satellite data service even when traditional ship board communications systems and alarm transponders may have been compromised.

Post-piracy tracking and reporting via S-AIS can be also used to identify typical ships traffic patterns and activities in high-risk sea areas, which can significantly help local and national security organizations proactively counter piracy hijackings, kidnappings and extortion.

5.4.1.3. Better Facilitated Fisheries and Environmental Monitoring

The new S-AIS network is providing access to timely, accurate vessel data as instrumental in supporting fisheries management, environmental protection, pollution prevention and modern operational compliance programs in global waterways. From the prevention of marine daily pollution incidents to the enforcement of fishery regulations for vessels traffic management, S-AIS service provides the maritime industry with complete and reliable visibility over vessel activity worldwide. The S-AIS data service is also a cost-effective and reliable resource for vessel owners, ship operators, port authorities and government agencies to help prevent environmental disasters, enforce fishery regulations and ensure the safety of mariners.
The S-AIS service can be used to manage fishing activities, quotas and harvesting limits by alerting authorities of vessels entering closed or protected environmental zones. The best result is a reduction in illegal fishing and the preservation of depleting ocean resources. Thus, this system is also able to track historical traffic patterns and identify violators within these protected areas(ORBCOMM 2014).
Environmental organizations leverage S-AIS data to determine if a vessel has been in an area where oil, hazardous waste or ballast has been deliberately discharged or leaked to determine who is responsible for polluting the water. This service can also provide valuable data to all maritime authorities regarding the activity of vessels around and within such environmental or navigation hazards at sea, enhancing maritime safety and enabling those authorities to take immediate necessary actions. In support of fisheries control and environmental protection, relevant maritime authorities around the world have to detect and identify illegal, unreported and unregulated fishing activities. As stated earlier, S-AIS system can integrate its satellite data with sensors such as SSAR and deliver comprehensive monitoring reports to authorities responsible for fisheries, exclusive economic zones and environmental monitoring.

5.4.1.4.More Reliable Search and Rescue Operations

In a search and rescue incident when loss of life or the watercraft is imminent or threatened by grave danger, timing is everything. The faster that information can be communicated to first responders such as coast guards, maritime or other competent authorities, the faster that help can be sent on the way. The most effective solution for improving maritime safety and the precision and efficiency of international search and rescue operations is Cospas-Sarsat, GST and after that global S-AIS service.
In an SAR incident when loss of life or the watercraft is imminent or threatened by grave danger, timing is everything. Thus, the faster that information can be communicated to first responders such as coast guards and competent authorities, the faster that help can be sent on the way. The one of most effective solution for improving maritime safety and the precision and efficiency of international SAR operations is S-AIS data service. This service is a new shipboard broadcast system that transmits a vessel’s identification, position, detecting and other critical data to provide a complete and reliable situational picture of near-real-time vessel activity worldwide.
For vessels in distress alert and during SAR operations the S-SIS service can identify exactly where a vessel is located anywhere in the world even if it continues to drift from the distress location. Access to accurate, reliable and timely data about the position and status of a vessel and its crew can greatly improve response time by focusing search and rescue resources to a specific area and enhancing overall rescue coordination. Most importantly, S-AIS data can help minimize damage to and loss of the vessel, potentially saving lives. Thus, this valuable positioning service is also helpful in tracking the status of the rescue team and reducing risk to the rescuers, especially in treacherous weather or water conditions.

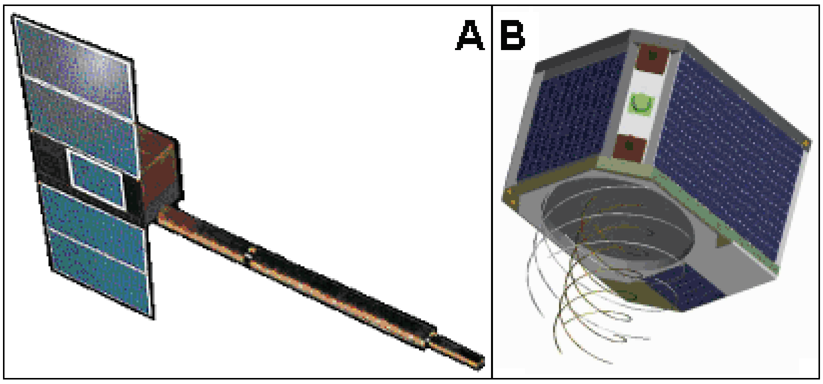

Figure 5.22. Satellite AIS Network – Courtesy of Paper: by Ilcev/Skoryk

Orbcomm and other Non-GEO satellite operators today are providing efforts to develop VHF or UHF S-AIS for all mobile applications and especially for maritime commercial and SAR on scene operations. In such a way, Orbcomm Little LEO satellite operator is the first mobile commercial satellite network who is developing and implementing S-AIS Data Service.

In 2008, Orbcomm launched the first LEO satellites specially equipped with the capability to collect AIS data and has plans to include these capabilities on all future satellites for ongoing support of global safety and security initiatives. Orbcomm mobile satellite operator recently has successfully launched six satellites with S-AIS equipped payloads. Orbcomm's next launches started in 2011, which AIS satellite is shown in **Figure 5.22 (A).** Following the development of Orbcomm system is designed sample of the M3MSat Maritime AIS CubeSat (Nano) satellite for the Canadian government, shown in **Figure 5.22(B),** which is already launched in 2012.

The future S-AIS network is ideal for global satellite ships tracking and surveillance useful by maritime or government administration, but as stated earlier, is not dedicated for collision avoidance of ships. In such a way, to enhance R-AIS and S-AIS service has to be provided the similar system as GST with Tracking Control Centre (TCC) for collecting positioning data of all ships in any sea area, indicating them on the radar like display and distributing them on any ship request sailing in certain sea area. The problem with Nano satellites is their short life time, so to get better and more reliable S-AIS network has to be employed GEO and Not-GEO (Big LEO) satellite constellations or even SCP airships. In **Figure 5.23** is shown by Cain & Meger one of the S-AIS operational results to globally track the ships, which is useful for commercial purposes(Skoryk, Ilcev 2014).

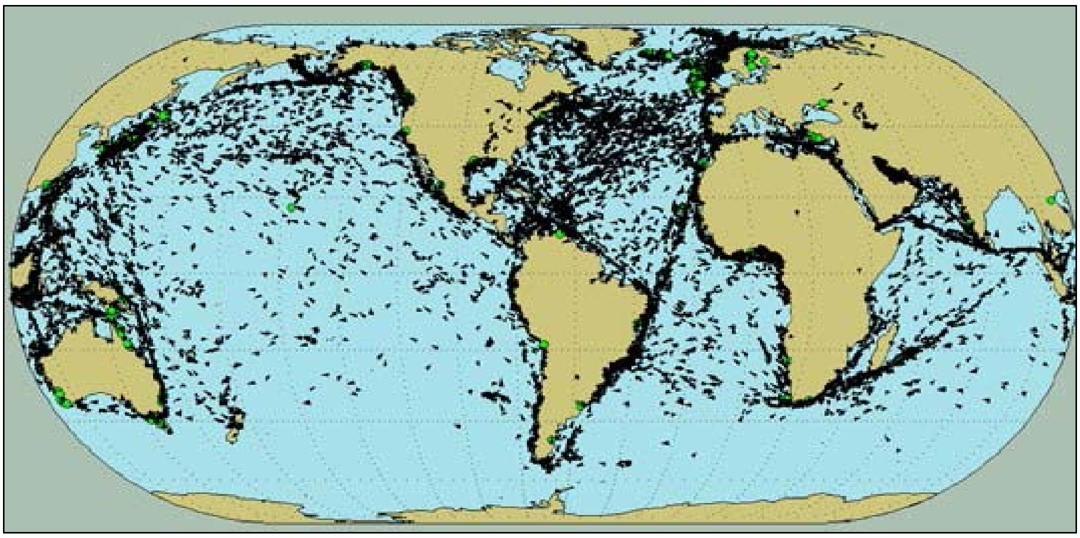

Figure 5.23. Operational results of S-AIS Network – Courtesy of Manual: by Ilcev

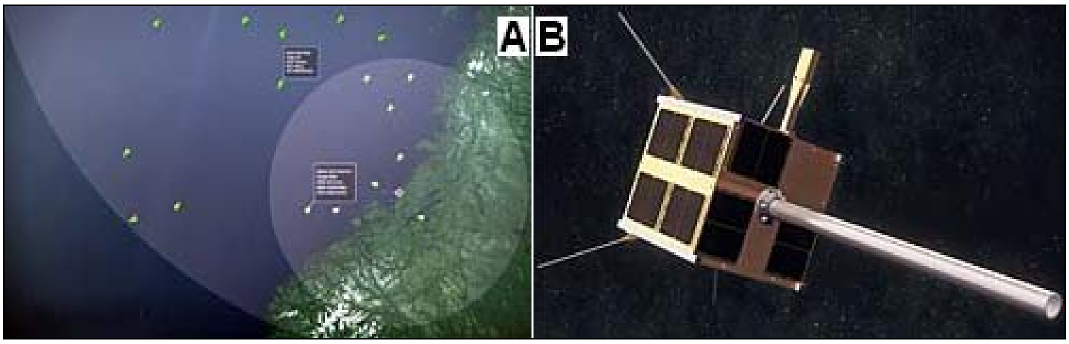

Figure 5.24. Coverage of AIS Networks and Nano-AIS – Courtesy of Paper: by Ilcev/Skoryk

5.4.2. Nano Satellite AIS (Nano S-AIS)

An AIS receiver using SCP airship or satellite will be able to extend the VHF range of R-AIS systems considerably and make it easier to monitor ship traffic and fishing in the High North areas. In **Figure 5.24 (A)** is illustrated larger coverage area using S-AIS or AIS via SCP versus using smaller coverage of conventional system of VHF R-AIS. The altitude of the LEO satellite or SCP gives the AIS receiver a large range of coverage and both can therefore make observations over extended sea areas. The VHF AIS signals are strong enough to be received by an SCP or satellite(Høye *et al.* 2008).

The new AISSat-1 is a Nano/LEO satellite measuring 20x20x20 cm, weight is 6 Kg and is shaped like a cube (CubeSat), shown in **Figure 5.24 (B).** The payload is designed by Kongsberg-Seatex AS and the purpose of the satellite is to improve ship's surveillance of maritime activities in the High North sea areas. It is believed that the low traffic density in the High North requires one receiver and antenna only to handle the expected volume of AIS messages. The AISSat-1 satellite is being launched in order to test these presumptions. Thus, the Norwegian AIS transponder is placed in a custom made Canadian satellite, built by the University of Toronto. The satellite's life span is estimated to three years. AISSat-1 will operate in a Polar orbit at an altitude of 600 Km and will be launched by the PSLV rocket of Indian Space Research Organization (ISRO). The Norwegian Space Centre is project owner and the Norwegian Coastal Administration (FFI) will receive the data and the Norwegian Defense Research Establishment is responsible for the technical implementation. Additional information about is possible to see at Web pages of Kongsberg Maritime.

The total cost of the satellite is approximately 30 million NOK (Norwegian Crown). After launch, FFI will start testing the Polar orbiting satellite. The FFI will control it for about a year before Kongsberg Satellite Services (KSAT) take over recently and so the FFI started to integrate the AIS data in the current land based AIS system locally and internationally. The ESA operator has asked FFI and Norwegian companies to take part in a study on a satellite based AIS solution for the whole of Europe, while both USA and Canada have also shown keen interest in the project(Skoryk, Ilcev 2014).

5.4.3. Stratospheric Communication Platform AIS (SCP-AIS) Network

The new proposed AIS network via Stratospheric Communication Platforms (SCP) or High Altitude Platforms (HAP) nominated as SCP-AIS will be the best solution in the future for regional or local coverage. As stated earlier, the R-AIS network is typically envisioned as a short-range system, which may also play a long-range role using S-AIS network via GEO, LEO or Nano satellite constellations. In fact, the current R-AIS vessel tracking may be accomplished through high elevation shore sites allowing reception of AIS signals to nominally 24 NM that loosely puts it in the category of a short-range sensor.

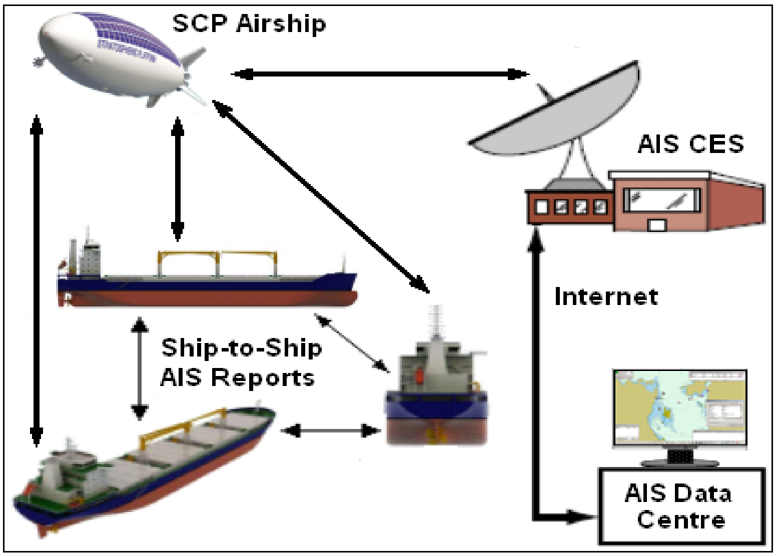

Figure 5.25. SCP AIS Network – Courtesy of Paper: by Ilcev/Skoryk

Additionally, except S-AIS solutions, the Research Group in Space at DUT is conducting research and development efforts to determine the feasibility of using AIS receive capability onboard high altitude and long endurance SCP airships or balloons known also as HAP, which network diagram is shown in **Figure 5.25**. Illustration shows SCP-AIS airship network configuration similar to the S-AIS network shown in **Figure 5.21**.

In **Figure 5.26** is illustrated SCP-AIS regional network, which connects AIS equipment onboard ships (SES) via CES and Internet to the shore AIS Base Station. In addition, SCP airship can be connected to other airships or one SCP network can be connected with another distant SCP network via GEO or Non-GEO satellites. As usually all AIS SES terminals can be connected via intership AIS links. Employing AIS interlink between satellites and SCP, users are able to follow ships all around the globe, even in deep sea and remote areas. Extensive vessel database and all its advanced research tools are fully satellite-enabled: Port Call Logs, Events, Voyage Report, Estimated Time of Arrival (ETA) and Schedule tables all benefit from the superior data quality and provide a consistent and complete picture of any ship's behavior, trading patterns and port activities(Skoryk, Ilcev 2014).

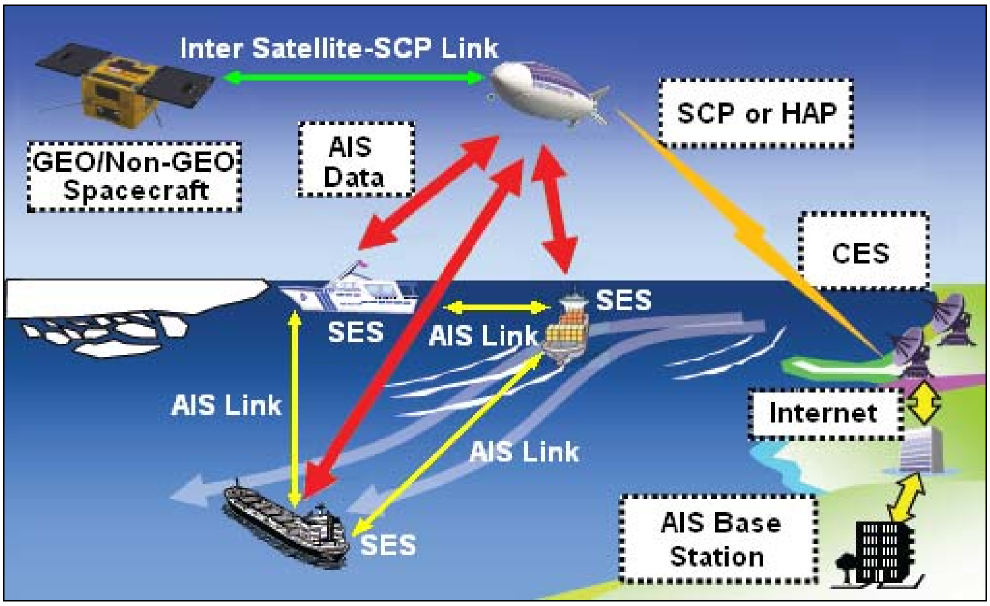

Figure 5.26. Maritime AIS Network via SCP (SCP-AIS) – Courtesy of Manual: by Ilcev

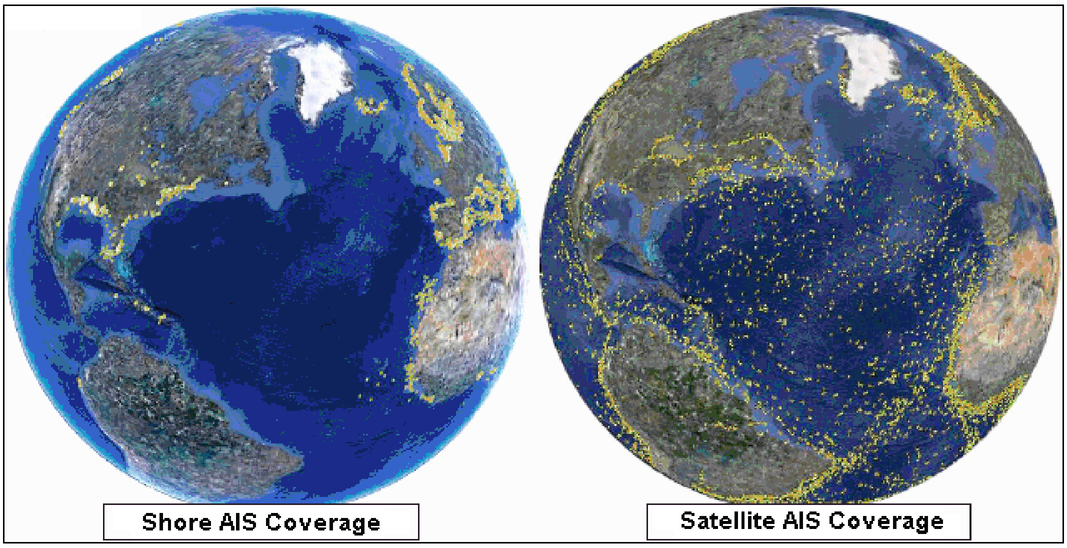

Figure 5.27. Maritime Shore and Satellite AIS Networks – Courtesy of Manual: by Ilcev

5.4.4. Integration of R-AIS and S-AIS with SCP-AIS

Complete fleet management of merchant ship movement worldwide can be provided with an integration of R-AIS and S-AIS networks, shown in **Figure 5.27**. Thus, on the left side of illustration is presented shore AIS coverage of yellow marks indicating ships sailing in the VHF coastal areas, and on the right side is presented satellite AIS coverage of yellow marks indicating ships sailing globally. In such a way, ships of interest can easily be collected in a convenient watch list using either coastal or global AIS network coverage. Together with the fleet navigation chart module, weather and sea state forecasting and live monitoring capabilities, this makes a solution for fleet monitoring, suitable for ship owners, managers and all others involved in maritime transport and freight.

At this point, diameter of covered area depends on two important parameters such as altitude *h* of SCP levitation (stratosphere layer begins from 20 Km and ends to 50 Km above of Earth surface) and angle α as a minimal angle between boundary line of antenna radiation pattern and horizon line (angle α should not be lower than 5°). The angle α depends on mounted onboard of SCP VHF AIS antenna with radiation pattern per solid angle. Obviously, using bigger angle α and higher altitude *h* of SCP above sea level, then larger diameter of covered area is obtained. Schematically SCP measurements are shown in **Figure 5.28.**

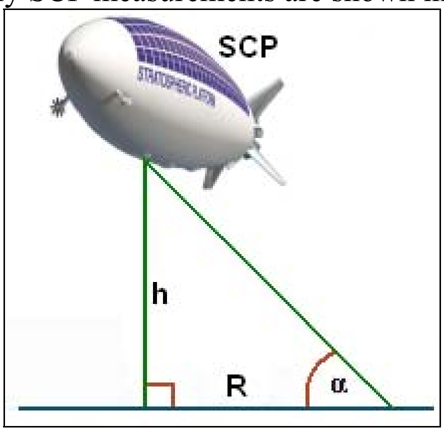

Figure 5.28. Coverage Area with one SCP-AIS– Courtesy of Manual: by Ilcev

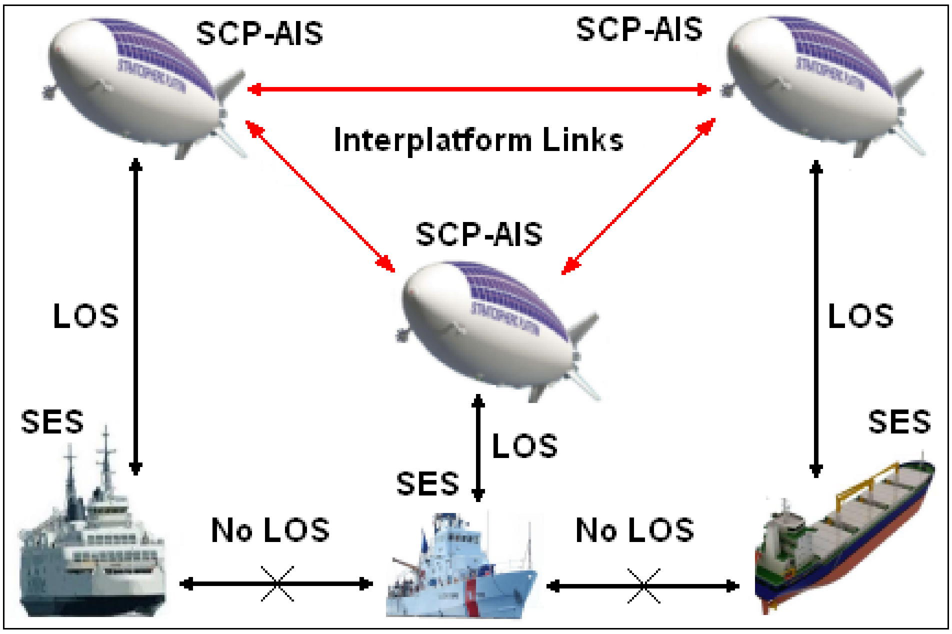

Figure 5.29. Inter-platform AIS Network – Courtesy of Paper: by Ilcev/Skoryk

In addition, using the Pythagorean Theorem for calculation of diameter covered area and formula of square circle can be simply calculated to cover an area with one SCP airship by the following quotation:

$$D = 2R = [h \text{ x} ctg\ (\alpha)]; \qquad (5.1)$$

where: h = altitude of SCP levitation and α = angle of antenna radiation pattern. Inserting in previous formula numeric data, such as altitude h = 20 Km and angle $\alpha = 5^{o,}$ is giving:
The big advantage of SCP that it can be installed and moved to any geographical point where necessary to increase redundancy. The SCP able to keep AIS ships in Line-of-Sight (LOS) due to high altitude and in such way can be engulfed large areas of sea surface by one SCP with equipment equal to onshore AIS BS.
Also between two or more SCP airships can be arranged radio or optical inter-platform links that in turn significantly increase flexibility of system application. With SCP inter-platform links (highlighted in red) ships (SES) can exchange information even in considerable distance between AIS ships without LOS between them, shown in **Figure 5.29.** On the other hand, direct intership communications is not possible because there is not LOS between SES terminals (highlighted in black).

$$D = 2R = 2[20 \text{ x } ctg\ (5)] = 455 \text{ Km} \qquad (5.2)$$

In case that one onshore AIS BS is not capable to provide reliable coverage due to geographical features of the landscape, should be installed as many as necessary Base Station (BS) sites to cover particular sea surface. The new system under development phase is S-AIS and new proposed AIS via SCP have both to upgrade radio coverage and reliability of the AIS system globally.
The potential alternative for improving the range and reliability of Maritime AIS is a system of SCP by special airships located at altitude of about 25 Km. The main idea in this proposal will be to use SCP as a very convenient tool to apply them in some areas where geographically complicated Earth surface or around groups of islands and fiords as well.

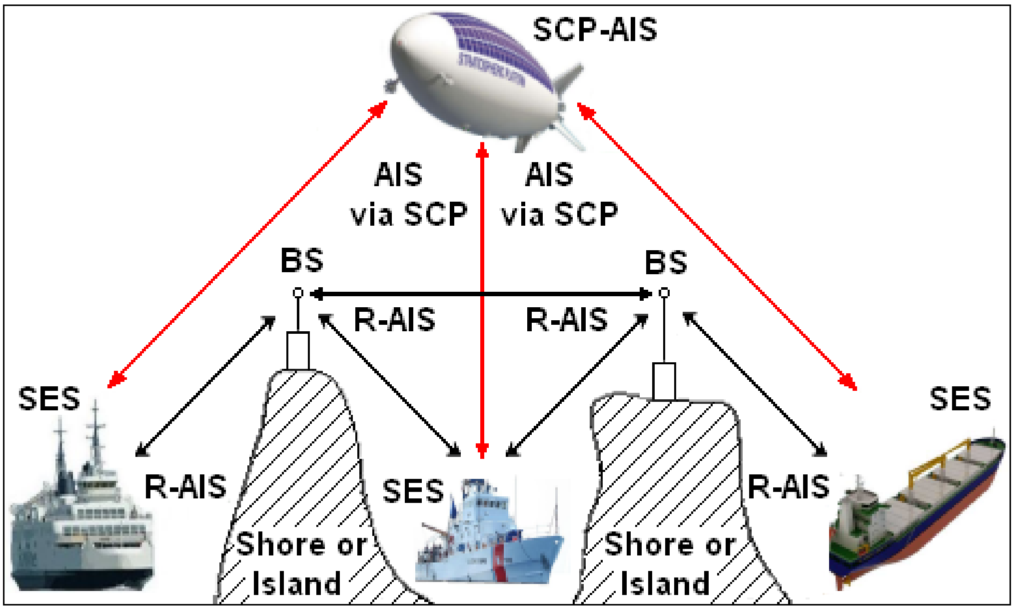

Figure 5.30. SCP-AIS vs R-AIS Network – Courtesy of Paper: Ilcev/Skoryk

Due to geographical complications of Earth's surface and onshore mountainous terrains can be difficult to lay LOS between onshore AIS BS and ships in shadowing and not covered sea areas, so the SCP solutions can be successfully used instead of onshore BS and partly instead of satellites. Thus, as example group of islands can be covered by one or several SCP without installing onshore AIS BS on every island along of coastal line. In **Figure 5.30** is shown how onshore AIS BS can be replaced by one SCP in problematic landscape where is not possible to get direct LOS**.** Links between ships (SES) and SCP are highlighted in red and between ships and BS highlighted in black. However, in **Figure5.31** shown integration network of S-AIS (violet lines), SCP-AIS (yellow lines), R-AIS (black links) and inter-platform-satellite lines (red links), as an important chain of modern global maritime AIS.

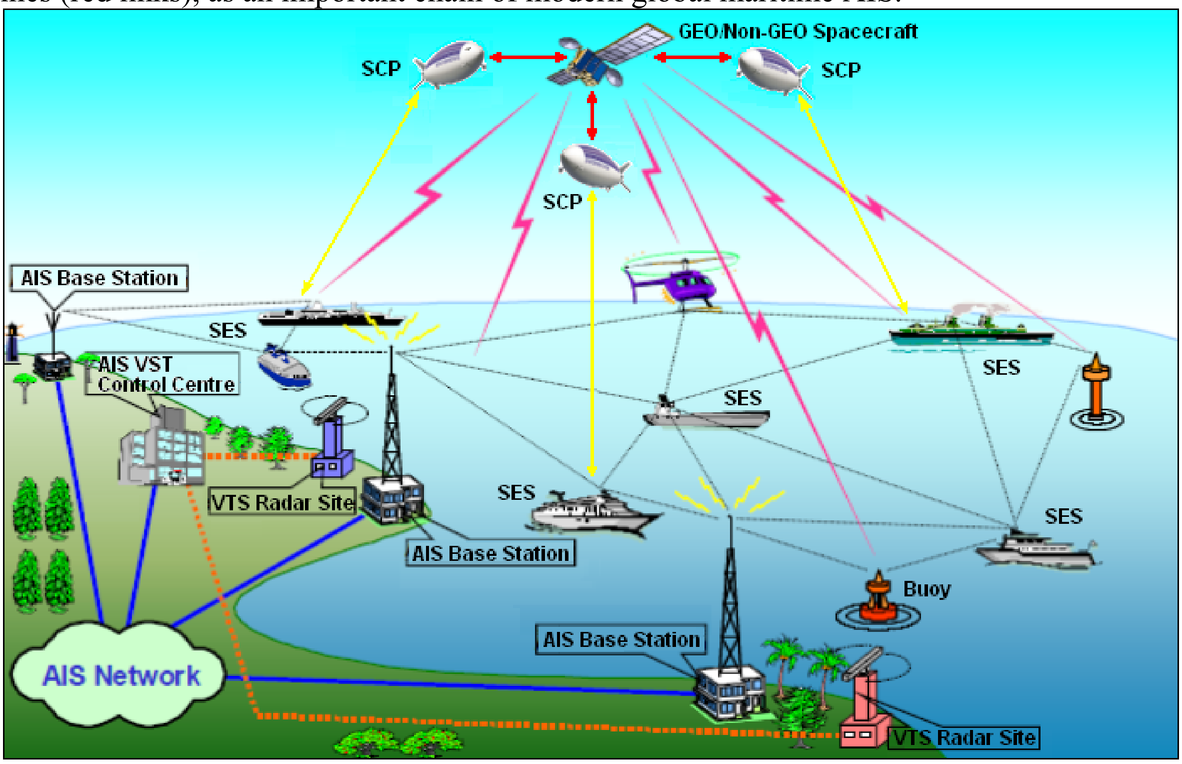

Figure 5.31. SCP-AIS vs R-AIS Network – Courtesy of Paper: Ilcev/Skoryk

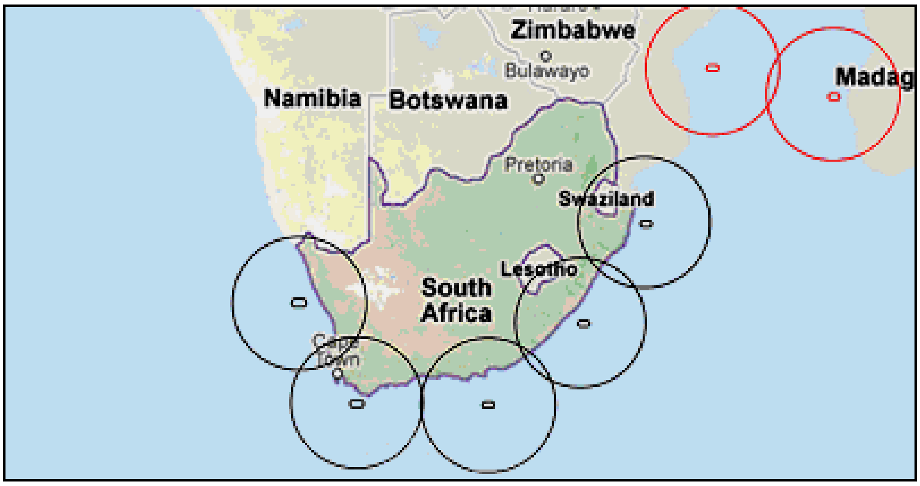

Figure 5.32. Coastal SCP-AIS Network – Courtesy of Paper: Ilcev/Skoryk

The onshore AIS BS terminal collects information and receives them through WAN to AIS database center where data analyze and processing is occurred. Every onshore AIS BS should be connected to power supply source and to WAN in order to provide remote control of AIS BS from control centre and data flowing to data centre and from one's.

The current shore AIS system communicates in VHF-band with ships using LOS facilities only. This fact means that AIS BS should be installed in such way to provide LOS to every possible point for ship from place where AIS BS is installed. The proposed integrated AIS system is providing global network and in such a way it will be not necessary a number of additional BS shore terminals for reliable coverage.

To upgrade maritime AIS surveillance in coastal waters will be necessary to deploy several SCP airships as the best solution. One SCP with altitude of 20 Km is able to cover area with diameter in 455 Km. Thus, if increase altitude of SCP up to 30 Km, diameter of covered area increase in 50 % or becomes 680 Km in radius.

In **Figure 5.32** is shown network that with 5 SCP is possible to cover all costal line of South Africa and to provide Maritime AIS via SCP airship, which highlighted by 5 black circles. This illustration shows that with 2 to 4 SCP airships, placed between Madagascar Island and Africa can be provided reliable AIS coverage in Mozambique Channel as well, shown by 2 highlighted in red circles(Ilcev, SD 2011; Skoryk, Ilcev 2014).

5.4.5. Space AIS Information Management System (IMS)

The Information Management System **(**IMS) network can be developed for local, using SCP airships, or regional, using GEO or Not-GEO (LEO) satellites, AIS space infrastructures as a collaboration platform developed for the offshore and maritime industry in one country or particularly in South Africa.

The IMS network infrastructure includes different system components such as portal, data logging, secure network, malware protection, replication, security and integration by standard protocols such as OPC and Web services, unites all data logging and communication into a single and secure and maintainable solution.

The System also provides proven and flexible offshore-to-onshore replication and supports low band with a high latency SCP airship or/and satellite connections. Service Oriented Architecture (SOA) enables an information highway for applications across control systems, third party and business systems. In such a way, the portal is based on rich Internet application technology and it can be accessed using a standard web-browser and can provide an intuitive user interface.

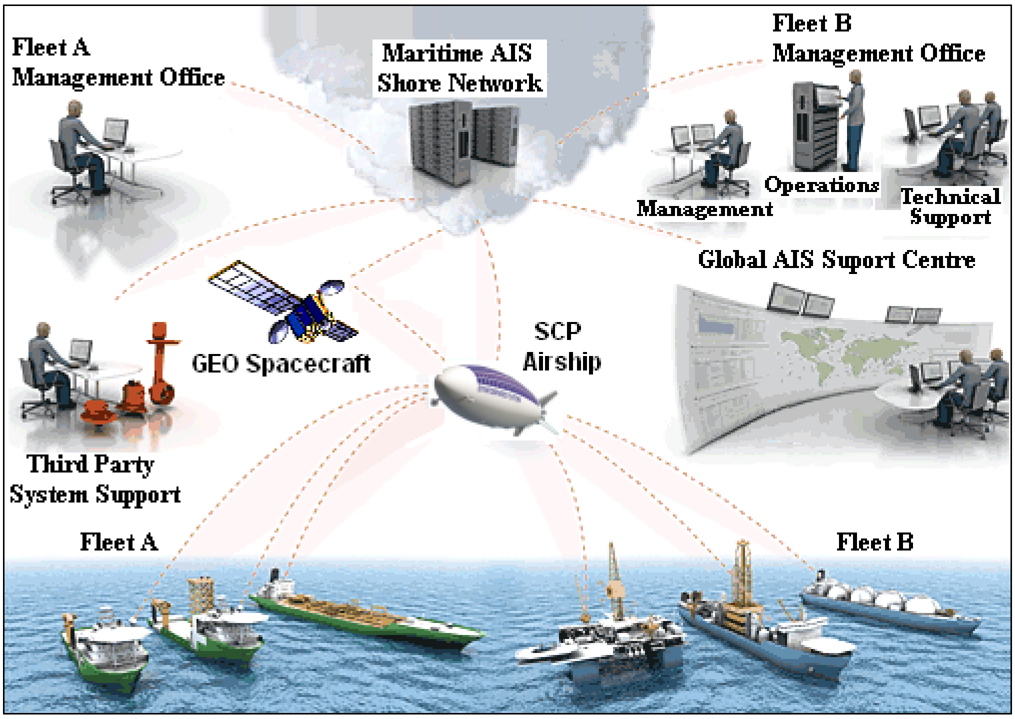

Figure 5.33. Satellite and SCP Airship IMS AIS Network – Courtesy of Paper: Ilcev/Skoryk

The IMS network can be designed to enable continuous access to data both onboard and onshore through an interactive Web-based solution and to provide an efficient information flow via satellite or SCP, illustrated in **Figure 5.33.**The AIS IMS via SCP airship or satellite constellation solves the increasing challenge that each sub supplier needs his own maritime IMS communication data configuration. The IMS AIS network infrastructure unites all data logging and communication into a single secure and maintainable solution. Thus, it gives the merchant fleet owner's possibility to control information flow and security of fleet. In effect, without space segment of satellites or SCP airships the IMS will be not able to transfer AIS data to Fleet A and B of vessel in certain deep sea or ocean areas not covered by VHF R-AIS infrastructure.

The AIS IMS network can use either satellite or SCP airship constellation to provide more reliable coverage and communication of data. This system also enables secure and reliable information sharing between offshore and onshore locations. Namely, the IMS via SCP or satellites provides a complete and up-to-date information portal for better traceability of ships and enhanced quality of AIS communications between offshore and onshore organizations.

Accordingly, the space IMS network improves critical decision making and support, reduces need for service personnel onboard vessels, improves troubleshooting, enhances Statistical Analysis System (SAS) through visualization and supervision and other features. This novel network will support overall systems interoperability through use of well-established open standards as well. The service-oriented architecture enables an information highway for applications across control and to business systems.

The AIS IMS network provides authorities with valuable information on routes, approaching, cargo and the ships themselves. It is a major task for police, customs, military, SAR Centers and coastal and harbours authorities to monitor traffic in their territorial waters. This system increases the situational awareness, the efficiency and the safety and decreases the workload for those authorities tasked with monitoring and controlling coastal and offshore waterways. Finally, the main tasks of this Network is to improve transfer of AIS data, to enable better system for collision avoidance prevention of seagoing ships and what is very important to provide better protection of propriety and lives at sea.

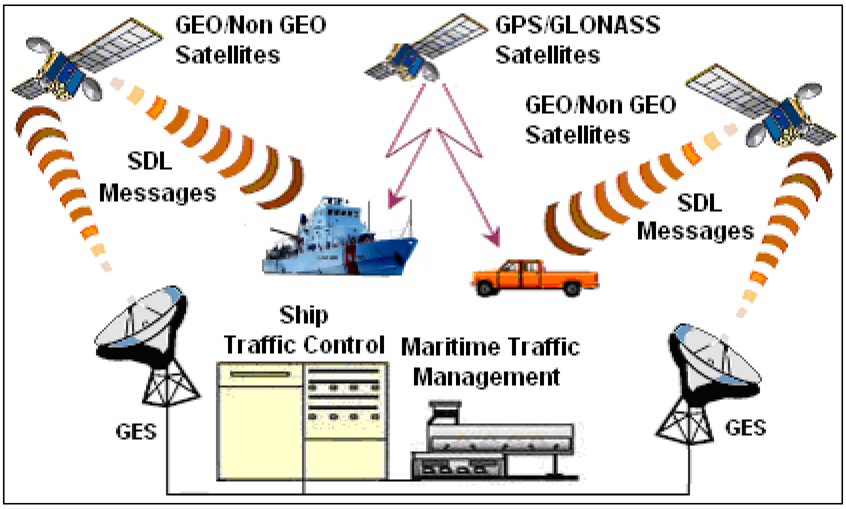

Figure 5.34. Satellite Data Link (SDL) – Courtesy of Paper: Ilcev/Skoryk

The AIS SCP is more cost-effective solution for AIS application in sea areas not covered by AIS VHF-bands. The SCP does not need many Base Stations for VHF-based AIS and huge expenses for launch and technical maintenance of satellite constellations. Similar to some satellite networks, between SCP airships can be arranged by inter-platform links, so in this case system becomes more efficient and the need of shore station will be reduced. Moreover, the SCP payload can be equipped by some extra equipment to provide more safety at sea, such as optical or infrared photo camera with high resolution or observation radar and can be used for other CNS systems. Also identification of pirated ships and captured ships can be provided with installation of similar equipment on board of SCP airships or airplanes.
The major goal of SCP is that, similar as satellite, provides Azimuth and Elevation angles and also can enable greater speed that Cellular and Terrestrial Telecommunication Networks (TTN), including Fiber Optic Networks (FON). Via SCP will be possible to implement novel transmission techniques at Ultra High Speed (UHS) of data, such as new Infinite-capacity wireless vortex beams up to 2.5 Tb/s, Superchannel Real-time Transmission of 1 Tb/s data across the trans-oceanic distance of Optical-OFDM over 10,000 Km, Photonic Networks and Systems of Optical Time Division Multiplexing (OTDM) ranging from 10 Gb/s up to 10.2 Tb/s over a 29 Km, Communications Via Laser Beam, and Communicating at the speed of light via Lasers System for Space Communications solutions(Skoryk, Ilcev 2014).

5.5. Satellite Data Link (SDL) Tracking Messages Service

The SDL network is similar to aeronautical VDL Mode 4 system, which is able to provide a satellite broadcast link supporting ships navigation and surveillance functions via Short Burst Messages (SBM) and High Speed Data (HSD) service for CNS purposes.
The SDL network is a part of the following total maritime communication solution:
1. SDL Tracking Messages Service – The concept of this service is similar to VDL Mode 4 system, which is able to provide a satellite data broadcast link supporting navigation and surveillance functions. The SDL system can provide transmission of Short Burst Messages (SBM) between mobile stations or mobile units with Coast Earth Station (CES), Control Centre and Maritime Operation, shown in **Figure 5.34.** In mobiles, such as ships and surface vehicles (trucks, cars, locos and rail trucks), can be installed satellite transponders or satellite tracker devices introduced in previous and this chapters. Mobile transponders can operate autonomously inside the coverage of certain CES terminal or can work with any compatible CES worldwide. The SDL transponder can support the similar services that provides VDL4, but if it is using Iridium transponder will be able to provide global coverage including Poles.

According to illustration, the SDL system is providing tracking data for ships and vehicles, which are receiving GNSS signals from GPS or GLONASS spacecraft. Then all mobiles are sending SDL messages of derived position and other related information via GEO or LEO (Not-GEO) spacecraft and same CES to the Ship Traffic Control (STC) and Maritime Traffic Management (MTM). In opposite way, STC and MTM can send instructions and positioning data of near by ships for collision avoidance on ship request. In this sense, the master mariner of ship can provide better management and security of his ship sailing in area with increased traffic. The SDL messages send to all vehicles in area of seaport can be used for enhanced traffic control on the seaport surface, which also improves safety and security(Kaul 1978; Giri *et al.* 2011).

The transponder allows master mariner and ship traffic controllers to "display" vessel traffic in deep ocean navigation, coastal waters, approaching to anchorages and in inside seaports, including vehicle movements with the highest possible precision, which can improve SAR at sea and Ship and Port Facility Security (ISPS). The convenient CES terminals can cover Inmarsat, Globalstar, Iridium, Orbcomm or same new Nano networks worldwide. Moreover, the CES units can easily interface with other ship surveillance systems through the standardized Asterix protocol, which enables a complete surveillance picture at the seaport derived from several tracking and detecting sources. The ground network and CES will provide increased functionality and capability for Wide Area Network (WAN) coverage of advanced Ship Traffic Control (STC) and Maritime Traffic Management (MTM) system. The functionality of the coast station is tailored to system specific service applications by its software configuration.

2. SDL of SBM and High Speed Data (HSD) Service – Every seagoing vessel, ground vehicle and pilot helicopter caring transponders or satellite tracker devices will be able to send and receive SBD or HSD for CNS purposes. Thus, as a part of the total maritime communications solution, it is proposed SDL system for direct delivery to its future customers global SDL services and accurate Advice of Charge(AOC) messages. This new data transfer technology can deliver to the customers global SDL services and accurate Maritime Operational Control (MOC) messages. Two-way text messaging, sailing movement data, text and graphical weather warning (WX), navigation warning (NX) and sailing route planning are just a few of the applications made possible by Inmarsat, Iridium, Globalstar and Orbcomm satellite services around the world. Both operators also provide valuable redundancy for satellite communication services while requiring minimal equipage or upgrade costs, creating a cost-effective, safety, security and vital communications service for ships. However, using VDL service also will be provided real-time information on sailing, destinations, Estimated Time of Arrival (ETA), engine parameters, delays, positioning, maintenance, weather bulletin and so on.

5.6. Satellite GNSS Augmentation SDL (GASDL)

The new developed Regional Satellite Augmentation System (RSAS) is able to transmit and receive augmentation GNSS signals via SDL for maritime CNS solutions, improved safety and security at sea and enhanced collision avoidance system.

The current communication systems for maritime application are combined with Radio (MF, HF and VHF) and satellite communications, while the current Navigation applications are represented by old fundamental systems for Position, Velocity and Time (PVT) military determination systems such as GPS and GLONASS for US or Russia (former-USSR) requirements, respectively. In fact, the GPS and GLONASS are the first generation of GNSS-1 infrastructures giving positions to about 30 meters, using simple GNSS receiver onboard chips or aircraft, and they therefore suffer from certain weaknesses, which make them impossible to be used as the sole means of navigation.

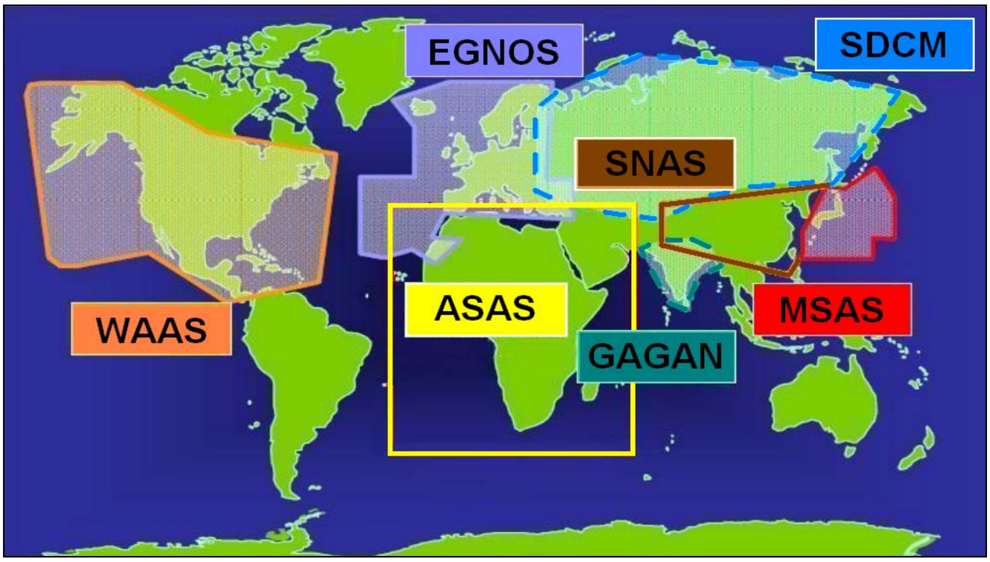

Figure 5.35. Global Satellite Augmentation System (GSAS) – Courtesy of Book: by Ilcev

Technically GPS or/and GLONASS GNSS-1 networks used autonomously are incapable of meeting civil maritime, land and aeronautical mobile very high requirements for integrity, position availability and precision in particular and are insufficient for certain very critical navigation stages. Because these two GNSS1 systems are developed to provide navigation particulars of position and speed on the ship's bridges or in the airplane cockpits, only captains of the ships or airplanes know very well their position and speed, but people in traffic control centres cannot get in all circumstances their navigation or flight data without service of new CNS facilities. Besides of the accuracy of GPS or GLONASS, without new CNS is not possible to provide full traffic management in every critical or unusual situation. Also these two GNSS1 systems are initially developed for military utilization only, and now are also serving for all transport civilian applications worldwide, therefore, today many countries and international organizations would never be dependent on or even entrust people's safety to GNSS systems controlled by one or two countries. Thus, for these reasons China already developed own GNSS2 (2^{nd} generation) known as Compass (Beidou) and the European Union is developing Galileo.
Augmented GNSS-1 solutions known as Regional Satellite Augmentation System (RSAS) were recently developed to improve the mentioned deficiencies of current military systems and to meet the present transportation civilian requirements for high-operating Integrity, Continuity, Accuracy and Availability (ICAA). These new operational CNS systems are the US Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay System (EGNOS) and Japanese MTSAT Satellite-based Augmentation System (MSAS), and there are able to provide CNS data from mobiles to the TCC in their RSAS network coverage. However, those three RSAS networks or Satellite-Based Augmentation System (SBAS) are recently operational and are interoperable and compatible. However, all RSAS infrastructures together are integrated parts of Global Satellite Augmentation System (GSAS), which has to integrate all current and future RSAS projects worldwide.
These three operational systems are part of the GSAS network and integration segments of the GNSS-1 system of GPS and GLONASS and new GNSS-2 of the European Galileo and Chinese Compass, including Inmarsat CNSO (Civil Navigation Satellite Overlay) and new project of African Satellite Augmentation System (ASAS). The additional three GNSS-1 networks in development phase are the Russian System of Differential Correction and Monitoring (SDCM), the Chinese Sino (Satellite) Navigation Augmentation System (SNAS) and Indian GPS/GLONASS and GEOS Augmented Navigation (GAGAN)(Ilcev, DS 2013a).

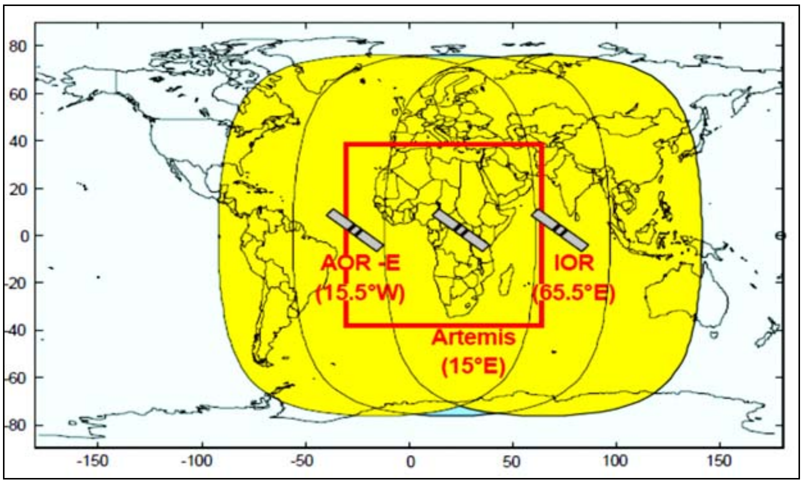

Figure 5.36. ASAS Space Segment – Courtesy of Book: by Ilcev

5.6.1. Development of ASAS Network for GASDL over Africa and Middle East

The African Satellite Augmentation System (ASAS) project is designed by the Research Group in Space Science at DUT. The ASAS network is de facto RSAS infrastructure for the entire African Continent and Middle East Region. It is interoperable and compatible with above discussed RSAS networks as integration segments of GSAS network. It will be identical to the US WAAS as a system and with the same service as EGNOS providing solutions for maritime, land (road, rail and ground) and aeronautical application. The difference of this System is that other RSAS networks are just developed by one government, while ASAS project has to be invested and developed by 54 African and 15 countries from Middle East.

During the past 10 years the European Commission (EC) is providing efforts to develop an extension of EGNOS over Africa and Middle East. At first, sometimes in 2003 EC started planning with South African ATNS for development so called "Mini Project" with Ground Network of 13 RS terminals associated with the EGNOS ground facility. The problem was that EGNOS Test bed couldn't provide safety and security and would be entirely dependent on the proper operations of the EGNOS system, network and maintenance of GES terminals and ground communications infrastructure. Therefore, this project was abandoned in 2007.

To start with the realization of the ASAS project is necessary to form Augmentation Standards Service and to establish the Transport Augmentation Board (TAB), which will be responsible for providing the leadership role in engineering, realization and coordination the operational implementation of existing and emerging modern satellite CNS technologies into the African Continent and the Middle East Region. The TAB team has to be instrumental in the project and the development of the criteria, standards and procedures for the use of unaugmented and as well an augmented GNSS signal by the ASAS space and ground segments.

The ASAS Space Segment can be designed by implementing own project of Multipurpose GEO satellite constellation as a better solution, or by leasing existing GEO Inmarsat-4 and Artemis spacecraft. The operational system can use 3 GEO satellites: Inmarsat-4 AORE at 15.5ºW; Inmarsat-4 IOR at position 64ºE, and ESA Artemis at 21.5ºE over the equator, shown in **Figure 5.36**. Thus, the navigation payloads on these GEO spacecraft are essentially bent-pipe transponders, so that a data messages uploaded to a satellite are broadcasted to all users in the GEO broadcast area of the satellite over the entire African Continent and the Middle East region. The ASAS network can employ the service of existing Monitoring and Ranging Station (MRS) infrastructures located in Aussaguel (France), Kourou (French Guiana) and Hartebeeshoeck (South Africa), for monitoring GEO satellite constellation and to implement a wide triangular observation base for ranging purposes(Ilcev, D and Moyo 2011).

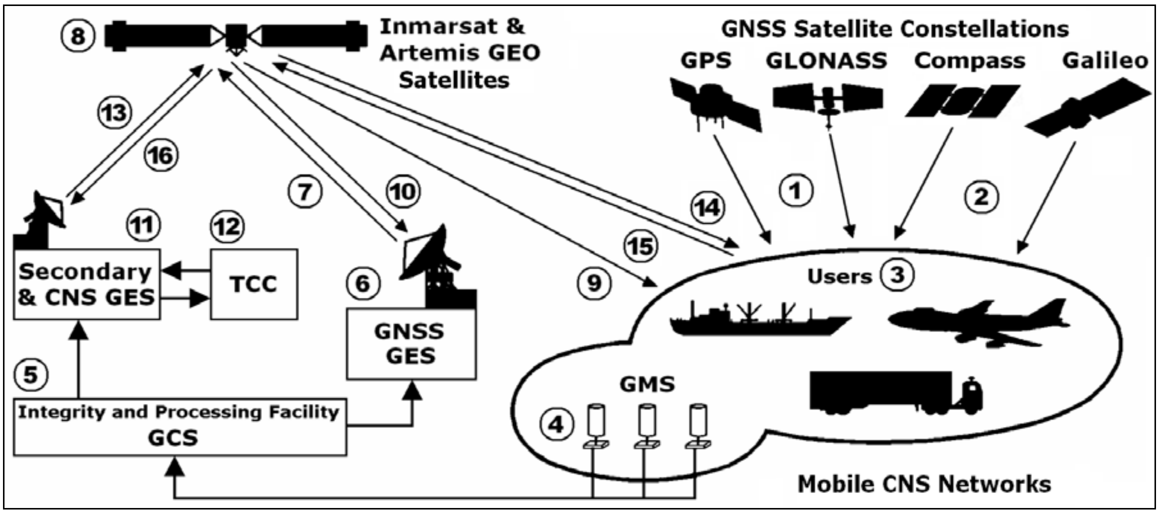

Figure 5.37. ASAS Space and Ground Segments – Courtesy of Book: by Ilcev

5.6.2. ASAS System Configuration

The concept of ASAS infrastructure is to develop and implement new Coastal Movement Guidance and Control(CMGC) configuration as a special maritime security and control system that enables a port controller at shore to control, guide and monitor all vessels movements in coastal navigation, in the cramped channel strips and fiords, approaching areas to the anchorage and harbours, ship movement in harbours, including land vehicles in port and around the port's coastal environment, even in poor visibility conditions at an approaching to the port. Thus, the controller issues instructions to ship Masters and Pilots with reference to a command display in a control tower that gives vessels position information detected via satellites and by sensors on the ground.

The ASAS is implemented as the primary means of satellite CNS for vessels routes in ocean waters, coastal navigation, anchorage and for managing of all movements inside of seaports. It was intended to provide the following services:

1) The transmission of integrity and health information on each GPS or GLONASS satellite in real time to ensure all users do not use faulty satellites for navigation, known as the GNSS Integrity Channel (GIC).

2) The continuous transmission of ranging signals in addition to the GIC service, to supplement GPS, thereby increasing GPS/GLONASS signal availability. In such a way, increased signal availability also translates into an increase in RAIM availability, which is known as Ranging GIC (RGIC).

3) The transmission of GPS/GLONASS wide area differential corrections has, in addition to the GIC and RGIC services, to increase the accuracy of GPS/GLONASS signals nominated for civilian applications. Namely, this feature has been called the Wide Area Differential GNSS (WADGNSS).

The combination of the GEO spacecraft will be referred to as the ASAS network illustrated in **Figure 5.37.** As observed previous figure, all mobile users **(3)** receive navigation signals **(1)**from GNSS-1 of GPS or GLONASS satellites. In the near future can be used GNSS-2 signals of Compass and Galileo GNSS2 satellites **(2).** These signals are also received by all reference Ground Monitoring Station (GMS) terminals of integrity monitoring networks **(4)** operated by governmental agencies in many countries within Africa and Middle East. The monitored data are sent via land lines or VSAT to a regional Integrity and Processing Facility of master or Ground Control Station (GCS) **(5)**, where the data is processed to form the integrity and WADGNSS correction messages, which are then forwarded to the Primary GNSS Ground Earth Station (GES) **(6)**.

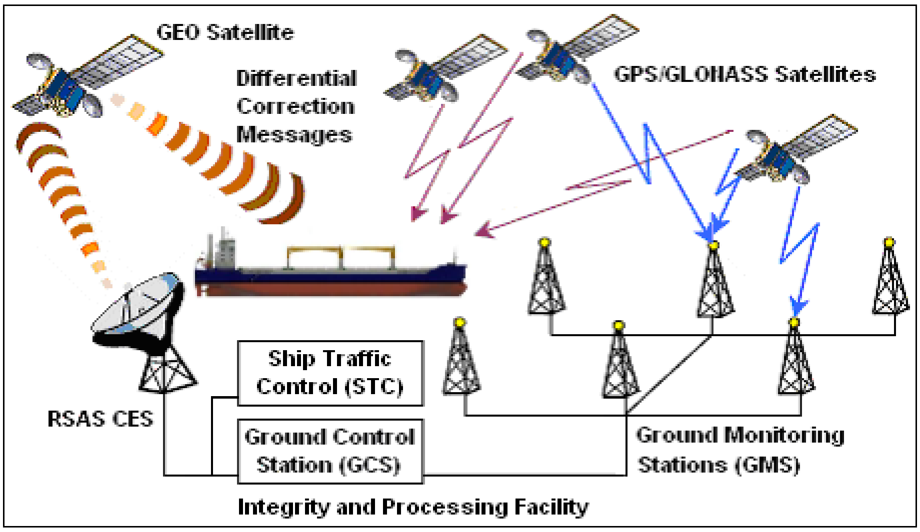

Figure 5.38. GNSS Augmentation SDL (GASDL)– Courtesy of Paper: by Ilcev

At the GES, the navigation signals are precisely synchronized to a reference time and modulated with the GIC message data and WADGNSS corrections. The signals are sent to a satellite on the C-band uplink **(7)** via GNSS payload located in GEO Inmarsat and Artemis spacecraft **(8)**, the augmented signals are frequency-translated to the mobile user on L1 and new L5-band **[9]** and to the C-band **(10)** used for maintaining the navigation signal timing loop. The timing of the signal is done in a very precise manner in order that the signal will appear as though it was generated on board the satellite as a GPS/GLONASS ranging signal. The Secondary GNSS GES can be installed in Communication CNS GES **(11)**, as a hot standby in the event of failure at the Primary GNSS GES. The Traffic Control Centre (TCC) ground terminals **(12)** could send a request to all particular mobiles for providing CNS information by Voice or Data, including new Voice, Data and Video over IP (VDVoIP) on the C-band uplink **(13)** via Communication payload located in Inmarsat or Artemis spacecraft and on the C-band downlink **(14)** to all mobile users **(3)**. These mobile users are able to send augmented CNS data on the L-band uplink **(15)**via the same spacecraft and L-band downlink **(16)**. The TCC terminals are processing CNS data received from mobile users by Host and displaying on the surveillance screen their current positions very accurate and in the real time. Therefore, the ASAS will be used as a primary means of navigation during all phases of traveling for all mobile applications**.** In such a way, the ASAS or RSAS augmentation signals for TCC can be sent to all ships in certain sailing areas for improved safety and security in navigation and for enhanced collision avoidance(Ilcev, D and Moyo 2011; Ilcev, DS 2013a).

5.7. Satellite GASDL via RSAS networks

The RSAS network infrastructure is a combination of ground and space equipment to provide augmentation of standard GPS or GLONASS signals, which is shown in **Figure 5.38.**The service procedure is the same as the ASAS system configuration being provided by RSAS:
- Differential corrections are determined to improve accuracy;
- Integrity monitoring is predisposed to ensure that errors are within tolerable limits with a very high probability and thus ensure safety; and
- Ranging is proposed to improve availability.

The numbers of Reference Stations (GMS) are receiving not augmented signals of GPS or GLONASS satellites, processing and forwarding this data to Master Station (GCS). The GCS terminals process the data to determine the differential corrections and bounds on the residual errors for each monitored satellite and for each area.

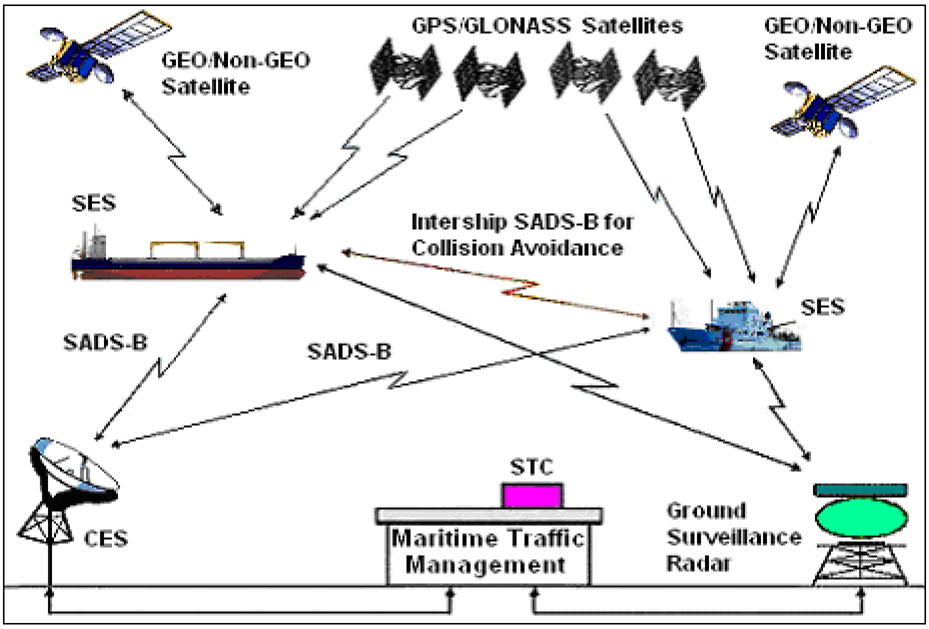

Figure 5.39. Satellite SADS-B– Courtesy of Presentation: by Ilcev

Therefore, GCS is providing determination of the clock, ephemeris and ionospheric errors (ionospheric corrections are broadcast for selected area) affected during propagation. The corrections and integrity information from the GCS terminal are then sent to each RSAS GES and uplinked to the GEO Satellites. Thus, these separate differential corrections are broadcast by RSAS GES through an GEO satellite data link via GNSS transponder at the same frequency used by not augmented GPS or GLONASS receivers. Augmented GNSS Rx is receiving augmented signals of GPS/GLONASS and determined more accurate position of ships. Not augmented GNSS Rx can also receive augmented signals if is provided an adequate software or hardware. The most important stage in this network is to provide technical solution that augmented position of aircraft can be sent automatically via SDL or voice to CES and Control Centre. Finally, these positioning signals can be processed by special processor and displayed on look like radar display, whish traffic controller is using for Ship Traffic Control (STC) and Ground Control Station (GCS). Finally, the captain of ship can request STC to send position data of all ships sailing in his area, and in such a way get better picture for collision avoidance and enhanced safety and security at sea(Ilcev, D and Moyo 2011; Ilcev, DS 2013a).

5.8. Satellite Automatic Dependent Surveillance - Broadcast (SADS-B)

The SADS-B system is new proposed satellite broadcasting from vessels known as service Oceanic Sailing Guidance and Control (OSGC) and Coastal Movement Guidance and Control (CMGC) providing Position, Velocity and Time (PTV), positional integrity, ship identity and other data that have been detected and computed by onboard ship sensors for enhanced safety and security in deep sea navigation, which is similar system to RADS-B.
The satellite SADS-B system is modern satellite broadcasting from ships to provide position, velocity, positional integrity, sailing identity, ship address and other data that have been detected and computed by onboard aircraft sensors. Typical SADS-B application is similar to the RADS-B with differences that the SADS-B network is covering long distances and is using service of Coast Radio Station (CES), shown in **Figure 5.39.** A single CES can provide coverage in the areas of ocean regions for deep-sea sailing, coastal navigation and seaport guidance and control surveillance. SADS-B requires new equipage for aircraft and SADS-B accuracy and integrity is subject to the source of the navigation data (usually GNSS).

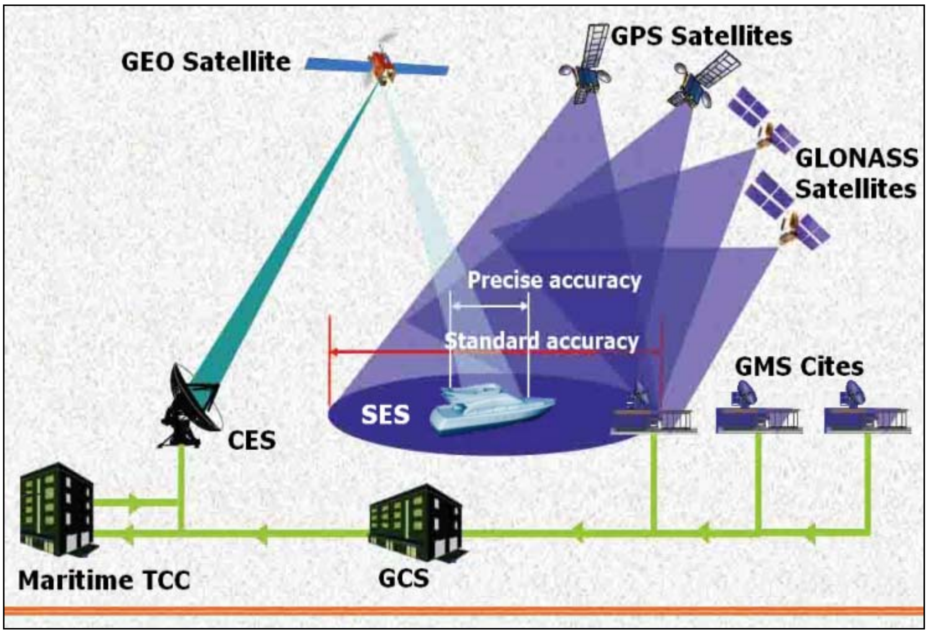

Figure 5.40. Satellite OSGC – Courtesy of Presentation: by Ilcev

The maritime SADS-B system is a surveillance technique that relies on the ship deriving its own position from the GNSS and periodically broadcast a data packet consisting of all other information along with vessel identification and intention to near-by SADS-B receivers installed on other ships, on fixed Coast Earth Stations (CES) or on ground vehicles. Once the data packet is received by the CES site, it is forwarded to an STC and a Maritime Traffic Management (MTM) central processing facility via a conventional data network where a traffic picture is generated then sent for display on the STC screen.
The result is that master mariners and controllers share the same accurate picture of the sea traffic in a given satellite coverage. The maritime SADS-B network can be broken into two primary functions, namely Ship Earth Stations (SES) equipped with SADS-B device works by sending GNSS-derived position and other data from the ship systems, through an SADS-B VHF/UHF powerful transponders to other ships, vehicles inside seaports and CES, which receive this data and send it to STC displays for the purpose of enhanced collision avoidance and coordination. In return the SADS-B provides transmission of STC information from CES or from other ships onboard SADS-B devices and their reception by SADS-B onboard equipment. Thus, this allows a bridge display data of nearby ships to the ship officer of the SADS-B equipped ship. The SADS-B information can be used to augment existing ground surveillance radar or used in lieu of those radar technologies(Ilcev, S 2010c).

5.8.1.Oceanic Sailing Guidance and Control (OSGC)

The Oceanic Sailing Guidance and Control (OSGC) can use SADS-B or new generation of Maritime Mobile Satellite Communications (MMSC) system to send GNSS data from GPS or GLONASS received by Ship Earth Station (SES) to the Coast Earth Station (CES) on L/C, Ku or Ka-band, what depends on the type of GEO spacecraft, illustrated in **Figure 5.40.**The OSGC system is ideal for CNS solutions of ships sailing in deep ocean waters far away from shore, which is working on the similar way then ASAS or any RSAS network. Namely, GMS sites are getting GNSS signals and forwarding them to GCS for processing and then via CES are sending augmented signals to SES via L1 or L5-band. From GCS signals can also be sent to maritime MTC for processing and displaying them at radar like display, while STC can send to any ship position of near by ships for awareness and collision avoidance(Ilcev, S 2010c).

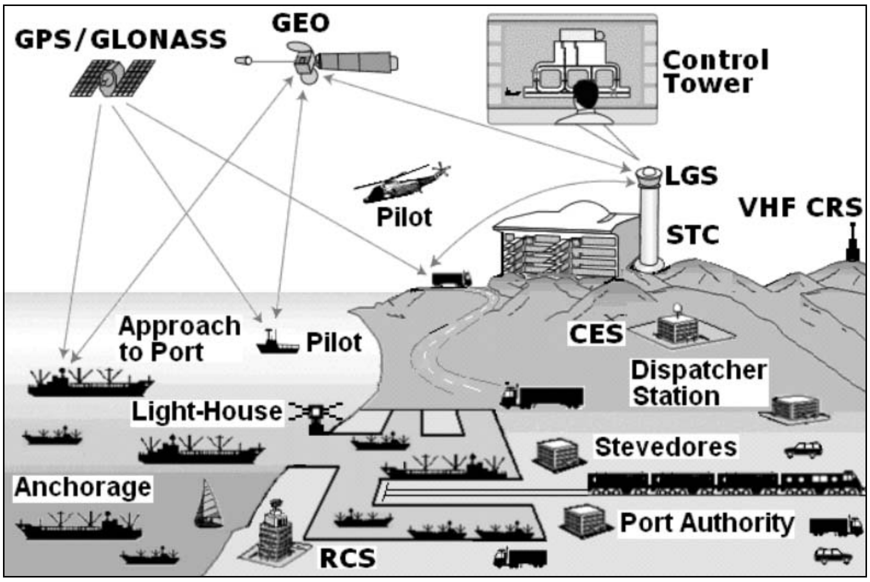

Figure 5.41. Satellite OSGC – Courtesy of Presentation: by Ilcev

5.8.2.Coastal Movement Guidance and Control (CMGC)

The Coastal Movement Guidance and Control (CMGC)infrastructure is a special security, control and surveillance system that enables a controller at STC to guide and monitor all vessels movements at sea in coastal navigation, in the cramped channel strips, approaching areas to the anchorage and ports, all movement in harbours: ships, land vehicles in port and around the port's coastal environment, in poor visibility conditions at an approaching to the port, shown in **Figure 5.41.** The controller issues instructions to ship master mariners, deck officers and pilots with reference to a command display in a control tower that sends vessels position information via satellite SADS-B or MMSC and by sensors on the ground. The STC site can use RDAS-B to send the same information to near by ships in the range of radio VHF-band coverage(SEASPACE 2014).

The CMGC infrastructure is providing the following segments:

1. GPS or GLONASS GNSS-1 spacecraft provides accurate position data to the vessels or port vehicle's;
2. GEO Satellite is transferring GNSS augmented or not augmented positioning data between vessels and STC terminal;
3. Control Tower is providing control and monitoring the traffic situation on the channel strips, approaching areas, in the port and around the port's coastal surface. The location of each vessel and ground vehicle is displayed on the command monitor of the STC site;
4. Light Guidance System (LGS) is managed by the controller at STC.
5. Radar Control Station (RCS) is a part of a current system for STC;
6.VHF Coast Radio Station (CRS) is a part of the maritime radio communications system for safety and security, which can be also used for RDAS-B;
7. Coast Earth Station (CES) is a part of maritime satellite communications system between SES terminals and shore infrastructures via GEO;
8.The pilot is a small boat or helicopter carrying the special trained man known as a Pilot, who has to proceed vessels in and out of ports; and
9.A bridge instrument of vessel displays the ship position and course.

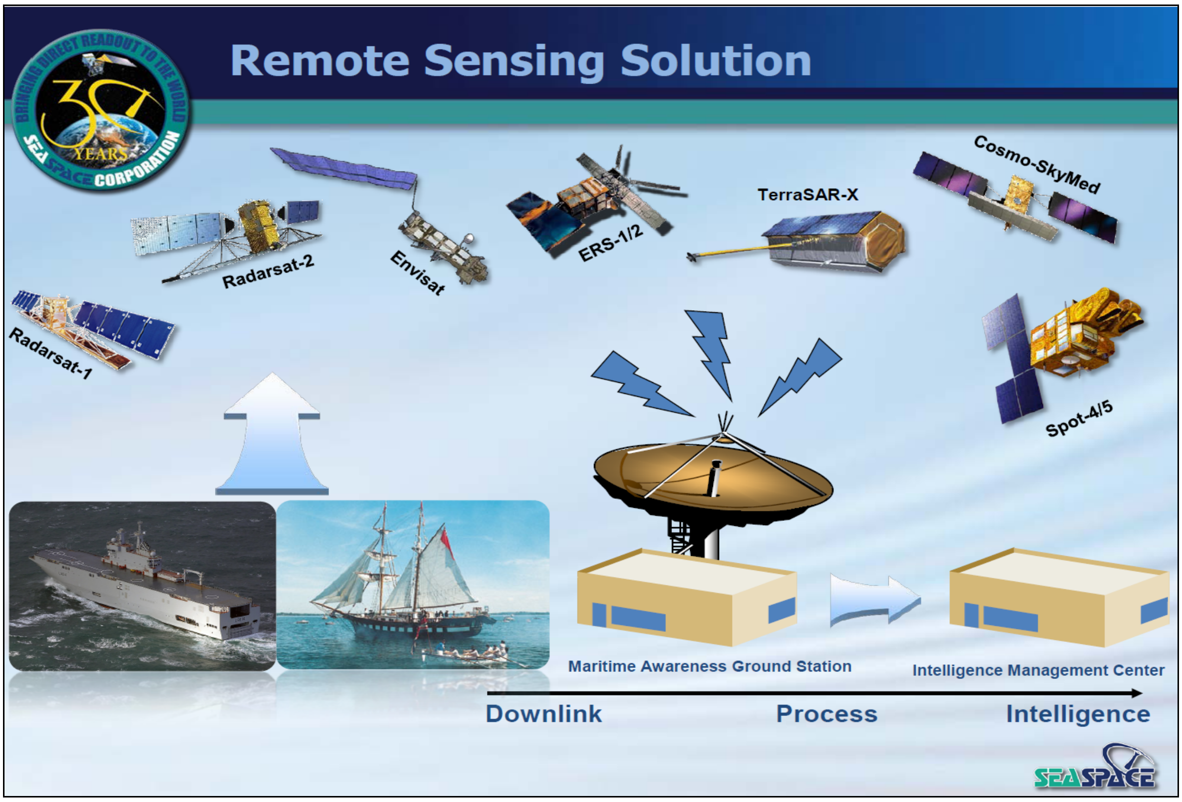

Figure 5.42. Remote Sensing Solutions via Satellites – Courtesy of Presentation: by Sea Space

5.9. Space Remote Sensing System (SRSS)

Space Remote Sensing System**(**SRSS) technology is providing surveillance and detecting of ships via Satellite Synthetic Aperture Radar (SSAR), Ladar, Lidar and Electro-Optical Space Surveillance (EOSS) using the existing facilities of GEO and Non-GEO satellite constellations including SCP or UAV platforms. The remote sensing services for the ground and sea is provided by many operators globally, shown in **Figure 5.42.**

5.9.1.Satellite Synthetic Aperture Radar (SSAR)

Satellite Synthetic Aperture Radar (SSAR) onboard spacecraft instruments or sensors can provide an efficient way of detecting ships in the open sea and measuring, through wake and Doppler displacement their movement, speed and direction. During the past years, request for maritime surveillance with new high-resolution sensors has increased, particularly in the field of maritime security and maritime safety. Coastal surveillance systems are widely used but are limited in their coverage, while satellite imagery gives the possibility to overcome these limits. The possibility to provide efficient ship surveillance over wide regions and all weather conditions makes SSAR a very well suited instrument for this application. Different satellite images at a variety of modes are available and can be selected depending on the extent of the area in order to monitor the different size of targets of interest. Repeated SSAR observation can contribute to a maritime surveillance system, complementing information on routes from HF coastal radars and shipboard R-AIS or S-AIS and other tracking systems.
The area accessible from SSAR generally increases with the elevation of the satellite, while the map coverage rate is a more complicated function of platform velocity and beam agility. The LEO satellite coverage is basically given by the ground velocity times the relatively narrow swath width. The instantaneously accessible area will be limited to some hundreds of kilometers away from the sub-satellite point(Curlander and McDonough 1991).

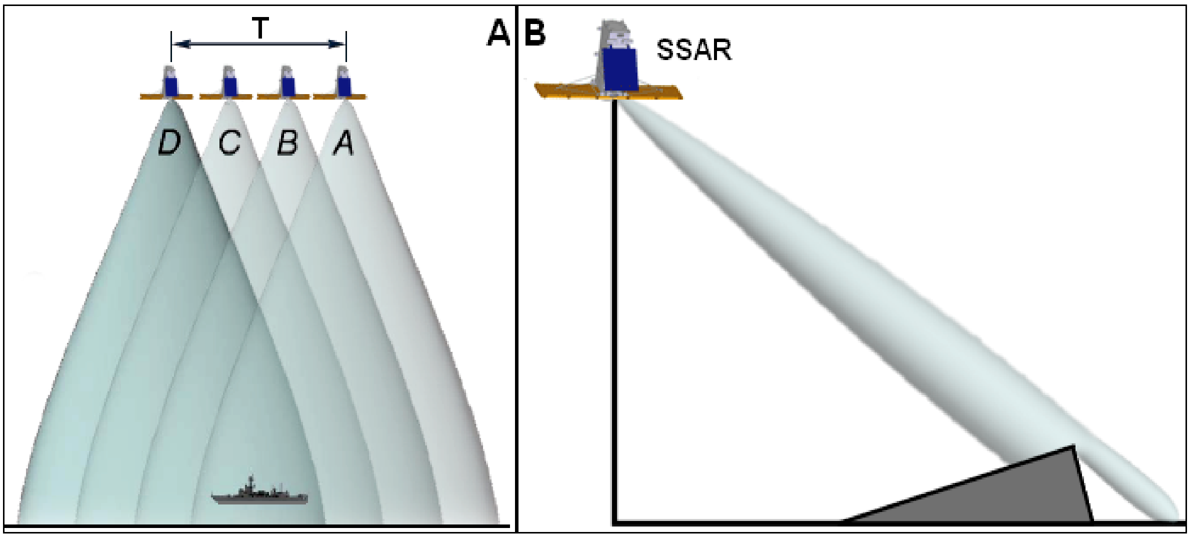

Figure 5.43. Synthesized Expanding Beamwidth and Shadowing– Courtesy of Presentation: by Radar tutorial

In the other extreme, the sub satellite point of GEO SSAR will move relatively slowly, while the area which can be accessed at any given time is very large, reaching thousands of kilometers from the sub satellite point. In such a way, to effectively use the accessibility provided by a high vantage point, very large antennas with electronically steered array beams are required. Interestingly, MEO satellite will enable powerful observational systems which provide large instantaneous reach and high mapping rates, while pushing technology less than alternative systems at higher altitudes. Thus, using interferometric SSAR techniques that can reveal centimeter-level(potentially sub-centimeter) surface displacements, frequent and targeted observations might be key factor to developing such elusive applications as earthquake forecasting.

Although not strictly environmental measurements like the other parameters, ship signatures are found in ocean imagery made by many SSAR operators. These significant signatures can provide information useful to environmental scientists, coastal and fishery managers, and law enforcement agencies. Characteristics such as high resolution (10to100 m), sensitivity to small variations in surface roughness (on the order of centimeters), and especially the strong signal return from hard targets like ships make SAR systems particularly adept at detecting vessels at sea. Ships may be detected via three main mechanisms: Identification of radar energy reflected directly from the vessel, Detecting of wake patterns and Identification of slicks on the ocean surface resulting from release of engine or fish oils.

The SSAR application is coherent mostly space borne or airborne side looking radar system which utilizes the flight path of the space platform to simulate an extremely large phase antenna or aperture electronically and that generates high-resolution remote sensing imagery. The individual transmit/receive Pulse Repetition Time (PRT) cycles are completed with the data from each cycle being stored electronically. The signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture.

After a given number of cycles, the stored surveillance data is recombined (taking into account the Doppler effects inherent in the different transmitter to target geometry in each succeeding cycle) to create a high resolution image of the land or sea surface being over flown. The SAR-processor stores all the radar returned signals, as amplitudes and phases, for the time period T (Synthetic Length of SSAR coming from Imagine Phased Array) from position A to D, which Synthesized Expanding Beamwidth is shown in **Figure 5.43 (A).**

The accessible area of SSAR radiating antenna sometimes decreases or even is suppresses, because a slope away from the radar illumination with an angle that is steeper than the sensor depression angle provokes radar shadows, shown in **Figure 5.43 (B).**

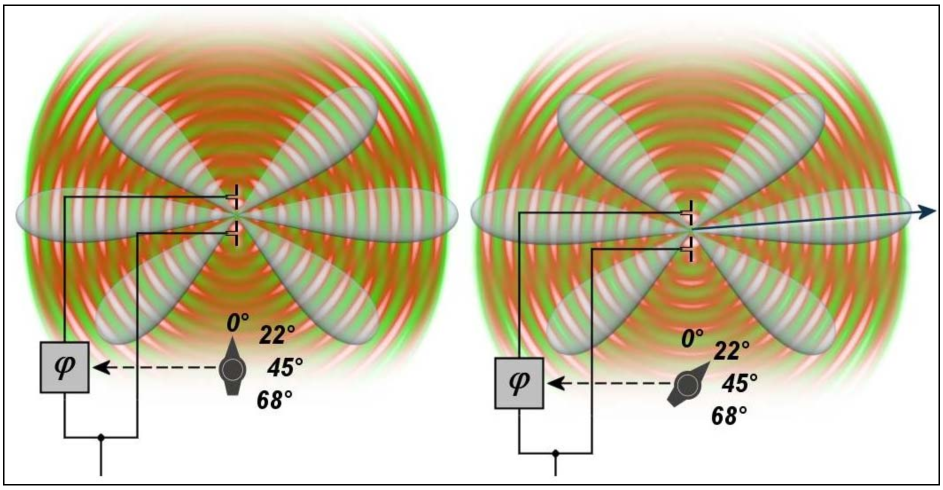

Figure 5.44. SSAR Phase Array Antenna – Courtesy of Presentation: by Radar tutorial

The shadowing effect increases with greater incident or look angle (θ), just as our shadows lengthen as the sun sets. Thus, it should be also noted that the radar shadows of two objects of the same height are longer in farther range than in the near range. Shadow regions appear as dark (zero signal) with any changes due solely to system noise, sidelobes and other effects normally of small importance.

Therefore, the SSAR system works similar of a phased array, but contrary of a large number of the parallel antenna elements of a phased array, SSAR uses one antenna in time-multiplex, shown in **Figure 5.44.**The different geometric positions of the SSAR antenna elements are a result of the moving platform in progress.

The Pulse Repetition Frequency (PRF) value of the radar system is the number of pulses that are transmitted per second, shown in **Figure 5.45 (A),** and the principle of SSAR operation is shown in **Figure 5.45 (B).** Radar systems radiate each pulse at the carrier frequency during transmit time or Pulse Width (PW), wait for returning echoes during listening or rest time, and then radiate the next pulse, as shown in the figure. The time between the beginning of one pulse and the start of the next pulse is already stated PRT and is equal to the reciprocal of PRF and is defined as follows:

$$PRT = 1/PRF \tag{5.3}$$

The radar system pulse repetition frequency determines its ability to unambiguously measure target range and range rate in a single coherent processing interval as well as determining the inherent clutter rejection capabilities of the radar system.

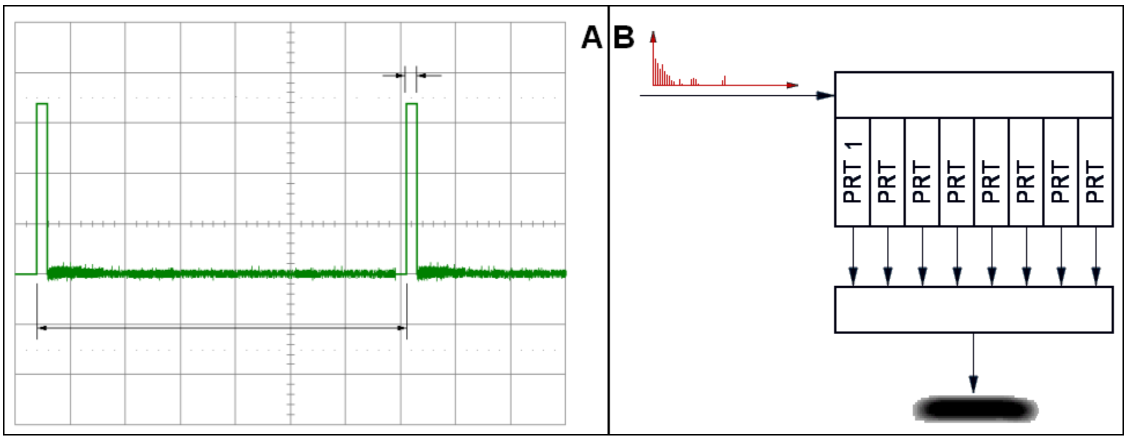

Figure 5.45. Value of PRF and Principle of SSAR Operation – Courtesy of Brochure: by Radar tutorial

In order to obtain an unambiguous measurement of target range, the interval between radar pulses must be greater than the time required for a single pulse to propagate to a target at a given range and back. The maximum unambiguous range (R_{un}) in relation to the velocity of electromagnetic propagation or speed of the light (c_o) is then given by the equation:

$$R_{un}= c_o/2 \cdot PRF = c_o \cdot PRT/2. \qquad (5.4)$$

The SSAR processor stores all the radar returned signals, as amplitudes and phases, for the time period (T) from position A to D. Thus, now it is possible to reconstruct the signal which would have been obtained by the geometric length of the antenna (L) as follows:

$$L = v \cdot T = Ro\lambda/Dsin\theta o; \qquad (5.5)$$

where: v = speed of platform, R= slant range from the antenna to the midpoint of swath, λ= wavelength of the transmitted pulses(transmitted signal), D = distance and θ = look angle.
As the line of sight direction changes along the radar platform trajectory, a synthetic aperture is produced by signal processing that has the effect of lengthening the antenna. Presenting T large makes the „synthetic aperture" large and hence a higher resolution can be achieved. As a target (like a ship) first enters the radar antenna beam, then the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target (ship) for each pulse are recorded during the entire time that it is within the beam. The point at which the target leaves the view of the radar beam some time later determines the length of the simulated or synthesized antenna. The synthesized expanding beamwidth, combined with the increased time a target is within the array beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath. The achievable azimuth resolution of a SSAR is approximately equal to one-half the length of the actual antenna and does not depend on platform altitude (distance).
The platform (aircraft or satellite) of a Side-Looking Airborne Radar (SLAR) travels forward in the flight direction with the nadir directly beneath the platform. The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a swath. Range refers to the cross-track dimension perpendicular to the flight direction, while azimuth refers to the along-track dimension parallel to the flight direction. The swath width refers to the strip of the Earth's surface from which data are collected by side-looking airborne radar. It is the width of the imaged scene in the range dimension.
The longitudinal extent of the swath is defined by the motion of the aircraft with respect to the surface, whereas the swath width is measured perpendicular to the longitudinal extent of the swath. The SLAR is real aperture radar primarily, which requires a reasonable large antenna for adequately angular resolution. The azimuth resolution (R_a) is defined as:

$$Ra = H \cdot \lambda/L \cdot \cos\theta; \qquad (5.6)$$

where: H = height of the antenna (height of the spacecraft/airplane), λ = wavelength of the transmitted pulses, L = geometric length of the antenna and θ = incidence angle.
The equation shows that with increasing altitude decreases the azimuth resolution of SLAR and very long antenna (i.e., large L) would be required to achieve a good resolution from a satellite. The SSAR system is used to acquire higher resolution. The size of the ground resolution cell increases on the side of the nadir as the distance between the radar platform and the ground resolution cell increases. This means that the ground resolution cells are larger towards the edge of the image than near the middle. This causes a scale distortion, which must be accounted for.

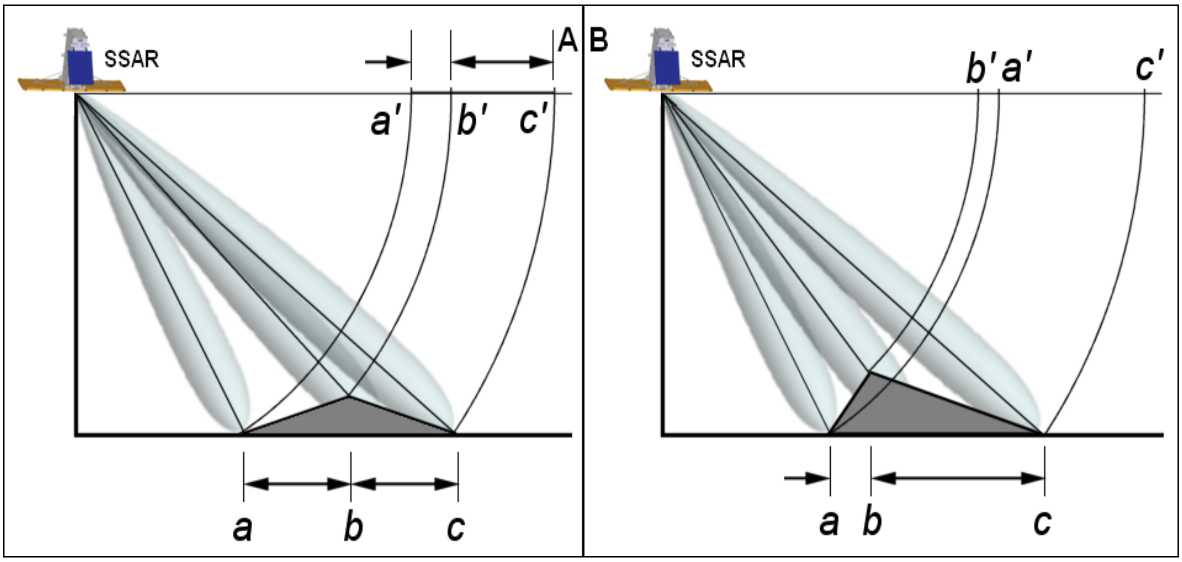

Figure 5.46. SSAR Foreshortening and Layover –Courtesy of Presentation: by Radartutorial

At all ranges the radar antenna measures the radial line of sight distance between the radar and each target on the surface. This is the slant range distance. The ground range distance is the true horizontal distance along the ground corresponding to each point measured in slant range. The cross-track resolution (R_r) is defined as:

$$Rr = co \cdot tp/2 \cos \theta; \qquad (5.7)$$

where: c_o = speed of light and t_p = pulse duration of the transmitter.
The practical example is given for the SLAR applications with the following characteristics: λ = 1 cm, L = 3 m, H = 6000 m, θ = 60° and t_p = 100 ns. It has got a resolution of R_a = 40 m and R_r = 17.3 m. The same SLAR on a platform in a height of 600 Km would achieve an azimuth-resolution of Ra = 4000 m.
The requirements of SSAR are: Stable, full-coherent transmitter, An efficient and powerful SSAR processor and Exactly knowledge of the flight path and the velocity of the platform. Using such a technique, radar designers are able to achieve resolutions which would require real aperture antennas so large as to be impractical with arrays ranging in size up to 10 m. The SSAR radar can be partnered by what is termed Inverse SAR (abbreviated to ISAR) technology, which in the broadest terms, utilizes the movement of the target rather than the emitter to create the synthetic aperture. The ISAR radars have a significant role aboard maritime patrol aircraft to provide them with radar image of sufficient quality to allow it to be used for target recognition purposes. The slant-range distortion occurs because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground. This results in a varying image scale, moving from near to far range.
Foreshortening of the SSAR system occurs when the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top. Because the radar measures distance in slant-range, the slope (from point a to point b) will appear compressed and the length of the slope will be represented incorrectly (a' to b') at the image plane, shown in **Figure 5.46 (A).**
Layover of the SSAR system occurs when the radar beam reaches the top of a tall feature (b) before it reaches the base (a). The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and „lays over" the base of the feature (b' to a'), shown in **Figure 5.46 (B)**(ESA 2014; Radartutorial 2014)**.**

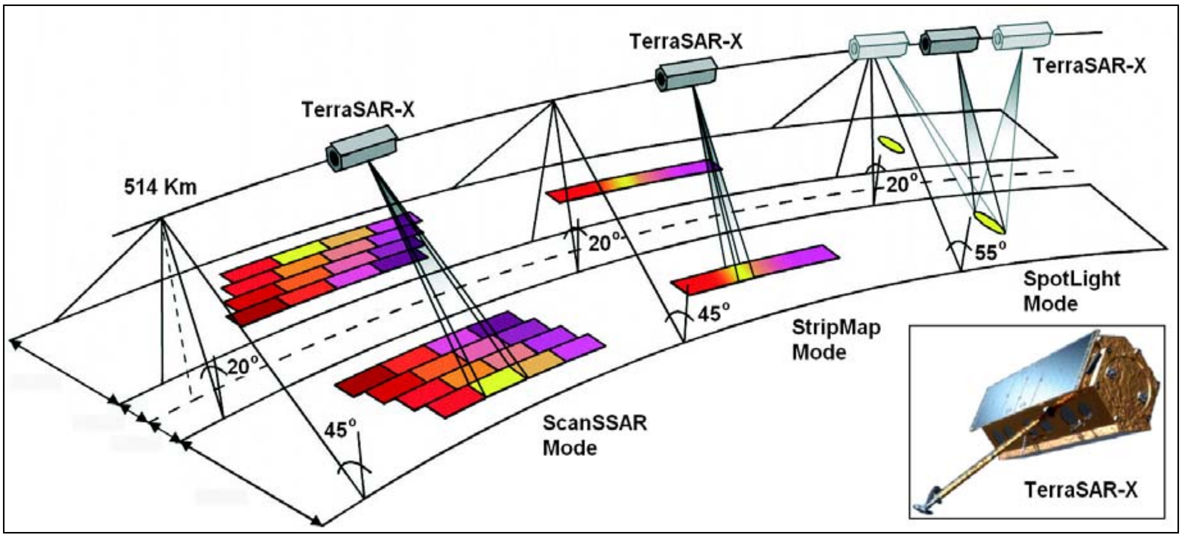

Figure 5.47. Terra SAR-X Spacecraft and Operational Parameters –Courtesy of Presentation: by Astrium

5.9.1.1.Ships Surveillance and Detecting via SSAR TerraSAR-X Spacecraft

Ship surveillance and detecting is an important application of global Earth environment and surface monitoring for ecological, safety and security purpose. In order to overcome the limitations by other systems, surveillance with SSAR is used because of its possibility to provide ship detecting at high resolution over wide swaths and in all weather conditions. During the last years, the demand for the vessel surveillance has increased both for fisheries control and for maritime transport security and safety. In order to overcome the limitations posed by conventional systems, surveillance with SSAR is being adopted more frequently because of its possibility to provide ship detecting over wide swaths and under many weather and environmental conditions. Up to now, different satellite sensors have been available for the vessel surveillance, which additional availability is of great interest. Considering revisit and reliable coverage requirements of different SSAR operators, here is chosen and introduced Terra SAR-X (Scan SAR mode), which gives a preliminary impression about its performance for vessel detecting and which includes the pirate boats activities and movements as well.

TerraSAR-X as a radar SSAR Earth observation satellite is a joint venture being carried out under a public-private-partnership between the German Aerospace Center (DLR) and EADS Astrium provider. The exclusive commercial exploitation rights of TerraSAR-X are held by the geo-information service provider Astrium. Terra SAR-X was launched on 15 June 2007 and has been in operational service since January 2008. With its twin satellite Tan DEM-X, launched on 21 June 2010, Terra SAR-X acquires the data basis available from 2014.

New X-band SSAR imager onboard the TerraSAR-X (TS-X) satellite gives access to spatial resolution as fine as 1 m, which orbital parameters and TerraSAR-X spacecraft are shown in **Figure 5.47.**The quality of TS-X images with respect to ship detecting is important together with first assessment of its performance. Therefore, the velocity of a moving ship globally is estimated using complex TS-X data. As test cases, images were acquired over the North Sea, Baltic Sea, Atlantic Ocean, and Pacific Ocean in Stripmap mode with a resolution of 3 m at coverage of 30x100 km(Paloscia *et al.* 2011; Dabrowska-Zielinska *et al.* 2013).

With its active phased array X-band SSAR antenna (wavelength 31 mm, frequency 9.6 GHz), Terra SAR-X acquires new high-quality radar images of the entire planet whilst circling Earth in a polar orbit at 514 km altitude. The satellite orbit is selected such that the satellite flies in a sun-synchronous dusk-dawn orbit, which means that it moves along the day-night boundary of the Earth and always presents the same face to the Sun, ensuring an optimum energy supply via the solar cells.

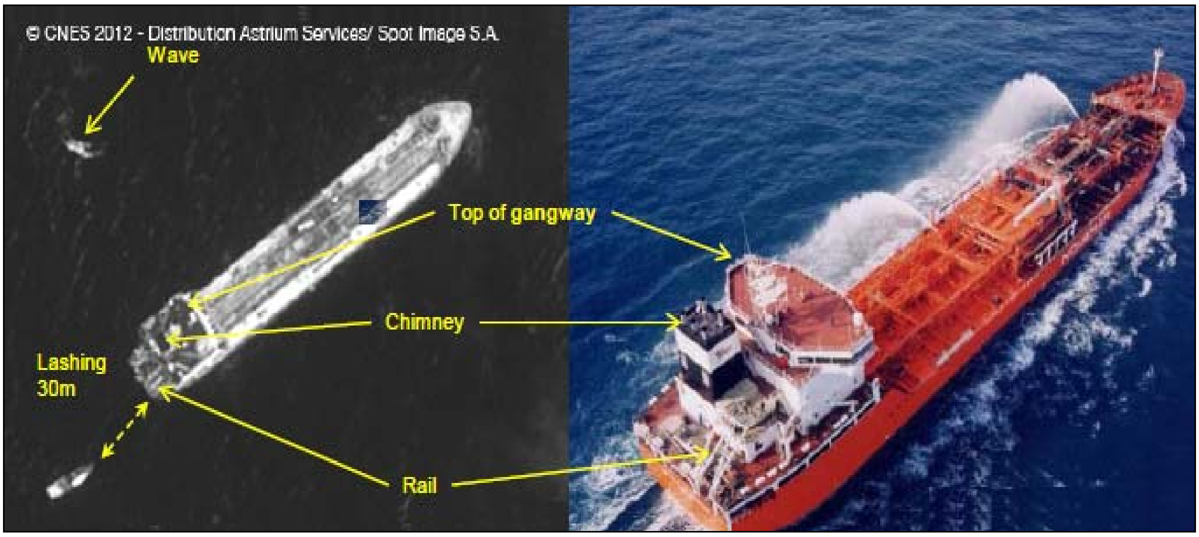

Figure 5.48. Image of Captured Ship by Pirates–Courtesy of Presentation: by Astrium

Terra SAR-X satellite is designed to carry out its task for five years, independent of weather conditions and illumination, and reliably provides radar images with a resolution of up to 1m. Features of Terra SAR-X satellite are: resolution of up to 1 m, excellent radiometric accuracy and geometric accuracy unrivalled by any other commercial spaceborne sensor, quick site access time of 2.5 days max. (2 days at 95% probability) to any point on Earth, unique agility (rapid switches between imaging modes and polarizations). Terra SAR-X acquires radar data in the following three main imaging modes:

Spot Light provides up to 1 m resolution, scene size 10 km (width) x 5 km (length);

Strip Map provides up to 3 m resolution, scene size 30 km (width) x 50 km (length); and

Scan SAR provides up to 18 m resolution, scene size 100 km (width) x 150 km (length).

However, Strip Map and Scan SAR: acquisition length extendable to up to 1,650 km.

In addition, the unique design of Terra SAR-X's SSAR satellite antenna allows a variety of polarimetric combinations: single or dual polarization and even full polarimetric data takes, are possible. Otherwise, depending on the desired application, one of four different product types (processing levels)can be selected: Single Look Slant Range Complex (SSC); Multi Look Ground Range Detected (MGD); Geo coded Ellipsoid Corrected (GEC) and Enhanced Ellipsoid Corrected (EEC).

TerraSAR-X will exhibit some technical-industrial novelties. One of these innovations is a kind of zoom shot, with the resolution and scanning field vice versa changeable in a 1:10 relationship, either a larger area to grasp or a small area with the highest possible resolution. Furthermore the antenna can be aligned by electronics within an angle range so that the point of view is adjustable. Earlier radar satellites could radiate the antenna only in one direction.

Except other SSAR applications, TerraSAR-X serves for different purpose vessel tracking and detecting in normal situations and for anti piracy activities. Integrated Maritime Security and Safety Services provides full range of information for enhanced security, safe shipping and sustainable resources exploitation on a modular basis, benefiting from complementary capabilities of space SSAR sensors such as: Ships Tracking and Detecting Service, Oil Spill Detecting Service and Sea Ice Monitoring Service. Therefore, the Terra SAR-X sensors can be employed for identification of starting points of ships and destinations, typical traveling routes, contraband, smuggling and pirate activities. Thus, identification of oil spills and leakages caused by vessels and also characterization of typical drift behavior of ice bergs in certain area and time have significant impact by using Terra SAR sensors and service.

In **Figure 5.48** is shown SSAR ship identification of hijacked by pirates Italian tanker m/t Enrico Iveoli with Pleiades-1A in March 2012.

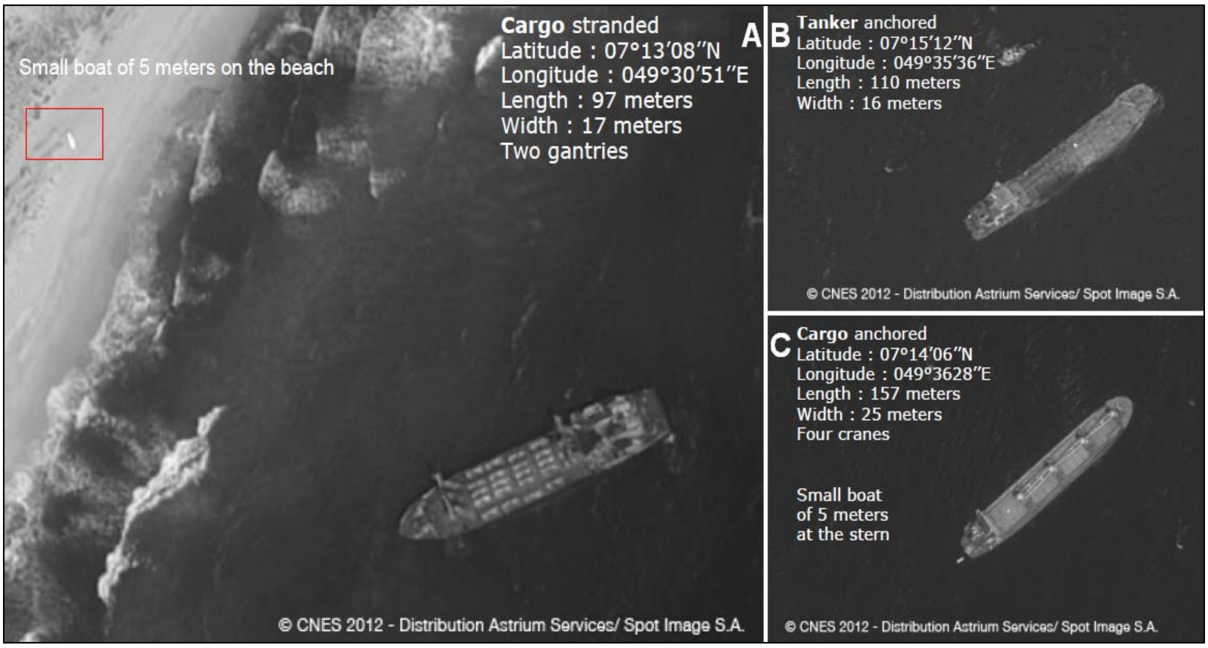

Figure 5.49. Localization of other Ships in the area of m/t Enrico Iveoli–Courtesy of Presentation: by Astrium

Therefore, this ship is easily detected and identified by aid of Terra SAR-X SSAR with the following size characteristics at position: Latitude = 07°13'29"N. Longitude = 049°35'11"E, Length = 138 m, Width = 22 m, Dhow = 17 meters and Course = 053°. All these particulars are enough to find out and trace and assist the ship.

In **Figure 5.49** is illustrated example of localization of further vessels in the area of m/t Enrico Iveoli for possible immediate assistance in SAR and released activities.

Traffic monitoring from space, day and night, from more than 500 kilometers up above are the service solutions ships tracking and detecting, oil spill detecting and sea ice monitoring, as very important parameters for enhanced safety and security of ships. In **Figure 5.50** is illustrated example of ships tracking and detecting service via Terra SAR sensors in Gulf of Aden as the hottest sea area in the world.

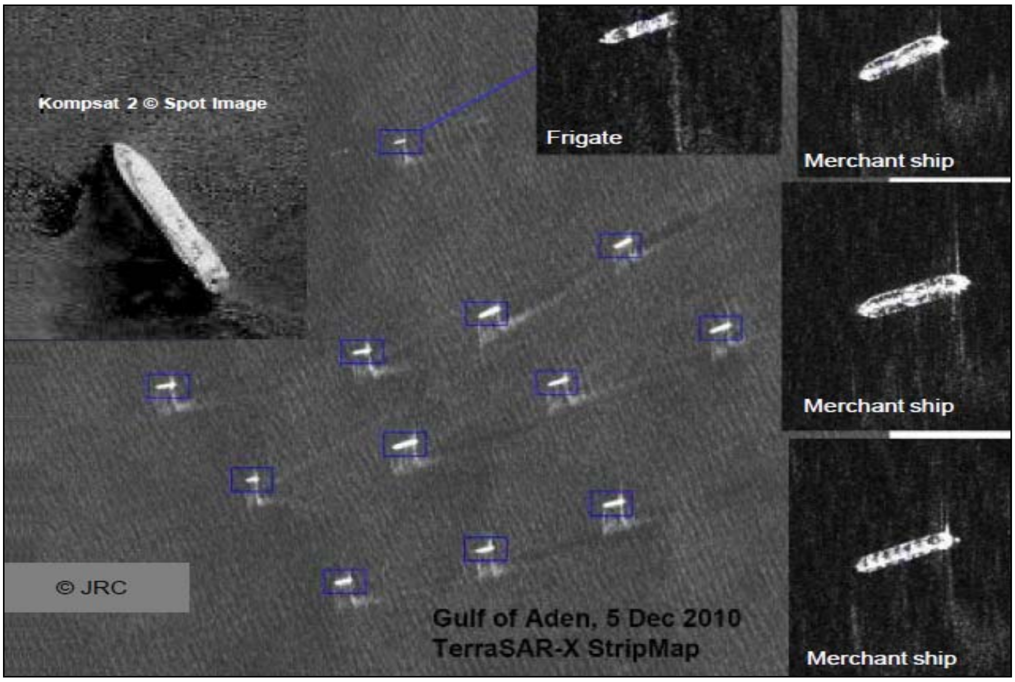

Figure 5.50. Ships Tracking and Detecting Service –Courtesy of Presentation: by Astrium

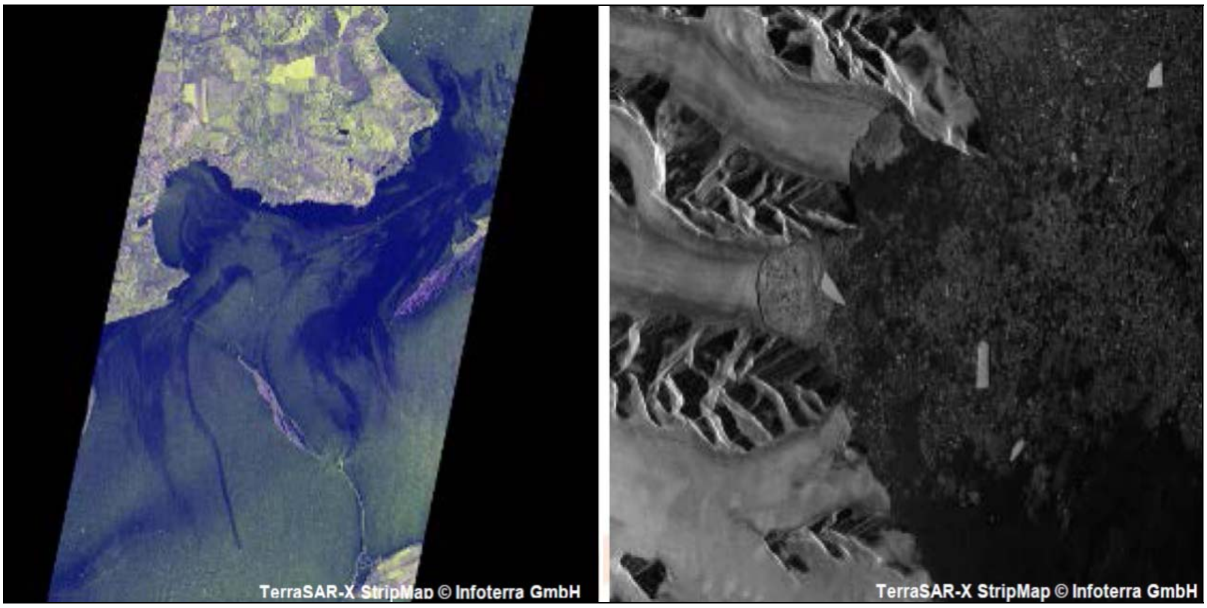

Figure 5.51. Oil Spill Detecting and Sea Ice Monitoring Service–Courtesy of Presentation: by Astrium

In **Figure 5.51(Left)** is illustrated example of oil spill detecting service, and **Figure 5.51(Right)** is illustrated example of sea ice monitoring service, both by aid of TerraSAR sensors for enhanced ecological and safety solutions at sea.

The orbital parameters of TerraSAR-X spacecraft are: type of orbit circular, sun-synchronous and with orbit altitude of 514 Km, orbit period is 95 min, inclination angle is 97.4^0, period repeat cycle is 11 days, imaging frequency in 95% cases – 2 days, maximum – 4 days, and life time is 5 years.

Therefore, TerraSAR sensors can be used for detecting of all kind of ships including small and non-metal boats (what Radar cannot provide), identification and detailed information gathering on identified suspicious vessels and pirate activities, such as images with provision of high resolution: ship position, dimension, heading and even with R-AIS cooperativeness. Then, the system is providing accurate identification oil spills, small scaled leakages at oil rigs and natural oil seeps. Finally, the important impact of the Terra SAR sensors is tactical support to ships and oil rigs operating in ice waters, which delivery detailed information on ice objects and conditions, route optimization and navigation safety of ships and enhanced coordination of ice breakers (ICEMAR project), and early warning and protection of oil rigs.

The TerraSAR-X spacecraft is equipped with active synthetic aperture radar. Active in this context means that the beam can be aligned in a slewing range of 20 to 60 degrees. This is not done by mechanically moving the antenna or the complete satellite, but by superimposing many individual radar beams. The SSAR radar operated in the so-called X-band spectrum. The radio signals emitted in this spectrum have a frequency of 9.65 GHz, which corresponds to a wavelength of about 3 cm, thus allowing for such an extremely high image resolution.

With the adjustable angle radar sensor - along with other course refinements (precession by the Earth flattening) any place on earth can be observed preferentially within 1–3 days. For a specific point on the equator TerraSAR X has a revisit cycle of 11 days. The revisit time decreases towards the poles, e.g. northern Europe has a revisit time of typically 3–4 days.

The ground operating mechanism and controls for the TerraSAR X is developed by the DLR in Oberpfaffenhofen. It consists of mission operating equipment, payload ground segment and instrument operation and calibration segment. At the base of the ground segment lies the German Space Operation Center (GSOC), the German Remote Sensing Datum Center (DFD) as well as Institutes for Methodology of Remote Sensing (MF) and the Institute for High Frequency Engineering and Radar Systems (HR) which are all part of the DLR(Knabe, AS 2012a; Knabe, S 2012b).

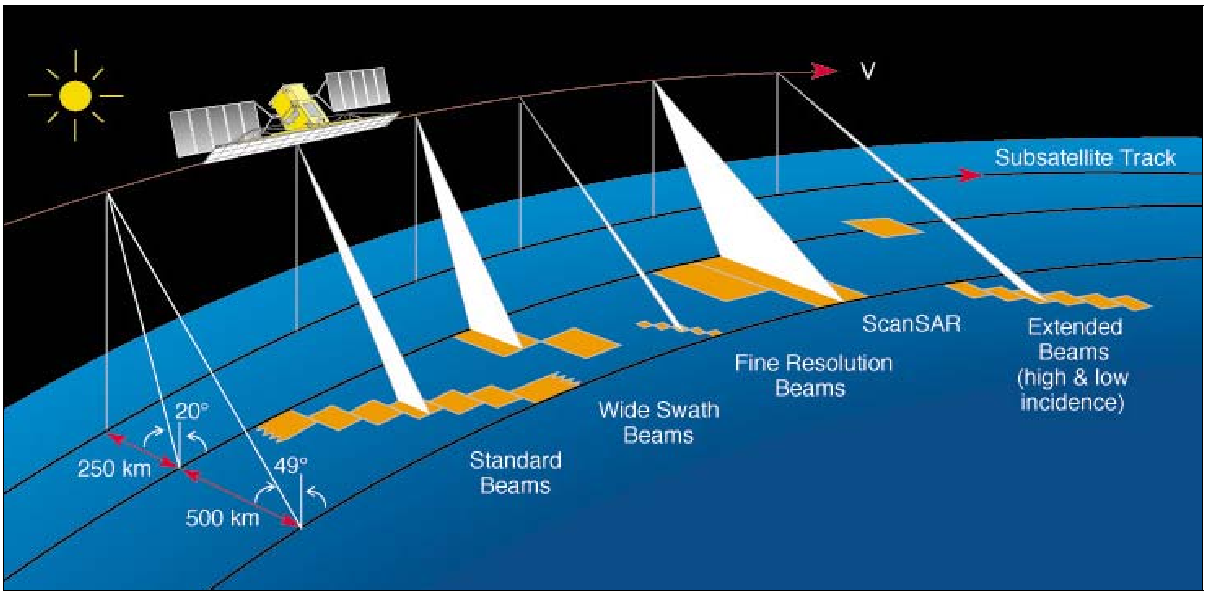

Figure 5.52. Radarsat Spacecraft and Operational Parameters –Courtesy of Presentation: by Radarsat

5.9.1.2. Ships Surveillance and Detecting via SSAR Radarsat Spacecraft

The Radarsat SSAR system is an innovative Earth observation satellite program developed by Canada to monitor environmental conditions and natural resources of the country's vast land mass and its territorial waters. Since its launch in November 1995, the versatile SSAR instrument aboard Radarsat-1 has also acquired, on demand, large amounts of data in many other parts of the globe. Moreover, the suite of high and low resolution imaging modes and data products has become a reliable source of geospatial information, which Spacecraft and Operational Parameters are shown in **Figure 5.52.**The Radarsat-2 SSAR shown in **Figure 5.53**is an Earth observation satellite that was successfully launched on 14 December 2007 for the Canadian Space Agency by Starsem, using a Soyuz FG launch vehicle, from Kazakhstan's Baikonur Cosmodrome.

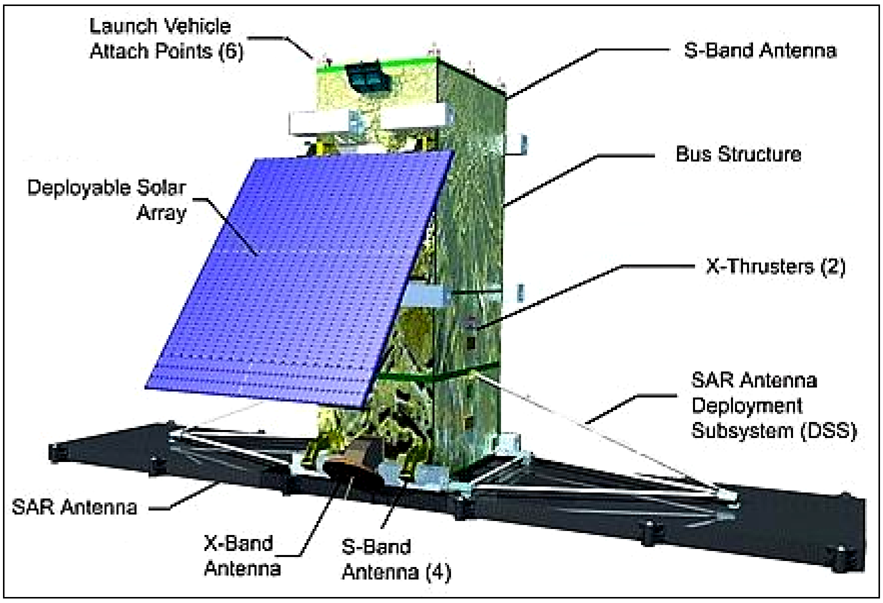

Figure 5.53. Radarsat-2 Spacecraft –Courtesy of Presentation: by Radarsat

Radarsat-2 was previously assembled, integrated and tested at the David Florida Laboratory near Ottawa, Ontario before the start of its launch campaign. The end of the spacecraft and ground segment commissioning period was declared on April 27, 2008 after which routine commercial operation started. Hence, SSAR images were delivered not only to Canadian

users but also to a multitude of scientific institutions, government agencies and commercial clients worldwide. It has proven itself in frequently cloud covered tropical regions, in cases of environmental emergencies, ocean and ships surveillance.
Satellite has SSAR sensors with multiple polarization modes, including a fully polarimetric mode in which different polarized data are acquired. Its highest resolution is 1 m in Spotlight mode (3 m in Ultra Fine mode) with 100 m positional accuracy requirement. In ScanSAR Wide Beam mode the SSAR sensor has a nominal swath width of 500 Km and an imaging resolution of 100 m. Its left looking capability allows the spacecraft the unique capability to image the Antarctic on a routine basis providing data in support of scientific research.
The prime contractor on the project is MacDonald Dettwiler (MDA), and other collaborating companies included EMS Technologies and Alenia. Radarsat-2 is owned and operated by MDA;Radarsat-2 is a follow-on to Radarsat-1. It has the same sun-synchronousat 798 Km altitude with 6 PM ascending node and 6 AM descending node. Radarsat-2 is separated by half an orbit period of ~50 min from Radarsat-1 in terms of ground or subsatellite track it would represent ~12 days ground track separation.
Some of the orbit characteristics are 24 days repeat cycle of 343 orbits, 14.29 orbits per day, each orbit being 100.75 minutes duration. It is filling a wide variety of roles, including sea ice mapping and ship routing, iceberg detecting, marine surveillance for ship and pollution detecting, terrestrial defense surveillance and target identification, geological mapping, land use mapping, agricultural crop monitoring, wetlands mapping and topographic mapping.
As of January 2013, Radarsat-2 is entering its 5th operational service year. Thus, numerous enhancements have been added to the original capabilities both on the ground and space segments. The operational performance is well within the specification with an acquisition success rate above 98%. Moreover, the usage of SSAR data have been steadily growing from an average of 3.5 minutes per orbit in 2008 to an average of 9.0 minutes per orbit in 2012.
The many advances in RADARSAT-2 technology were developed to respond to specific needs for radar data in hundreds of environmental monitoring applications in Canada and around the world. Through programs, conferences and funding opportunities, applications are being developed all the time. This is an overview of the important maritime in Radarsat-2 Earth observation data applications:
1. Ice and Oil Spill Monitoring – The Radarsat program was born out the need for effective monitoring, so Canada is one of world leaders in the operational use of space radar for sea ice and oil spill monitoring. Satellites operate day and night in all weather conditions covering timely coverage of vast areas. Some Radarsat-2 capabilities that benefit sea and river-ice applications are the multi polarization options that improve ice-edge detecting, ice-type discrimination and ice topography and structure information. Earth observation satellites have an advantage over aerial surveillance, because clauds cannot affect SSAR surveillance.
2. Marine Surveillance - Worldwide offshore resource-based operations such as fishing and oil and gas exploration and production have intensified over the past few decades. Thus, to monitor the world’s oceans, Canada has provided radar data for operational applications such as ship detecting and tracking including pirate activities, oil spill monitoring at sea and wind and surface-wave field estimation. The Radarsat-2 SSAR sensors improves ship detecting and monitoring with its Ultra-Fine beam mode using three-metre resolution and offers the potential for ship classification and enhanced safety. In addition, it can provide surveillance of pirate boats and captured ships by pirates. Government and industry require powerful solutions for assessing the resources and risks associated with the ocean environment.

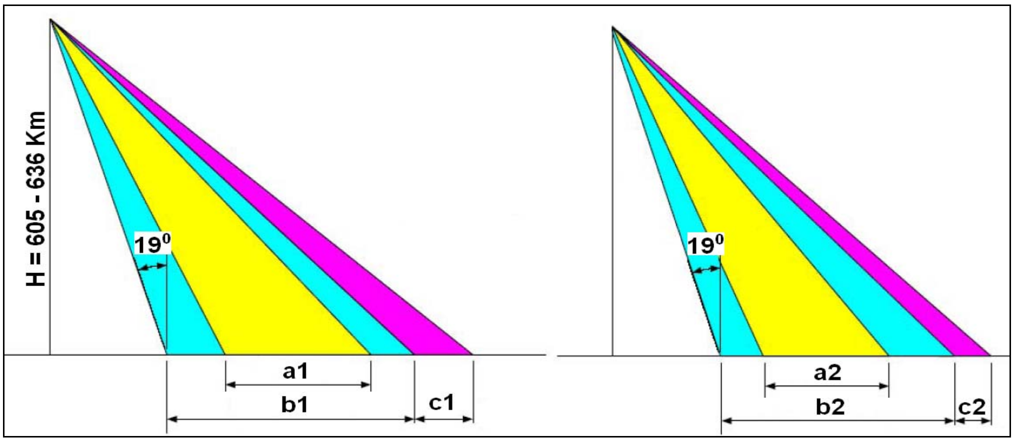

Figure 5.54. ScanSAR and Stripmap Beam Modes–Courtesy of Presentation: by Radarsat

The Canadian Space Agency (CSA) is currently conducting a feasibility study on the development of a C-band SAR satellite constellation referred to as Radarsat Constellation Mission (RCM).The current mission concept considers a three-satellite constellation that covers Canadian territory and waters on average once daily by combining ScanSAR data with a 50 resolution, acquired from ascending and descending orbits. The low-cost SSAR concept requires that the design of the SSAR system is in terms of mass, power consumption, volume and antenna size in compliance with the constrains imposed by using a low-cost launch vehicle and a small satellite bus. In this regard, a two-panel deployable SSAR antenna was selected with the dimensions of 1.375m x 6.88 m. Thus, a full implementation of the constellation is planned for 2014/15.The challenge for maritime surveillance is to achieve a wide-area SSAR data coverage at are solution that suitable for ship detecting. Two principal imaging modes are considered: a wide-area medium-resolution ScanSAR and a high resolution Stripmap mode(Geudtner and Séguin).
The ScanSAR mode is designed to have a swath width of 350 Km with a 500 Km accessible region, shown in **Figure 5.54 (Left).**Using 4-looks in range and one look in azimuth, this ScanSAR mode provides a medium resolution of 50 m. Thus, the trade-off is that 8 ScanSAR subbeams will be necessary to achieve the desired swath width. In this respect, however, other parameters are currently being analyzed, involving variations of the Noise Equivalent Sigma Zero (NESZ) and resolution across the swath. Regarding image quality assurance, there is a requirement on the ScanSAR beam to provide a mean NESZ of –22 dB with an acceptable radiometric variation of 0.2 dB at the beam boundaries. Additionally, no nadir returns shall be visible in the ScanSAR image. The high-resolution Stripmap, shown in Figure 5.54 (Right) beam mode with a spatial resolution of 5 m and a swath width of 20 km is intended for specific on-demand image acquisitions. The RCM key system parameters or Radarsat-2 are summarized in **Table 5.2.**

Table 5.2. Key System Parameters of RCM

Radar Frequency	C-band: 5.405 GHz
Chirp Bandwidth	100 MHz
Swath Width	20 - 350 Km
Accessible Swath Width	500 Km
Spatial Resolution (1-look)	5-50 m
Orbital Altitude	~ 500 Km
Imaging Time	12 min per Orbit
Repeat Orbit Circle	12 Days
Polarization	HH or Dual-pol (HH-VV)

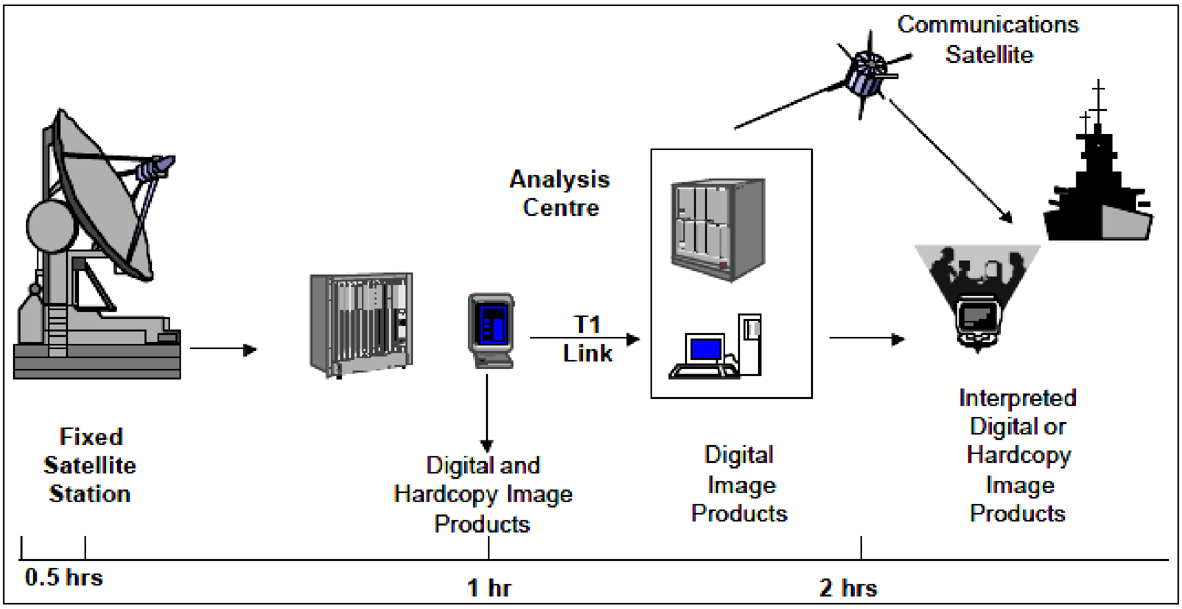

Figure 5.55. Radarsat Ground Segment and Processing Facilities–Courtesy of Presentation: by Radarsat

The Radarsat-2 ground segment has been designed based on the need to support the advanced capabilities of the Radarsat-2 spacecraft, the need to support a commercial mission with increased data and order volumes, and the body of experience and lessons learned from the operation of the Radarsat-1 mission, which architectural design is shown in **Figure 5.55**. The design was produced in consultation with the key organizations and agencies that will be critical to the success of the mission. The ground segment is responsible for operating the spacecraft, accepting and implementing orders, planning and tasking for image acquisition, product processing and distribution, and image quality control. In **Figure 5.56** is illustrated Radarsat-2 spacecraft coverage map of ground stations(SAT 1998).

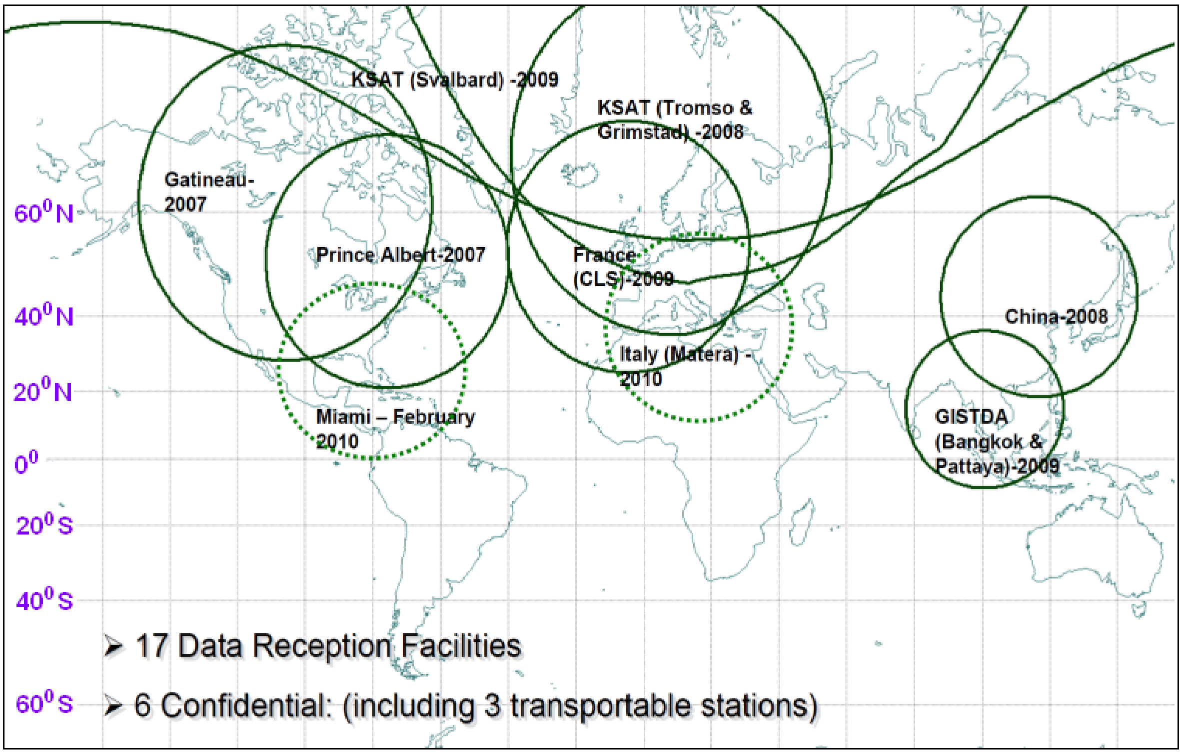

Figure 5.56. Radarsat-2 Reception Coverage–Courtesy of Presentation: by Radarsat

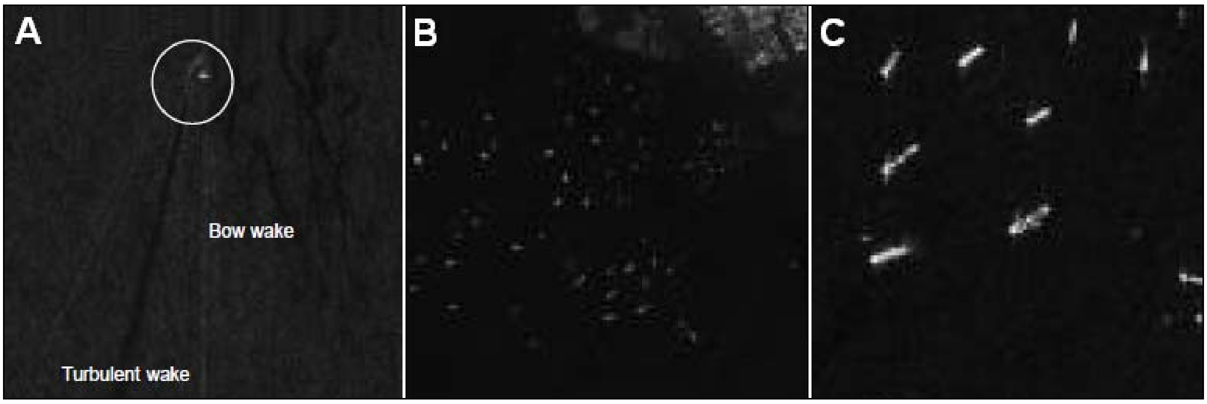

Figure 5.57. Radarsat SAR Ships Monitoring and Detecting–Courtesy of Presentation: by Radarsat

The ground support is provided for the addition of external network stations via a complete set of interfaces and the ability to reuse ground segment building block components. In **Table 5.3** is presented compariosn particulars of Radarsat-1 and Radarsat-2 Spacecfart.

Table 5.3. Comparison of Radarsat-1 and Radarsat-2 Spacecraft

	 RADARSAT-1	 RADARSAT-2
Launch	November 1995	December 2007
Owner	Canadian Space Agency	MDA
Design Life	5 years (now @ +14)	7 years
Imaging Frequency	C-Band; 5.3 GHz	C-Band; 5.405 GHz
Spatial Resolution	8 to 100 meters	1 to 100 meters
Beam Modes	7	12
Polarization Channels	HH	HH, VV, HV, VH
Look Direction	Right	Right & Left

In **Figure 5.57 (A)** is shown detecting of ship wake and speed dome by Radarsat-1 sensors acquired on 28 February 1998 with location in Arabian Gulf via beam in wide 2, resolution 27 m and bow wake scene size of 8.5 x 8.5 Km. In **Figure 5.57 (B)** is figure acquired also by Radarsat-1 on 8 January 1996 in Singapore using beam fine 2 and resolutions 27 m and in **Figure 5.57 (C)** is illustrated the same image in resolution of 8 m.

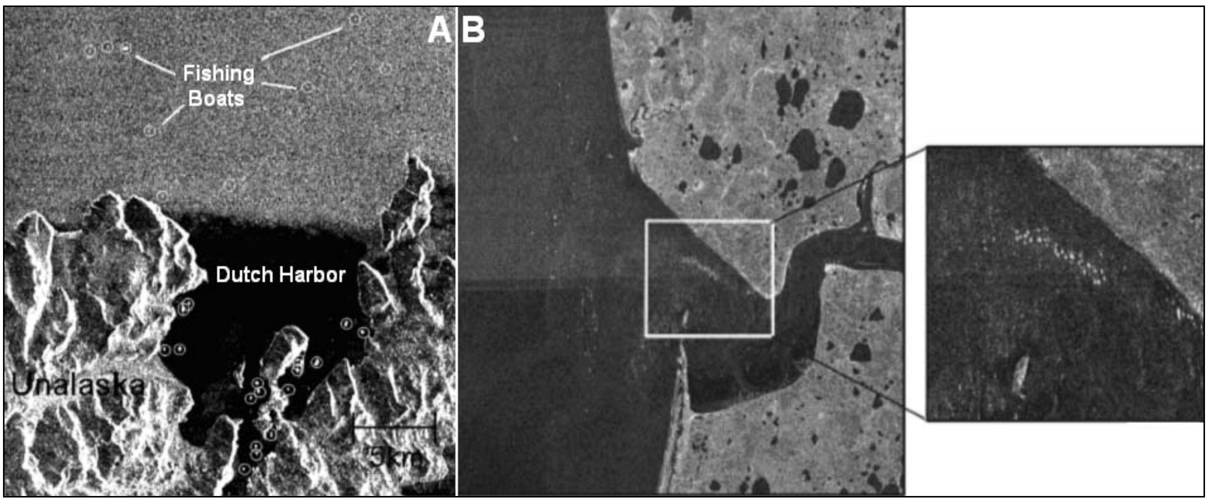

Figure 5.58. Radarsat SAR Fishing Vessels Monitoring and Detecting–Courtesy of Presentation: by Radarsat

Figure 5.58 (A) presents image acquired by Radarsat-1 sensors on 20 February 1998 at 1929 UTC on C-band, HH ScanSAR wide B indicating US trawler fleet vessels (circled) anchored under very low wind conditions in Dutch Harbor, Alaska. In such a way, all vessels are easy to detect since their large backscatter makes them stand out against the calm waters of the harbor. However, outside the protection of the harbor where the wind is much higher and therefore the ship and sea contrast is reduced on the upper part of image.
In **Figure 5.58 (B-Left)** is shown image also acquired by Radarsat-1 on 5 July 2004 at 0411 UTC on C-band HH standard mode image showing small fishing vessels with approximately 10 m in length in the Egegik Bay salmon fishery in Bristol Bay, Alaska at position 58.2N and 157.5W. In **Figure 5.58 (B-Right)**is illustrated the same image of big ship and group of fishing vessels in higher resolution of 8 m(Geudtner and Séguin ; Jackson and Apel 2004; EO 2014).

5.9.1.3. Vessels Detecting System (VDS) via SSAR

The SSAR systems were developed as a means of overcoming the limitations of real aperture radars, what is significant for VDS service. These systems achieve good azimuth resolution that is independent of the slant range to the target, yet use small antennae and relatively long wavelengths to do it. A synthetic aperture is produced by using the forward motion of the radar. As it passes a given scatterer, many pulses are reflected in sequence. By recording and then combining these individuals signals, a "synthetic aperture" is created in the computer providing a much improved azimuth resolution. It is important to note that some details of the structure of the echoes produced by a given target change during the time the radar passes by. This change is explained also by the Doppler Effect, which among others is used to focus the signals in the azimuth processor, what can illustrate this point with an analogy.
The SSAR radar sensors are usually divided into two groups according to their modes of operation. Active sensors are those that provide their own illumination and therefore contain a transmitter and a receiver, while passive sensors are simply receivers that measure the radiation emanating from the scene under observation. To provide ships surveillance and detecting is SSAR maritime CNS specialists have to be interested in radar imaging systems.
The basic principle of SSAR system is transmission and reception of pulses, so short (microsecond) high energy pulses are emitted and the returning echoes recorded, providing information on: Magnitude; Phase; Time interval between pulse emission and return from the object; Polarization; and Doppler frequency.
The same antenna is often used for transmission and reception of signals. This animation presents the basic elements of an imaging radar system. The two types of imaging radars most commonly used are: Satellite Real Aperture Radar (SRAR) and Satellite Synthetic Aperture Radar (SSAR). In fact, Real Aperture radars are often called SLAR (Side Looking Airborne Radar). Both Real Aperture and Synthetic Aperture Radar are side-looking systems with an illumination direction usually perpendicular to the flight line. The difference lies in the resolution of the along-track or azimuth direction. Real Aperture Radars have azimuth resolution determined by the antenna beamwidth, so that it is proportional to the distance between the radar and the target (slant-range).
Thus, Synthetic Aperture Radar uses signal processing to synthesize an aperture that is hundreds of times longer than the actual antenna by operating on a sequence of signals recorded in the system memory. These systems have azimuth resolution (along-track resolution) that is independent of the distance between the antenna and the target. The nominal azimuth resolution for a SAR is half of the real antenna size, although larger resolution may be selected so that other aspects of image quality may be improved. Generally, depending on the processing, resolutions achieved are of the order of 1-2 meters for airborne radars and 5-50 meters for spaceborne radars.

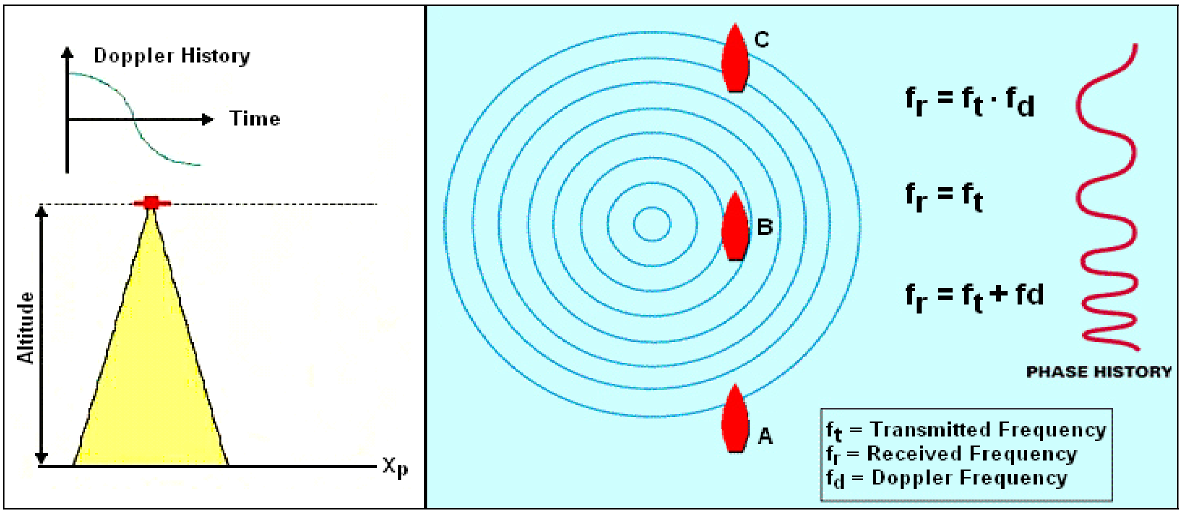

Figure 5.59. SSAR Doppler and Phase History–Courtesy of Presentation: by ESA

Let to consider, as in the case shown in **Figure5.59 (Left)** is illustrating Doppler History determined in time of SSAR in certain altitude. In **Figure5.59 (Right)**is shown Phase History, where a plunger going up and down in the water, producing circles of radiating waves, each with a constant frequency (f). These waves travel at a known speed and the plunger is a source of waves analogous to those from radar. Observers are interested in the appearance of this wave field at a certain distance. Consider a ship is moving along the line. At position B, a passenger on the ship would count the same wave number as emitted, since he is moving neither toward nor away from the waves (source). However, at position A, the ship is moving towards the waves and the passenger will count a higher number of waves. The traveling speed of the waves is slightly increased by the speed of the ship. Thus, on the contrary, at position C, the ship is moving away from the buoy and the apparent frequency is lower, so the waves are moving in the same direction as the ship. Doppler frequency is the difference between received and emitted frequencies where the difference is caused by relative motion between the source and the observer.

Equivalently, the relative spacing between crests of the wave field could be recorded along the line AC, measured as if the wave field were motionless. This leads to a phase model of the signals that is equivalent to the Doppler model. During the movement of the ship from position A to position C, the recording by the observer of the number of waves would look like the curve at the right of the figure. Instead of a plunger, let us now consider a spacecraft or aircraft emitting a radar signal. The ship corresponds to a target appearing to move through the antenna beam as the radar moves past. The record of the signals backscattered by the target and received would be similar to the record of the passenger in the ship. Such a record is called the Doppler history (or phase history) of the returned signals. When the target is entering the beam, the Doppler shift is positive because the source to target distance is decreasing. The phase history is then stored to be used during the SSAR processing. By the time the antenna is abeam relative to the target, the received frequency is nominal, with the Doppler frequency being zero. Late it decreases as the satellite moves away. The phase history is then stored to be used during the SSAR processing.

The VDS service uses the detecting of ships from acquired SSAR imagery. The advantage of such system is the all weather and day or night vision capability as well as its noncooperative nature (meaning that vessels are imaged regardless of their actions). These features make VDS ideal source of data to combine with other cooperative sources such as R-AIS, LRIT and noncooperative VMS for its use in Maritime Surveillance and Fisheries Enforcement.

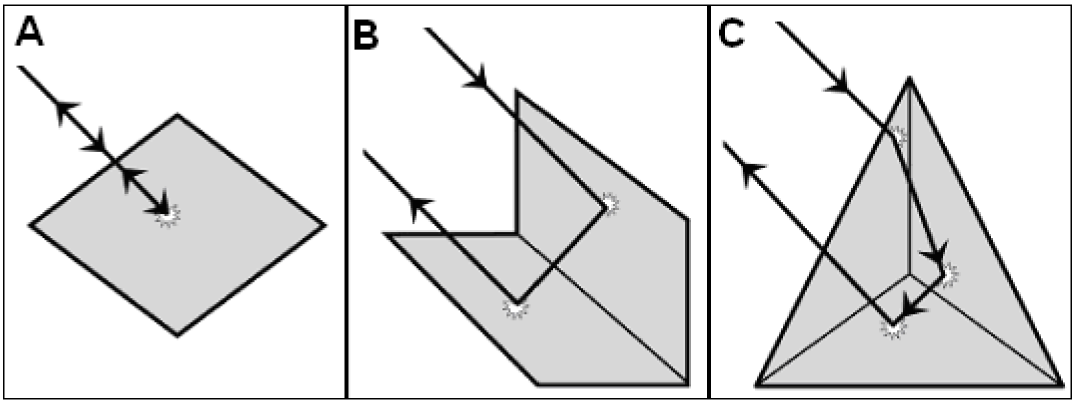

Figure 5.60. SSAR Doppler and Phase History–Courtesy of Presentation: by NOAA

For realization of ships and wake detecting is important as follows:

1. SSAR Physical Process – Spaceborne instruments send out pulses of electromagnetic radiation and then measure the amplitude and phase of reflected radiation from the ocean, the land or man-made objects (referred to as hard targets such as ships and sea platform). Strong radar returns result from direct reflection from objects with high dielectric constant, namely conductors such as steel and even wood, oriented so that large surfaces are perpendicular to the incoming radar beam or arranged in angular corner-shaped structures, namely corner reflectors. Corner reflectors have the property of returning radiation back to the source, parallel to its incoming direction. Ships constructions often contain superstructure or deck configurations that act as direct reflectors or corner reflectors.

In addition, under the right orientation with respect to the radar beam, the hull and ocean together can, through a double reflection, return significant energy back to the satellite SSAR antennas, which shapes are illustrated in **Figure 5.60.** Radar pulses from a satellite can be reflected back to the detector by: (**A**) direct reflection, e.g. from portions of the ship perpendicular to the radar beam, (**B**) a double bounce off a dihedral reflector, e.g. the ocean and then the ship or vice versa, or (**C**) a corner reflection (triple bounce) e.g. from the ship superstructure.

2. SSAR Imaging Characteristics – The direct radar return from a ship is the most common ship signature in SSAR imagery. Thus, depending on the SSAR sensor resolution, the SSAR image signature of a ship direct return may simply be a single pixel with significantly greater normalized radar cross section (i.e. large backscatter and therefore brighter) than surrounding pixels or, at higher resolution (e.g. 30 m or better), an elongated series of brighter pixels. Thus, at the highest resolutions (10 m, 8 m or less), details of the ship superstructure may become distinguishable. As long as the ship has good radar backscatter characteristics, even ships smaller than the SAR pixel resolution can be easily detected under a fairly wide range of wind and wave conditions.

The direct return from the ship is often the only ship signature, particularly (1) when the ship is not underway, (2) when higher winds or waves quickly destroy wake and slick signatures, or (3) when lower resolution modes, such as ScanSAR, are employed. Figure 12.2 is a collection of ship direct return signatures. Automated ship detecting algorithms generally look for a statistically significant contrast between the ship and the local ocean background. A single detecting threshold cannot be used for the whole image since the background backscatter changes substantially with SSAR angle of incidence, wind speed, and sea state. At this point, various algorithm approaches have been developed which automatically adapt to changing background backscatter during the search for targets.

Limitations to the success of direct detecting of ships and wakes with SSAR sensor systems can be grouped into the following five categories: (1) ship characteristics, (2) environmental conditions, (3) radar characteristics, (4) image quality, (5) image resolution and (6) wakes.

1. Ship Characteristics – Structural ship configuration with respect to the radar reflection, ship size and structural material have a highly significant effect on the ability of SAR systems to detect a particular vessel. In fact, a ship made from materials with high dielectric constant such as steel is a better radar reflector than a vessel made of non-conducting materials such as fiberglass or wood. A vessel with substantial superstructure consisting of natural corner reflectors is particularly good target. Also, a ship traveling perpendicular to the radar beam, in the same direction as the satellite is flying, generally North or South, presents as a larger target and has the possibility of a greater double reflection return.

2. Environmental Conditions – Environmental characteristics such as sea state, wind speed, proximity to land, and presence of ice affect the ability to distinguish SSAR ship signatures from the ocean background return. Thus, the greater the wind speed or the higher the waves, the greater the environmental contribution to the radar return signal, and thus the weaker the contrast between the vessel and the ocean background.

3. Radar Characteristics – Characteristics of the radar instrument (sensors) such as angle of incidence (i.e. the angle between lines connecting the radar with the reflecting surface being viewed and the local normal to the surface), polarization, resolution, and sensitivity affect the ability to detect vessels with a SSAR system. The signal return from the ocean's surface is a function of angle of incidence with the return falling off as the angle of incidence increases. A ship return does not change as dramatically with angle of incidence; thus, at higher angles of incidence there is improved contrast between the ship and the ocean background.

4. Image Quality – SSAR image processing errors and the inherent speckle noise in SSAR imagery can interfere with vessel detecting algorithms. The effect of speckle is noise in the image manifesting as random pixels that are much brighter or darker than the average of surrounding pixels. The speckle noise is a result of constructive or destructive interference during the coherent addition of backscatter from many different scatterers within a resolution cell of the SSAR image during the image integration time. Speckle noise in low-backscatter regions of an image where the surface return is below the noise floor of the SSAR instrument can appear as small vessels to a ship-detecting algorithm. The speckle noise of a SSAR image will also ultimately limit the minimum vessel size that can be detected, since smaller vessels will become indistinguishable from speckle. Processing problems such as obvious seam boundaries between beams in ScanSAR imagery, nadir ambiguities (an along-track bright line resulting from the timing of the direct return from the Earth surface immediately below the satellite), scalloping in ScanSAR imagery (a cyclic banding pattern caused by errors in Doppler processing) and cross-track noise lines caused by processing errors can all be problematic, mainly by masking hard ship targets within erroneous high backscatter anomalies. It should be noted that these processing problems are processor dependent on different SSAR processors will produce slightly different SAR images when attempting to handle difficulties encountered during processing. Finally, image earth location errors can interfere with the correct discrimination between small coastal islands and coastal vessels.

5. Image Resolution – Although all the different modes (with their specific resolution and swath width characteristics) of available satellite SSAR imagery are useful for detecting of ships, particularly larger ships, some modes are better than others. The higest resolution of radar images is 1m and going up to weekest one as 10 m..

6. Wakes – The track left in the water by a moving vessel, the wake, is an important clue in the detecting of ships. Wake structures fall into four categories: (1) turbulent wakes stretched out directly behind the vessel, (2) Kelvin wake formed by decameter-scale surface gravity waves generated by the passage of the vessel and propagating outward from the vessel track, (3) narrow-V wakes visible through Bragg scattering from short centimeter-scale waves generated by hydrodynamic processes along the ship's hull, and (4) internal wave wakes generated under conditions of shallow stratification.

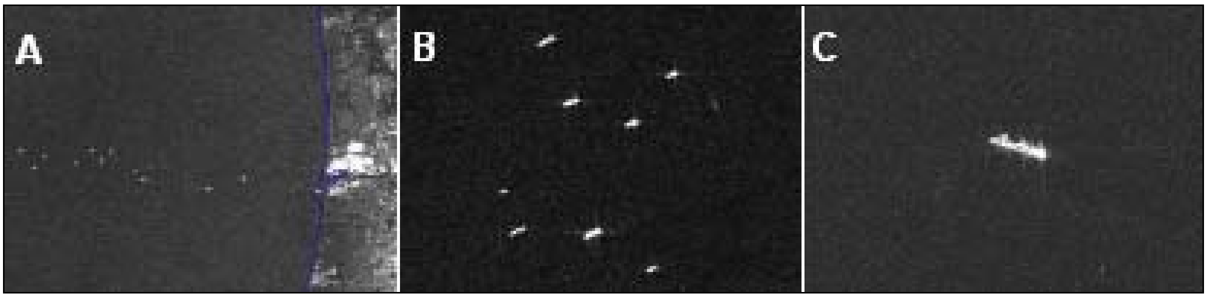

Figure 5.61. SSAR 50, 25 and 8 m Resolutions of Ships Images–Courtesy of Presentation: by Metaaps

As new SSAR satellites are becoming available, the VDS solutions should evolve in order to cope with the enhanced capabilities of the sensors, especially higher resolution. Namely, the intention of VDS developments and improvements is VDS evolution in higher resolution of images, which will be used for enhanced tracking and detecting of vessels. In **Figure 5.61** is shown that three SSAR images with resolution of 50 m (**A**), 25 m (**B**) and 8 m (**C**). Namely, as resolution increases new details from the vessels are revealed.

The significant tracking and detecting at sea is an identification and flagging of Suspicious Vessels from SSAR imagery in integration and correlation with other similar systems such as R-AIS/Satellite and AIS/LRIT/VMS data. This tracking and detecting integration is shown in **Figure 5.62 (Left),** which illustrate the image of all ships passing in the area of Gibraltar.

Satellite acquired SSAR vessel detecting (VDS) provides the position of vessel targets during the image acquisition time. In such a way these vessels positions can be confirmed by other systems, so if some image of the ship is not matching with shore data means that is suspicious. In most cases, it is impossible to id the vessel from its SSAR signature, therefore fusion with other positional data (namely R-AIS,LRIT, VMS tracks) is essential, which integration system for anti pirate actions is shown in **Figure 5.62 (Right).**

Therefore, correlation methodologies use the prediction of the position at the time of the image together with the size information (obtained from both registered and radar signature) to find the best match and make possible the identification of the vessels on the image and flagging of suspicious vessels(Jackson and Apel 2004).

5.9.2.Platforms Synthetic Aperture Radar (PSAR)

Platforms Synthetic Aperture Radar (PSAR) is the same technology and technique as SSAR, just with the difference that radar surveillance equipment with antennas are deployed onboard Stratospheric Platforms (SCP), such as airships and aircraft, High Altitude Platforms (HAP) or onboard Unmanned Aerial Vehicles (UAV).

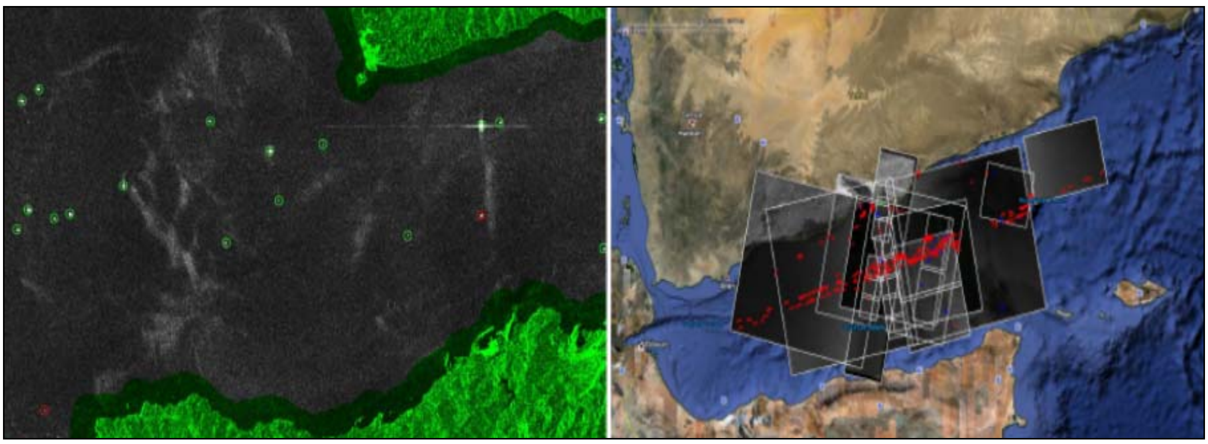

Figure 5.62. SSAR Identification of Suspicious and Pirated Vessels –Courtesy of Presentation: by Ilcev

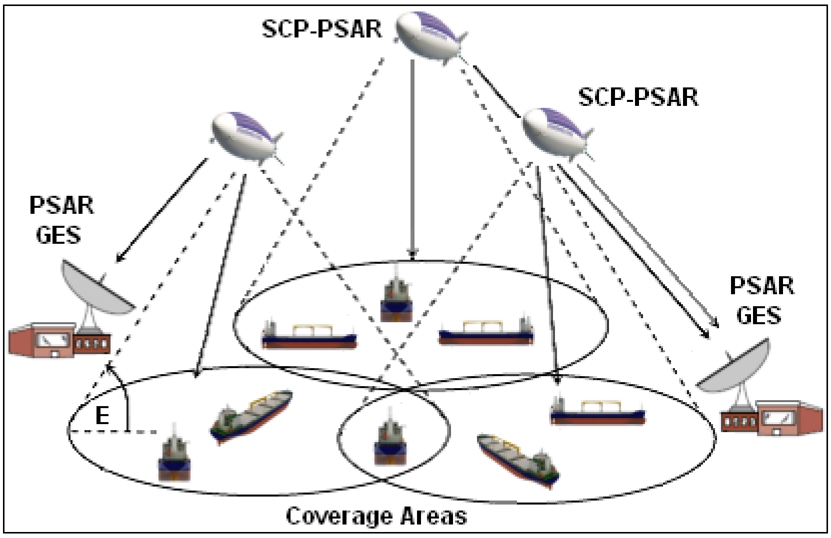

Figure 5.63. PSAR for Ships Detecting –Courtesy of Presentation: by Ilcev

The SCP solutions are emerging systems based on challenging technology with goal to create a platform, payload and mission design which are able to complement satellite services on a local scale. Applications are close to traditional business in telecommunication science and Earth observation including mobile CNS, tracking and detecting, atmospheric research and border control. The airship platform could potentially support monitoring activities related to safeguards at sea e.g. by imagery of ships movements and activities in local areas of interests, such as SAR, anti pirate and smuggling, pollution and fishery control and so on.
Stratospheric platforms are intended to be flown in an altitude band between 16 and 30 Km, while 16-20 Km are usually selected to take advantage of lower wind speeds for facilitating station keeping. At 20 km altitude 90 % of the atmosphere is already below the stratospheric platform. Therefore, this region is frequently referred to as near space environment and thus platforms can be divided into lighter than air systems that receive their entire buoyancy from a gas cell that contains a gas, which is lighter than air, e.g. Helium or Hydrogen, or hybrid systems which substitute a small fraction of the lighter than air lift with an aerodynamic lift component that is generated by small wings and the propulsion system.
Stratospheric platforms could substitute satellites, which are expensive and lack upgrade capabilities for new equipment and applications including synthetic aperture radars onboard. Furthermore they have practically an unlimited time over an area of interest, in contrary to low flying satellites. It is intended to keep the platforms operational and maintenance free on a 24/7 basis with an average deployment time of 3 years(Yang *et al.* 2013).

5.9.2.1. Platforms Synthetic Aperture Radar (PSAR) onboard Airship

Stratospheric platforms of airship can be divided into Lighter Than Air (LTA) systems that receive their entire buoyancy from a gas cell that contains a gas, which is lighter than air, e.g. Helium or Hydrogen, or hybrid systems which substitute a small fraction of the lighter than air lift with an aerodynamic lift component that is generated by small wings and the platform propulsion system. The airship platform can carry the same synthetic aperture radars for all applications including ships tracking and detecting, illustrated in **Figure 5.63.** For instance, 3 SCP airships can cover large area of sea surface and each can provide SCP-PSAR of ships in own coverage area with Elevation angles (E) similar as spacecraft. The SCP airship can send PSAR images to fixed or mobile (onboard ship) PSAR GES for processing.

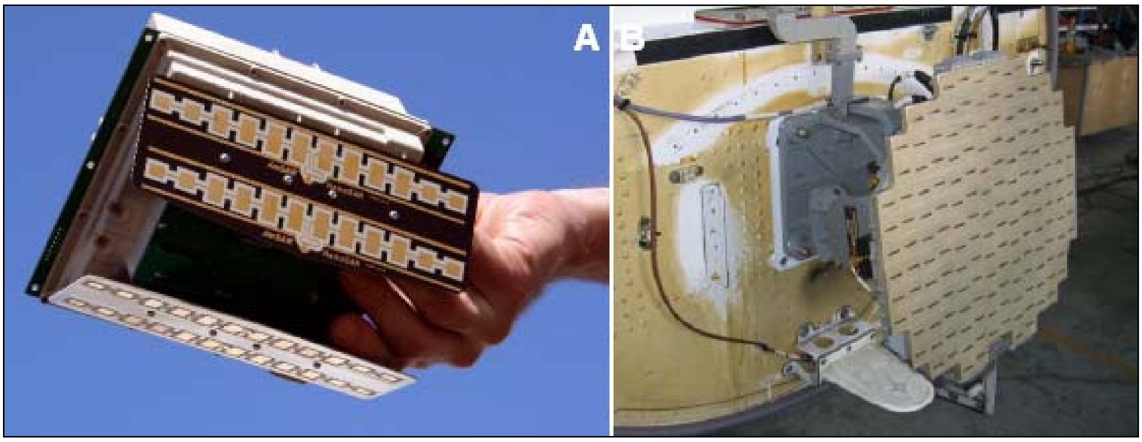

Figure 5.64. Synthetic Aperture Radar Equipment –Courtesy of Presentation: by Ilcev/Bendisch

The SCP airships will offer better resolution than geostationary satellites due to their close distance to the object under investigation. At the same time they are still enabling large observational areas to be covered. An airship located at an altitude of 20 km would have a horizon line at 250 to 300 Km ground distance, larger in smooth terrain or water and smaller in rough terrain. Onboard SCP or UAV can be installed any kind of synthetic aperture radar in an effort to bring all type of surveillances such as environment, weather, vessels and any other solutions. In **Figure 5.64 (A)** is shown one of tiny surveillance PSAR equipment with capabilities to provide maritime surveillance for all kind of ships and maritime activities(Barnard 2014; Bendisch 2014).

5.9.2.2. Platforms Synthetic Aperture Radar (PSAR) onboard Aircraft

Maritime surveillance aircraft performs a number of missions such as SAR of ships including aircraft landed at sea, maritime environment monitoring, fishery control, border patrol task related to illegal immigration, smuggling and piracy. For these tasks, efficient and high reliable mission system using state of the art technology is required similar employed onboard airships and spacecraft. The aircraft platform flying at altitude of 15 to 20 km can carry the same synthetic aperture radars for all PSAR applications including vessels tracking and detecting in coverage area from 100 to 500 Km, which similar network is shown in **Figure 5.63.**The only difference is that instead of airship can be used aircraft and that airship is almost stationary, while aircraft is flying in small circles over certain area. Onboard aircraft can be installed synthetic aperture radar equipment to bring all type of surveillances for mobile and fixed objects including vessels, with processing onboard aircraft or at shore.

In **Figure 5.64 (B)** is shown one of PSAR equipment with capabilities to provide maritime surveillance for all kind of ships and activities. In **Figure 5.65 (Left)** is shown Aero Mission equipped DO 328 aircraft and in **Figure 5.65 (Right)** is shown modifications of Synthetic Aperture Radar Equipment on the DO 328-100 TP aircraft(Barnard 2014; J. Bendisch 2014).

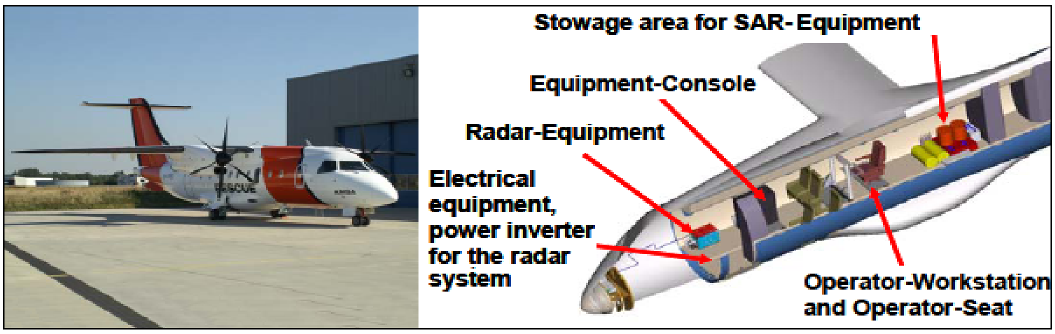

Figure 5.65. PSAR Aircraft and onboard Equipment–Courtesy of Presentation: by Aero Mission

5.9.3. Electro-Optical Space Surveillance (EOSS)

Aerial remote sensing is the process of recording information, such as photographs and images, from sensors on spacecraft or aircraft. Available airborne systems include aerial cameras, multispectral scanners, thermal Infrared (IR) scanners, passive microwave imaging radiometers and already introduced Side-Looking Airborne Radars (SLAR). The systems offering the most practical and useful data in the context of integrated development planning and natural hazard assessments are EOSS solutions via spacecraft and airship or aircraft, such as aerial cameras, multispectral scanners and thermal IR scanners.

Availability of aerial remote sensing imagery varies for the type of data required. Thus, aerial photography is readily available for many areas of study in most parts of the world, although in some instances it must be declassified for non-military use by the country involved in the study and developments. However, acquisition of IR and radar data is more complex than aerial photography, although for a large area, radar may be less expensive than photography. Due to the specialized systems and operators required to produce IR/SLAR imagery, which usually available only from a limited number of organizations which either own or lease the systems. The cost to mobilize aircraft, equipment and crews is high, but the cost of coverage data per line kilometer or per unit area can be reasonable if the area to be flown is large.

Thermal EOSS of IR imagery information is the most transitory of any sensor data. Namely, there is a procession of changes in the thermal contrasts between the different materials on the ground, both terrain and vegetation. The transitions occur over daily and seasonal cycles and are modified considerably by the weather, climate, soil, relief, slope direction, land use practices and other particulars concerning maritime surveillance(Blasch *et al.* 2012).

Radar differs from aerial photography as an aerial remote sensor. Unlike photography, which is a passive sensor system using the natural reflection from the sun, radar is an active sensor that produces its own illumination. Radar system illuminates the terrain and then receives and arranges these reflective signals into an image that can be evaluated, so these images appear similar to black and white photographs. However, an airborne or spaceborne electro-optical scanner using a semiconductor detector sensitive to the thermal IR part of the spectrum is the best way to produce imagery that defines the thermal pattern of the terrain. In fact, alternative methods using a television-like presentation have inadequate spatial resolution and so cannot be used effectively from aircraft altitudes. They also lack adequate thermal resolution.

5.9.3.1. EOSS Sensors onboard GEO and Non-GEO Satellite Constellations

Vessel detecting on electro-optical satellite images can extend the conventional SSAR based systems. Optical Satellite Images (OSI) can have a higher spatial resolution enabling the detecting of smaller vessels and enhancing the vessel type classification. Thus, the human interpretation of an optical image is easier than as of an SSAR image (e.g. for a large vessel, its name can be read from the side of the ship). The tasking of an optical satellite is more agile as of a SAR satellite. The drawback of optical satellites is that they heavily depend on the weather and they can work only during day time. Because of these reasons their image production is less reliable, but they can be tasked more reliable by using different off nadir angles. Therefore, optical satellite system combined with SSAR satellites can provide a more frequent and accurate monitoring.

The vessel detecting on OSI is still a challenging task, especially for small vessels. In many cases the visual appearance of background objects (e.g. rocks, shore, port and waves) is very similar to the vessels looking from the space. This makes the correct classification difficult. The vessels have a high variability in both shape (e.g. fishing boat, ferry, yacht, oil tanker, etc.) and size (from a few meters to a few hundred of meters).

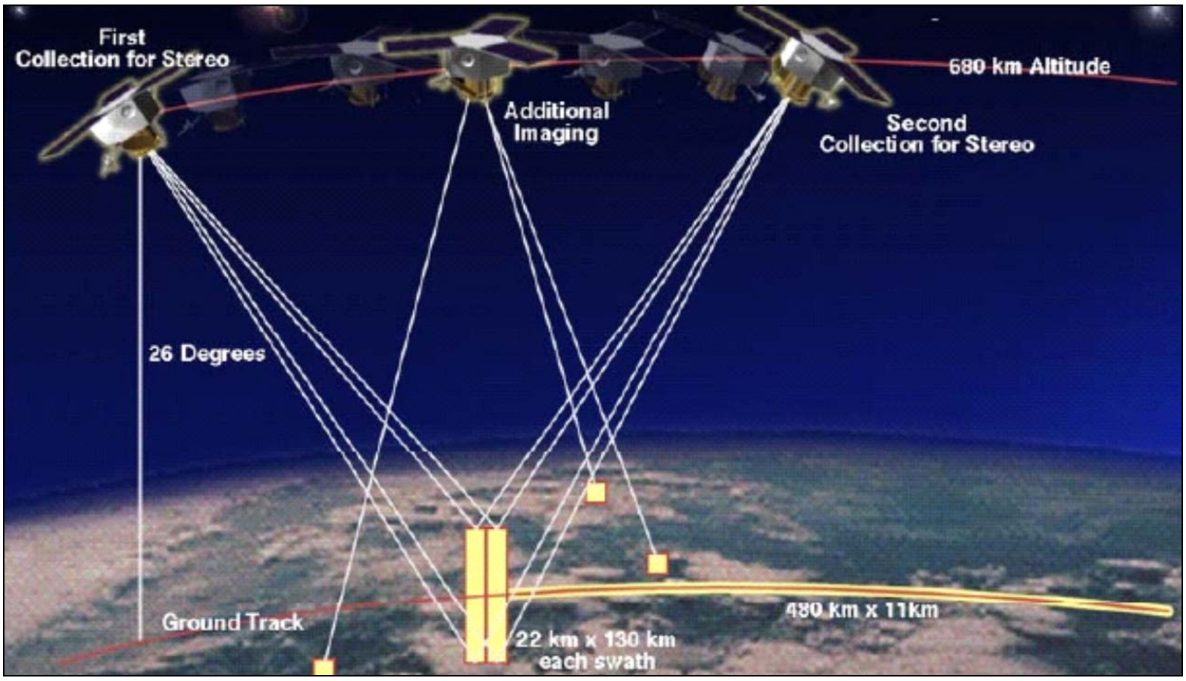

Figure 5.66. Ikonos Satellite Network for Image Collection–Courtesy of Presentation: by GeoEye

In fact, the optical images can have different off-nadir angles which results in different visual appearances. The OSI onboard detector has to consider all these varieties and in such a way new methods are still investigated to deal with these challenges.

The Ikonosis the world's first commercial OSI satellite designed to collect panchromatic (black-and-white)images with 0.80 m resolution and multispectral (color) imagery with 3.2metre resolution, which satellite network with the same pass stereo image collections shown in **Figure 5.66.**Stereo image pair can be collected on the same orbital pass of Ikonos satellite with identical content and lighting in both images facilitates terrain extraction. Asymmetric stereo collection angles for images provide one image at >72°elevation for orthorectification and 2^{nd}image at >60°elevation with$0.5 < B/H < 0.8$for Digital Elevation Models (DEM).

Therefore, satellite imagery from the panchromatic (PAN) and multispectral (MS) sensors can be merged to create 0.80 m color imagery (pan-sharpened). Ikonosimagery is being used for national security, military mapping, air and marine transportation and by regional and local governments. From a 423-mile-high orbit, Ikonos has a revisit time of once every three days and downlinks directly to more than a dozen ground stations around the globe.

The Ikonos spacecraft is a commercial Earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1 and 4-meter resolution. The Ikonos launch was called "one of the most significant developments in the history of the space age", which imagery began being sold on 1 January 2000.The Ikonos satellite is a three-axis stabilized spacecraft designed by Lockheed Martin (LM), which later became known as the LM900 satellite bus system. The satellite's altitude is measured by two star trackers, a Sun sensor and controlled by four reaction wheels and location knowledge is provided by a GPS receiver. The design life is seven years, the size of S/C body is 1.83 m × 1.57 m (hexagonal configuration), the mass is 817 Kg, power is 1.5 kW provided by three solar panels.

The Ikonos LM900 spacecraft bus, however, is designed to carry scientific payloads in LEO constellation. It provides precision pointing on an ultra stable highly agile platform. In addition, the satellite payloads for a variety of scientific and remote sensing applications may be accommodated with other instruments such as laser sensors, imagers, radar sensors, electro-optical and astronomical sensors, as well as planetary sensors. The LM900 bus shares a hardware heritage with Iridium, which is the basis for the LM700 bus.

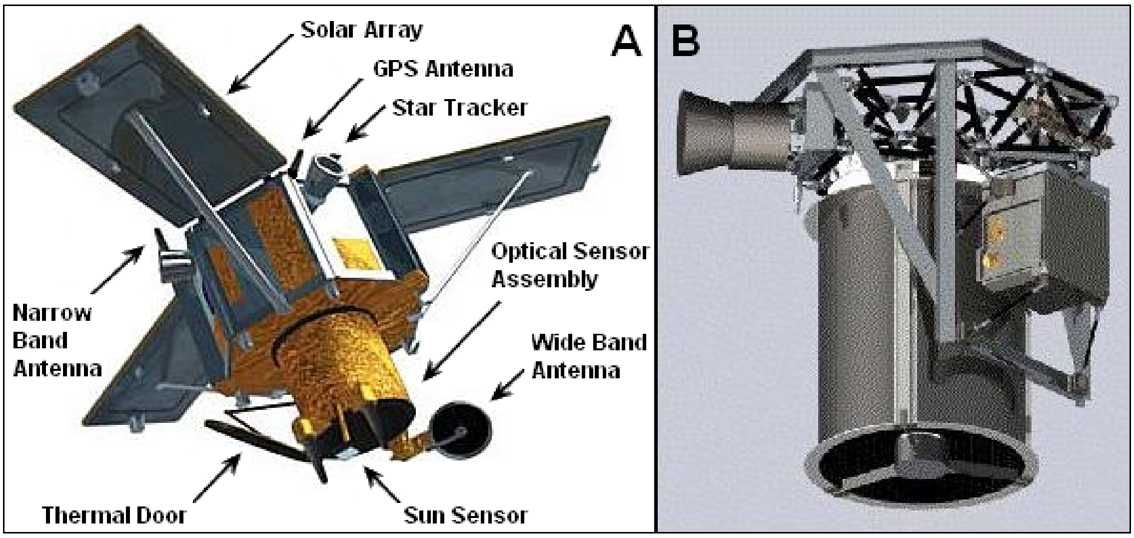

Figure 5.67. Components of Ikonos Spacecraft and Camera Telescope–Courtesy of Manual: by GeoEye

For communication purposed Ikonosconducts TT&C in the 8345.968–8346.032 MHz band (downlink) and 2025–2110 MHz band (uplink). Its downlink data carrier operates in the 8025-8345 MHz band. The components of Ikonos spacecraft are shown in Figure 6.67 (A), while the illustration of the OSA telescope system type Kodak’s Model 1000 camera system is shown in Figure 6.67 (B).

For optics and detectors Ikonos spacecraft provides a primary mirror aperture of 0.7 m (2.3 feet), and a folded optical focal length of 10 m (about 33 feet) using 5 mirrors. The main mirror features a honeycomb design to reduce mass. The detectors at the focal plane include a pan-chromatic and a multi-spectral sensor, with 13500 pixels and 3375 pixels respectively (cross-track).Total instrument mass is 171 kg (377 pounds) and it uses 350 watts.

Therefore, Ikonos is the new generation of very high resolution satellites. High resolution means that they can see the Earth’s surface in far greater detail than other satellites. Anything that is 1 m large on the Earth’s surface can be easily distinguished on the Ikonos imagery. One can detect individual cars, ships and trees on an Ikonos image. Due to their very high resolution Ikonos images sometimes look similar to air photos and can be used for mapping and GIS solutions, for example, in **Figure 5.68 (A)** Ikonosimage shows downtown San Francisco and in **Figure 5.68 (B)** shows image of the Rio de Janeiro Port with ships.

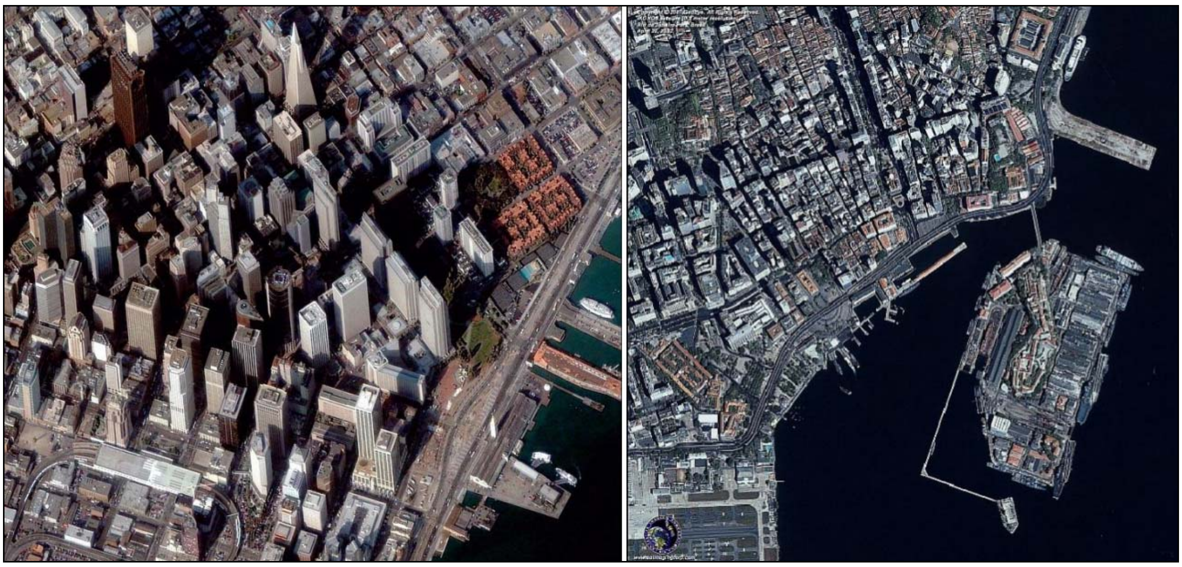
Figure 5.68. Ikonos Images of San Francisco and Rio de Janeiro –Courtesy of Presentation: by GeoEye

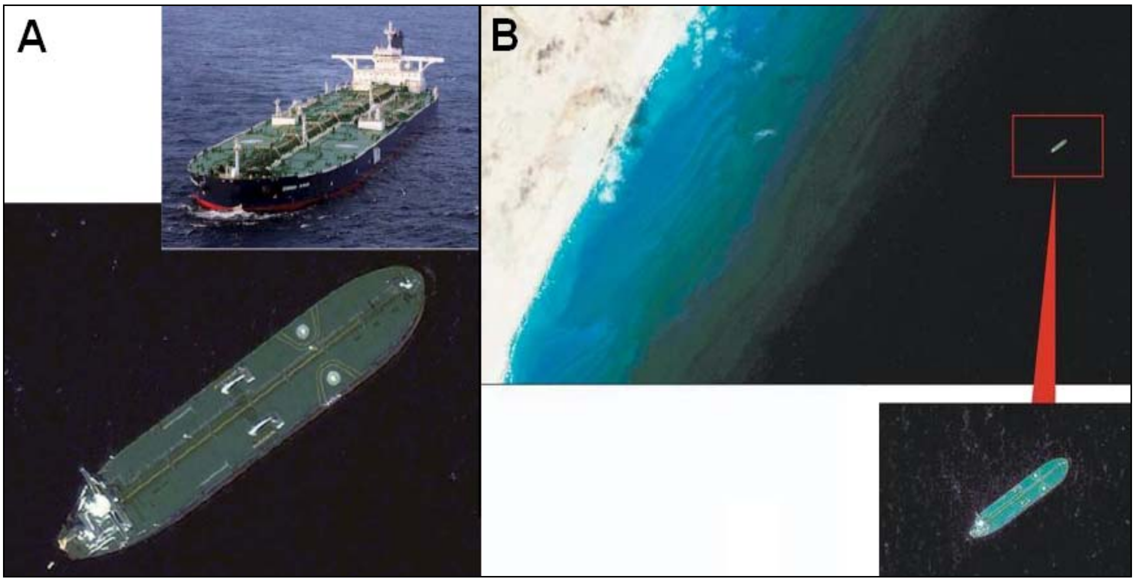

Figure 5.69. Ikonos Images of m/v Sirius Star –Courtesy of Brochure: by GeoEye

Except all other application that Ikonos satellite and network is providing, the most important issue is that Ikonos spacecraft is providing Vessels Detecting System (VDS) via onboard EOSS sensors. The EOSS systems were developed as a means of overcoming the limitations of the SSAR to produce high resolution images, what is significant for VDS service.

Therefore, Ikonos network acquires high-resolution satellite images of ships during daylight and clear sky or partly cloudy weather. In **Figure 5.69 (A)** is shown image of supertanker motor vessel m/v Sirius Star, which was hijacked by Somali pirates on 15 November 2008. In upper image is showing normal photo of the same ship made by camera and below image is showing his high-resolution image made by Ikonos spacecraft. In **Figure 5.69 (B)**are illustrated additional two images of the same ship made by Ikonos sensor, below image is made in medium and above image in low resolution.

In **Table 5.4** are introduced characteristics of all Ikonos sensors.

Table 5.4. Ikonos Satellite Sensors Characteristics

Launch Date	24 September 1999 at Vandenberg Air Force Base, California, USA
Operational Life	Over 7 years
Orbit	98.1 degree, sun synchronous
Speed on Orbit	7.5 kilometers per second
Speed Over the Ground	6.8 kilometers per second
Revolutions Around Earth	14.7, every 24 hours
Altitude	681 kilometers
Resolution at Nadir	0.82 meters panchromatic; 3.2 meters multispectral
Resolution 26° Off-Nadir	1.0 meter panchromatic; 4.0 meters multispectral
Image Swath	11.3 kilometers at nadir; 13.8 kilometers at 26° off-nadir
Equator Crossing Time	Nominally 10:30 AM solar time
Revisit Time	Approximately 3 days at 40° latitude
DynamicRange	11-bits per pixel
Image Bands	Panchromatic, blue, green, red, near IR

Figure 5.70. Ikonos Image of Ship and Comparison of Images–Courtesy of Manual: by GeoEye

Visible satellite images can be thought of as photographs of the earth from space, such as a typical optical image of cargo ships passing Bosporus Channel in Istanbul, shown in **Figure5.70 (Left).** It can be realized that this image is like made by photo camera. Since images are like a photograph, they are dependent on visible light (brought by the sun). As a result, visible satellite pictures only work during daylight hours. This is the greatest drawback to using visible imagery. Also, since a visible satellite picture is basically a photograph, thicker clouds (which reflect the most sunlight) show up very bright, while thinner clouds (like cirrus) are hard to distinguish(Martignoni 2011; Aguilar *et al.* 2013; Leica 2014).

However, infrared satellite technology works by sensing the temperature of infrared radiation being emitted into space from the Earth and its atmosphere. Basically, all objects (including water, land and clouds), radiate infrared light. However, human eyes are not “tuned” to see this kind of light, which cannot be notice. Weather satellites not only sense this infrared light, but they can also sense the temperature of the infrared emissions. Therefore, for maritime powerful surveillance can be used onboard spacecraft and SCP airships or aircraft.

In the further context will be introduced comparison of SSAR, such as Radarsat (RSAT), vs optical EOSS, such as observation SPOT (French Spacecraft), EROS (Israel Spacecraft) or Ikonos spacecraft, which images are shown in **Figure5.70 (Right).** Illustration shows that a 216 m long ship is imaged with both optical and radar instruments. The instrument corresponding to each image Optical (O) or Radar (R) is described in **Table 5.5.**

Table 5.5. Optical (O) vs Radar (R) Images of the same Ship

Overview	(O) SPOT 5 m	(R) RSAT 8 m
(O) SPOT 5 m	(R) RSAT 8 m	(O) EROS 1.8 m
(O) SPOT 2.5 m	(R) RSAT 8 m	(R) RSAT 8 m

5.9.3.2.EOSS Sensors onboard SCP or UAV

The SCP or UAV airships and aircraft are promising solutions for installation onboard EOSS sensors. Proposal to implement these technologies for ships tracking and detecting is very cost effective and even with better results. Namely, the EOSS sensors are situated on lower altitude and so will allow images in higher resolutions than from spacecraft. The position of airship is almost stationary, so the system can provide surveillance in local sea area for any ships movement and especially for pirates activities(Leica 2014).

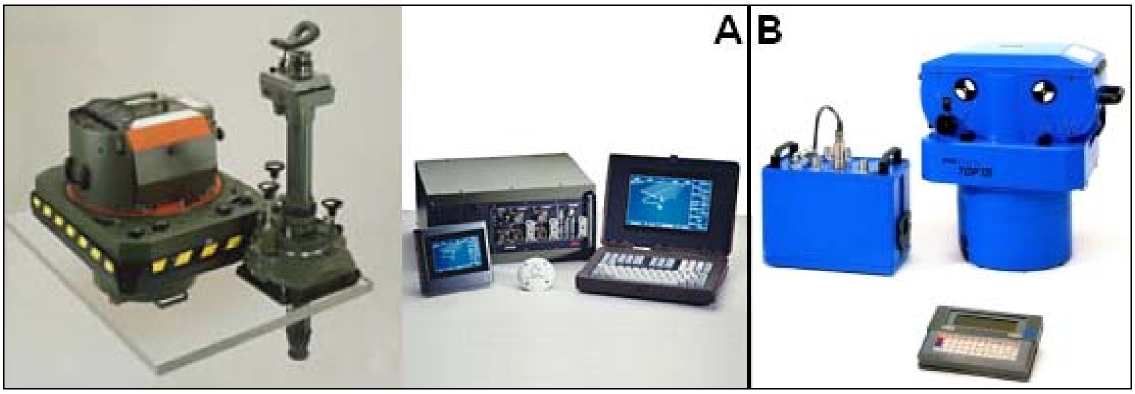

Figure 5.71. RC Leica and RMK Carl Zeiss Aerial Cameras–Courtesy of Brochures: by Leica/Zeiss

5.9.4. Aerial Digital Photogrammetric Systems

Aerial survey cameras, sometimes called metric cameras are usually used on board aircraft or spacecraft and the new proposal is to be used on SCP or UAV airships or aircraft for topographic mapping by taking stereo photographs with overlap. Thus, a typical aerial survey camera is RC series made by Leica and RMK made by Carl Zeiss producers.

In **Figure 5.71 (A)** is shown the Leica RC series of Aerial Camera Systems (Left) together with Leica ASCOT Aerial Survey Control, which for decades has been the number one choice for customers all over the world. These cameras are renowned for their quality and long-term reliability. The latest model, the RC30, offers two interchangeable lenses with negligible distortion, which reach lens or film resolutions well over 100 lp/mm. Apertures up to f/4 and shutter speeds from 1/100 to 1/1000 per second is maximizing their applicability. Forward motion compensation produces crystal clear photos at low light levels and altitudes. Thus, additional film cassettes are inexpensive, so prolonged missions are feasible. Other big advantages include the PEM-F automatic exposure control and the flexible data annotation on each photograph. Navigation sights, viewfinders and a wide range of filters complete this solution. The RC30 can be combined with the PAV30 gyro-stabilized camera mount and the Aerial Survey Control Tool (ASCOT) for a complete aerial survey system.

In **Figure 5.71 (B)** is shown the Carl Zeiss RMK TOP Aerial Camera, which comes with Plegon A3 4/153 high performance wide angle lens, offering maximum resolution and freedom from distortion, including case T-TL terminal for operation of the camera systems with keyboard display.

Most conventional Digital Photogrammetric Systems (DPS) are designed for processing digitized images taken from aerial metriccameras and intended for users with strong photogrammetric background knowledge for Earth observation of fixed and moving objects including for GIS and mapping. On the other hand the geo-spatial information and images from remotely sensed images taken from various kinds of cameras are now more applicable and accessible for a variety of GIS professionals. These changes challenge photogrammetric to find modern ways to meet the new market developments and maritime surveillance.

Acquisition of Infrared (IR) and SSAR imaging is more complex than aerial photography, although for a large area, radar may be less expensive than photography. Thermal IR imagery information is the most transitory of any sensor data. There is a procession of changes in the thermal contrasts between the different materials on the ground, both terrain and vegetation.

Both aerial photography and radar have advantages and limitations. Photography cannot be used at any time in any weather as can radar. Radar can map thousands of square miles per hour and an area can be surveyed much more rapidly by radar than by aerial photography, and the final product provides an excellent synoptic view. Distance can be measured more accurately on radar than photography(BBB 2014; Bendisch 2014; Colorado 2014).

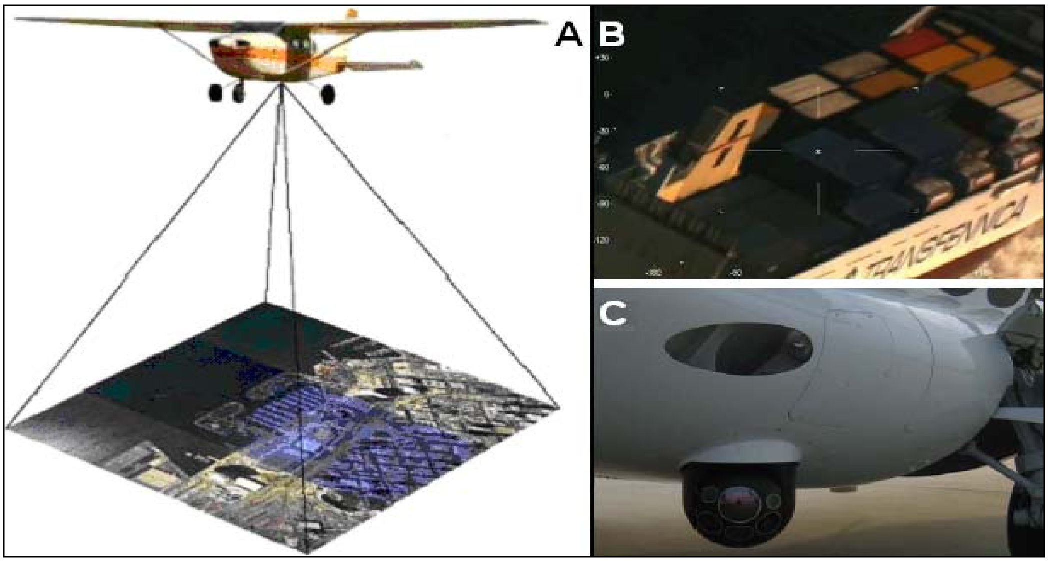

Figure 5.72. Photogrammetry and Infrared Sensor–Courtesy of Brochure: by San-Lo/Bendisch

5.9.4.1.Aerial Metric and Large Format Camera Systems

Photogrammetry is the technique of measuring different fixed or mobile objects in 2D or 3D from photographs. The results of these photographs can be used for topographical and the matical maps. In fact, one of the most important features is that the objects are measured remotely and sometimes the term remote sensing is used instead of camera photogrammetry, although it is more closely associated with image interpretation, and so that the whole area is covered by many overlapping photographs. In **Figure 5.72 (A)** is illustrated aerial metric photogrammetry made by metric camera in aircraft, but can be spacecraft or SCP airship instead. On the other hand, this technique can be used for any kind of photogrammetry at sea for maritime applications, which visible band image of the ship is illustrated in Figure **5.72 (B)**.

The main difference between aerial camera systems and traditional cameras is the need for aerial camera systems being spatially accurate. Metric precision is necessary because aerial photography is often used to measure very small distances, and to create high resolution elevation models from stereo imagery. Thus, certified metric quality cameras are expensive sensitive devices, but necessary if precise and accurate measurements are required, which samples are illustrated in **Figure 5.73.** This figure **(Left)** illustrates multispectral cameras were is involved precursor in the development of digital camera of multispectral satellite remote sensing systems, and figure **(Right)** shows stereo strip camera for aerial surveillance.

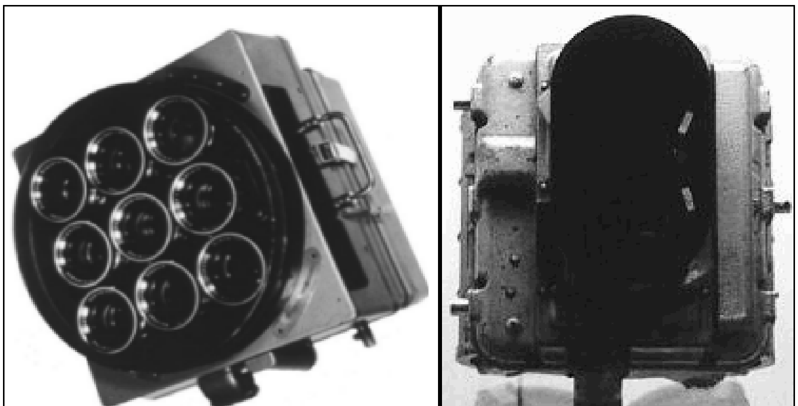
Figure 5.73. Aerial Multispectral and Stereo Cameras –Courtesy of Presentation: by Ilcev

Figure 5.74. Onboard Processing Workstation and Infrared Image of Ship–Courtesy of Presentation: by Ilcev

The availability of this excellent stereophotography, which can be enlarged ten times or more with little loss of image quality, is limited to certain areas covered by the ground track of the spacecraft or aircraft. Some of this coverage includes clouds or heavy haze, but despite the limitations of coverage and occasional poor quality, the existing photography should be examined for its possible use in any regional natural hazards assessment and planning study for other applications, such as maritime local surveillance.
Of all the sensors, aerial photography gives the closest representation to what the human eye sees in terms of wavelength response, resolution, perspective, stereoscopic viewing and tonal or color values. The interpreter familiar with photographs can easily present these scenes, whereas other sensors, such as thermal IR scanners and SLAR surveillance systems, produce imagery whose appearance and physical basis is completely foreign to the inexperienced eye. Aerial photographs are probably the remote sensing data source with which the planner can be most familiar and comfortable enough. Therefore, the metric and large metric cameras are promising technique to be used for local tracking and detecting facilities onboard spacecraft, airships and aircraft for maritime surveillance and monitoring of all kinds of ships including pirate boats and activities. In such a way, cameras mounted onboard aircraft flying in circles and on the stationary SCP airship can easily detect even name of hijacking ships by pirates.
The operator workstation onboard aircraft or remote workstation onboard spacecraft or SCP airship forms integral part of the aerial metric and large camera system, which sample is shown in **Figure 5.74 (Left).** It is designed to serve most advanced requirements for modern aerial surveillance for maritime applications including ships tracking and detecting(Lh-Systems 2014).

5.9.4.2. Thermal Infrared Aerial Scanners

An airborne electro-optical scanner using a semiconductor detector sensitive to the thermal IR part of the spectrum is the best way to produce imagery that defines the thermal pattern of the terrain and moving objects. In Figure **5.74 (Right)** is illustrated infrared image of ship in navigation. Alternative methods using a television-like presentation have inadequate spatial resolution and thus cannot be used effectively from aircraft altitudes. They also lack adequate thermal resolution.
Airborne electro-optical scanners, in general, can cover the electromagnetic spectrum using semiconductor electronic sensors from the UV through the visible and near IR into the thermal IR range of the spectrum. Despite of any deficiencies, scanning from aircraft or airship continues to be a very valuable method of obtaining thermal infrared imagery with reasonable spatial and thermal resolution for fixed and moving objects.

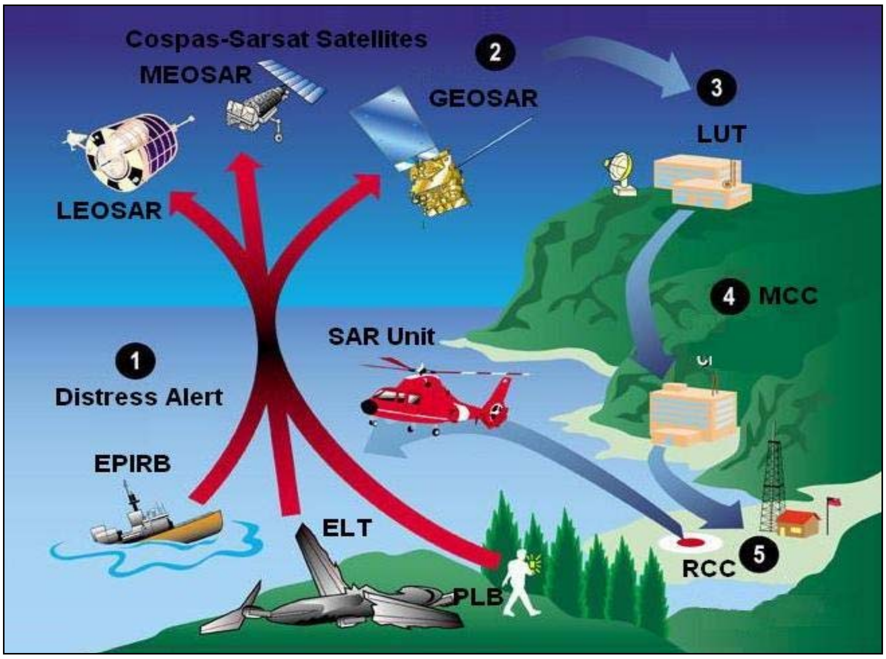

Figure 5.75. Cospas-Sarsat Network–Courtesy of Presentation: by Ilcev

5.9.4.3.Space Light and Laser Surveillance Radars

Devices which measure the physical characteristics such as distance, density, velocity, shape etc., using scattering, returned time, intensity, frequency and/or polarization of light and laser are called optical sensors. However, as the actual light used by the optical sensor is mostly laser, it is usually called Laser Detection and Ranging(LADAR) or Light Detection and Ranging (LIDAR). These types of radars are an active sensor which is used to measure air pollution, physical characteristics of atmospheric constituents in the stratosphere and its spatial distribution. The theory of laser radar is also utilized to measure distance, so that for this application it is called laser distance meter or laser altimeter, which can be implemented for moving objects such as ships and aircraft. In addition, the main measurement object is the atmosphere, although they are also used to measure water depth, thickness of oil film or vividness of chlorophyll in vegetation. There are several additional solutions for this kind of surveillance such as: clouds, aerosol, gases, wind profiles, depth of ocean and lakes, water surface roughness and turbidity, fish and marine mammal density, individual and group of ships detecting and Earth surface surveillance(Lang *et al.* ; SANGAM).

5.10. Satellite Distress Beacons for SAR Operations

The Cospas-Sarsat mission is a satellite system designed to provide emergency and distress alert to assist Search and Rescue (SAR) operations, using spacecraft and ground facilities to detect and locate the signals of distress beacons. The Cospas-Sarsat system has Space, Ground and Users segments, shown in **Figure 5.75.**

The Cospas-Sarsat Space segment is integrated networks by three separate subsystems, such as Low Earth Orbit SAR (LEOSAR), Geostationary Earth Orbit SAR (GEOSAR) and new Medium Earth Orbit (MEOSAR) satellite constellations.

The Ground segment is getting alert signals from ships in distress, their positions and other related emergency information by Local User Terminals (LUT), which is forwarded by the responsible Mission Control Centres (MCC) to the appropriate national Rescue Coordination Centres (RCC) and SAR authorities. According to the used subsystem, the LUT stations can be LEOLUT, GEOLUT and MEOLUT.

Figure 5.76. Cospas-Sarsat Network–Courtesy of Presentation: by Ilcev

The Cospas-Sarsat is a satellite-aided SAR system designed to locate distress and alert signals on 406 MHz from ships Emergency Position Indicating Radio Beacons (EPIRB), shown in **Figure 5.76 (A),** land or Personal Locator Beacons (PLB), shown in **Figure 5.76(B)** and aircraft Emergency Locator Transmitters (ELT), shown in **Figure 5.76 (C).** Thus, satellite beacons are User segment, which is important for SAR of ships, persons and aircraft in distress and emergency situations.

The Cospas-Sarsat system is a joint international satellite-aided SAR system established and operated by organizations in Canada, France, Russia (ex-USSR) and the United States. In such a way these nations and other state members are organizing additional ground network necessary for receiving, processing and maintaining all alert and distress calls and to forward them to SAR forces and operations.

The Cospas-Sarsat LUT stations are state-of-the-art ground stations for acquisition of LEOSAR, GEOSAR and new MEOSAR distress beacon data. Using a software-defined receiver, the LUT station offers unprecedented flexibility in signal detecting and processing. Capable of receiving all beacon types and next generation beacon signals, the LUT stations provide a path to the next generation of Cospas-Sarsat networks.

The Cospas-Sarsat Mission Control Centres (MCC) sites have been set up in most of those countries operating at least one LUT station. The MCC terminals are located all over the globe and they serve as the hub of information sent by the Cospas-Sarsat system Their main MCC functions are to: collect, store and sort the data from all LUT stations and other MCC; provide data exchange within the entire Cospas-Sarsat system and distribute alert and location data to associated RCC or SAR Point of Contact (SPOC) and other MCC hubs. The SAR mission is usually conducted by near by ships, helicopters and aircraft.

The 406EPIRB beacons are designated for use on board ships, hovercraft, sea platforms and even aircraft for distress alert and signals. They are divided into two categories:

1. Category I EPIRB beacons are activated either manually or automatically. The automatic activation is triggered when the EPIRB is released from its bracket. Hence, these units are housed in a special bracket equipped with a hydrostatic release. This mechanism releases the EPIRB at a water depth of 1 – 3 m. The buoyant EPIRB then floats to the surface and begins transmitting the distress signals. This type of beacon has to be mounted outside the vessel's cabin, on the deck where it will be able to "float free" of the sinking vessel. Both categories of EPIRB beacons can be detected by both LEOSAR and GEOSAR systems.

2. Category II EPIRB beacons are manual activation only units and in this sense, they should be stored in the most accessible location on board, where it can be quickly accessed in an emergency situation. At all events, before eventual use and testing of EPIRB beacons it will be necessary to follow the manufacturer's recommendations and guidelines for general beacon testing and inspection procedures(Ilcev, S 2013b).

6. Chapter 6

EXPERIMENTAL FRAMEWORK

This chapter contains analyses of current and proposed solutions for radio and satellite ship tracking and detecting system considered in previous chapters. Particularly have been analyzed piracy issues for which special solutions were designed. The scope of the chapter is divided in three main infrastructures, such as radio, SCP and satellite tracking systems. For development of each infrastructure has been used own analyses of certain related problems for which are proposed practical solutions. The chapter includes experimental results of designed and implemented QHA VHF AIS antenna for satellite communication and the tracking terminal tested on board of motorboat in Durban's harbour.

6.1. Proposing of Radio Systems for Ships Tracking and Detecting

Tracking and detecting radio systems are important solutions for ship safety and security in coastal waters, approaching to the anchorages and inside of seaports. Here is provided an intensive research and experiments for several practical solutions, which can be installed onboard ships for every day tracking and detection operations or can be discreetly installed for special solutions of tracking hijacked ships.

6.1.1. Discreet Installation of Radar Transmitter Onboard Ship

Discreet installation of SART radar transponder onboard any hypothetical ship is an excellent solution to eliminate probability that pirates after hijacking can find and switch of the radar transmitter. The purpose of discreet installation of radar transmitter is to provide possibility to SAR forces easier to find a captured ship with the help of surveillance radar onboard SAR ships or helicopters. In the same time pirates can disable or shut down all satellite and radio navigation system onboard hijacked ship during the capturing operations. The secret installed SART device will be able to send permanently special pulse sequences with determined carrier frequency, which can be received by surveillance radar during searching operations. The main advantage of the discreet installation is that it can operate autonomously from the ship's main power system since equipped with its own long life battery. However, SART unit will not work during normal circumstances, but it can be activated just manually before came up emergency situation of possible attack of pirates or will be activated automatically in case that any onboard communication or navigation equipment is switched off.
The discreet SART installation transmits pulse signals that can be received by surveillance radar installed onboard SAR units for a long time before the cross section of a ship becomes sufficient to detect the ship, which diagram is shown in **Figure 6.1.** However, it implies that receiving signal from the onboard SART unit is much stronger than backscattered signal at long distances, where it is still weak to be detected.

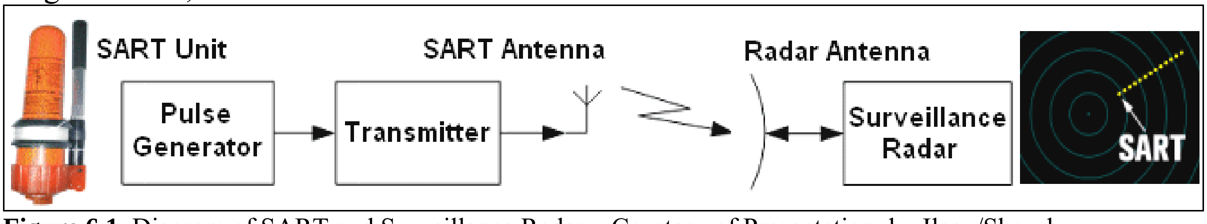

Figure 6.1. Diagram of SART and Surveillance Radar – Courtesy of Presentation: by Ilcev/Skoryk

6.1.1.1. Calculations of SART Application Efficiency

Radio Frequency (RF) propagation is defined as the travel of electromagnetic (EM) waves through or along a medium. For RF propagation between approximately 100 10 GHz, radio waves travel very much as they do in free space and travel in a direct Line of Sight (LOS). There is a very slight difference in the dielectric constants of space and air. So, the dielectric constant of space is one and the dielectric constant of air at sea level is 1.000536. In all but the highest precision calculations, the slight difference is neglected.

The surveillance radar mathematical operation principals are based upon physics of signal propagation, which are able to reveal difference of search effectiveness of a ship with and without onboard ship SART unit with the help of surveillance radar. An antenna unit or aerial is an electrical device that as an isotropic radiator converts electricomagnetic power into radio waves, and vice versa, which is usually used with a radio transmitter or receiver. Thus, in transmission, a radio transmitter supplies an oscillating RF electric current to the antenna's terminals, which radiates in all directions the energy from the current as electromagnetic waves or radio waves. Namely, the power of a transmitter that is radiated from an isotropic antenna will have an uniform power density (power per unit area) in all directions.

Suppose that an isotropic source of electromagnetic pulse peak power is radiating EM power in free space. In reception, an antenna intercepts some of the power of an EM wave in order to produce a tiny voltage at its terminals that is applied to a receiver to be amplified. The power density PD at any distance from an isotropic antenna is simply the transmitter power divided by the surface area of a sphere 4πR2 at that distance. The surface area of the sphere increases by the square of the radius, therefore the power density PD decreases by the square of the radius, which is presented by the following equation:

$$P_D = P_t/4\pi R^2 [W/m^2]; \tag{6.1}$$

where Pt = either peak or average transmitting power in Watts (W) depending on how P_D is to be specified; and R = radar to object range in meters (m). Radars use directional antennas to channel most of the radiated power in a particular direction. The gain G of an antenna is the ratio of power radiated in the desired direction as compared to the power radiated from an isotropic antenna presented as:

$$G = U_{MAX}/U_{IA} [dB]; \tag{6.2}$$

where U_{MAX} = maximum radiation intensity of actual antenna; and U_{IA} = radiation intensity of isotropic antenna with same power input. At this point, an adequate antenna concentrates the radiated energy of the pulse from isotropic to a confined solid angle known as an antenna gain G_r. The power density at a distant point from radar with a transmitting antenna gain G_t is the power density from an isotropic antenna multiplied by the radar antenna gain, which power density from radar is realized by the following equation:

$$P_D = P_t G_t/4\pi R^2. \tag{6.3}$$

The power density is intercepted by a target. A portion of energy is backscattered or reflected back to radar depends on cross section of target σ (in our case the target is a ship). The power reflected P_R from the target coming back to the radar is given by equation as follows:

$$P_R = P_t G r\sigma/4\pi R^2; \tag{6.4}$$

where σ = target cross section in square meters (m^2).

The pulse of energy radiated toward the target from surveillance radar is the first stage and the second stage is when pulses of energy reflected from the target toward an antenna of surveillance radar, so at this moment the target can be represented as a new source that radiates new pulses of energy. The arriving back P_A power energy at the surveillance radar from the target is given by the equation:

$$P_A = P_tG_t \sigma/(4\pi)2R^4. \tag{6.5}$$

The power density collected by the effective area of the receiving antenna can be defined as a magnitude of an effective area of the receive antenna for receiving signals, which are given by the equation:

$$S = P_tGt \sigma A_E/(4\pi)2R^4; \tag{6.6}$$

where S = received signal power (W); A_E = effective area of the receive antenna (m), which is defined as antenna efficiency ($0<\rho<1$, no unit) multiplied by the physical area of the antenna (A, meters).
The gain of radar antenna is directly related to its efficient area, which is given by the following formulas:

$$G = 4\pi A_E/\lambda^2; \tag{6.7}$$

$$A_E = G \lambda^2/4\pi;$$

However, if the transmit and receive radar antenna is usually the same, the resulting single-pulse received signal power can be combined by formula (6.6) and (6.7) in the following equation:

$$S = P_tG_2 \lambda^2 \sigma/(4\pi)3R^4. \tag{6.8}$$

With the help of the equation (6.6) can be derived two formulas of distance, first shows differences of maximum detecting distances to the ship without the radar transmitter onboard:

$$R_1 = 4\sqrt{}P_{SR} G_{SR}2 \lambda^2 \sigma/(4\pi)3S_{threshold}; \tag{6.9}$$

where R_1 = maximum detecting distance to the ship without the radar transmitter onboard; P_{SR} = transmitted signal power by onboard ship surveillance radar; G_{SR} = antenna gain of surveillance radar; and $S_{threshhold}$ = threshold of minimum coming signal power sensitivity of surveillance radar receiver.
In order to derive formula of detecting range to the ship with the radar transmitter should be used formula (6.4) multiplied by antenna gain of the radar transponder and by transmitting power, what ultimately is giving formula as follows:

$$R^2 = 2\sqrt{}P_{RT} G_{RT} \sigma_{SR} \rho_{SR}/\lambda^2S_{threshold}; \tag{6.10}$$

where R^2 = maximum detecting distance to the ship with the radar transmitter onboard; P_{RT} = transmitted signal power from the radar transponder onboard ship; G_{RT} = antenna gain of the onboard radar transponder; σ_{SR} = effective square of surveillance radar antenna; and ρ_{SR} = surveillance radar antenna efficiency.

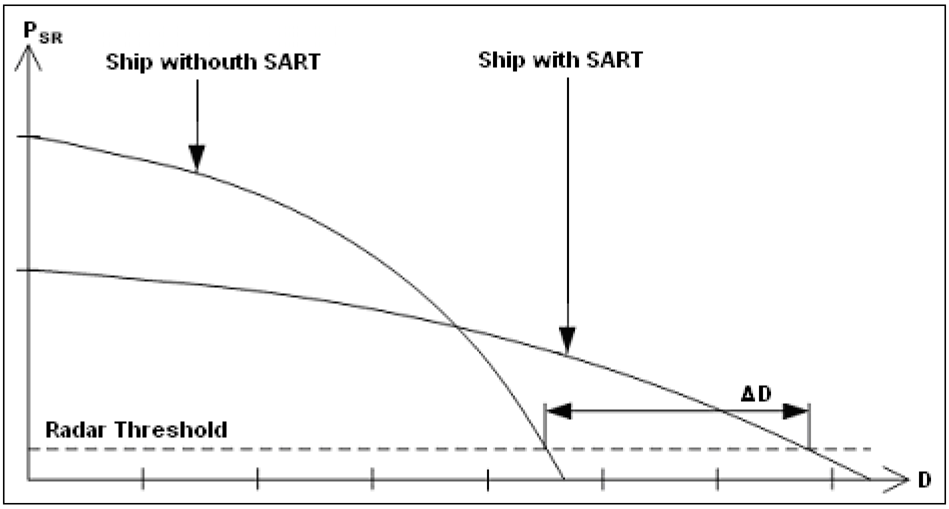

Figure 6.2. Ship Detecting Distance with and without onboard SART – Courtesy of Presentation: by Skoryk

6.1.1.2. Comparison of Ultimate Effectiveness for Real Signal Receiving Efficiency

In order to show the real efficiency of receiving signal by the surveillance radar with and without the radar transmitter onboard ship should be provided by a comparative analysis of mathematical qualitative calculations done in the previous section and plot charts of distance versus receiving signal power over the distance to the ship by surveillance radar.
Two equations (6.9) and (6.10) should be taken for effectiveness comparison of surveillance radar performance in searching operations. The equation (6.9) shows detecting distance of unequipped ship with the radar transmitter (SART) at given parameters of the equation and the equation (6.10) shows a detecting distance of a ship with the radar transmitter on board at given parameters of the equation. The analyze of equations (6.9) and (6.10) should be taken in consideration with variables such as follows: the threshold minimum receiving signal and power sensitivity of receiver and antenna GSR gain of surveillance radar is taken equal for both cases.
In the equation (6.9), distance R depends on forth root of expression under with transmitted signal power PSR by surveillance radar and target σ cross section. In the equations (6.10), distance R depends on the square root of expression under with transmitted signal power PRT by the radar transponder and the radar transmitting antenna GRT gain.
Using two equations (6.9) and (6.10) can be plotted the chart of distance versus receiving signal power over the distance by surveillance radar with the help of MathCAD software, which chart is shown in the Figure 6.2.
At this point, the illustrated diagram clearly shows that detection distance of a ship with the radar transmitter (SART) onboard ship is considerably larger than if the ship without the radar transmitter at given surveillance radar receiving signal threshold power, which distance difference is pointed as value ΔD.
Thus, as can be seen from the above diagram the backscattered signal from a ship damps considerably faster than transmitting signal form the radar transmitter. This short analysis illustrates how more effective can be increased detecting distance to the ship with utilizing onboard radio transmitter (SART) as long as the backscattered signal is still significantly below radar threshold.
Therefore, in case of capturing some ship by the pirates, discrete SART installation onboard ship will provide to the SAR forces enhanced possibility for tracking and detecting position of hijacked ship at far distance and with more effectiveness. Without SART installation onboard ship will be very difficult to determine the position and movements of the hijacked ships.

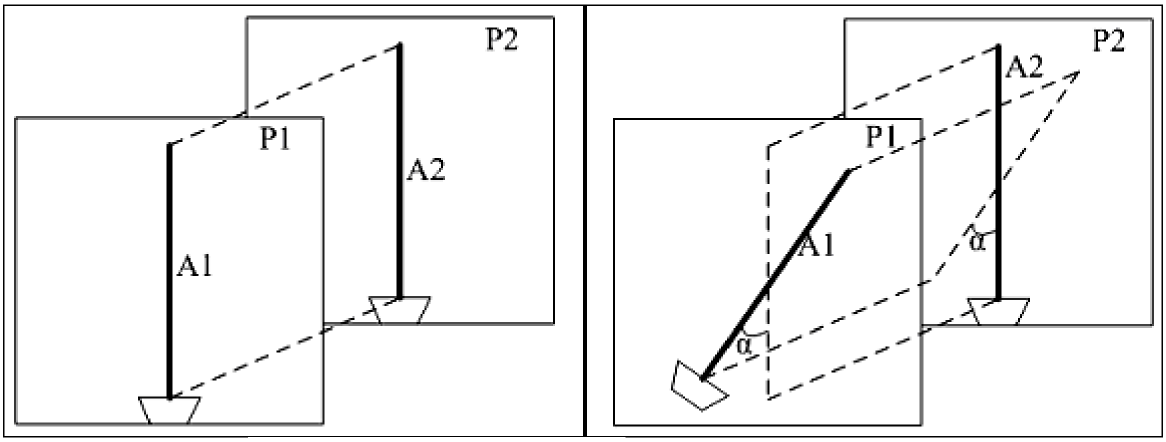

Figure 6.3. Inclination of AIS Dipole Antenna – Courtesy of Presentation: by Skoryk

6.1.2. Improvements of AIS Tracking and Detecting Equipment

This section will introduce proposals of two antenna solutions for R-AIS and S-AIS onboard ships implementing classical dipole antenna and Quadrifilar Helical Antenna (QHA) for the VHF-band.

6.1.2.1. Analyses of VHF-band AIS Antenna for Satellite Tracking

Classical dipole antenna for the VHF-band has quite a simple construction suitable for many applications and in particular for radio and satellite AIS systems. However, the conventional dipole antenna has some disadvantages for AIS application. In fact, the main aspects for of the VHF radio antenna analyzes concerning to VHF AIS aspects are: Polarization, which is particular the same for VHF AIS; Radiation pattern of radio VHF antenna and antenna gain; Influence of different and extreme weather conditions on the communication between ground and mobile AIS units with different VHF radiation pattern and various antenna gains; and Ability of VHF R-AIS antenna to communicate with VHF S-AIS Orbcomm satellite.

1. First Aspect – The first considered aspect of the VHF AIS or dipole antenna is regarding vertical or horizontal polarization, which depends on the antenna position in space. Particularly onboard of the ship is used vertically polarized antenna. At this point, both types of polarization, such as vertical and horizontal, are called a linear polarization, that means the location of the EM component of radiated EM waves of such antenna never change own location in space. Such kind of antenna that radiates EM waves with constant position of EM components in space is called linearly polarized antenna. In fact, for both VHF antennas, receiving and transmitting, simultaneous location for their installations becomes critical in working space onboard ships. Thus, to provide reliable radio communication will be necessary to employ linearly polarized antennas, which reciprocal elements are placed strictly in parallel planes, otherwise radio communication becomes significantly unreliable. This process for simultaneous placing of linearly polarized antennas is illustrated in **Figure 6.3 (Left and Right).** The **l**eft side shows an inclination between antennas A1 and A2 $\alpha=0^0$ as a condition of the best communication, and Right side shows an inclination between antennas A1 and A2 $\alpha>0^0$ as a condition of worsening communication. In accordance with the above illustration, the best communication of linearly polarized antennas, when the simultaneous inclination between the antennas A1 and A2 in parallel planes P1 and P2, is equal to $\alpha= 0^0$. In contrary, radio communication becomes worse when simultaneous inclination is at $0<\alpha<90^0$ and there is not radio communication at all when inclination between antennas A1 and A2 is equal to $\alpha= 90^0$. This is case of ideal conditions for communication during good weather conditions, when pitching and rolling of a ship is not causing negative fluctuation to the antenna reception.

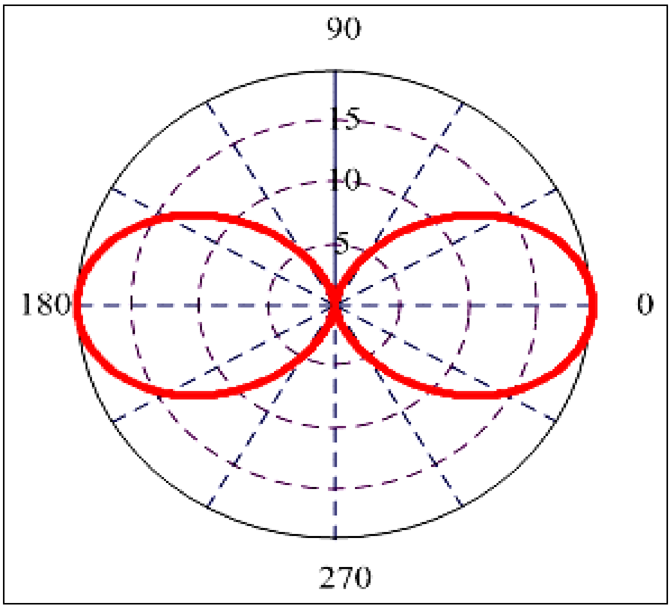

Figure 6.4. Dipole Antenna Radiation Pattern – Courtesy of Presentation: by Skoryk

2. Second Aspect – The second aspect of dipole antenna is concerning to the antenna gain. The radiation pattern of antenna depends on antenna gain, so the higher antenna's gain, the more transmitting power concentrates or radiating power focuses. The dipole antennas with a high dB rating concentrates energy perpendicular to the antenna shaft in a field that is shaped like a disk or "donate". To provide mathematical analysis of dipole antenna radiation pattern, will be used well known Maxwell's equations for radiation pattern and with equation antenna directivity. The equation for radiation intensity is radiated power per solid angle. The dipole antenna radiation pattern (case antenna gain is 3 dB) is shown in **Figure 6.4.**
In the far field radiation intensity is following:

$$P_{rad} = \int^{o}{}_{2\pi} \int^{o}{}_{\pi} U(\theta,\varphi) \sin\theta \, d\theta \, d\varphi = \int^{o}{}_{2\pi} \int^{o}{}_{\pi} U(\theta,\varphi) \, d\Omega; \qquad (6.11)$$

where $d\Omega = \sin(\theta)d\theta \, d\varphi$ defines the differential solid angle.
The average radiation intensity is defined by dividing the radiation intensity (6.11) with the area of the unit sphere (4π), which relation gives:

$$U_{avg} = \int^{o}{}_{2\pi} \int^{o}{}_{\pi} U(\theta,\varphi) \, d\Omega/4\pi = Prad/4\pi. \qquad (6.12)$$

The directivity equation is the ratio of the radiation intensity (6.11) in a given direction from the antenna to the average radiation intensity (6.12) over all directions. Hence the formula for antenna directivity is as follows:

$$D(\theta,\varphi) = U(\theta,\varphi)/U_{avg} = 4\pi U(\theta,\varphi)/P_{rad}. \qquad (6.13)$$

Inserting the expression for P_{rad} in directivity expression, yields:

$$D(\theta,\varphi) = 4\pi \, F(\theta,\varphi)/\int^{o}{}_{2\pi} \int^{o}{}_{\pi} F(\theta,\varphi) \sin(\theta) \, d\theta \, d\varphi; \qquad (6.14)$$

where $F(\theta,\varphi)$ = function of radiation pattern intensity. To plot radiation pattern, radiated pattern function of dipole antenna is needed, which mutual relation is presented by the following equation:

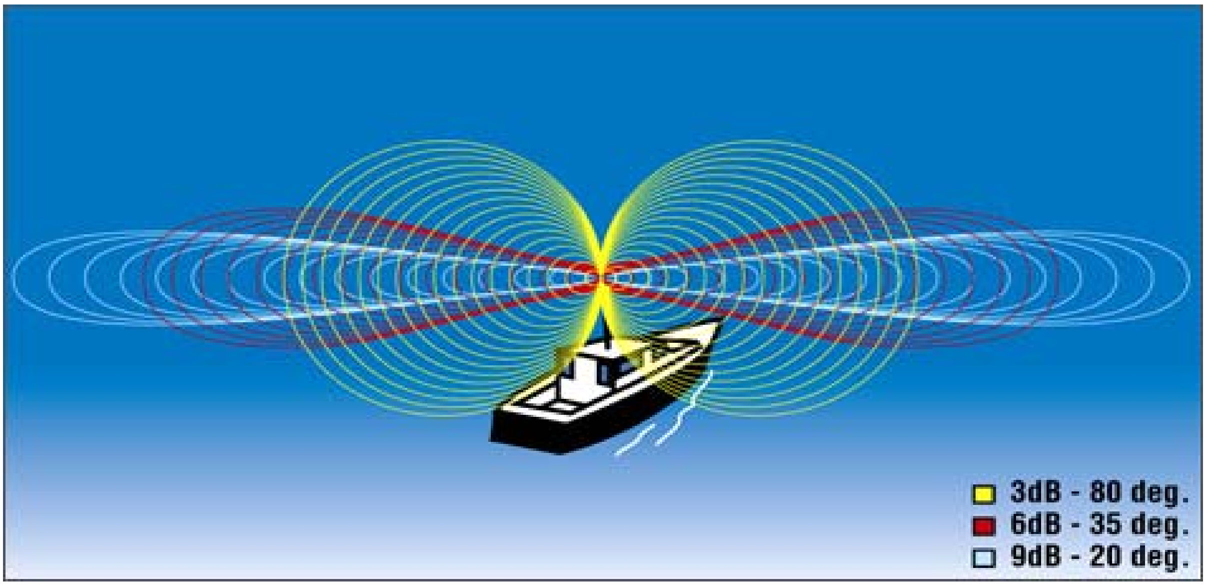

Figure 6.5. Dipole Radiation Pattern at Different Antenna Gains – Courtesy of Presentation: by Skoryk

$$F(\theta) = 0.64 \cos2(\theta). \qquad (6.15)$$

Inserting formula (6.15) into (6.14) and with the help of computer software "MathCAD", dipole antenna radiation pattern diagram was plotted with a vertical cross-cut. In **Figure 6.4** can be seen two lobes of radiation pattern known as main lobes of radiation pattern.

Radiation patterns of the VHF dipole antenna for the AIS system at different antenna gains (Yellow is 3 dB, red is 6 dB and blue is 9 dB) shown in **Figure 6.5.** Thus, the higher antenna gain the better radiating energy concentration is in space, which reduces the amount radiated energy above or below the antenna perpendicular line toward the antenna axis. Should be considered communication of AIS equipped ships with the VHF high and low gain antenna 3 and 9 dB, respectively. This consideration is vital to analyze and define necessary antenna gain for AIS.

The radiation pattern of high gain antenna concentrates radiating energy in narrow lobes along the horizontal line. The high antenna gain is suitable for long range communication, owing to high concentration of radiation energy. However, this is an advantage only in normal weather conditions without pitching and rolling of a ship. In contrary, radio communication becomes significantly worse when the ship begins pitching or rolling due to agitated sea, hence the radiation pattern of VHF antenna becomes inclined relatively to a horizon line, what is shown in **Figure 6.6.** This figure shows a ship equipped with the VHF High Gain Antenna (HGA).

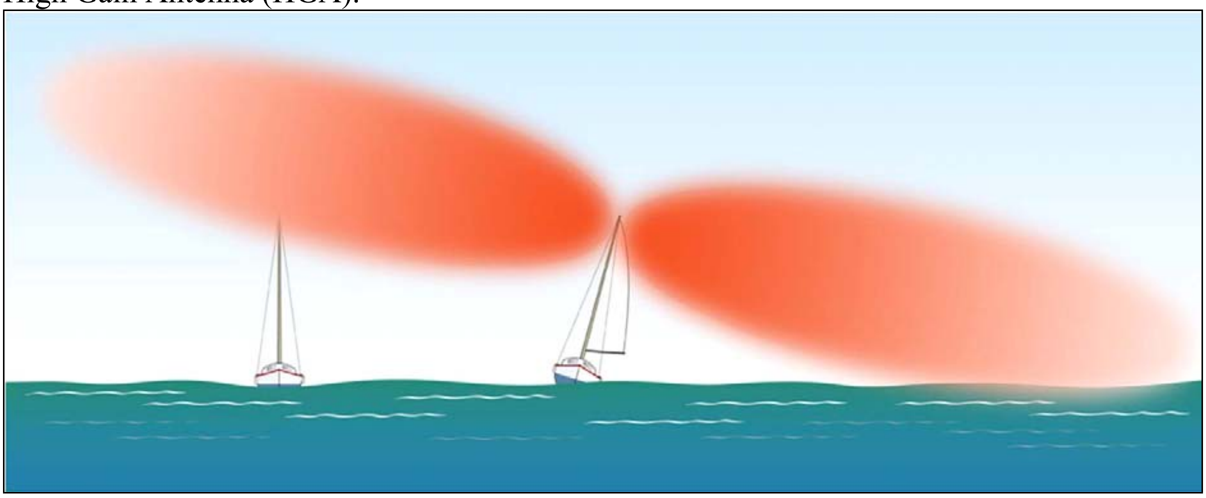

Figure 6.6. Ship Equipped with HGA – Courtesy of Presentation: by Skoryk

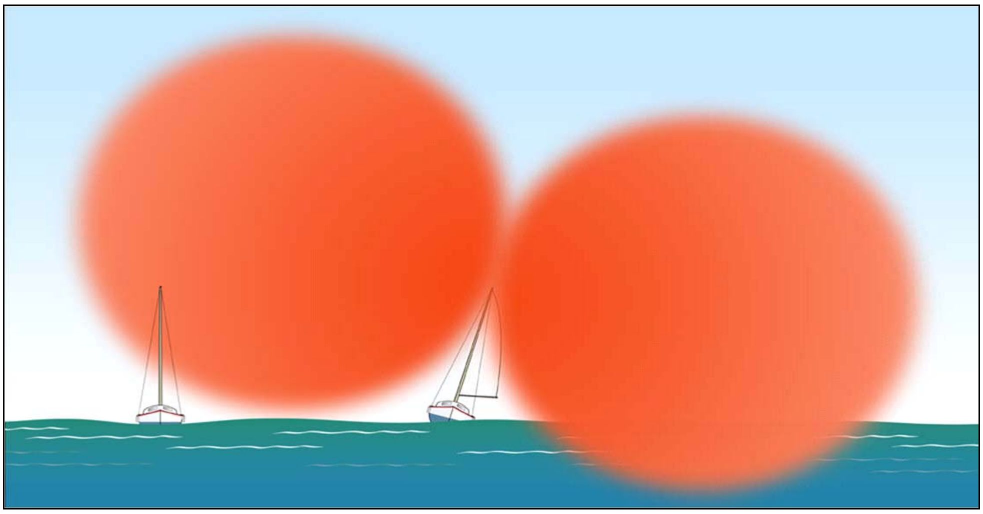

Figure 6.7. Transmission with LGA – Courtesy of Presentation: by Skoryk

In case when VHF Low Gain Antenna (LGA) is used, then main lobes of antenna radiation pattern become significantly wider. The radiated energy by LGA quickly is spreading out, what significantly reduces communication range. But in case of very high sea agitation, when ship is pitching and rolling, the transmitting or receiving VHF antenna of nearby ships is still capable to receive or transmit signal as shown in **Figure 6.7**.

3. Third Aspect – The third aspect is presenting satellite communication with standard AIS VHF antenna, which deserves special consideration. Thus, to provide radio communication between AIS Orbcomm (S-AIS) satellites constellation and AIS ship-borne terminal (R-AIS) should be used the same low gain VHF antenna as for R-AIS.

Conducting analyses of radio communication between S-AIS and R-AIS terminal can be seen that radio communication between them is not possible due to features of VHF antenna radiation pattern. In such a way, satellite communication with the VHF antenna is possible in two following cases:

- Radio waves reflection from sea water surface; and
- Radiation pattern ship-borne VHF antenna matches its radiation pattern with satellite's antenna in LOS.

The graphic analyses of two considered communication cases are illustrated in **Figure 6.8.** Therefore, in order to resolve above described communication problems, should be selected another type of antenna for S-AIS. The convenient type of antenna can be spiral or helical antenna, which radiates circular polarized signal.

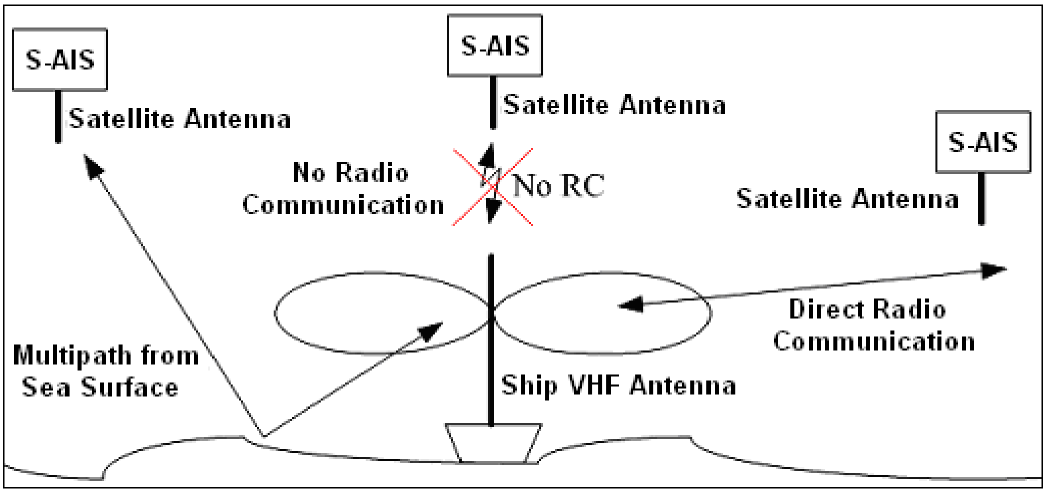

Figure 6.8. Graphic of Possible S-AIS via VHF Antenna – Courtesy of Presentation: by Skoryk

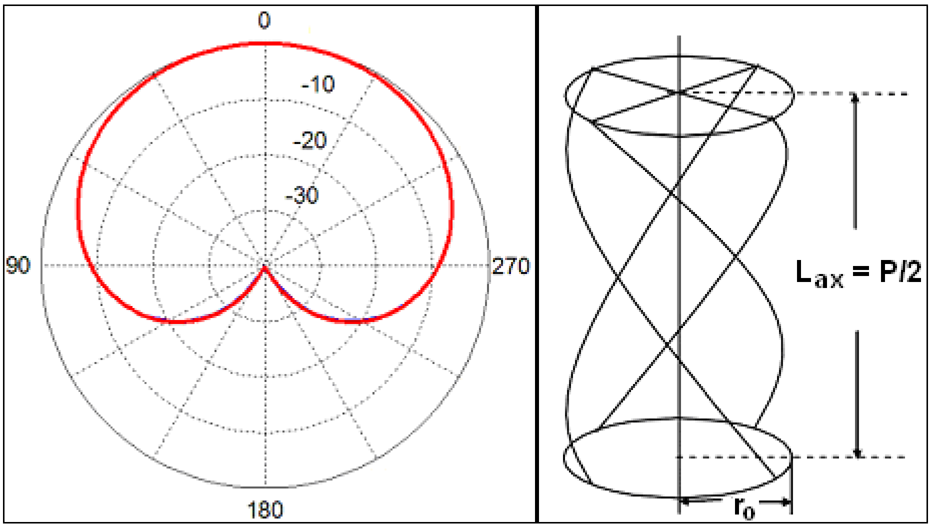

Figure 6.9. QHA Radiation Pattern and Model – Courtesy of Presentation: by Skoryk

6.1.2.2. Calculation and Design of Helical VHF Antenna

In order to choose necessary construction of VHF helical antenna should be considered environmental conditions where this antenna is going to be used. Analyze of whip antenna provided earlier shows which type of an antenna should be applied to achieve S-AIS and in the same time communication between ships (R-AIS). According to the current and new research analyses, the most suitable antenna for S-AIS is Quadrifilar Helical Antenna (QHA). Consequently, it will be necessary to select needed radiation pattern of QHA with open circuit, which can be plotted by the known radiation pattern formula for helical antenna:

$$F(\theta) = \cos(\theta)\sin(N\psi/2)/\sin(\psi/2); \qquad (6.16)$$

where N = number of turns for every given helix; and $\psi = kS\cos(\theta)+\alpha$ = summarized variable determined by the type of circulation k and pitch angle of helix α, which equation is:

$$\alpha = s/\pi d; \qquad (6.17)$$

where s = space between turns of helix; and d = diameter of helix turns.
Executing several simple conversions of equation provides the QHA formula and inserting converted equation (6.16) of QHA radiation pattern into equation (6.14) can be plotted chart with the help of "MathCAD" software.
The QHA radiation pattern is illustrated in **Figure 6.9 (Left)** and model of QHA resonant for R-AIS system is shown in Figure **6.9 (Right)** (Ali Mirkamali *et al.* 2003)**.**
Considering presented radiation pattern can be seen that radiation pattern has hemispherical shape, therefore, such radiation pattern is suitable for satellite communication (S-AIS) and intercommunication between ships (R-AIS) due to the broad radiation pattern within a horizontal plane. This resonant QHA antenna consists of four spiral arms separately fed by currents which have equal amplitude and 90° difference between two orthogonal. The resonant QHA antenna can be divided into two types, open and shorted circuit at the non-feed end. Thus, the main parameters of a resonant QHA antenna for implementation onboard ships are following: r_o — spiral radius; P = thread pitch; N = turns numbers; L_{ele} = helix length; and L_{ax} = axial length. All these variables are included in equation as follows:

$$P = \sqrt{}(1/N2(L_{ele} - A_{ro})2 - 4\pi 2\ r_{o2}; \qquad (6.18)$$

Figure 6.10. Experimental Sample of the QHA Antenna – Courtesy of Presentation: by Skoryk

where $L_{ele} = (2n+1)\lambda/4$ (opened at non-feed); $n = n\lambda/2$ (shorted at non-feed) both values are considered with $n = 0,1,2, \ldots$; $A = 1$ (if open at non-feed) and $A = 2$ (if shorted at non-feed). Also important aspect of the QHA antenna is auto-phase shifting structure that produces 90^0 differences through its antenna arms. The principle is that the length of two bifilar helices is different. This, one slightly longer than resonant length that can produce a capacitive input impedance with negative 45^0 phase shift different to resonance; another arm is slightly shorter than resonant length that produces a inductive input impedance with positive 45^0 phase shift different to resonance. Therefore, two bifilar helices can produce 90^0 phase shift difference without any auxiliary structure used to produce phase shift (Krzysztofik 2012) (Hou *et al.* 2011).
In addition, main parameter of the QHA antenna that determines size depends on central operation frequency, so R-AIS system uses two radio channels at 161.975 and 162.025 MHz and with spectrum width at 25 kHz. The resonant QHA is broad band device, hence central frequency should be selected as $f_{cnt} = 162$ MHz. Knowing central frequency value it makes simple to calculate wavelength for this central frequency, what is presented by formula:

$$\lambda = c/f_{cnt} = 3 \text{ x } 1.8/162 \text{ x } 106 = 1.8[\text{m}]. \tag{6.19}$$

Using $\lambda = 1.8$ [m] can be calculated necessary wire length L_{ele} for open and shorted circuit of the QHA antenna. Other dimensions and parameters of the QHA antenna should be selected empirically during experiment to achieve the desirable radiation pattern.

6.1.2.3. Implementation and Testing of Helical VHF Antenna

According to the provided design and calculations of the QHA antenna in the previous subsection, the QHA antenna was designed. The resonant QHA antenna has been implemented as “turn, quarter lambda” type. Two twisted wire frames are placed upon each other at right angles and connected to the antenna cable at the top (feeding provided at the top) with QHA-cylinder equals to approximately 0.4 m. The photo of experimental sample of QHA antenna that can be used onboard of ships simultaneously for both R-AIS and S-AIS is shown in F**igure 6.10.**

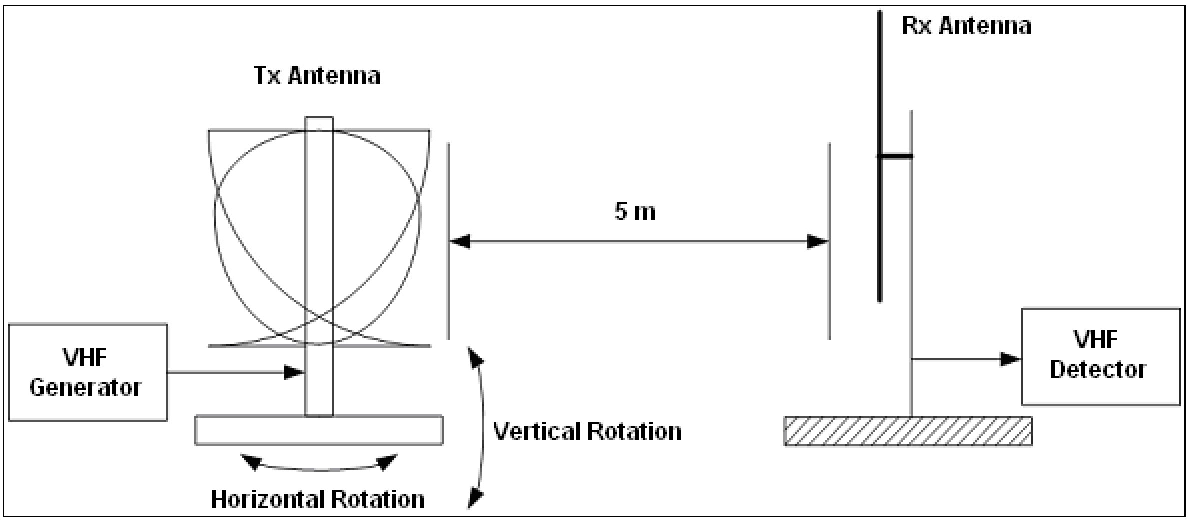

Figure 6.11. Measuring of Radiation Pattern of QHA Antenna – Courtesy of Presentation: by Skoryk

For the measuring of the radiation pattern of QHA was used special laboratory equipment which provides rotation of antenna with fixed steps of degrees in two plans what necessary to obtain measuring of radiation pattern antenna in two cross-sections:
- The vertical cross-section of radiation pattern shows the antenna ability for S-AIS satellite communication; and
- The horizontal cross-section of radiation pattern shows ability of the antenna for R-AIS or VHF radio communication between nearby ships.

The structure of fully equipped laboratory stands for measuring radiation pattern of the both QHA antennas: transmit (Tx) and receiving (Rx) is illustrated in **Figure 6.11.** Thus, the QHA antenna is Tx antenna connected to VHF generator that generates sinusoidal signal at central frequency 162 MHz that corresponds to R-AIS central frequency. However, the Rx antenna is simple half-wave dipole connected to VHF detector which can show the level of receiving signal in relative units. The Rx antenna is fixed in distinction to transmitting antenna because only in this case is possible to measure antenna radiation pattern. The distance between both experiment antennas was selected 5 meters, since radiation pattern measurements should be provided in far-field region (Fraunhofer region). In order to calculate far-field region can be used the following equation with numerical data:

$$R = 2D2/\lambda = 2\ (0.9)2/1.8=0.9[m]; \qquad (6.20)$$

where D = maximum antenna dimension (in our case D = 0.6 meter); and λ = wavelength (in our case for 160 MHz λ = 1.8). The theoretical far-field region is 0.9 meter, which means that taken 5 meters of distance between Rx and Tx antenna for measuring of radiation pattern is sufficient for correct measurements.

With help of the laboratory stand was provided measurements of both vertical and horizontal cross-sections of antenna radiation pattern which in qualitatively shown in the **Figure 6.12**. Measurements were provided with steps in 22.5^0 to achieve smooth curvatures.

The measurement of the radiation patterns done in relative units is maximum magnitude in achieved radiation pattern of left or right unit shown in the **Figure 6.12**. In order to convert relative units into dB, logarithmic equation should be used. In such a way, it will be taken into account that measurements provided by the detector connected to antenna. Such detector provides measuring of voltage, hence should be used logarithmic equation as follows:

$$dB = 10\log(U_{12}/U_{02}); \qquad (6.21)$$

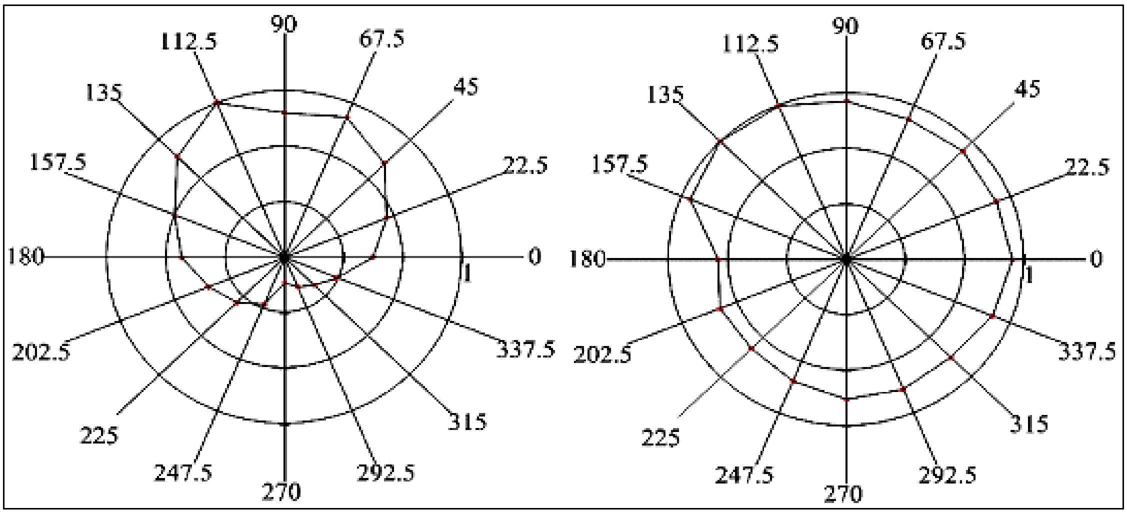

Figure 6.12. Radiation Pattern of QHA Antenna – Courtesy of Presentation: by Skoryk

where U_1 = magnitude of voltage given by detector; U_0 = is threshold magnitude of voltage; and dB = antenna gain. Therefore, in the left side of **Figure 6.12** is shown radiation pattern with vertical cross-section and in the right side is shown radiation pattern with horizontal cross-section. Simple calculation with the help of the equation (6.18) shows that the QHA antenna produces radiation patter with gain higher than 3 dB within confined angle 10^0 and 175^0, the vertical-cross section radiation patter diagram is shown in **Figure 6.12.** Thus, this is sufficient for reliable satellite communication of S-AIS. In the left side of the same figure is shown horizontal-section of the radiation patter diagram, where antenna gain is lower than 3 dB, but also still enough for communication with nearby ships.

6.1.3. Proposal of Over Horizon Radar (OTH) for RSA Sea Area

Over the Horizon (OTH) radar is an oceanic surveillance system for monitoring and tracking of ships. It may be used for tracking icebergs, oil spits, environmental protection, resource protection, sovereignty monitoring, remote sensing of ocean surface currents, winds and SAR operations.
The OTH radar has an important advantage in contrast to usual surveillance radar systems, that the OTH radar can bend the Earth surface what allows provide surveillance far beyond the horizon. The main advantage of the OTH radar is that the maximum range of these radars is not limited by the optical horizon. More details and operation principals of the OTH radar are described in Chapter 4. The radiation pattern of OTH radar is shown in **Figure 6.13.**

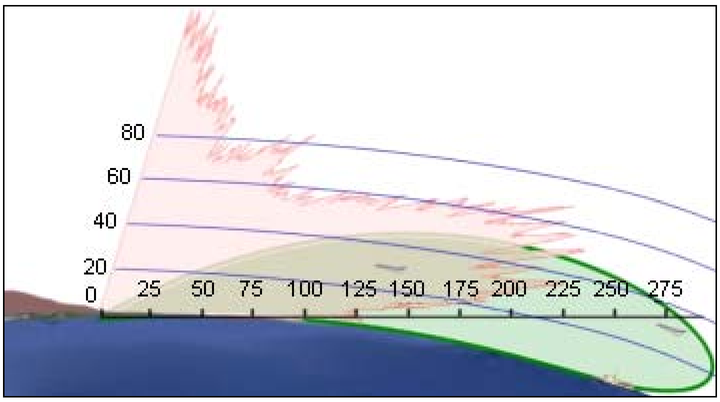

Figure 6.13. OTH Radar Radiation Pattern – Courtesy of Presentation: by Skoryk

Figure 6.14. South African Coverage with OTH – Courtesy of Presentation: by Skoryk

The OTH radar solution can be used as an extra proposal to provide extended security, safety and tracking of South African coastal area. Maximum distance of OTH radar visibility over horizon line can be between 300Km and 500 Km. Thus, only two OTH radar systems installed on the South African shore are sufficient to cover almost all sea area, which diagram is shown in the **Figure 6.14.**

6.2. Stratospheric Communication Platform (SCP) Systems

The SCP airships are new space technique with top technologies for fixed and mobile CNS and remotes sensing. They use unmanned or manned on solar or fuel energy aircraft and unmanned on solar power airships only, both carrying payloads onboard with transponders, antenna systems and TT&C equipment. With a few very cheap remote controlled and solar powered airships can be covered territory of some region providing many applications.

6.2.1. Video Surveillance from SCP

Video surveillance from SCP is very prospective and convenient technique to take picture of certain sea surface area affected by the pirates activities, with special high resolution optical photo digital devices. Arranging of video surveillance with SCP airship is similar task in employing SSAR solution, but more simply, cost effective and suitable in local task to detect and track pirated ships, which diagram is shown in **Figure 6.15**.

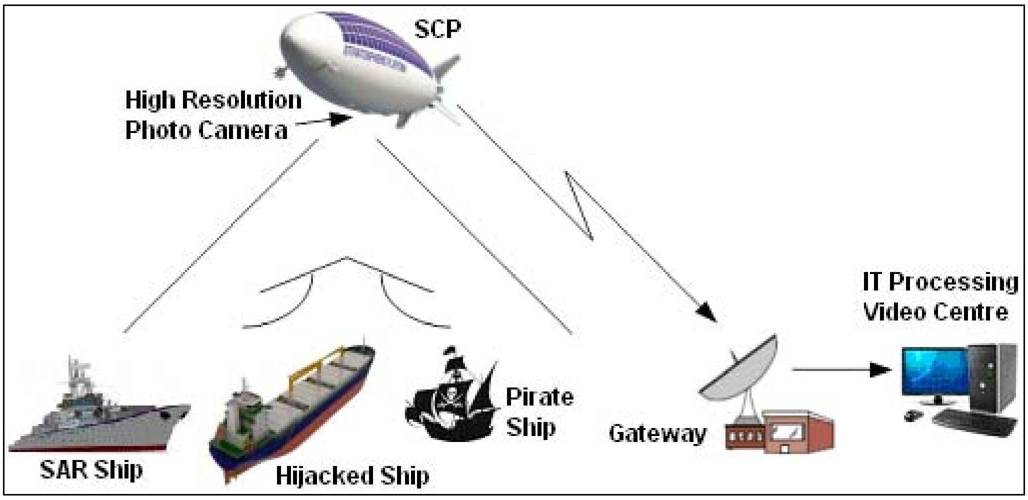

Figure 6.15. Video Surveillance via SCP – Courtesy of Presentation: by Skoryk

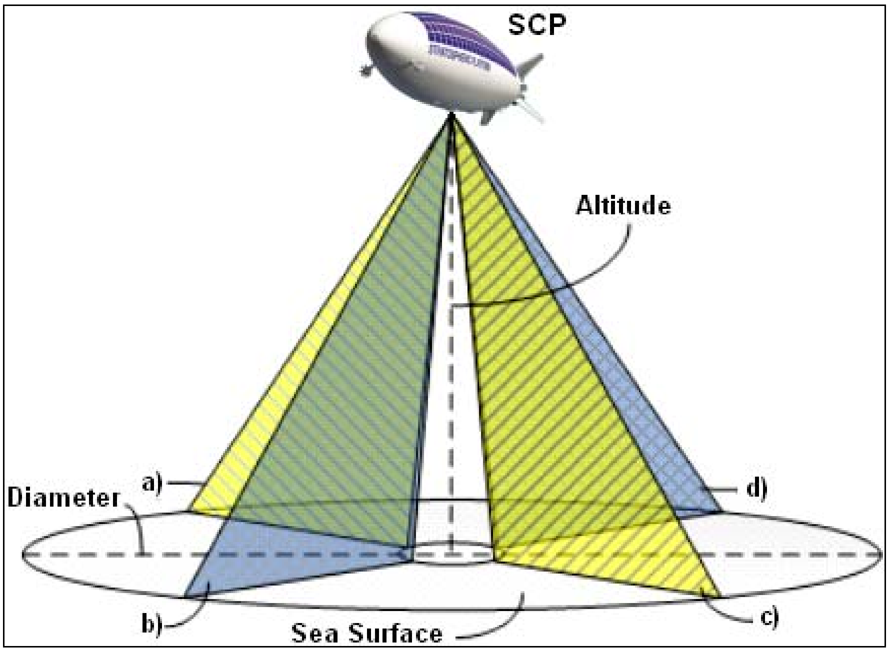

Figure 6.16. Observation of Sea Surface – Courtesy of Presentation: by Skoryk

With the help of high resolution optical camera taken pictures can be zoomed as required for sufficient visibility of ships in certain area. To increase flexibility of the optical equipment should be used camera with different technology such as infrared and other mentioned in previous chapter. For delineated video surveillance solution from SCP can be identified underlying disadvantages and advantages. The disadvantages are as follows:

- Probability to obtain high resolution images of ships from SCP in bad weather conditions is affected by increased cloud density and precipitations; and
- Sea area that can be captured ships by SCP photo equipment is relatively confined, what depends on the camera optical system.

The advantages are as follows:

- Low altitude of SCP levitation reduce expenses for the photo equipment; and
- Since the SCP airship can land ant take off in stratosphere at anytime, the maintenance of equipment is highly opportune.

6.2.2. Surveillance Radar from SCP

Radar devices are complex of specific electronic and electromagnetic systems, and in the same time radar devices are mechanical structures as well. Radar systems are composed of many different subsystems and subcomponents. There is a great diversity in the radar system design what depend on purpose, solution, fundamental operation and main set of subsystems. Surveillance radar onboard SCP airship or even aircraft can work only in LOS and to identify targets millimeters wave length is used.

The classical installation of observation surveillance radar is at shore, onboard ships or SCP airships. Radar installed onboard SCP has good LOS, however radar onboard ship and shore surveillance radars have to be at higher place as possible to provide maximum visibility range up to line of horizon.

However, the surveillance tracking radar onboard of SCP should comprise several sectored radar observations beams: a, b, c and d, which schematical diagram is shown in **Figure 6.16,** which is permanently turning around clockwise or anticlockwise rotation providing scanning of the sea surface and ships?

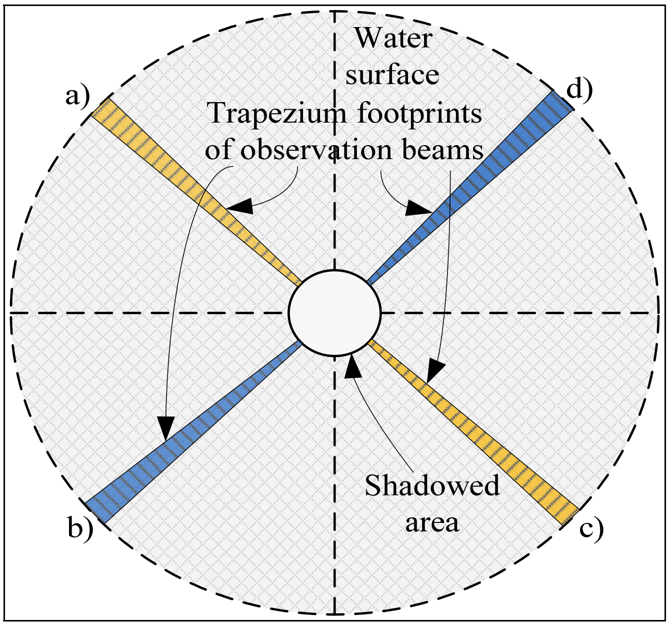

Figure 6.17. Footprints Shapes of Observations Beams – Courtesy of Presentation: by Skoryk

The radar system architecture is capable to provide observation of circular area with certain diameter and to detect all targets (vessels) within this area. The system shown in **Figure 6.17** can be exploited with different quantity and combination of the following observation beams: 1 observation beam "a", 2 observation beams "a" and "b", and 4 observation beams together "a", "b", "c" and "d".

In such a way, the quantity of observation beams can be automatically switched on or off by the system. The quantity of switched on observations beams should depend on the number of vessels, speed of their motion and necessity of target refreshment on the radar screen. Thus, automatic switching off observations beams allows effective consumption of energy from SCP main power supply, which depends on situation in the observation area.

All collected position and tracking ships data from the observation area will be saved and preliminary processed by onboard computer. Each SCP is equipped with radio transmission equipment able to provide permanent communication with ground tracking control centre through radio channels. In order to detect and track vessels with surveillance-tracking radar, firstly should be considered the fact that directly below the SCP airship equipped with radar there is blind area, which is out of radar visibility.

In the **Figure 6.17** are shown footprints of the observations beams on the sea surface and blind area in the center of the observation area. The shadowed areas are occurred as result of sophisticated shape of footprint of the radar observations beams, and as stated above detecting of targets are impossible in the blind area. Ideally the shape of footprint for such purpose must be shown as a sector of circle, which means should have three-angle shape. But real shape of radiation pattern for such system that can be implemented is close to the rectangular or trapezium shapes as shown in **Figure 6.17.**

However, the trapezium shape is self-overlapped and has a circular spinning. Hence as result of rotation this area becomes ambiguous for determination of a target and therefore length of observation beams should be technically shortened at the centre of the beam, as much as to prevent self-overlapping of the observation beams.

The square of the blind area is relatively small compared to the square of the entire observation area and can be selected optionally by designer, what depends on the width of the observation beam and diameter of the observation area. This radar observation system can provide detecting and tracking of targets that occurring in two stages:

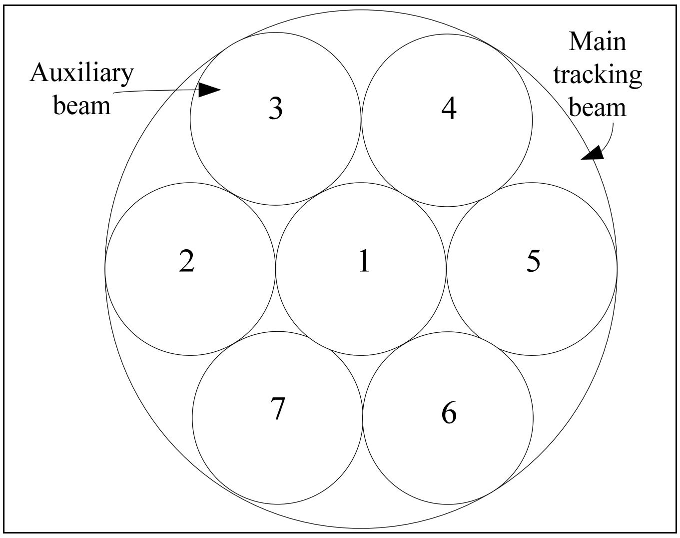

Figure 6.18. Structure of Radar Tracking Beam – Courtesy of Presentation: by Skoryk

1. First stage is to detect ship's position sector performed by the four main observation beams "a", "b", "c" and "d", as shown in the **Figure 6.17.** As discussed earlier, the number of radar observations beams can be automatically selected by the radar system from SCP. Therefore, if any ship comes into area of radar visibility, then its position can be detected as sectored position and memorized as observation beams received by reflected signal from the ship. In this case, a received signal shows that has been detected some ship or probably group of ships. However, cannot be identified exact number of targets (ships), because radar fixes reflected signal from entire observation beam footprint rather than from certain position of it. The square of area where can be detected ship or ships is equal to the square of observation beam footprint. Finally, when certain sector of ship's positions is determined, then the first stage of targets detecting is accomplished.
2. The second stage is to figure out information of ships quantity in the detected sector during the first stage of target detection and their exact positions in the sector. Certain determining of target's positions is performed by the tracking beam frequent scanning. The tracking beam may comprise seven separated auxiliary beams, which structure of tracking beams are shown in **Figure 6.18.**

Thus, such structure of the tracking beams allows detection of certain ships coordinates and also provides permanent tracking of their positions in the certain sector. The radar tracking beam works simply as seven separated beams of certain diameters, and in such a way, the diameters of auxiliary beams of the main tracking beam determine maximum resolution of detections. The seven separate beams of tracking beam work as seven separated radars. Each beam has its own radar that transmits signal toward sea surface and receives reflected signal from the target (ship).

The question is, how is working the tracking beam and being provides tracking of ships? The system tries to keep the ship in the auxiliary beam with number "1" exposed sector. Keeping some ship in the auxiliary beam number "1" means that certain ship is captured as is shown in the **Figure 6.19 (a).** However, if the ship permanently moves in other areas, the oobserved ship periodically comes to any auxiliary beam, which is placed around the central auxiliary beam with number "1" of the main tracking beam. Then dependently in which number of auxiliary beam the ship is detected, system shifts position of tracking beam in such a way that will keep the ship in the tracking beam centre of the auxiliary beam number "1" or radar system captures the ship again. Described process of capturing and tracking of the ship is illustrated in **Figure 6.19 (b)**.

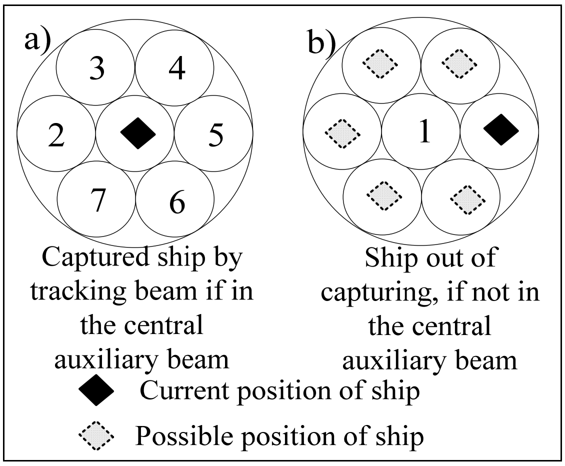

Figure 6.19. Ship Tracking Process – Courtesy of Presentation: by Skoryk

Just one radar beam is capable to provide tracking of several ships at same time, because speed of moving of the main tracking beam is much higher than speed of ships motions. The radar system moves the main tracking beam automatically for searching and capturing of the target only in special way and only along of the range of sector where target or targets are detected by the observation beam, as shown in the **Figure 6.20.** Such operation of the radar system provides permanent detection and surveillance of current position of tracking beam and every position points of the targets are memorised by the processor system.

If certain observation beam shows some targets around, the radar system provides searching of target again with help of the main tracking beam and provides refreshing of positions of the ships. All received new coordinates over the certain time are integrated with previous detected ones in the system and as result of integration of individual position dots, it gives own tracks of all targets captured in the observation area. All these processes are repeated automatically over again and second stage of detecting of certain coordinates and tracking of ships is finished. The observation sea surface area optionally is divided in four quarters as shown in **Figure 6.20.** Every quarter can be served by own radar tracking beam to provide more fast and reliable tracking of targets. Such division can be implemented dependently on preliminary analyzing of ship traffic in certain area before the radar system is deployed.

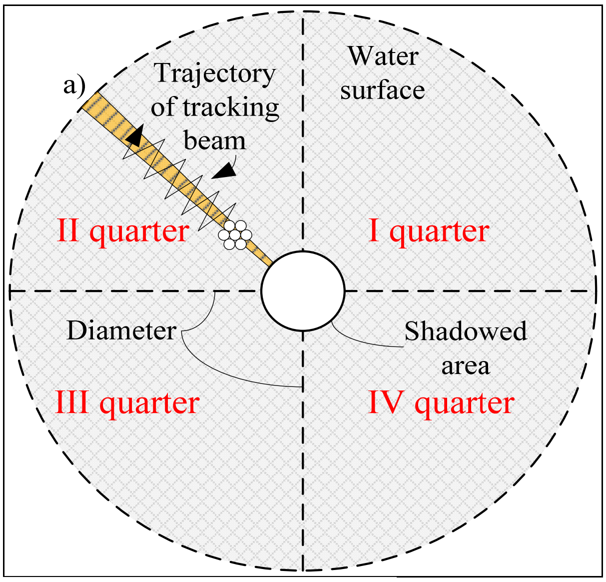

Figure 6.20. Target Detecting with the Tracking Beam – Courtesy of Presentation: by Skoryk

Figure 6.21. Ship's Navigation Bridge and Equipment – Courtesy of Presentation: by Skoryk

6.3. Maritime Satellite System

Satellite systems are new tools deployed onboard seagoing merchant ships, which play very important role in Maritime CNS including ship's tracking and detecting solutions. Thus, in previous chapter are introduced some maritime satellite systems concerned to the tracking and detecting systems, and in this section will be presented some specific proposals of GST, SSAR and S-AIS applications.

6.3.1. Discreet Installation of Tracking System onboard Ships

During merchant operations every ship uses few navigation and tracking devices for safety, security and collision avoidance at sea. But after capturing some ship pirates are in position to switch-off all onboard possible communication and tracking equipment. Their intention is to make hijacked ship "invisible" for SAR tracking and navigation forces and drive the ship away. All communication and navigation equipment can be switched-off or damaged by pirates without any difficulties, since all equipment are situated on navigation or compass decks, as shown in **Figure 6.21.**

In order to prevent possibility that pirates can hide somewhere hijacked ship, it should be necessary to provide discrete installation of Global Ship Tracking (GST) onboard every ship sailing in areas of pirates operations, shown in **Figure 6.22.**

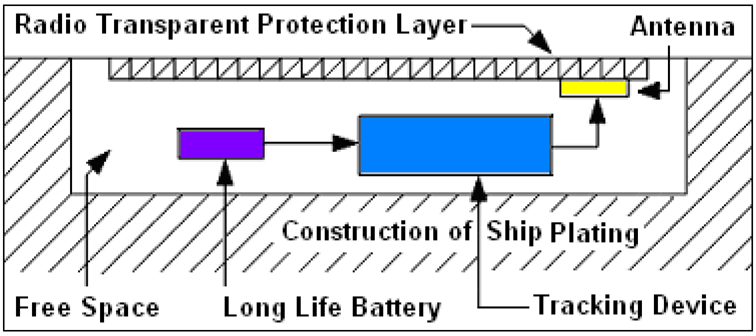

Figure 6.22. Discrete Installation of GAT Equipment onboard Ships – Courtesy of Presentation: by Skoryk

Namely, these tracking devices have to be installed secretly onboard ships without being able to be found. Antenna unit has to be fixed behind transparent plate, which has to allow access to EM waves.
The GST device has integrated GPS receiver and satellite transceiver, so transceiver can transmit Position, Velocity and Time (PVT) data obtained from GPS receiver to the Tracking Control Centre (TCC). The TCC station can provide position of hijacked ship to SAR forces, and pirates can be arrested before they realise what is going on. The GST equipment can be connected to the ships main power, however if pirates cut the current line, unit can use the own battery power supply and continuously sends ships PVT data via satellite to TCC.
There are few GEO and LEO satellite operators providing GST service and equipment. The only GEO operator is Inmarsat offering SkyWave tracking equipment, while LEO operators are Iridium, Globalstar and Orbcomm. Iridium offers much GST equipment made by many manufactures, such as Quake, Beam and so on. Globalstar uses Axon products and Orbcomm is using Magellan, Stellar ad Quake equipment.

6.3.2. Tracking and Surveillance of Ships with SSAR Spacecraft

The SSAR radar self-illuminates an area by transmitting pulses of microwave energy. These pulses of radar energy are reflected from the illuminated area of target and collected by the radar receiver. By the precisely measuring the time difference between the transmitted pulse and the receipt of the reflected energy, radar is able to determine the distance of the reflecting object, called rang or slant range.
The radar range resolution is its ability to distinguish two objects separated by same minimum distance. If the objects are adequately separated, each will be located in a different resolution cell and will be distinguishable. If not, the radar return will be a complex combination of the reflected energy from the two objects.
Spatial resolution in the range direction is not range directly wavelength dependent, but is instead a function of the effective (processed) pulse width τ multiplied by the speed of light c and divided by two. Range resolution can also be expressed as the reciprocal value of the effective pulse width (the pulse bandwidth β) multiplied by the speed of light, which relation is expressed by the following equation:

$$R_{res}\,(SSAR) = c\tau/2 = c/2\beta. \tag{6.22}$$

This equation shows that if range resolution becomes finer, the pulse bandwidth and data rate grows accordingly. Most modern radars, including SSAR, transmit pulse known as a Linear Frequency modulated (LFM) or “chirp”. The transmitter varies the frequency of the radar pulses linearly over a particular frequency range, so when it increases in frequency is calling up-chirp. That variation in frequency determines the Radio Frequency (RF) bandwidth of the system. The chirp length and slope are based on the radar hardware capabilities (RF pulse power, Pulse Repetition Frequency (PRF) and Analog-to-Digital (A/D) sampling conversion) and the range resolution requirements. Both Real Aperture Radar (RAR) and SSAR achieve their range resolution in this way. Typical spaceborne SSAR pulses bandwidth range is between 10 MHz and 40 MHz, which in accordance to the equation (6.22) produce quite slant range resolution of 15 and 3.7 meters.
However, in the direction orthogonal to the radar beam, also called cross range (azimuth or along track in broadside operation) the SSAR is distinctive in usage of aperture synthesis to improve the spatial resolution. However, by comparison, optical sensors and RAR obtain their resolution the physical dimensions of their aperture, sometimes referred to as diffraction limited performance.

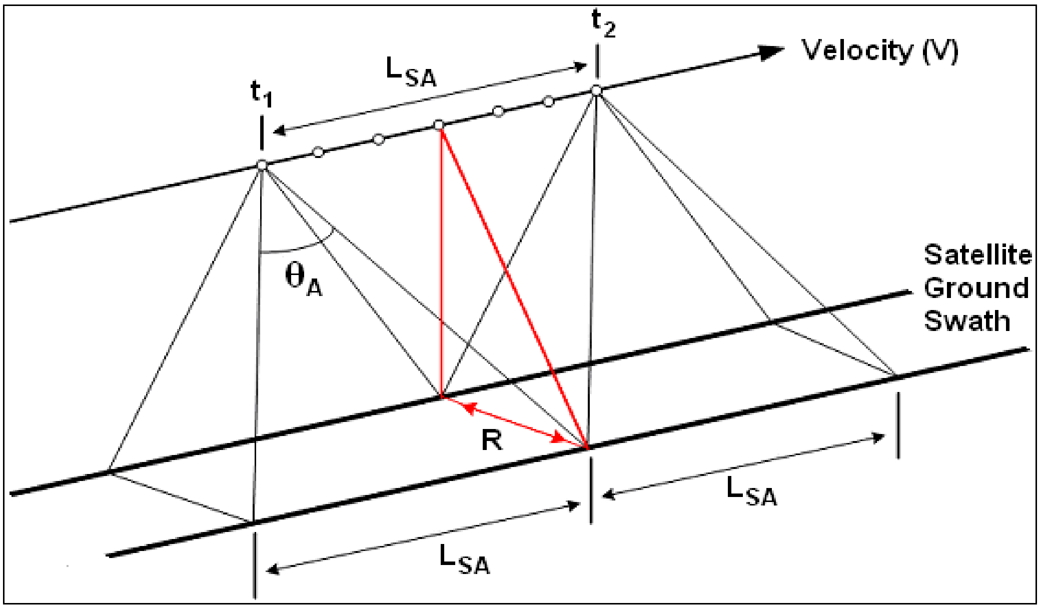

Figure 6.23. Basic Principle of SSAR Operations – Courtesy of Presentation: by Skoryk

The RAR cross range spatial resolution is a direct function of radar wavelength λ and target range R and an inverse function of antenna dimension D, which can be expressed by the equation as follows:

$$R_{res}\ (RAR) = \lambda R/D. \tag{6.23}$$

From space, the RAR range resolution problem can be solved but the poor cross range or along track performance, typically kilometers to tens kilometers, still has to be contented with. There are three possible ways to increase along-track performance:

1. To boost operation frequency;
2. To enlarge along track antenna length; and
3. To decrease the target range.

Thus, none of these options are still being insufficient from space. However, by using Carl Wiley's discovery, resolution is determined by the Doppler bandwidth of the received signal, rather than the along-track width of the radar's antenna beam pattern. In **Table 6.1** are shown summarized spatial resolution relationships for RAR and SAR systems.

Table 6.1. Function of Spatial Resolution Relationships

Spatial Direction	RAR	SSAR
Along-Track	λR/D	D/2
Range	c/2β	c/2β

The antenna beam illuminates the target when the platform reaches position t_1, not before. It continuous to illuminate the target for a distance L_{SA} (Synthetic Aperture Length) until it reaches t_2. The time required to translate along-track beam through a point target is called the integration time or dwell time, which can be expressed with equation as follows:

$$T_{DWELL} = L_{SA}/V = \lambda R/VD_{AT}; \tag{6.24}$$

where $L_{SA} = \lambda R/D_{AT}$, T_{DWELL} — Integration time between time points t_1 and t_2; V = velocity; L_{SA} = synthetic aperture length (distance radar satellite moves to illuminate target); R = target range; D_{AT} = along-track antenna length; and λ = operation wavelength (Jackson and Apel 2004).

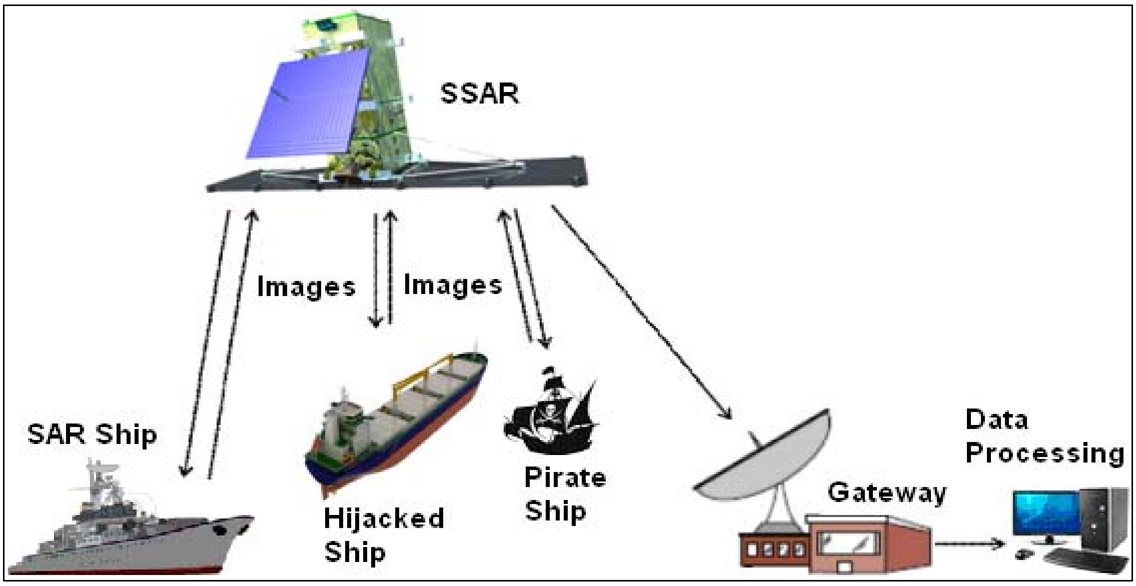

Figure 6.24. System for SSAR Imaging of Area of Pirated Ships – Courtesy of Presentation: by Skoryk

The antenna aperture azimuth bandwidth θ_A of SSAR can be calculated by equation:

$$\theta_A = \lambda / D_{AT} \tag{6.25}$$

Earth target resolution element along-track dimension σ_{AT} can be calculated by equation:

$$\sigma_{AT} = (\lambda/2L_{SA})\, R = [\lambda/2(\lambda R/D_{AT})]\, R = D_{AT}/2; \tag{6.26}$$

where $L_{SA} = \lambda R/D_{AT}$.
In fact, this equation apparently shows that along-track resolution is independent on range R and radar frequency (can be derived as wavelength λ) and improves with smaller real antenna aperture.

6.3.2.1. System Organization of Ship Tracking and Surveillance by SSAR Satellite

The SSAR consists of an end-to-end system that includes conventional radar building blocks such as an satellite antenna, transmitter, receiver and high technology data collection system providing coherent Doppler phase histories and similarly advanced signal processor capable to make an image out of these phase histories. In fact, the satellite radar should maintain stringent control of the signal characteristics and collect coherent phase information to allow the construction of the image.
In this sense, such system can be successfully applied for determination of pirated ships via images as shown in **Figure 6.24**. The SSAR satellite is radiating and intercepting reflected microwave energy from target and transmitting coherent Doppler phase histories through the ground Gateway to IT Data Processing Facility in the Tracking Control Centre (TCC), where producing of images and analyze of the ship's position are occurred.
Thus, if pirates capture some ship and switch-off all communication and navigation devices, the SSAR satellite can independently search for hijacked ship and produce images of Earth and identify location of captured ship by pirates.
Soon after location of hijacked ship, the TCC station can send position data via Gateway and communication satellite to the SAR ship and other SAR forces. In addition, there is also possibility to install IT Data Processing Facility onboard SAR ship and much earlier release captured ship and crew.

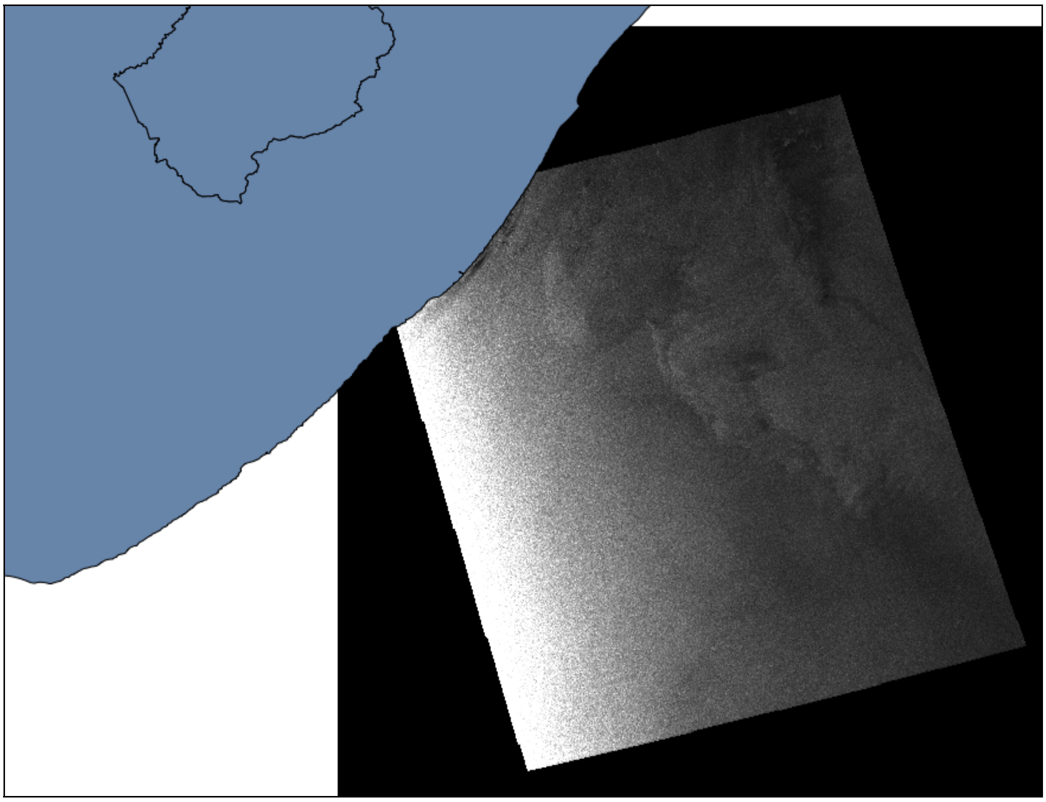

Figure 6.25. Two SSAR Image Layers of South Africa – Courtesy of Presentation: by CSIR

6.3.2.2. Practical Determination of Ships by SSAR Satellite

In reality, using processed SSAR images will be not possible to identify the ship at sea without special software and data processing. Thus, in order to determine location of ship as dotes on the pure SSAR photo, the SSAR image has to be integrated with existing LRIT geographical data position of ships at particular moment of time.
For the experimental part of study, have been taken photo produced by Wide Swath Mode of Advanced Synthetic Aperture Radar (ASAR) satellite images covering portions of the South African Coastline were obtained during the period January 2012 to March 2012. The ASAR operates at C-band ensures continuity with the SSAR image mode and the wave mode of the ERS-1/2 AMI, which main features enhanced capability in terms of coverage, range of incidence angles, polarizations and modes of operation.
Thus, this enhanced capability is provided by significant differences in the instrument design: a full active array antenna equipped with distributed transmit and receive modules, which provide distinct transmit and receive beams, a digital waveform solution for pulse "chirp" generation, a block adaptive quantization scheme and a ScanSAR mode of operation by beam scanning in elevation.
The ASAR C-band imaginary was one of the instruments onboard the ENVISAT satellite platform that was launched in 2002 with the mission ending in April 2012. Thus, the spatial resolution for wide swath mode was approximately 150×150 m. The ASAR system hardware provides processing of coherent back scattered waves from particular Earth surface converted into image of that Earth surface. With help of computer software "Quantum GIS".
In **Figure 6.25** is illustrated SSAR imaging of two layers of South-west costal line of South African seashore, which gray square shape is SSAR image of Earth surface. This image of Earth surface can be opened as one layer, shown as a gray square on black background, and another layer shows part of African Continent, which is presented as a blue area partly on white background.

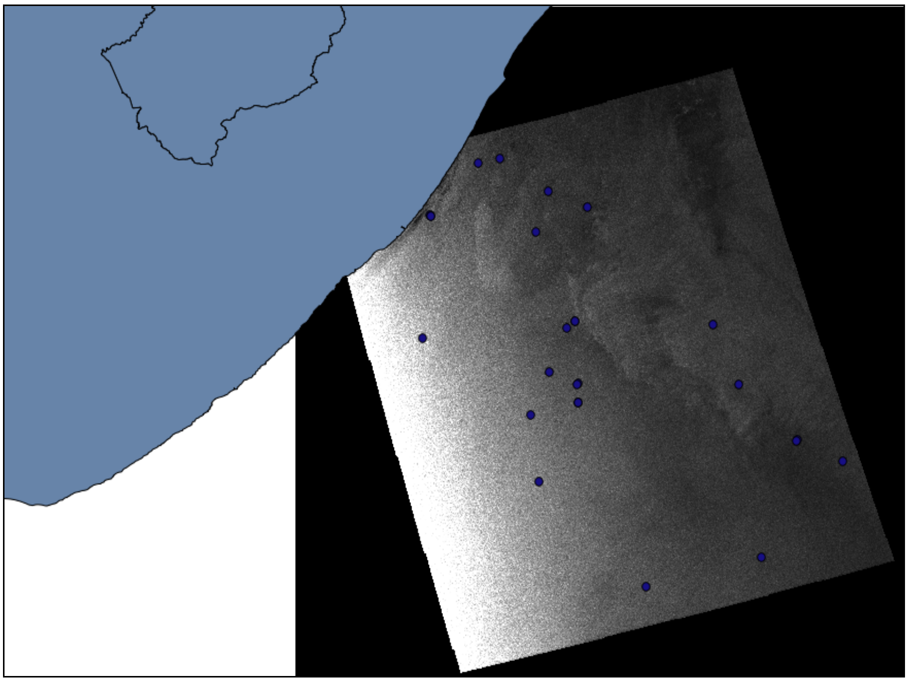

Figure 6.26. SSAR and LRIT Image Layers – Courtesy of Presentation: by CSIR

In the **Figure 6.26** is illustrated integration of SSAR and LRIT image layers. In such a way, the processed LRIT position data base points can be added over the SSAR image layer, what gives possibility to find out where ships positions on the SSAR image are. Here are also presented two imaging layers of South-west costal line of South Africa. First layer is the gray square shape on the black background showing SSAR image of Earth surface together with LRIT positions data points layer.

In the next stage is demonstrated how ships images look like and how they can be determined on the SSAR images. This is possible to realize with zooming in SSAR images in several hundred times as illustrated in **Figure 6.27**. The ships can be seen as few bright pixels among the number of gray pixels, presented as background or neutral non-received signal by SSAR from those areas. These white pixels clearly show presence of two ships, which in addition are confirmed by two blue color dotes of processed LRIT position data points on top of them.

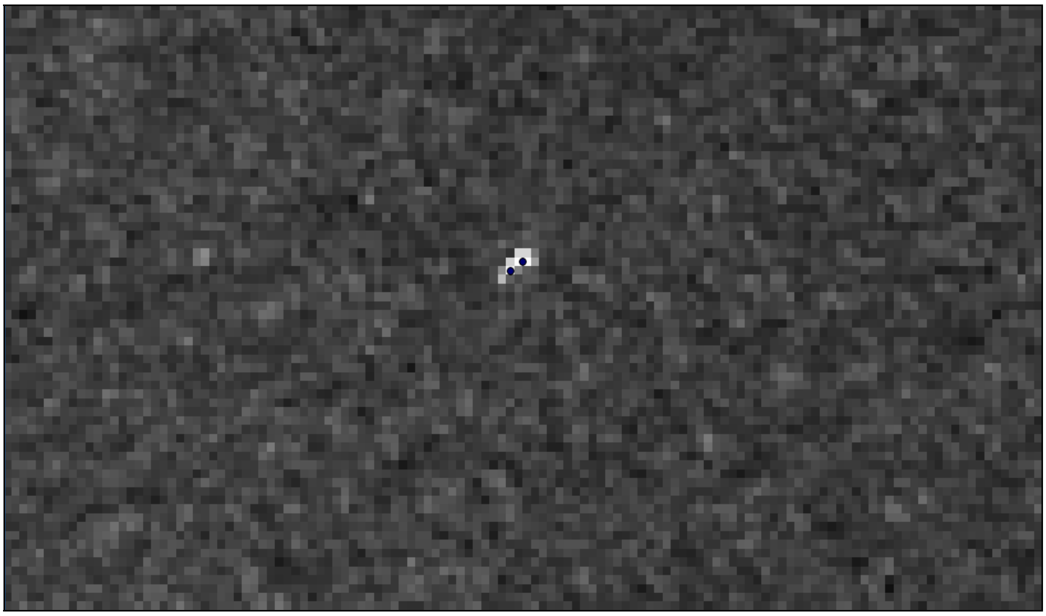

Figure 6.27. Ships Images Placed in Zoomed SSAR Image – Courtesy of Presentation: by CSIR

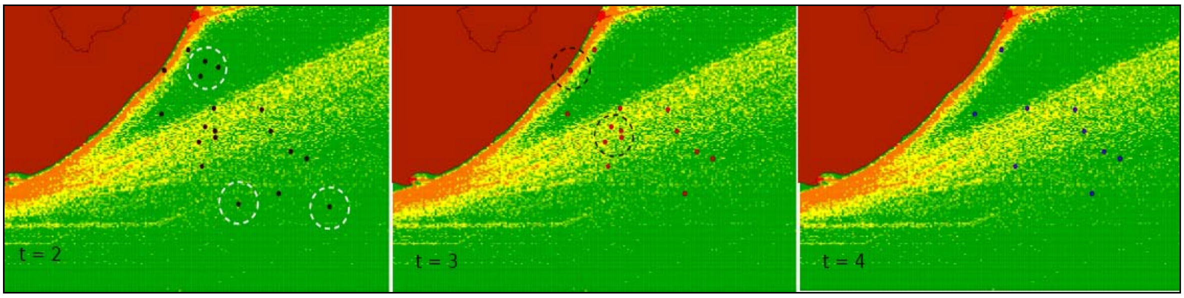

Figure 6.28. Ships detection by Cell Averaging CFAR Detector – Courtesy of Presentation: by CSIR

Ships can be detected using SSAR images because its radar backscatter tends to be much stronger than the returns from sea surface. Thus, typical returns from the ocean are widely accepted to approximate a K-distribution. The cell averaging Constant False Alarm Rate (CFAR) detector, which makes use of a moving window that contains a target box, guard area and back ground area, was used for ship detection in this study. A target pixel is flagged as a ship according to the following relations:

$$\text{Detected Ship} = \text{true if } x_t > \mu_b t \text{ and false if } xt < \mu_b t; \tag{6.27}$$

where x_t = backscatter value in the target window; t = threshold value; and μb = mean of the backscatter.

The idea is that, if the target pixel's backscatter value is significantly larger than the average background value, and than the target pixel is flagged as being a ship. The value of threshold determines the false detection rate, and can be determined statistically when the sea clutter statistics does not vary significantly. Practically, the sea surface is often not homogeneous and the sea clutter statistics can vary from point to point, which will often lead to an increase in the number of expected false alarms. To reduce the number of false alarms in this study, a prior vessel distribution map was utilized. This distribution map was generated using a full year's reported LRIT vessel location points. The idea is that the initial value of this relaxed images and that an operator overlay the detected points with that of the prior vessel density map. An initial plotting of all the detected ships will inevitably get ships detected in areas having a very low probability of realizing any vessel traffic, which will consequently have a high probability of being a false alarm. By increasing the threshold value, it is expected that the detected ships in these areas will be reduced. The threshold will be increased up to the point where exclusions in areas with high probability of ship traffic are noticed thereafter the threshold is set to the previously evaluated value.

In **Figure 6.28** are illustrated images of ships detected by using the cell averaging CFAR detector with a threshold values are t = 2, t = 3 and t = 4, respectively. At this point, the background image is a vessel distribution map created using processed LRIT positioning data, where a green backdrop on the image indicates very low historic vessel occurrence and with yellow, orange and red indicate increasing historic vessel occurrence.

The background image is a vessel distribution map created using 12 month's reported vessel locations from the LRIT dataset. Looking **Figure 6.28,** it is clear, when the threshold is low (t = 2), there are a number of vessels reported in certain areas having both high and low occurrence probabilities. When increasing the threshold value to t = 3, it can be seen that five of the vessels previously detected in areas with a low vessel occurrence probability, are excluded and assumed to be false alarms.

On the other hand, when increasing the threshold value to t = 4 it is noticed that five vessels located in areas with a high occurrence probability are excluded, indicating that the threshold is too high and should be reverted to the previous threshold for better results.

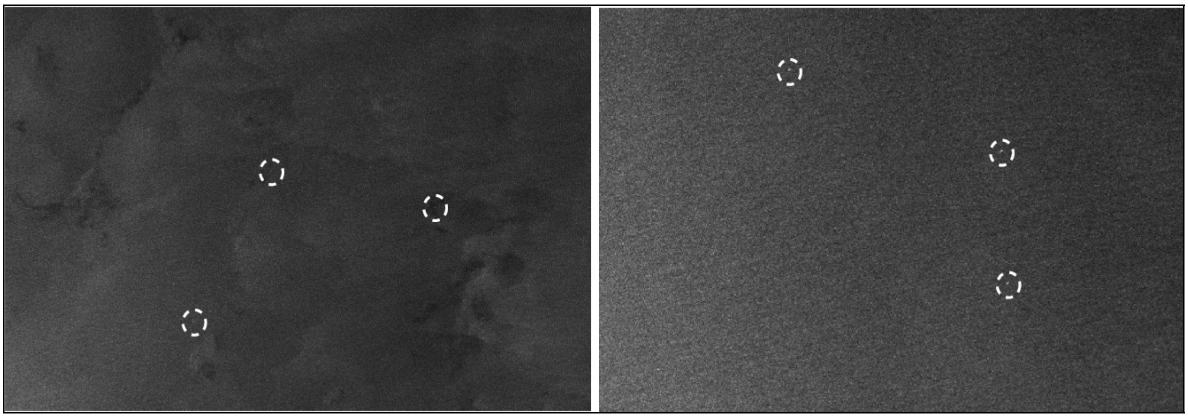

Figure 6.29. Reported Ships Actual and False Detection – Courtesy of Presentation: by CSIR

In **Figure 6.29 (Left)** are shown reported vessels (false alarms) excluded when changing the threshold from t = 2 to t = 3. In **Figure 6.29 (Right)** are illustrated reported vessels (actual vessels) excluded when changing the threshold from t = 3 to t = 4.

Therefore, analyzing the SSAR image in detail, it was found that the five vessels excluded when adjusting the threshold from t = 2 to t = 3 were in all likelihood false alarms as the sea clutter around these detections were not homogeneous and large areas with very little ocean backscatter were observed near the reported vessel locations. When increasing the threshold from t = 3 to t = 4, it is obvious that actual vessels were not reported and that the threshold was too high (Kleynhans *et al.*).

6.3.3. Preposition to Utilize S-AIS Network through L/C-band

As known S-AIS system is using VHF band for communication between S-AIS shipborne terminals, costal S-AIS base station and Orbcomm LEO satellites that provides S-AIS. The distribution of S-AIS data occurred with SOTDMA coding technique. Each S-AIS station determines its own transmission schedule (slot), based upon data link traffic history and an awareness of probable future actions by other stations. A position report from one station fits into one of 2250 time slots established every 60 seconds on each frequency.

The S-AIS ship stations continuously synchronize themselves to each other, for the reason to avoid overlap of slot transmissions. Slot selection by an S-AIS station is randomized within a defined interval and tagged with a random timeout of between 0 and 8 frames. When a station changes its slot assignment, it announces both the new location and the timeout for that location. In such a way new stations, including those stations that suddenly come within radio range close to other vessels will always be received by those vessels.

There is a problem, because by using of VHF signal, the carrier has narrow spectrum that in turn is quite noisy, so the system frequently receives noisy time slots and that information in the time slot cannot be recognized by system, hence system is losing them. This problem can be solved by shifting spectrum in higher frequency band that allows decreasing noise and widening spectrum of transmission signal.

In order to provide shifting carrier signal in higher frequency band and wide spectrum of carrying signal it should be deployed standard bands using by communication satellites. The proposal of a new solution is to deploy L/C-band for S-AIS network through global satellite communication systems such as Iridium, Inmarsat, Globalstar and other regional satellite to provide reliable worldwide coverage.

In order to communicate via L/C-band S-AIS, special adapter should be connected to VHF S-AIS shipborne terminal via adequate Matching Device. Thus, the diagram of the proposed L/C-band S-AIS adapter is presented in the **Figure 6.30.**

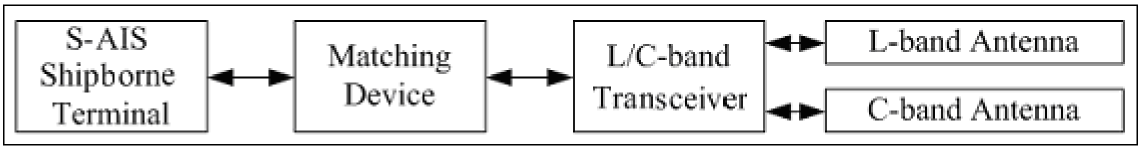

Figure 6.30. Diagram of L/C-band S-AIS Adapter – Courtesy of Presentation: by Skoryk

In addition, the stated GEO and LEO mobile satellite systems can be deployed for direct use of L/C-band spectrum for transmissions of S-AIS messages. At this point, in the future it can be developed the separate S-AIS independent of the VHF R-AIS network.

6.3.4. Testing of GST Terminal in Durban's Harbour

In previous chapter are introduced GST and its advantages over LRIT equipment. To provide test of mobile tracking terminal produced by the manufacturer of the US Company Quake were taken into consideration as easy accessible and at an affordable price. The Quake QPro satellite data modem was purchased as a kit together with two optional solutions with airtime (bandwidth) and tested as very flexible terminal with different convenient features.
The Quake Global QPro is dual 3G and Iridium transceiver integrated with GPS receiver as a self-contained global communication and navigation system situated in a very small, rugged, environmentally-sealed IP67 form factor, illustrated in **Figure 6.31 (A).** This data modems incorporate the latest in advanced programmable features allowing developers and integrators to tailor their PVT data communications. These data modems are ideal for customers wanting to send most of their data over 3G (GPRS), but needing satellite as a back-up for critical information when out of cellular coverage.
Key features of this modem is that delivers reliable two-way communication through the Iridium and terrestrial 3G/NextG GPRS networks, equipped with an advanced 50-channel GPS system for location and navigational applications, customization options include routing of data over satellite/3G, inputs/outputs, memory, Controller Area Network (CAN) bus and antenna detection, including Application Programming Interface (API) allows developers to create customized onboard applications. Detailed configuration software tool (available for a fee) can be used to set up the QPro for specific needs without detailed programming.
The Quake QPro GPS receiver and Satellite/GPRS transceiver with both antenna units was installed onboard motorboat "Discovery" and the test was conducted in port of Durban, shown in **Figure 6.31 (B).** The Quake QPro GPS/Satellite and GPRS antenna must be located at least 50 cm (preferably 1 metre) from any other radio or cellular antenna fitted to the mobile and the Quake QPro device. Failure to ensure this separation may result in the impeded ability of the device to track data correctly.

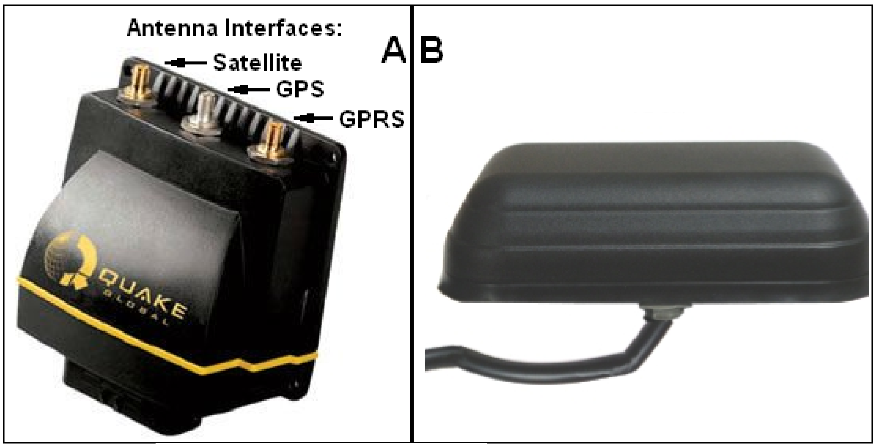

Figure 6.31. QPro Transceiver and Antenna – Courtesy of Brochure: by Quake

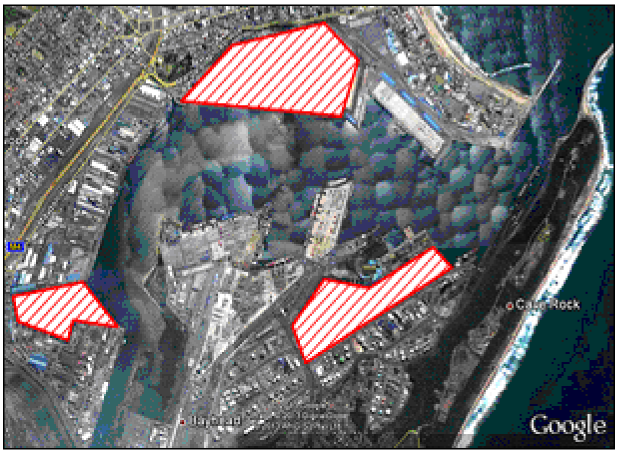

Figure 6.32. Defined Geographic Regions of QPro – Courtesy of Presentation: by Skoryk

During testing Quake QPro tracking terminal independently has received PVT data by the GPS receiver via GPS antenna and in the same time onboard motorboat Satellite transceiver sent message of PVT data via transceiving antenna. The PVT data was received by the Iridium Gateway or Coast Earth Station (CES) Tempe in Arizona, US via Iridium satellites and forwarded via Internet to Tracking Control Centre (TCC) computer at Durban University of Technology (DUT). Our PC in TCC has received and processed PVT data by special Microsoft software.

When GPRS communication is available the Quake QPro can transmit standard location PVT messages via integrated Cellular/3G modem at a separate configurable logging interval. This allows satellite communications costs to be managed. For example the Quake QPro can be configured to report at a 60 second interval via GPRS, however can be configured to report at 1 hour intervals using the satellite network when GPRS is not available. Using the Vodacom GSM network our onboard motorboat Quake QPro unit sent PVT message to the PC at DUT. The PVT message contains name of motorboat, position, speed and time.

Advantages of Quake QPro unit are: fully user self-programmable, individual inputs can be specifically configured to continuously monitor sensors and to report at selected intervals, alarm conditions can be pre-programmed and the QPro reports the condition automatically and immediately, and reports can be generated on a regular schedule (1 minute to 23 hours), by exception-only reporting, or a combination of both. In addition, the Quake QPro unit can be optionally adopted for Inmarsat or Orbcomm networks in combination with GPS receiver and 3G (GPRS) transceiver.

During testing with motorboat in port of Durban, therefore, for the tracking device were determined geographic regions in the harbor. The geo-fences were appointed with the help of "DOTA" software and as longitude and latitude data were uploaded to the tracking device. The defined geo-fences for the tracking device in Durban's harbour are shown **Figure 6.42.**

The testing QPro device was capable to report and alarm on the movement of the device into and/or out of predefined geographic regions. This geo-fencing was defined on the device rather than being applied on processed data. Up to 30 geographic regions can be defined, and the regions are defined as closed polygons with up to 50 points (Latitude and Longitude). For controlling presence in predefined area the device is capable to drive 2 digital outputs based on the location of the device inside or outside of the predefined geo-fence regions. In such a way, these outputs can be used to take an action when the device enters or exits the regions. Output state can be set: ON while inside the geo-fences/OFF while outside; and OFF while inside a geo-fence/ON while outside.

7. Chapter 7

ANALYSIS OF RESULTS AND CONCLUSION

This chapter provides an overview and outlines of the results obtained during the research in this thesis.

7.1. Results and Summery of Satellite Anti-piracy Solutions

In this thesis have been designed and proposed four anti-piracy solutions. During scientific studies and research were conducted several steps and explanations of how to carry out the installation of independent discrete anti-piracy tracking and SART devices onboard ships, how to implement new S-AIS and integrate with existing R-AIS networks, how to provide installation of discrete SART devices onboard ships, how to conduct proposals of new space technologies such as SSAR or video (electro-optical) surveillance onboard spacecraft and SCP, how to provide installation of GST devices onboard ships and so on.
The special proposed radio and space solutions for ship tracking and detecting are as follows:
1. Coastal HF Surveillance Radars for coastal and seaport monitoring and management;
2. Radio Multiband and Multifunctional Direction Finders for ships and personal detecting;
3. Radio AIS (R-AIS) Airborne VDL System onboard airplane and helicopters for SAR;
4. Radio VHF Data Link (R-VDL) suitable to support CNS functions of ships;
5. Radio Automatic Dependent Surveillance - Broadcast (RADS-B) of PVT ships data;
6. Radio GNSS Augmentation VDL-Broadcast (GAVDL-B) for CNS via GNSS;
7. Satellite Data Link (SDL) for ships navigation and surveillance functions;
8. Satellite GNSS Augmentation SDL (GASDL) for CNS via GNSS; and
7. Satellite Automatic Dependent Surveillance - Broadcast (SADS-B) of PVT ships data.
Therefore, to improve tracking and detecting facilities including collision avoidance of ships will be important to implement or integrate some of above listed technologies.

7.1.1. Analyze of Discreet Installation of Ships Tracking Terminals

The discreet installation of GST device implies that has to be compact and independent from ship main power supply and installed in the special secret place somewhere on top of ship's construction body. The tracking device must be connected to small compact omnidirectional antenna and to the independent power supply, which can be mounted in the very small cavity with transparent cover for radio waves. Therefore, the cavity cover has to be not visible and painted with the same color of body surface.
The particulars about tracking equipment that can be used as GST are introduced in Chapter 5 and the literature overview about can be found in listed references or on the Google. There are many tracking devices that can be installed onboard ships as discrete GST devices, such as SkyWave for Inmarsat, Beam and Quake for Iridium, Axonn for Globalstar and Stellar and Quake for Orbcomm satellite systems. All these devices are integrated with GPS receivers and all have duplex transmission (transmitter and receiver mode), except Globalstar devices are simplex devices just providing transmission mode.
All stated tracking devices can be used as normal GST devices during navigation or can be discreetly installation onboard ships. In fact, the discrete installation of GST can be used in case when some ship is captured by pirates. The secret GST installation will transmit PVT data to the TCC and in such a way captured ship will be found and released very quickly.

7.1.2. Analyze of Anti-piracy SSAR Solutions

In the Chapter 5 has been calculated spatial resolution of SSAR. The spatial resolution of SSAR depends on pulses bandwidth range by which illuminates Earth surface. It was calculated that with pulse bandwidth in 40 MHz is possible to obtain spatial resolution of SSAR between 15 meters and 7 meters and furthermore this spatial resolution is not limited.

In the Chapter 6 has been provided real SSAR image of near coastal ocean area with SSAR satellite with equipment, which capable to provide building of imaging of Earth surface with pixel of spatial resolution 150 by 150 m, and which is sufficient to apply in anti-pirate tasks as for detecting and tracking of pirated ships. This resolution is capable to determine ship with size equal or more than size of SSAR resolution pixel, but in case if ship is several times smaller than SSAR pixel resolution than must be applied higher spatial resolution.

In such a way, it can provide important derivation, which can deploy different types of SSAR satellites and with different spatial resolutions to provide detecting and tracking of different size of ships. Thus, technically in order to use one type of SSAR satellite with high spatial resolution it will be necessary to provide transfer of high data rate.

In order to obtain possibility to detect ship of small size, then must be used SSAR satellite with low spatial resolution just to detect ship in some pixel. However, if ship has been detected in some pixel of visible area by low resolution SSAR, then should be used second SSAR satellite with higher spatial resolution to check and determine the certain points where was detected the ship.

7.2. Results and Summery of Radio Anti-piracy Solutions via SART Transmitter

The discreet installation of SART transmitter is similar to discreet installation of the tracking terminal. The difference is only that this unit transmits signals with small time intervals in all directions from the ship, which can be detected by the surveillance radar onboard SAR ships or helicopters. This equipment in normal circumstances is used for detection and SAR of ships or crew members during distress alert or as a passive device can help for detection of captured ships by pirates. The detecting distance is

The radar-SART may be triggered by any X-band radar within a range of approximately 8 NM (15 kilometers). Each radar pulse received causes the SART to transmit a response which is swept repetitively across the complete radar frequency band onboard SAR ships and helicopters. Thus, this unit is a self-contained, waterproof transponder/transmitter intended for emergency use at sea during SAR operations or in the case to detect captured ships by pirates. These devices may be either a radar-SART or an GPS-based R-AIS device.

7.3. Result and Summery of Anti-piracy Solutions via SCP

The SCP is modern technique and new part of space technology which able to carry big diversity of radio equipment and to provide different types of quality services. It has been proposed several new applications with SCP with regards to arrange the following maritime tracking solutions:

1. Mounting of high resolution optical video equipment onboard SCP airship or aircraft and to provide video surveillance of ships in certain coverage area at sea;
2. Mounting of SSAR on board of SCP to provide monitoring and tracking of ships in certain coverage area at se;

Mounting of surveillance-tracking radar on board of SCP for the same proposes; and

3. Mounting of R-AIS equipment on board of SCP instead of S-AIS equipment onboard spacecraft and to connect all ships in area for local or regional tracking system.

The SCP tracking solutions can be integrated with Terrestrial and Satellite systems as an alternative and complementary means of tracking and communications. In comparison to

Terrestrial communication technologies, SCP airships and aircraft require considerably less communications infrastructure. They can serve potentially large coverage areas from a single site, the cell planning is straighter forward since they are able to provide LOS links and finally they are more cost effective.

Uniqueness of characteristics of SCP allows utilizing for the following applications:

1. Fixed and Mobile Communication Systems for Urban, Suburban and Rural solutions;
2. Integration with GNSS and CNS solutions for precise positioning and determination;
3. Traffic Control and Management at sea, on the ground and in the air;
4. Tracking and Monitoring of mobiles, peoples, animals and assets;
5. Remote Earth Sensing and Weather Observation;
6. Disaster Monitoring, Emergency Response and Security Management;
7. Broadcast Contents, News Gathering, Broadband, Multimedia and fast Internet;
8. Service Providers Platforms (SPP), Enterprises and Private Networks; and
9. Defense and Police Information Management.

The nearest future follows after the SCP which can successfully replace most of satellites systems. In order to show advantages and disadvantages of SCP and satellites in **Table 7.1** is presented comparative analyze of their properties:

Table 7.1. Comparison of SCP and Satellite Systems

Properties	SCP	Satellite
Signal Delay Trip	Delay approximately from 0.01 up to 0.02 ms due to small altitude	In case of GEO satellite delay can be up to 250 ms due to big altitude
Inter Links	Can be provided	Can be provided
Life Span	In 6 months deployed on the ground for maintenance, up to 30-40 years	Up to 12 years
Coverage	One SCP can cover about 700 Km in diameter depending on altitude	By one GEO satellite can be covered 35% of Earth surface
Payload	Due to small distance uses smaller low gain antennas systems and less power consumption of equipment	Due to large distance uses high gain antennas systems and high power consumption of equipment to produce enough strong signal
Maintenance	After finishing of 6 months life span SCP can be grounded for reparation and maintenance, and another SCP is taking position in stratosphere, so 2 SCP can be used alternately in many times	After termination of life span high orbits satellite cannot be landed, but can be transferred to the satellite graveyard, while satellites using lower orbits may be put on re-entry course to burn before reach the Earth surface
Cost Effectiveness	Cheap construction of CSP, very cost effective maintenance and reparation, simple payload, and because doesn’t need launch mechanism can be used repeatedly	Expensive satellite bus, what depends on the satellite type, not possible any maintenance, but can be provided TT&C from the ground and satellite needs launching system to be put into adequate orbit

The SCP infrastructures, whether airship or aircraft, have many unique attributes enabling them to offer a broad array of services at low cost. The inexpensive SCP systems provide flexibility, reliability, enhanced capabilities and the lowest cost wireless infrastructure per subscriber. Using several SCP stations, it is possible to provide local or regional coverage, which can be enlarged with inter-platform and satellite links. Owing to high cost of satellite systems, the SCP networks are the best and very cost effective solutions for further development as a backbone to the Cellular and Terrestrial networks.

7.4. Results and Summery of Improvements of R-AIS Equipment

The R-AIS system onboard ships need improvements of VHF antenna in the way to be used for both R-AIS and S-AIS communications. In addition, to improve reliability, coverage and effectiveness of S-AIS system will be necessary to provide S-AIS via L/C-band using GEO and Big LEO satellite constellations.

7.4.1. Comparison of Whip VHF versus QHA Antenna for R-AIS System

Current R-AIS intership communication system and ships with shore base stations uses VHF whip antenna with gain of 3 dB. The detail analyzes and derivations of problem in the R-AIS radio communication with using of whip VHF antenna are provided in Chapter 6. The main disadvantages of utilizing whip VHF antenna for the R-AIS systems are as follows:
1. The whip VHF antenna is able to provide radiation of EM waves with linear polarization, which lead to unstable communication at sea during pitching and rolling of ships.
2. The whip VHF antenna has such radiation pattern which provides concentration of radiated energy along horizon, what depends on antenna gain. Mainly this antenna radiation pattern is not suitable for satellite transmissions, because it does not provide have vertical radiation of energy, only horizontal. In order to provide reliable radio communication ship to ship with whip VHF antenna can be used only with low gain, otherwise high antenna gain lead to bigger concentration of radiate energy and in case of pitching and rolling losing of radio communication is occurred.
All above radio communication problems with whip VHF antenna can be solved by QHA antenna. The benefits of the QHA antenna to S-AIS system are as follows:
1. Circular polarization (no effect on quality of the radio communication from pitching and rolling of ship);
2. Semicircle directivity of radiation patter (Such shape of radiation pattern can provide simultaneous radio communication between: ship to ship, ship-to-shore and ship-to-satellite).
In order to provide experimental test of the QHA antennas, that antenna has been implemented. The QHA antenna is an antenna of resonant type, due to length of its arms equal to quarter of wavelength, what makes if highly adoptive for impedance matching.
The result of directivity measuring showed that the antenna is reliable and reasonable for satellite communication with ORBCOMM satellite constellation and with nearby ships as standard whip antenna without any extra applications.
The disadvantages of the tested and assembled QHA antenna for utilizing on board of a ship are following:
a) The considerably bigger physical size of the QHA antenna in contrast to the whip antenna requires special mounting equipment to mount it on board of a ship;
b) Due to construction features of the QHA antenna, it should be made out of special materials, which can reduce vibration of the antenna arms;

7.4.2. Benefits of Deployment R-AIS and S-AIS Networks through L/C-band

The R-AIS and S-AIS communication system currently use VHF-band. This frequency band requires deployment of considerable antenna size due to appropriately long wavelength in contrast to size of antennas for communication in microwave band. Second negative aspect of using VHF-band is a weak spectrum of signal, which can be declined easily by some others electromagnetic distortions. Also VHF signal spectrum contains self-noise which can make interference of caring time slots in R-AIS channels.
Proposed solutions for deployment an L/C- band converter gives follow benefits:
1. Safety transmitting AIS time slots;
2. It makes possibility to use smaller antenna size; and
3. Utilizing of L/C-band gives possibility to communicate with GEO and LEO satellites.

7.5. Experiment Analyze of Tracking and Detecting Equipment

Selected tracking equipment such as “Quake Pro”, which can work with Orbcomm, Iridium or Inmarsat satellite constellations has been used for experimental tracking of boat in Durban harbor. This tracking device is very flexible in settings and operations, whereby can provide quiet cheap service dependently on transmitting data rate via GPRS as well. This tracking terminal has been used for controlling entering and outgoing of boat in certain security zones, which were set up optionally for experiment. The tracking terminal gave exact report about occurred events with extra information of installed sensors of stirring gear, engine load, fuel expenditure.
Result of experiment shows that such simple in installation and operation equipment can be used in all around SA costal line for fishing ships and other small boats. If the tracking terminal is being exploited close to land where there are cellar towels, then data transmission can be occurred through them, this reduce cost for data traffic transmission.

7.5.1. Recommendation for Future Satellite Coverages

Every tracking and detecting systems are capable to provide quality services and some other solutions, but for the following reasons are still insufficient to satisfy all requirements:
1. Quality of oceans coverage for maritime and aeronautical applications;
2. Quality of land coverage for road and rail applications;
3. Quality of Earth’s poles coverages;
4. More cost effective services; and
5. Applicability of tracking and detecting tools under different operation conditions.

For instance, Inmarsat as professional operator has near-global coverage up to 80^0 North and South, but doesn’t have coverage on the Earth’s poles. Cause of it operation of Inmarsat can be combined with other hybrid satellite orbits introduced in Chapter 3. Iridium operator is providing only full global coverage including both poles, because of their inter-satellite links. Same tracking and detecting solutions can be applied for Globalstar and Orbcomm system, which have quality coverage of land masses, except some areas of African continent, but the oceans coverage is still not enough realized. Therefore, because Globalstar and Orbcomm are not providing ocean coverages, they need additional ground infrastructures.

7.5.2. Outputs for Future Research and Developments

The future developments of tracking and detecting systems and networks need new research and efforts for their improvements and integration with new solutions. In addition, these systems also need more reliable and cost effective radio, satellite and platform networks.
For instance, satellite and platform network are providing more reliable and secure service, but radio systems are providing more cost effective service. However, radio systems and networks are providing limited coverages and not enough reliable service during very bad weather condition. Thus, the best solution in the future is to provide integration of radio and satellite or platform infrastructures, such as R-AIS, P-AIS and S-AIS networks.
On the other hand, new deployments of SCP will be more cost effective and reliable for any of tracking and detecting systems, then LEO or GEO instead, because SCP are more near to Earth surface, they don’t need launching systems and can be landed for maintenance.
The future research and developments has to be concentrated on new development in SCP and UAV infrastructures and networks for tracking, detecting and CNS systems. At fist has to bi provided design and experiments with smaller size of airships or aircraft for all type of systems introduced in Chapter 5. In the next stage of developments will be necessary to provide further research for design and deploying of real size SCP airship for all tracking and detecting solutions.

Finally, to provide real global coverages will be necessary to provide development of multi purpose GEO, LEO and Nano satellite constellations for integration of tracking, detecting and CNS applications and solutions.

7.6. Additional Software and Firmware for CNS Systems

In previous Chapter 4 and 5 are introduced some kind of software for tracking and detecting systems. Here will be presented some additional software for R-AIS, Lidar and SSAR.

7.6.1. Software for R-AIS Systems

1. The SeaPro Software - New IMO requirements provides compulsory for merchant ships to carry an R-AIS transponder, which has to transmit the vessel position, ID and other data. The SeaPro software provides possibility that R-AIS will be able to visualize received R-AIS information on the chart. Therefore, information from other R-AIS equipped vessels can be displayed on the chart much like radar screen that also includes an extra level of confidence to navigation and for collision avoidance. This solution is an ideal as a standalone system for ships fitted with ECDIS systems that want visual R-AIS data without compromising ECDIS approval status. As stated in Chapter 4, an Electronic Chart Display and Information System (ECDIS) is a computer-based maritime navigation information system that complies with IMO regulations and can be used as an alternative to paper nautical charts onboard ships.
2. Ship Plotter Software for R-AIS - Ship Plotter displays complete information about ships that are within VHF range of their position using the universal R-AIS. As a part of the Global Maritime Safety System, R-AIS provides communication of ships positions to each other. As stated earlier, from December 2004, all ships over 300 tons must carry an R-AIS system to broadcast information about the ship to any suitably equipped receiver.
The R-AIS radio network uses very short bursts of high speed data on two VHF channels in the marine band. The two frequencies used are 161.975 (Marine Ch 87 R-AIS) and 162.025 (Ch 88 R-AIS) MHz. Ships broadcast their identity, position, course, speed and destination so that other ships can take account of their movements. Using a low cost radio scanner tuned to one or other of these channels and Ship Plotter software running on PC, operator will be able to see a radar-like real-time map (below) of all the large ships maneuvering in ships area together with information about their destination, Estimated Time of Arrival (ETA) and even the dimensions of each vessel. Ship Plotter decodes the R-AIS digital signals from each ship using the sound card in ship's PC. The system needs a suitable VHF-band radio receiver tuned to one of the two R-AIS channels.
The suitable program of R-AIS decodes the received digital data and displays it in a variety of the following formats: Signal mode, Message mode, Chart mode, Ship details, Message log, Radar view, Serial input, GPS input, Message sharing, Local sharing, Multiple sound card support, Automatic chart selection, Automatic chart downloading, Multi map support, Memory map support, Waypoint/track/route overlays, Peer-to-peer sharing, TCP/IP client, TCP/IP server, Google Earth server, HTTP server, Language versions, Route window, Navigation window, SMS Alerts and NV (navigation) charts.

7.6.2. Lidar Software

The Lidar solutions can use many types of software, such as follows:
1. QuikGrid – This is a free Windows program that can quickly turn millions of x, y, and z points into a grid and contour plot. The DXF file export is supported for import into OCAD or other programs. This program can handle huge amount of data and provide fast date processing of the contour. Can also be achieved a view of the data density by overlaying the points themselves on the contours made out of them.

2. Global Mapper – This program allows mapping and is built-in to support downloads of certain topos (USGS) and aerial photos overlaid immediately on (or under) the Lidar data. This demo program is also available free and can generate contours, has DXF export, and many data of inter-conversion utilities.
3. QT Modeler – This is very convenient Windows/PC program designed for very fast visualization of large datasets like Lidar data. In fact, this software is easy to use, powerful and numerous built-in algorithms.

7.6.3. Software for SSAR Solutions

7.6.3.1. Analyze of SSAR Simulation Toolbox

Satellite Synthetic Aperture Radar Simulation Toolbox (SSAR Simulation Toolbox) provides radar scientists and engineers with a powerful suite of tools for analyzing the performance of SSAR imaging systems. Using this SSAR Simulation Toolbox, the radar data collection and SSAR image formation process may be modeled from end-to-end, namely from the simulation of raw radar data sets, through motion compensation and SSAR image formation processing, to the analysis of the quality of the resulting images.
Purchase of the SSAR Toolbox includes a comprehensive course in Synthetic Aperture Imaging theory and training in the use of the Toolbox software. The SSAR scientists are available to provide timely assistance throughout a customer's SSAR development program from the initial definition of requirements to the final qualification of the completed system.
With each delivery, additional capabilities such as new imaging algorithms have been added to the product according to customer requirements. This tool offers competitive rates for the implementation of additional imaging modes and algorithms in order to meet specific and suitable customer's requirements.

7.6.3.2. Analyze of SSAR Software

In recent years, the usage of Satellite Synthetic Aperture Radar (SSAR) data became more and more popular tool and is used in many scientific fields implementing several new and promising algorithms. However, the remote sensing type of software like Erdas Image or Environment for Visualizing Images (ENVI) are including only some basic and very well established SSAR functionality.
The ENVI software combines advanced spectral image processing and proven geospatial analysis technology with a modern, user-friendly interface. Whether you use panchromatic, Lidar, SSAR, multispectral or hyper-spectral imagery, ENVI has the latest processing and analysis tools to help you extract meaningful information to make better decisions.
Advanced algorithms for SSAR often have to be implemented by system developer with the consequence that in many cases they are almost exclusively used by respective developer as free software suite, such as RAT (Radar Tools): Polarimetry SSAR (PolSAR), Interferometry (InSAR) and Polarimetric Interferometry (PolInSAR) and more,
The main motivation RAT mode is to offer some kind of experimental platform for advanced SSAR image processing. This can be achieved by providing software with basic SSAR data handling functionality, like data import and export, and SSAR specific preprocessing and display functions as well. The programming interface of RAT is kept simple and adding new functionality is quite easy. Function templates and a step-by-step description of how to program a RAT module is included in the distribution. In this way, everybody who is interested might use RAT as framework for his own, possibly experimental developments. In addition, RAT can be used to for better promotion of own algorithms to the public. Even smaller developments, made for example in the frame of diploma thesis, can be implemented as a RAT module and easily distributed to a wider audience.

The second motivation of this software package is a better distribution of modern SSAR algorithms to the base of non expert users. Application oriented research laboratories are in many cases dependent on the limited offerings of commercial software packages. The complex multi dimensional SSAR data is often found to be hard to handle by non-SSAR experts. RAT tries to simplify the handling of such data by simple menu-driven functions and a visual feedback of all functions on the screen. This can allow non-experts to benefit from RAT and from SSAR data as well. In general RAT can be downloaded and used free of charge as open-source software. This means that its complete source-code is available to everybody who is interested about. The source code can be modified, corrected and even used for other projects. However, it is important to note that RAT mode is not a professional development kit. It is generally seen as an experimental project, so there will be always bugs and wrong or not working modules and no guarantee can be given for any of its functions.

7.7. Conclusion

In this thesis are proposed and introduced the following projects:
1. Four anti piracy solutions;
2. Two tracking systems: Global via satellite and Regional via SCP networks;
3. Improved communications of R-AIS tracking equipment and antenna system;
3. Proposed applications of tracking devises with utilizing of SCP, so with few airships can be covered entire coastal lines in South Africa;
4. Two OTH radars will be able to cover South African coastal waters; and
5. Few solutions for tracking and detecting of ships via GNSS and CNS networks.

In today’s information age, where data travels faster than a rocket, terrorism of pirates in territorial sea has been trans-nationalized and suppressed by exploiting many new CNS commercially available-off-the-shelf technologies like GPS/Satellite Transceivers, R-AIS and S-AIS, Radar Systems, Satellite Maps/Charts/Picture and Internet application like social networking, etc. It is now the turn of the counterterrorism SAR and security forces to utilize the speed of information to counter strategy and actions against terrorists. Tomorrow, there could still be more solutions articulating better ways to counter the threat of pirates, but the solutions proposed by this thesis can eliminate pirates activities in the future. In addition, to improve effects of anti-pirates actions it will be necessary to eliminating terrorist’s actions on land as well, especially in the countries where pirates are coming from.

On the other hand, the same technologies will help to improve tracking and detecting of ships during every day merchant operations, to enhance safety, security, collision avoidance and distress SAR operations to save lives at sea. Finally, it can be also summarized that proposed new technologies can provide enhanced transparency in large maritime space to determine icebergs floating freely in open sea and to detect oil spills of a liquid petroleum hydrocarbon into the environment of ocean and coastal waters.

LIST OF ACHRONIMS

AIS	Automatic Identification System
AMSS	Aeronautical Mobile Satellite Service
APR	Automatic Position Report
ARINC	Aeronautical Radio Incorporated
ARNSS	Aeronautical Radio Navigation Satellite Service
ASAS	African Satellite Augmentation System
ASP	Application Service Provider
ATC	Air Traffic Control
CCD	Charge Coupled Device
CDMA	Code Division Multiple Access
CES	Coast Earth Stations
CM	Central Microcontroller
CMGC	Coastal Movement Guidance and Control
CMRC	Convectional Maritime Radio Communications
CNS	Communication, Navigation and Surveillance
COG	Course *Over Ground*
COMINT	Communication Intelligence
CRS	Coastal Radio Station
CRT	Cathode Ray Tube
CCIR	Consultative Committee on International Radio
CSC	Common Signaling Channel
DCS	Digital Selective Call
DCU	Display Control Unit
DDC	Digital Down Converter
DDP	Data Distribution Plan
DF	Direction Finding
EC	European Commission
ECS	Electronic Charting System
EGNOS	European Geostationary Navigation Overlay System
EM	Electromagnetic
EOSS	Electro-Optical Space Surveillance
EPIRB	Emergency Position Indicating Radio Beacon
ESA	European Space Agency
FCC	Federal Communications Commission
FES	Fixed Earth Stations
FFT	*Fast Fourier Transform*
FSS	Fixed Satellite Service
GAGAN	Indian GPS/GLONASS and GEOS Augmented Navigation
GASDL	GNSS Augmentation SDL
GAVDL-B	GNSS Augmentation VDL-Broadcast
GCC	Gateway Control Centers
GCSS	Global Communication Satellite Systems
GEO	Geostationary Earth Orbit

GEO	Geostationary Earth Orbits
GIO	Geosynchronous Inclined Orbits
GLONASS	Global Navigation Satellite System
GMDDS	Global Maritime Distress and Safety System
GMDSS	Global Maritime Distress and Safety System
GMSC	Global Mobile Satellite Communications
GNSS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSAR	Ground Synthetic Aperture Radar
GSAS	Global Satellite Augmentation Systems
GST	Global Ship Tracking
GST	Global Ship Tracking
HAP	High Altitude Platforms
HEO	High Elliptical Orbit
HFSWR	High Frequency Surface Wave Radars
HSC	High Speed Craft
HSD	High Speed Data
HSS	Homeland Security System
Hz	Hertz
IDC	International Data Centre
IHO	International Hydrographic Organization
IMCO	Intergovernmental Maritime Consultative Organization
IMO	International Maritime Organization
Inmarsat	International Maritime Satellite
IRR q	International Routeing Rules
ISAR	Inverse Synthetic Aperture Radar
ISL	Inter-Satellite Link
ISPS	International Ship and Port Security
ITS	Intelligent Transportation Systems
ITU	International Telecommunications Union
ITU	International Telecommunications Union
LADAR	Laser Detection and Ranging
LCD	Liquid Crystal Display
LEO	Low Erath Orbit
LES	Land Erath Station
LGA	Low Gain Antenna
LIDAR	Light Detection and Ranging
LMSS	Land Mobile Satellite Service
LNA	Low Noise Amplifiers
LOS	Line-of-Sight
LPA	Log Periodic Antenna
LRA	Loop Receive Array
LRIT	Long Range Identification and Tracking

LRNSS	Land Radio Navigation Satellite Service
LVAS	Local VHF Augmentation System
MAROTS	Maritime Orbital Test Satellite
MCC	Master Control Center
MEO	Medium Earth Orbit
MES	Mobile Earth Stations
MES	Mobile Earth Stations
MLQ	Multi-Level Quantization
MMSC	Maritime Mobile Satellite Communications
MRNSS	Maritime Radio Navigation Satellite Service
MSAS	MTSAT Satellite-based Augmentation System
MSC	Mobile Satellite Communications
MSI	Maritime Safety Information
MSS	Mobile Satellite Systems
MSUA	Mobile Satellite Users Association
NCC	Network Control Centres
NCC	Network Control Centres
NCS	Network Coordination Station
NCS	Network Coordination Stations
OSGC	Oceanic Sailing Guidance and Control
OTDM	Optical Time Division Multiplexing
OTHR	Over the Horizon Radars
OTS	Orbital Test Satellite
PCI	Peripheral Component Interconnect
PEO	Polar Earth Orbit
PES	Personal Earth Stations
PLB	Personal Locator Beacon
PMSS	Personal Mobile Satellite Service
PVT	Position, Velocity and Time
QHA	Quadrifilar Helical Antenna
R&D	Research and Development
RADAR	Radio Detection and Ranging
RADS-B	Radio Automatic Dependent Surveillance - Broadcast
R-AIS	Radio Automatic Identification System
RCC	Rescue Coordination Centre
RDF	Radio Direction Finder
RDSS	Radio Determination Satellite System
RF	Radio Frequency
RR	Radio Regulations
RSAS	Regional Satellite Augmentation Systems
RW	Radiowaves
Rx	Receiver
SADS-B	Satellite Automatic Dependent Surveillance - Broadcast
SADS-B	Satellite Automatic Dependent Surveillance - Broadcast
S-AIS	Satellite AIS

SAR	Search and Rescue
SAS	*Statistical Analysis System*
SATFM	Satellite Asset Tracking and Fleet Management
SBAS	Satellite Based Augmentation System
SBM	Short Burst Messages
SCC	Satellite Control Centre
SCP	Stratospheric Communication Platforms
SCU	Subscriber Communication Units
SDCM	Russian System of Differential Correction and Monitoring
SDL	Satellite Data Link
SDL	Satellite Data Link
SES	Ship Earth Station
SOG	*Speed Over Ground*
SOLAS	Safety of Life at Sea
SRS	Ship Radio Station
SSAR	Satellite Synthetic Aperture Radar
SSAR	Space Synthetic Aperture Radar
STC	Ship Traffic Control
STW	Speed Through the Water
TCC	Tracking Control Centre
TCU	Terminal Control Unit
TDM/TDMA	Time Division Multiple/TDM Access
TES	Transportable Earth Stations
TT&C	Satellite Tracking, Telemetry and Command
TTN	Terrestrial Telecommunication Network
TTN	Terrestrial Telecommunications Network
TTN	Terrestrial Telecommunication Network
TTP	Transitional Telecommunication Project
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
UT	Universal Time
UTIAS/SFL	Aerospace Studies/Space Flight Laboratory
VDL	VHF Data Link
VES	Vehicle Earth Station
VRM	Variable Range Marker
VRS	Vehicle Radio Stations
WAAS	Wide Area Augmentation System
WMO	World Meteorological Organization

LIST OF REFERENCES

Aguilar, M., Saldaña, M. and Aguilar, F. 2013. GeoEye-1 and WorldView-2 pan-sharpened imagery for object-based classification in urban environments. *International Journal of Remote Sensing*, 34 (7): 2583-2606.

AIRBUS. 2014. *Defence and Space* Available: http://www.astrium-geo.com/na/4533-maritime-monitoring (Accessed 2014).

Ali Mirkamali, L. A., Keyghobad, K. and Soleimani, M. 2003. A novel quadrifilar helix antenna for use in LEO satellite communications.

Alizadeh-Shabdiz, F. 2009. *Method and system for determining location using a hybrid satellite and wlan positioning system by selecting the best wlan-ps solution*. Google Patents.

Alper, J. and Pelton, J. N. 1984. The Intelsat global satellite system. *Progress in Astronautics and Aeronautics*, 93.

Anderson, S. 1986. Remote sensing with the JINDALEE skywave radar. *Oceanic Engineering, IEEE Journal of*, 11 (2): 158-163.

Anderson, S. J. 2013. Optimizing HF Radar Siting for surveillance and remote sensing in the strait of Malacca. *Geoscience and Remote Sensing, IEEE Transactions on*, 51 (3): 1805-1816.

Bahar, M. 2007. Attaining Optimal Deterrence at Sea: A Legal and Strategic Theory for Naval Anti-Piracy Operations. *Vanderbilt Journal of Transnational Law*, 40 (1).

Balkin, R. 2006. International Maritime Organization and Maritime Security, The. *Tul. Mar. LJ*, 30: 1.

Barnard. 2014. *Microsystem*. Available: http://www.barnardmicrosystems.com/index.html (Accessed

BBB. 2014. *SAN-LO AERIAL SURVEYS*.

Bekiashev, K. A. and Serebriakov, V. V. 1981a. International Hydrographic Organization (IHO). In: *International Marine Organizations.* Springer, 478-485.

Bekiashev, K. A. and Serebriakov, V. V. 1981b. World Meteorological Organization (WMO). In: *International Marine Organizations.* Springer, 540-552.

Bendisch. 2014. *Barbard Microsystems* Available: http://www.barnardmicrosystems.com/index.html (Accessed

Berzins, G., Phillips, R., Singh, J. and Wood, P. 1989. Inmarsat-Worldwide mobile satellite services on seas, in air and on land. In: Proceedings of *Malaga International Astronautical Federation Congress.*

Blasch, E., Ling, H., Wu, Y., Seetharaman, G., Talbert, M., Bai, L. and Chen, G. 2012. Dismount tracking and identification from electro-optical imagery. In: Proceedings of *SPIE*

Defense, Security, and Sensing. International Society for Optics and Photonics, 84020H-84020H-84010

Bole, A. G., Dineley, W. and Wall, A. D. 2013. *Radar and ARPA Manual: Radar, AIS and Target Tracking for Marine Radar Users*. Butterworth-Heinemann.

Bonnet, R.-M. and Manno, V. 1994. *International cooperation in space: The example of the European Space Agency*. Harvard University Press.

Bradbury, L. M. 2011. Systems Development, Assembly and Testing, and Mission Operations for Nanosatellites in the CanX Program.

Cairns, W. R. 2005. AIS and long range identification & tracking. *Journal of Navigation*, 58 (02): 181-189.

Calcutt, D. and Tetley, L. 1994. *Satellite communications: Principles and applications*. Elsevier.

Cameron, A. 1995. The Jindalee operational radar network: its architecture and surveillance capability. In: Proceedings of *Radar Conference, 1995., Record of the IEEE 1995 International.* IEEE, 692-697

Cervera, M. A., Ginesi, A. and Eckstein, K. 2011. Satellite-based vessel Automatic Identification System: A feasibility and performance analysis. *International Journal of Satellite Communications and Networking*, 29 (2): 117-142.

Chobotov, V. A. 2002. *Orbital mechanics*. Aiaa.

Claramunt, C., Leroux, Y., Garello, R., Landrac, G., Vallee, F. and Ping, Y. 2006. MITS for safer seas. In: Proceedings of *ITS Telecommunications Proceedings, 2006 6th International Conference on.* IEEE, 65-69

Colorado, U. o. 2014. *Aerial Photography and Remote Sensing*. Available: http://www.colorado.edu/geography/gcraft/notes/remote/remote_ftoc.html (Accessed

COMPASS, S. and First, R. M. 1991. Operator's Manual. *Clear With Computers*.

Connolly, A., Szalay, A., Dickinson, M., Subbarao, M. and Brunner, R. 1997. The Evolution of the global star formation history as measured from the Hubble deep field. *The Astrophysical Journal Letters*, 486 (1): L11.

Cook, C. 2012. *Radar signals: An introduction to theory and application*. Elsevier.

COUNCIL, A. 2010. INTERNATIONAL AMATEUR RADIO UNION.

Coverdale, D. R. 1995. *Potential Applications of the ORBCOMM Global Messaging System to US Military Operations*. DTIC Document.

Curlander, J. C. and McDonough, R. N. 1991. *Synthetic aperture radar*. Wiley New York.

Dabrowska-Zielinska, K., Tomaszewska, M., Budzynska, M., Rychlik, S., Malek, I., Bartold, M., Gatkowska, M., Malinska, A. and Turlej, K. 2013. Institute of Geodesy and Cartography, Remote Sensing Department, Modzelewskiego 27, 02-679 Warszawa; Poland. In: Proceedings of *Geoscience and Remote Sensing Symposium (IGARSS), 2013 IEEE International.* IEEE, 1749-1751

Del Re, E., Ronga, L. S. and Piercucci, L. 2002. Trends in satellite communications. In: Proceedings of *Communications, 2002. ICC 2002. IEEE International Conference on.* IEEE, 2983-2988

DIMOV, S. I. Global Mobile Satellite Communications.

Djuknic, G. M., Freidenfelds, J. and Okunev, Y. 1997. Establishing wireless communications services via high-altitude aeronautical platforms: a concept whose time has come? *Communications Magazine, IEEE*, 35 (9): 128-135.

Dondl, P. 1984. LOOPUS opens a new dimension in satellite communications. *International Journal of Satellite Communications*, 2 (4): 241-250.

Dong-qing, W., Jiu-nu, L. and Zhe-lin, L. 2005. Realization and research on ship remote sensing monitorand communication system based on Inmarsat D+[J]. *Computer Applications*, 2.

Downing, J. 1985. The Intersputnik system and Soviet television. *Europe‐Asia Studies*, 37 (4): 465-483.

Doyle, S. E. 1977. INMARSAT: The International Maritime Satellite Organization-Origins and Structure. *J. Space L.*, 5: 45.

Elbert, B. R. 2004. *The satellite communication applications handbook*. Artech house.

Elbrecht, A., Dech, S. and Gottscheber, A. 2011. 1U CubeSat design for increased power generation. In: Proceedings of *Proceedings of the 1st IAA Conference on University Satellite Missions.* 1-7

ELECTRONICS, K. 2014. *Marine Electronic FInder*. Available: http://www.koden-electronics.co.jp/eng/marine/directionfinder/index.html (Accessed

EO. 2014. *Sharing Earth Observation Resources* Available: http://news.eoportal.org/ (Accessed

Eriksson, M. and Lundmark, J. 2002. Technical Verification and Validation of ADS-B/VDL Mode 4 for A-SMGCS.

ESA. 2014. *Earth Online*. Available: http://earth.esa.int/applications/data_util/SARDOCS/spaceborne/Radar_Courses/Radar_Course_II/synthetic_aperture_radar_SAR.htm (Accessed

Esper, J., Panetta, P. V., Ryschkewitsch, M., Wiscombe, W. and Neeck, S. 2000. NASA-GSFC nano-satellite technology for earth science missions. *Acta Astronautica*, 46 (2): 287-296.

Essen, H.-H., Gurgel, K.-W. and Schlick, T. 2000. On the accuracy of current measurements by means of HF radar. *Oceanic Engineering, IEEE Journal of*, 25 (4): 472-480.

Evans, B. G. 1999. *Satellite communication systems*. Iet.

Fenech, H., Pujante-Cuadrupani, A. and Lance, E. 2001. EUTELSAT multimedia satellites. *Space communications*, 17 (1): 145-164.

Forssell, B. 2008. Radionavigation systems.

Fossa, C. E., Raines, R. A., Gunsch, G. H. and Temple, M. A. 1998. An overview of the IRIDIUM (R) low Earth orbit (LEO) satellite system. In: Proceedings of *Aerospace and Electronics Conference, 1998. NAECON 1998. Proceedings of the IEEE 1998 National.* IEEE, 152-159

Gallagher, B. 1989. *Never Beyond Reach: The World of Mobile Satellite Communications*. International Maritime Satellite Organization.

Gavan, J. and Peled, A. 1991. Optimized LADAR/RADAR system for detection and tracking. *International journal of infrared and millimeter waves*, 12 (10): 1143-1150.

Gething, P. J. 1991. *Radio direction finding and superresolution*. IET.

Geudtner, D. and Séguin, G. Application Potentials of the planned RADARSAT Constellation.

Giri, C., Ochieng, E., Tieszen, L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20 (1): 154-159.

GLOBALSTAR. 2014. *GLOBALSTAR*. Available: http://www.globalstar.com/ (Accessed

Grajal, J., Asensio, A. and Requejo, L. 2004. From a high-resolution LFM-CW shipborne radar to an airport surface detection equipment. In: Proceedings of *Radar Conference, 2004. Proceedings of the IEEE.* IEEE, 157-160

Grewal, I. and Kaplan, C. 1994. Introduction. *Scattered hegemonies: Postmodernity and transnational feminist practices*: 1-33.

Grewal, M. S., Weill, L. R. and Andrews, A. P. 2007. *Global positioning systems, inertial navigation, and integration*. John Wiley & Sons.

Gunawardena, S. and Rankin, J. M. 2001. Controller-pilot communications using a VDL Mode 2 datalink for the NASA runway incursion prevention system. In: Proceedings of *Digital Avionics Systems, 2001. DASC. 20th Conference.* IEEE, 2D4/1-2D4/12 vol. 11

Gupta, O. P. 2011. Global augmentation of ADS-B using Iridium NEXT hosted payloads. In: Proceedings of *Integrated Communications, Navigation and Surveilance Conference (ICNS), 2011.* IEEE, 1-15

Gurgel, K., Essen, H. and Schlick, T. 2001. The University of Hamburg WERA HF radar–theory and solutions. In: Proceedings of *Proc. of the 1st International Radiowave Oceanography Workshop ROW-2001, Oregon, USA.* 19-25

Gustavsson, N. 1996. VDL Mode 4/STDMA-a CNS data link. In: Proceedings of *Digital Avionics Systems Conference, 1996., 15th AIAA/IEEE.* IEEE, 111-116

Harati-Mokhtari, A., Wall, A., Brooks, P. and Wang, J. 2007. Automatic Identification System (AIS): data reliability and human error implications. *Journal of Navigation*, 60 (03): 373-389.

Heiser, W. H. and Pratt, D. T. 1994. *Hypersonic airbreathing propulsion*. AIAA.

Hodgins, D. O. 1994. Remote sensing of ocean surface currents with the SeaSonde HF radar. *Spill Science & Technology Bulletin*, 1 (2): 109-129.

Hofmann-Wellenhof, B., Lichtenegger, H. and Wasle, E. 2007. *GNSS–global navigation satellite systems: GPS, GLONASS, Galileo, and more*. Springer.

Holsten, S. 2009. Global maritime surveillance with satellite-based AIS. In: Proceedings of *OCEANS 2009-EUROPE.* IEEE, 1-4

Horstmann, J., Grasso, R., Coffin, M., Gurgel, K. and Schlick, T. 2010. Evaluation of an HF-radar Ship Detection Algorithm by Comparison to AIS and SAR data. In: Proceedings of *IEEE IGARSS Conference, Honolulu, Hawaii.*

Horwath, J., Knapek, M., Epple, B., Brechtelsbauer, M. and Wilkerson, B. 2006. Broadband backhaul communication for stratospheric platforms: the stratospheric optical payload experiment (STROPEX). In: Proceedings of *SPIE Optics+ Photonics.* International Society for Optics and Photonics, 63041N-63041N-63012

Hou, J., Sun, X. and Yang, H. 2011. Design of a high gain quadrifilar helix antenna for satellite mobile communication. In: Proceedings of *Microwave Conference Proceedings (CJMW), 2011 China-Japan Joint.* IEEE, 1-3

Høye, G. K., Eriksen, T., Meland, B. J. and Narheim, B. T. 2008. Space-based AIS for global maritime traffic monitoring. *Acta Astronautica*, 62 (2): 240-245.

HUGHES, K. 2014. *Marine systems*. Available: http://www.kelvinhughes.com/marine/home (Accessed

IAI. 2014. *ISRAEL AEROSPACE INDUSTRIES.* Available: http://www.iai.co.il/2013/14467-40072-en/IAI.aspx (Accessed

Icev, S. 2011. Time division multiple access (TDMA) applicable for mobile satellite communications. In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2011 21th International Crimean Conference.* IEEE, 365-367

Ilcev, D. 2013a. Development and characteristics of African Satellite Augmentation System (ASAS) network. *Telecommunication Systems*, 52 (1): 121-137.

Ilcev, D. and Moyo, S. 2011. European Geostationary Navigation Overlay Service (EGNOS). In: Proceedings of *IST-Africa Conference Proceedings, 2011.* IEEE, 1-14

Ilcev, S. 2010a. Hybrid satellite orbits (HSO) for global coverage. In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2010 20th International Crimean Conference.* IEEE, 404-405

Ilcev, S. 2010b. Low Earth Orbits (LEO). In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2010 20th International Crimean Conference.* IEEE, 406-408

Ilcev, S. 2010c. Maritime Communication, Navigation and Surveillance (CNS). *DUT, Durban*.

Ilcev, S. 2010d. Medium and High Altitude Orbits. In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2010 20th International Crimean Conference.* IEEE, 409-412

Ilcev, S. 2010e. Polar Earth Orbits (PEO). In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2010 20th International Crimean Conference.* IEEE, 413-415

Ilcev, S. 2013b. Development of Cospas-Sarsat Satellite Distress and Safety Systems (SDSS) for Maritime and Other Mobile Applications. *Marine Navigation and Safety of Sea Transportation: Navigational Problems*: 269.

Ilcev, S. D. 2005a. *Global Mobile Satellite Communications: For Maritime, Land and Aeronautical Applications*. Springer.

Ilcev, S. D. 2005b. Global Stratospheric Platform Systems (GSPS). *Global Mobile Satellite Communications: For Maritime, Land and Aeronautical Applications*: 441-460.

Ilcev, S. D. 2011. Stratospheric communication platforms as an alternative for space program. *Aircraft Engineering and Aerospace Technology: An International Journal*, 83 (2): 105-111.

Ilcev, S. D. and Singh, A. 2004. Development of stratospheric communication platforms (SCP) for rural applications. In: Proceedings of *AFRICON, 2004. 7th AFRICON Conference in Africa.* IEEE, 233-238

Imagery, U. S. N. and Agency, M. 1994. *Radar Navigation Manual*. National Imagery and Mapping Agency.

INTERTANKO, I. 2009. *The East Africa/Somalia Situation*
Practical Measures to Avoid, Deter or Delay
Piracy Attacks. Available: http://www.isr-sensing.com (Accessed

Ippolito, L. J., Kaul, R. and Wallace, R. 1981. *Propagation effects handbook for satellite systems design*. National Aeronautics and Space Administration.

IRIDIUM. 2014. *IRIDIUM everywhere*. Available: http://www.iridium.com/default.aspx (Accessed

ISR. 2014. *Radar System and Analysis Tools for Measuring of Oceanic Surface Properties*. Available: http://www.isr-sensing.com/ (Accessed

J. Bendisch, H. H., T. Wieneke, H.-G. Niemöller. 2014. AIRMISSION - AN AIRBORNE SYSTEM FOR MARITIME SURVEILLANCE.

Jackson, C. R. and Apel, J. R. 2004. *Synthetic aperture radar marine user's manual*. US Department of Commerce.

Johnson, B. 1999. English in the Global Maritime Distress and Safety System. *World Englishes*, 18 (2): 145-157.

Jones, D., Wang, J. and Lewis, J. 2013. All-Terrain Network Service Robot Based on Tekkostu Framework. In: Proceedings of *The Twenty-Sixth International FLAIRS Conference.*

JORTON. 2014. *JORTON*. Available: http://www.jotron.com/ (Accessed

JOURN. 2010. *Fact Sheet Jindalee Operational Radar Network.* Australia Australian Air Forces.

Juszkiewicz, W., Muczyński, B., Gucma, M. and Bilewski, M. 2013. Functionality of navigation systems interfaces in the integrated interactive simulator for inland ship navigation. *Scientific Journals Maritime University of Szczecin, Zeszyty Naukowe Akademia Morska w Szczecinie*.

Kaul, A. 1978. Performance of High-level Data Link Control in satellite communications. *COMSAT Technical Review*, 8: 41-87.

KDDI. 2014. *Designing the future*. Available: http://www.kddi.com/english (Accessed

Kechichian, J. A. 1997. Optimal low-earth-orbit-geostationary-earth-orbit intermediate acceleration orbit transfer. *Journal of guidance, control, and dynamics*, 20 (4): 803-811.

Kemmelpark. 2011. *User Manual Installation and operation RT-500-M*. GERMANY.

Kleynhans, W., Salmon, B., Schwegmann, C. and Seotlo, M. Ship detection in South African oceans using a combination of SAR and historic LRIT data. In: Proceedings of *IEEE International Geoscience and Remote Sensing Symposium.* 1-4

Knabe, A. S. 2012a. *Product Line Maritime Services.*

Knabe, S. 2012b. *Astrium GEO's Maritime Safety & Security Services in the Context of GMES.*

Knott, E. F. 2006. *Radar cross section measurements*. SciTech Publishing.

Konigorski, D., Gratzel, U., Obersteiner, M. and Schneidereit, M. *Stratospheric platforms for monitoring purposes.* IAEA-CN-184/35.

Kopacz, Z., Morgas, W. and Urbanski, J. 2001. The maritime safety system, its main components and elements. *The Journal of Navigation*, 54 (02): 199-211.

Kosmodemyansky, A. 2000. *Konstantin Tsiolkovsky his life and work*. The Minerva Group, Inc.

Krajewski, J. M. 2008. Out of Sight, out of Mind-A Case for Long Range Identification and Tracking of Vessels on the High Seas. *Naval L. Rev.*, 56: 219.

Krzysztofik, W. J. 2012. Radiation properties of quadrifilar-helix antenna-An analytical approach. In: Proceedings of *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE.* IEEE, 1-2

Lang, M., McCarty, G., Wilen, B. and Awl, J. Light Detection and Ranging.

Lcev, S. 2011. High-gain mobile satellite antennas. In: Proceedings of *Microwave and Telecommunication Technology (CriMiCo), 2011 21th International Crimean Conference.* IEEE, 996-998

Lee, H., Lee, S. and Lee, H. 2007. The Realization of the Performance Estimation System on AIS SOTDMA Algorithm. In: Proceedings of *Industrial Informatics, 2007 5th IEEE International Conference on.* IEEE, 405-410

Lee, W. C. 1982. *Mobile communications engineering*. McGraw-Hill Professional.

Leica. 2014. *Geosystem*. Available: http://www.leica-geosystems.com/ (Accessed

Levanon, N. 2000. *Passive position determination using two low-earth orbit satellites*. Google Patents.

Levesque, D. 1993. The COSPAS-SARSAT system. In: Proceedings of *Satellite Distress and Safety Systems, IEE Colloquium on.* IET, 3/1-3/4

Lh-Systems. 2014. *HugeDomains*. Available: http://www.hugedomains.com/domain_profile.cfm?d=lh-systems&e=com (Accessed

MacLean, D. 2007. *International Telecommunication Union (ITU)*.

Maine, K., Devieux, C. and Swan, P. 1995. Overview of IRIDIUM satellite network. In: Proceedings of *WESCON/'95. Conference record.'Microelectronics Communications Technology Producing Quality Products Mobile and Portable Power Emerging Technologies'.* IEEE, 483

Maral, G. and Bousquet, M. 2011. *Satellite communications systems: systems, techniques and technology*. John Wiley & Sons.

Marine, M. 2014. *Musson Marine*. Available: http://www.mussonmarine.com/ (Accessed

Martignoni, M. 2011. Land use and cover classification using airborne MASTER and spaceborne GeoEye-1 sensors: Focus on coffee-banana agroforestry systems near Turrialba, Costa Rica.

Mathapo, K. F. 2007. A software-defined radio implementation of maritime AIS. Stellenbosch: University of Stellenbosch.

MCMURDO. 2014. *MCMURDO*. Available: http://www.mcmurdomarine.com/ (Accessed

Meinecke, G., Ratmeyer, V. and Wefer, G. 1999. Bi-directional communication into the deep ocean based on ORBCOMM satellite transmission and acoustic underwater communication. In: Proceedings of *OCEANS'99 MTS/IEEE. Riding the Crest into the 21st Century.* IEEE, 1405-1409

Mishra, S., Smithson, J. and Charron, P. 2007. Characterization of Aeronautical Earth Station Antennas for Communication using INMARSAT Satellites. In: Proceedings of *Antennas and Propagation, 2007. EuCAP 2007. The Second European Conference on.* IET, 1-4

Miura, R. and Oodo, M. 2001. 3-2 Wireless Communications System Using Stratospheric Platforms 3-2-1 R&D Program on Telecom and Broadcasting System Using High Altitude Platform Stations. *Journal of the Communications Research Laboratory*, 48 (4).

Monahan, K. 2003. *The Radar Book: Effective Navigation and Collision Avoidance*. FineEdge.Com LLC.

Montenbruck, O. and Gill, E. 2000. *Satellite orbits*. Springer.

Mukherjee, P. K. and Brownrigg, M. 2013. Private Shipping Organisations. In: *Farthing on International Shipping.* Springer, 27-50.

Mullen, L. J., Vieira, A. J., Herezfeld, P. and Contarino, V. M. 1995. Application of RADAR technology to aerial LIDAR systems for enhancement of shallow underwater target detection. *Microwave Theory and Techniques, IEEE Transactions on*, 43 (9): 2370-2377.

Narheim, B., Olsen, O., Helleren, O., Olsen, R., Beattie, A. and Zee, R. 2008. A Norwegian Satellite for Space-based Observations of AIS in the High North.

Navigation, S.-H. *Sea-Hawk Radar SHN X9 and SHN X12.* Available: www.sea-hawk.com (Accessed

Newland, F., Coleshill, E., DSouza, I. and Cain, J. 2009. Nanosatellite Tracking of Ships—Review of the First Year of Operations. In: Proceedings of *Proc. AIAA 7th Responsive Space Conference, Los Angeles, USA.*

ORBCOMM. 2014. *ORBCOM*. Available: http://www.orbcomm.com/ (Accessed

Organization, I. M. and Internacional, O. M. 1999. *Navigation at the Operational Level: Radar Navigation, Radar Plotting and Use of ARPA*. International Maritime Organization.

Paloscia, S., Pampaloni, P., Pettinato, S., Brogioni, E., Fontanelli, G. and Macelloni, G. 2011. Potentials of X-band active and passive microwave sensors in monitoring vegetation biomass. In: Proceedings of *General Assembly and Scientific Symposium, 2011 XXXth URSI.* IEEE, 1-3

Parkinson, B. W. and Spilker, J. J. 1996. *Global Positioning System: part 1 GPS fundamentals, part 2 GPS performance and error effects; vol. 2, part 3 differential GPS and integrity monitoring, part 4 integrated navigation systems, part 5 GPS navigation applications, part 6 special applications*. Aiaa.

Paulsen, G. W. 1982. Historical Overview of the Development of Uniformity in International Maritime Law. *Tul. L. Rev.*, 57: 1065.

PLATH. 2014. *Sharping the future of intelligence*. Available: http://www.plath.de/ (Accessed

POPA, L. V. Maritime Piracy and Long Range Identification and Tracking.

Pranajaya, F. M., Zee, R. E., Cain, J. and Kolacz, R. NANOSATELLITE TRACKING SHIPS: COST-EFFECTIVE RESPONSIVE SPACE.

Prasad, R. and Ruggieri, M. 2005. *Applied satellite navigation using GPS, GALILEO, and augmentation systems*. Artech House.

Prosch, D.-I. R. 2007. Technical Handbook For Radio Monitoring I. *Quadrature*, 8: 37.

Radartutorial. 2014. *Radar Tutorial*. Available: http://www.radartutorial.eu/ (Accessed

Rappaport, T. S. 1996. *Wireless communications: principles and practice*. Prentice Hall PTR New Jersey.

RHOTHETA. 2014. *Radio Direction Finder and More*. Available: http://www.rhotheta.com/ (Accessed

Roarty, H. J., Rivera Lemus, E., Handel, E., Glenn, S. M., Barrick, D. E. and Isaacson, J. 2011. Performance evaluation of SeaSonde high-frequency radar for vessel detection. *Marine Technology Society Journal*, 45 (3): 14-24.

SAAB. 2014. *Defence and security* Available: http://www.saabgroup.com/#NewZealand (Accessed

SANGAM, S. Light Detection and Ranging.

SAT, R. 1998. *Ship Surveillance Using RADARSAT SAR.*

SCHWARZ, R. 2014. *Radar Finders*. Available: http://www.rohde-schwarz.com/en/home_48230.html (Accessed

Schwehr, K. D. and McGillivary, P. A. 2007. *Marine Ship Automatic Identification System (AIS) for enhanced coastal security capabilities: an oil spill tracking application*. IEEE.

SEASPACE. 2014. *Earth on Demand*. Available: http://www.seaspace.com/history.php (Accessed

Sector, R. International Telecommunication Union (ITU). *General Aspects of Digital Transmission Systems–Terminal Equipments. Pulse Code Modulation of Voice Frequencies. ITU-T Recommendation G*, 711.

Septiawan, R. 2004. Multiservice Traffic Allocation in LEO Satellite Communications. Bond University.

Shah, N. H., Proulx, R. J., Kantsiper, B., Cefola, P. J. and Draim, J. 1998. *Automated station-keeping for satellite constellations*. Springer.

Shu-Sen, T. 2008. Development and Thought of Compass Navigation Satellite System [J]. *Journal of Astronautics*, 2: 003.

Shuang, Z. and Junzhong, B. 2007. General introduction of the development of the ships' long range identification and tracking (LRIT) system [J]. *China Maritime Safety*, 2: 022.

Singh, J. P. 2013. Inmarsat's Worldwide Mobile Satellite Services: Today and Tomorrow. *Defence Science Journal*, 43 (1): 17-25.

Skolnik, M. I. 1962. Introduction to radar. *Radar Handbook*: 1990.

Skolnik, M. I. 1970. Radar handbook.

Skoryk, I. 2014. Implementation of modern ship tracking and detecting systems. In: CapeTown

Skoryk, I. and Ilcev, D. 2013. Overview of Radio and Satellite Tracking Solutions for Aeronautical Applications. In: Proceedings of *International Aerospace Symposium of South Africa 2013.* 23

SkyWave. 2014. *SkyWave*. Available: http://www.skywave.com/ (Accessed

Solari, G. and Viola, R. 1992. M-HEO-The optimal satellite system for the most highly-populated regions of the Northern Hemisphere. *ESA Bulletin*, 70: 81-88.

SOLAS, V. Marine Notice No. 30 of 2008 Long Range Identification and Tracking of Ships (LRIT).

Sonnenberg, G. J. 1988. *Radar and electronic navigation*. Butterworths London et al.

Swan, P. A. and Devieux Jr, C. L. 2003. *Global Mobile Satellite Systems: A Systems Overview*. Springer.

System, C. 2012. *Maritime and Aviation Solution*. Available: http://www.cns.se (Accessed

Sze, J. Y. and Ou, Y. H. 2007. Compact CPW-fed square aperture CP antenna for GPS and INMARSAT applications. *Microwave and Optical Technology Letters*, 49 (2): 427-430.

TAIYO. 2014. Marine FInder.

Tandler, J. 1996. Automating the Operations of the ORBCOMM Constellation.

Teller, N., Phillips, K., Paiusco, L. and Howard, C. 1988. The Standard C communication system. In: Proceedings of *Satellite Systems for Mobile Communications and Navigation, 1988., Fourth International Conference on.* IET, 43-46

Tetreault, B. 2005. Use of the Automatic Identification System (AIS) for maritime domain awareness (MDA). In: Proceedings of *OCEANS, 2005. Proceedings of MTS/IEEE.* IEEE, 1590-1594

Tribble, A. C. 2003. *The space environment: implications for spacecraft design (revised and expanded edition)*. Princeton University Press, Princeton.

Trizna, D. B. 2008. A bistatic HF radar for current mapping and robust ship tracking. In: Proceedings of *OCEANS 2008.* IEEE, 1-6

Turner, A. E. 2001. Molniya/Tundra orbit constellation considerations for commercial applications. In: Proceedings of *Proceeding of the 11 th Annual AAS/AIAA Space Flight Mechanics Meeting, Santa Barbara, CA.* 1603-1615

Viggh, H., Stokes, G., Shelly, F., Blythe, M. and Stuart, J. 1997. Applying electro-optical space surveillance technology to asteroid search and detection: The LINEAR program results. In: Proceedings of *PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON LASERS-SOCIETY FOR OPTICAL AND QUANTUM ELECTRONICS.* SOCIETY FOR OPTICAL AND QUANTUM ELECTRONICS, 914-927

Vinti, J. P. 1998. *Orbital and celestial mechanics*. Aiaa.

Wang, J., Rizos, C., Stewart, M. P. and Leick, A. 2001. GPS and GLONASS integration: modeling and ambiguity resolution issues. *GPS solutions*, 5 (1): 55-64.

WAWRUCH, R. 2008. Global ships monitoring system–basic requirements and principle of introducing.

Weber, L. 2000. *INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)*.

Wheadon, N., Whitehouse, J., Milsom, J. and Herring, R. 1994. Ionospheric modelling and target coordinate registration for HF sky-wave radars. In: Proceedings of *HF Radio Systems and Techniques, 1994., Sixth International Conference on.* IET, 258-266

Whitehouse, B. G. and Hutt, D. 2003. Ocean Intelligence in The Maritime Battlespace: The Role of Spaceborne Sensors and HF Radar>.

Wiedeman, R. A. and Viterbi, A. J. 1993. The Globalstar mobile satellite system for worldwide personal communications. In: Proceedings of *Proc. 3rd Int. Mobile Sat. Conf., IMSC.* 291-296

Wilson, D. 2008. *The Chesapeake Bay Interpretive Buoy System*. IEEE.

Wu, W. W., Miller, E. F., Pritchard, W. L. and Pickholtz, R. L. 1994. Mobile satellite communications. *Proceedings of the IEEE*, 82 (9): 1431-1448.

Yang, H., Yang, J., Li, Z., Wu, J., Huang, Y. and Teng, L. 2013. Near-space slow SAR high-resolution wide swath and sustained imaging technology. *EURASIP Journal on Wireless Communications and Networking*, 2013 (1): 1-8.