Airborne Satellite Navigation and Other Integrated Antenna Systems

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Abstract: This paper is introducing the airborne satellite navigation and other integrated antenna systems for both weather and special navigation systems. In general, most of navigation antennas are omnidirectional, small and easy to install onboard aircraft, such as Global Navigation Satellite Antennas (GNSA) and other integrated antenna systems. However, in particular, some new developments of navigation antennas are providing miniaturized Global Navigation Satellite System (GNSS) antenna array technologies that significantly reduce the size of the antenna elements and the array dimensions. The passive and active GNSA for mobile applications including aeronautical are presented, which include all existing types of GNSS solutions. The GNSS antennas are usually omnidirectional, so they don't need to be always pointed towards the satellite in spite of aircraft motions. In this paper are presented commercial aspects of the aircraft GNSS antenna technologies, their importance and integration with a digital beam-steering antenna electronics package. In addition, the solutions of different cost effective integrated antenna systems with GNSS antennas, such as airborne WAAS, XM, Weather, Sirius, ISL, DME, ADF, VOR, LOC, GS and other antenna systems are discussed.

Key Words: GNSA, GNSS, CRPA, FRPA, LAAS, RSAS, ISL, Navigation, Weather, Sirius

1. Introduction

Mobile satellite navigation provides autonomous geospatial positioning with global coverage. With the signal from the satellites, small GNSS receivers determine their location within a few meters using special omnidirectional satellite antennas. A mobile satellite navigation system with global coverage may be termed an GNSS. Core currently operational satellite navigation systems that use GNSA solutions are the US Global Position System (GPS) and the Russian GLONASS (Global Navigation Satellite System) The Chinese BeiDou-2, known as a Compass Navigation Satellite System (CNSS) presently is providing regional coverage for Chinese territory and in 10 years has to allow a global service. The EU Galileo system is far a way to be operational, while the Japanese Quasi-Zenith Satellite System (QZSS) is regional operational system. Countries like France and India are developing regional navigation systems. The GNSS network will in effect be fully deployed and operational in a few years using the vastly broadened spectra spread densely across 1146-1616 MHz.

2. Miniaturized GNSS Antenna Array

The important issue of GNSA solutions is to deploy new miniaturized GPS or GLONASS antenna arrays technology that reduces the size of the GNSS antenna elements and the array dimensions. Thus, this technology enables GNSS Controlled Reception Pattern Antenna (CRPA) with anti-jamming capability to be installed onboard mobiles where their size has previously prohibited their use. Thus, this includes small private and military aircraft where size and weight constraints resulted in Fixed Reception Pattern Antenna (FRPA) installations instead of CRPA and munitions where space and surface area are at a premium. The next requirement for miniaturization of arrays is future integration of GNSS receivers with satellite transceivers for mobile tracking solutions, especially for aircraft tracking and detection. In such a way, the future designs of the antenna arrays have to be miniaturized for installation onboard aircraft.

The miniature array is composed of a ground plane, a substrate with the antenna elements on its surface with superstrate atop of the elements. The dielectric constant of the substrate is increased so that the size of the antenna elements can be reduced. In such a way, this allows the antenna element spacing to be reduced, thus by controlling the design of the antenna elements the efficiency is increased so that they have the same gain as a standard GPS antenna element. By adjusting the dielectric constant and shape of the superstrate, the mutual coupling between the antenna array elements is minimized and the reduced antenna array spacing is scaled so that it appears to be effectively $\lambda/2$ in its beamforming or null steering performance.

Many of the smaller GNSS antenna munitions in operation or in development do not have a form factor that allows for a conventional CRPA to be installed. Because of size and weight constraints, some host aircraft within the Air Force and Navy have also elected to install FRPA antennas which cannot provide the Anti-Jam (A/J) protection needed in many tactical environments. Thus, the GNSS mini-array will enable A/J capability to be provided on many small munitions, aircraft and other host vehicles where the size and weight of e conventional CRPA array has previously been prohibitive **[01, 02, 03]**.

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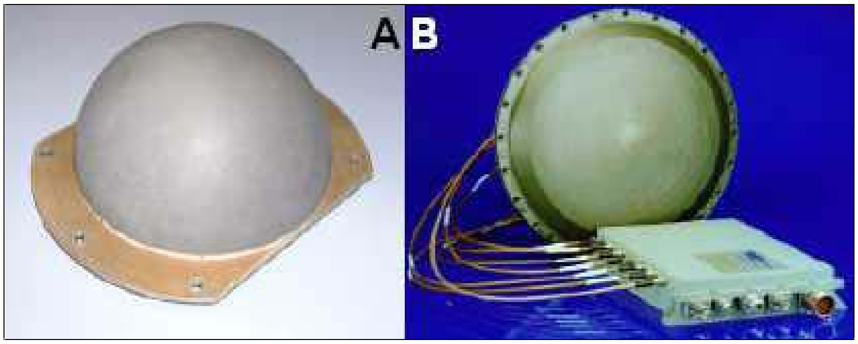

Figure 1. Miniaturized GNSS Arrays - Courtesy of Paper: by Brown **[03]**

1. GPS 4-element Mini-Array – The NAVSYS Corporation has developed a modern light GPS mobile antenna with miniaturized antenna and arrays elements. The operational principles of the Mini-Array and antenna unit are that provides measurement and processed data useful for the future consideration. This antenna provides the identical phase relationship to a full-size antenna array while reducing the over-all array physical dimensions. A high-dielectric lens is installed over the antenna array plane (patent pending), which allows the separation between elements to be reduced while still maintaining the same phase spatial separation. The NAVSYS' Mini-Array antenna is illustrated in **Figure 1 (A).** This antenna is significantly smaller than the CRPA but provides equivalent performance in terms of null-depth and beam-steering as a full-size antenna array. The Mini-Array has been tested for its null-steering performance by the Boeing experts in their anechoic chamber1 and will be flight qualified under contract to the Naval Air Warfare Center (NAWC) at Patuxent River. The antenna flight tests are planned in the near future on NAWC's Beechcraft aircraft will demonstrate this antenna system's performance in adequate support of the Joint Precision Approach and Landing System (JPALS) program. The JPALS program plans to use a similar architecture for precision approach and landing of military aircraft as the FAA propose for the Local Area Augmentation System (LAAS). This relies on differential corrections of the GPS code and carrier signals to compute the aircraft's location relative to the landing site. The JPALS system has the additional requirement that it must continue to operate in a jamming environment. On the other hand, the digital beam-steering electronics developed by NAVSYS for use with our High-gain Advanced GPS Receiver (HAGR) are conducted. This antenna electronics was used to test the Mini-Array performance in computing a kinematics GPS antenna solution. The HAGR electronics provide antenna beam-steering on up to eight GPS satellites simultaneously to enhance the performance of the GPS signals being tracked and to provide spatial filtering to reduce the effect of multipath or interference sources.

2. GAS 1-N Mini-Array Antenna– The GAS-1 Null-Steering antenna has been also tested for its null-steering performance, which is illustrated in **Figure 1 (B).** At this point, there are concerns that the analog electronics used in the military aircraft current CRPA and GAS 1-N antenna electronics will result in unacceptable errors on the pseudo-range and carrier-phase observations when nulling is applied. There is a desire to transition to more precise digital beam-forming and null-forming antenna electronics to enable high accuracy observations to be maintained in the presence of a jamming signal **[01, 02, 03]**.

2. Multisolutions Mini-Patch Antennas

1. PAM-7Q u-blox 7 GPS Antenna Module – This multisolutions patch antenna module have the exceptional performance of the 7Q u-blox 7 GNSS engine, which is the top view of patch antenna side and bottom view of shield side are illustrated in **Figure 2 (A).** This antenna delivers high sensitivity and minimal acquisition times in a mobile industry proven form factor. Thus, incorporating the PAM-7Q antenna array into customer designs is simple and straightforward, thanks to the embedded antenna array low power consumption, simple interface and sophisticated interference suppression that ensures maximum performance even in GPS hostile and harsh environments. The 18 x 18 mm patch antenna of PAM-7Q provides RHCP polarization, which is not achievable with smaller patch antenna array elements. The simple design and easy interfacing keeps antenna installation costs to a minimum. Thus, the PAM-7Q antenna targets industrial and consumer applications that require small and cost efficient smart antenna solutions.

Figure 2. Multisolution Mini-Patch Antennas - Courtesy of Manuals: by u-blox/Alpha **[04, 05]**

It is form-factor compatible with the UP501 module, allowing the upgrade of existing designs with minimal effort. PAM-7Q modules use u-blox 7 GPS chips qualified according to AEC-Q100 and are manufactured in ISO/TS 16949 certified sites. Qualification tests are performed as stipulated in the ISO16750 standard: "Road vehicles – Environmental conditions and testing for electrical and electronic equipment". PAM-7Q complies with green/halogen-free standards. The u-blox PAM-7Q receivers are designed to receive, track and detect the navigation L1C/A signals provided at 1575.42 MHz band by the GPS and QZSS satellites. In addition, this array antenna can also serve Differential GPS (DGPS), Assisted GPS (A-GPS), Augmented GPS and three Regional Satellite Augmentation Systems (RSAS), such us WAAS, EGNOS and MSAS.

In order to maintain good performance for the on-board patch antenna of the PAM-7Q, some design rules should be followed. This antenna modules designed with integrated patch antenna provides Right Hand Circular Polarized (RHCP) frequency at 1,580 MHz. They are relatively wideband arrays and tuned a few MHz above L1 customer housing (plastic) usually will de-tune center frequency back to L1. In **Figure 3** is shown the normalized patch antenna gain for chart of PAM-7Q antenna, with example of Radiation Pattern of 50mm square ground plane.

2. CAM-M8Q u-blox GNSS Antenna Module – The u-blox company has introduced the new type of CAM-M8Q for GNSS systems, such as GPS, GLONASS, Compass and QZSS antenna module, shown in **Figure 2 (B).** This module integrates u-blox M8 satellite receiver, Integrated Circuits (IC), Surface Acoustic Wave (SAW) filter, Low Noise Amplifier (LNA), Temperature Compensated Crystal Oscillator (TCXO), Real Time Clock (RTC), passive and a pre-tuned GNSS chip antenna in an ultra-small 9.6 x 14.0 x 1.95 mm package. The CAM-M8Q is a pre-tuned, performance and cost optimized module providing satellite positioning on an extremely small footprint and it is literally an antenna for "instant" positioning solution. The array u-blox CAM-M8Q module is designed for a wide range of applications, such as personal and all mobile locators, handheld navigators and telematics for all transport applications. Thus, the consistent omnidirectional antenna performance helps to ensure excellent performance regardless of the module orientation. The CAM-M8Q antenna model allows the internal chip antenna to be used as a backup antenna if the design incorporates an external antenna. This benefits companies where there is a risk that the primary external antenna may malfunction or suffer damage, for example in vehicle tracking systems where damage is possible to the external antenna **[01, 02, 04, 05]**.

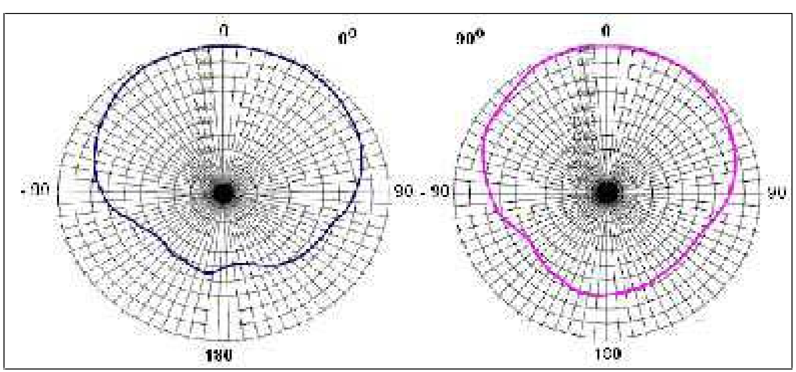

Figure 3. Antenna Gain Chart - Courtesy of Manual: by u-blox **[04]**

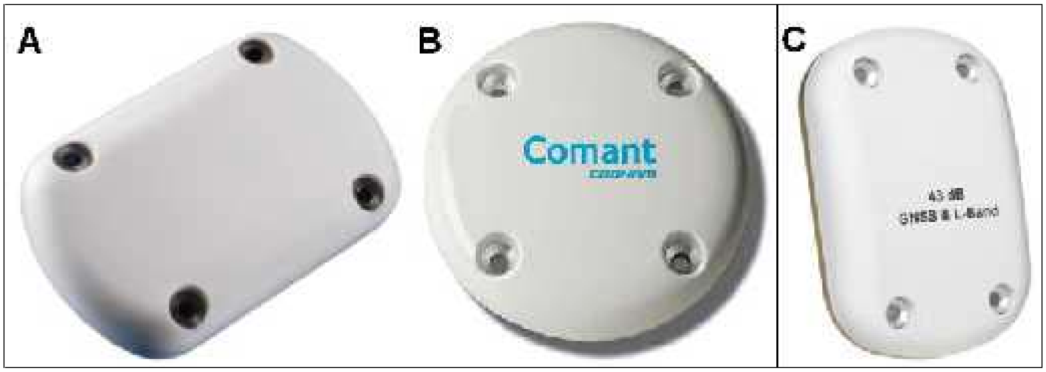

Figure 4. GNSS Aircraft Antennas - Courtesy of Prospects: by PCTEL/Cobham/Trimble **[06, 07, 08]**

3. G Top Gms-u1LP Antenna Module – The G Top Gms-u1LP aircraft antenna is low power high sensitivity GPS module with On-Board Patch Antenna of Alpha Micro Components Ltd. The new antenna technology offers a quick and easy route for embedding GPS Surface Mount Devices (SMD). This patch antenna module takes the hassle out of incorporating GPS into user Original Equipment Manufacturer (OEM) designs by combining a high sensitivity GPS module with onboard ceramic patch antenna, into a single surface mount solution. This antenna is working at frequency L1, 1575.42 MHz of C/A Code, which on-Board Patch Antenna (Above) and GPS Module (Below) are shown in **Figure 2 (C)**. Position accuracy without aid is 3.0 m 2D-RMS and for DGPS and RSAS (WAAS, EGNOS, MSAS and Indian GAGAN) is 2.5 m 2D-RMS.

3. Navigation and Integrated Antenna Systems

In this classification of aircraft antenna can be included not augmented and augmented GPS or GLONASS, all other integrated antennas.

3.1. Not Augmented GPS and GLONASS GNSS Antenna Systems

1. GPS Passive Antenna – The US Company PCTEL 12700 series airborne antenna module is designed for airborne applications, shown in **Figure 4 (A).** This antenna is robust, rigorously tested and environmentally sealed units suitable for a wide variety of GPS applications, including vehicle tracking, marine and airborne navigation. Thus, these antennas do not carry TSO or FAA certification, however they have been tested to five DO-160 environmental test requirements, which includes altitude, speed, temperature and temperature variation test, mechanical, vibration, shock and humidity test. These antennas feature a sealed o-ring that protects them against severe and harsh environmental conditions for reliable, long-lasting performance. Their antenna radome is constructed of high-grade polymer resin for UV and abrasion resistance. They will resist all de-icing fluids, jet fuels, and standard cleaning solvents. This antenna use 1575.42/±10 MHz RF range, VSWR is 1.5:1, polarization has RHCP and impedance is 50 Ohms.

2. GPS Active Antenna – The US Company Cobham CI 408-20 GPS Active antenna unit is designed for airborne applications with aircraft speeds up to 600 KTAS, shown in **Figure 4 (B).** Round footprint of antenna allows for drop-in replacement for many popular GPS applications. It meets RTCA DO 160-D operating standards including direct affects lightning. The antenna covers RF of GPS 1575.42 MHz - 28.0 db Gain and can be installed on most aircraft up to and including business jets.

3. GPS/GLONASS Antenna – The Trimble AV37 Aviation Antenna has been designed to support centimetre level accuracy for airborne applications and track RSAS signals all in one compact design, shown in **Figure 4 (C).** It is fully certified by the FAA for aircraft installations. Mapping and surveying from the air using GNSS requires survey grade antenna technology in a compact and reliable form factor. It achieves this facility without compromising performance. The AV37 antenna is designed to DO-160E, ARINC 743 Footprint, RTCA DO-210D and is ROHS compliant. Thus, this aircraft antenna is covering the following service: GPS and GLONASS L1/L2 RF, Galileo E1/E2, RSAS (WAAS, EGNOS, GAGAN and MSAS), QZSS and OmniStar. In addition, this is low-profile fuselage mounting antenna provides Gain at 43 dB, Axial ratio is 3dB max at boresight, RF is between 1570 ± 45 MHz or 1238 ± 21.5 MHz and Polarization is RHCP **[01, 02, 06, 07, 08]**.

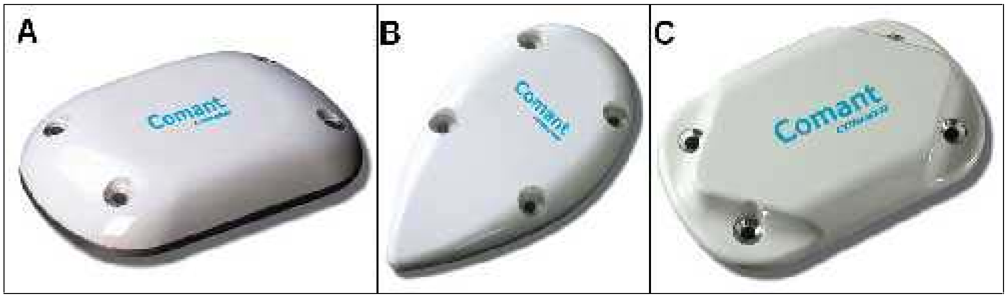

Figure 5. GPS/AGNSS and XM Aircraft Antennas – Courtesy of Prospects: by Cobham **[07]**

3.2. Augmented GPS and GLONASS GNSS/AGNSS and XM Antenna Systems

1. GPS WAAS/XM Antenna – The product of the US Company Cobham CI 428-410 GPS WAAS XM antenna is newest ComDat antenna for GPS, Augmented GPS (AGNSS) and XM receiver (Weather) designed specifically to meet the GPS/WAAS Gamma3 specifications required by the Garmin G1000 system, shown in **Figure 5 (A).** This antenna enables primary navigation using GPS WAAS including terminal navigation and approach to landing. The XM (WX) antenna is designed for low gain systems such as the Garmin GDL-69/69A or Heads Up systems with shorter coax runs. It conforms to the ARINC footprint, standard on many twin turbocraft and business jets. The antenna is frequencies covered for GPS at 1575.42 MHz with 26.5 dB gain and for XM at 2332.5 - 2345.0 with 25 dB gain.

2. GNSS/AGNSS Antenna – The US Company Cobham CI 419-200 WAAS GPS antenna is the first FAA certifies GNSS/AGNSS array antenna qualified under new, stringent the US C190 WAAS requirements, shown in **Figure 5 (B).** Using the popular ARINC 743 footprint, this antenna will operate with any DO-301 qualified WAAS GPS system providing full Gamma 2,d 3 and LPV capability. It is environmentally tested under RTCA DO-160E standards; the CI 429-200 offers an extensive test pedigree that will meet many GPS and other GNSS system and aircraft requirements. It is manufactured with a tough, skydrol resistant radome and nickel-plated aluminum base plate, the CI 429-200 part comes standard with a Nitrile "O" ring for positive sealing to the aircraft skin. Thus, it is frequencies covered just for GPS 1575.42 MHz RF band with 26.5 dB gain, and can be installed on most aircraft up to and including business jets.

3. GNSS/AGNSS/XM Antenna – The similar model to CI 428-410 antenna is CI 429-410 WAAS GPS/XM developed only for FAA, shown in **Figure 5 (C) [01, 02, 07]**.

3.3. Navigation, Weather and Sirius Radio Antenna Systems

1. GPS/WAAS, XM and Sirius Radio Antenna – The multifunctional aircraft antenna S67-1575-161/171 is product of the US Sensor System Inc., shown in **Figure 6 (A).** This active low-profile aircraft antenna is designed to incorporate not augmented GNSS, augmented GNSS, XM for weather (WX) data and Sirius radio for cabin passenger entertainment services. The advanced radome design of this antenna and material offers enhanced protection against lighting, rain and ice. Inside integrated 29.5 dB amplifiers are DC-grounded. These antennas are using RF at 2338 (±7) MHz for XM, 2326 (±7) MHz for Sirius radio, and 1565 to 1585 MHz for GPS Rx.

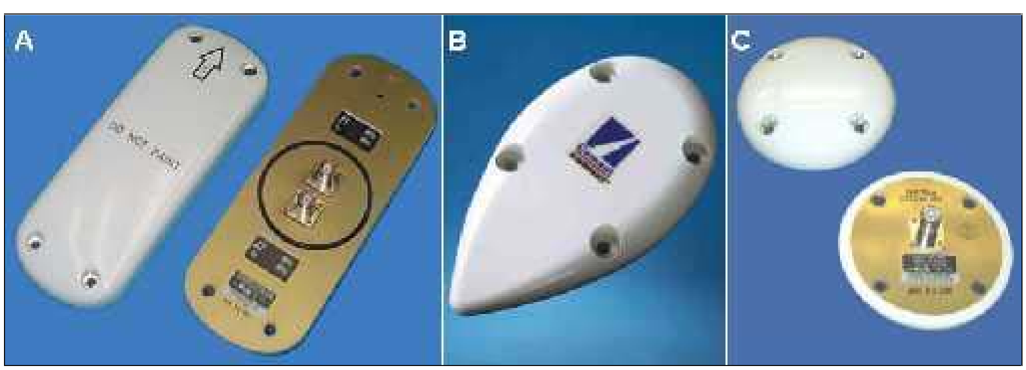

Figure 6. GNSS, XM and Sirius Aircraft Antennas – Courtesy of Prospects: by Cobham/ Sensor **[07, 09]**

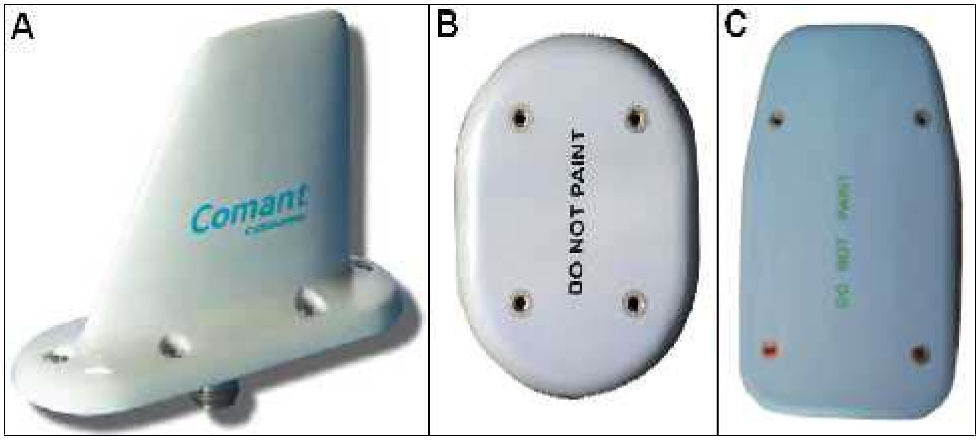

Figure 7. DME and ADF Antennas – Courtesy of Prospects: by Cobham/Verdant **[07, 10]**

2. XM Antenna – The product design of the US Company Cobham CI 420-10 ComDat is XM Weather antenna only, designed for Heads Up Technologies (HUT) aircraft radio receivers with longer coaxial cable runs, shown in **Figure 6 (B)**. This antenna features robust TNC female connector and conforms to the popular teardrop footprint standard on many general aviation aircraft and business jets for XM service at 2332.5 to 2345.0 with 26-30 dB gain.

3. XM and Sirius Radio Antenna – The aircraft antenna S67-1575-65 is product of the US Sensor System Inc., shown in **Figure 6 (C).** This active low-profile antenna is designed for use with XM WX and Sirius radio for passengers cabin entertainment services. The radome design and materials provide enhanced protection against rain, ice and lighting. The antenna is using RF at 2338 (±7) MHz for XM and 2326 (±7) MHz for Sirius radio.

4. Antennas for DME and ADF Systems

1. Distance Measuring Equipment (DME) Antenna – The Cobham product CI 105-20 is DME/Transponder Beacon wide band vertically polarized and omnidirectional antenna designed for high performance aircraft over the UHF/L Band of frequencies from 806 to 960 and 960 to 1220 MHz, which is illustrated in **Figure 7 (A).** This antenna has a low profile of blade-type features, low weight, DC grounding for lightning protection and skydrol/rain erosion resistance. It is useful for most aircraft up to and including business jets with transmitter frequencies at 894 - 896 MHz and Rx frequencies at 849-851 MHz.

2. Airborne Direction Finder (ADF) Loop Antenna – The Verdant Telemetry JM 708 is an airborne loop antenna used with the Automatic ADF system, shown in **Figure 7 (B)**. It is a fixed loop ferrite antenna encased in a low drag aerodynamic composite radome suitable for mounting on the top or bottom exteriors of the aircraft fuselage. It is used with Marconi ADF System AD 380 and HAL ADF System ARC 610A. This antenna is suitable for commercial and military aircraft qualified and is working at 190 to1800 KHz

3. Airborne Direction Finder (ADF) Ferrite Antenna – The Verdant Telemetry JM 705 is an airborne fixed loop ferrite antenna used with the Automatic ADF system, shown in **Figure 7 (C)**. This aircraft antenna is encased in a low drag aerodynamic composite radome suitable for mounting on the top or bottom exteriors of the aircraft fuselage. It is used with Marconi ADF System AD 380 and HAL ADF System ARC 610A at 190 to1800 KHz **[01, 02, 07, 09, 10]**.

Figure 8. Marker Beacon Antennas – Courtesy of Prospects: by Cobham **[07]**

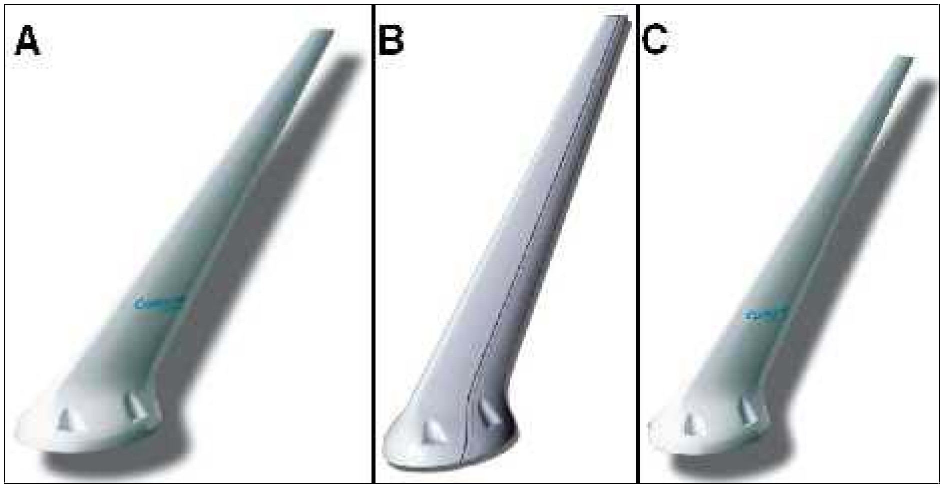

Figure 9. Navigation/Weather/XM Antennas – Courtesy of Prospects: Cobham **[07]**

5. Receiving Marker Beacon (MB) Antennas for Instrument Landing System (ILS)

1. Marker Beacon Blade Antenna – The Cobham CI 118-10 Marker Beacon antenna has been tested to the tough DO-160D environmental standards and is working on 75 MHz, shown in **Figure 8 (A).** This antenna is skydrol and rain erosion resistant and is DC grounded to minimize accumulation of precipitation static. This antenna can be installed on some light turbine and light jets.
2. Marker Beacon Flat Antenna – The Cobham CI 165 Marker Beacon antenna is for flat surface and curved fuselage mounting working at 75 MHz, shown in **Figure 8 (B).** This lightweight flush mount antenna was originally designed for use on military aircraft, and also can be installed on most aircraft up to and including business jets. It provides for dual marker beacon signal outputs at the antenna, eliminating the need for a separate marker beacon splitter. Antenna is housed in an aluminum enclosure with a glass laminate cover. Internal components are potted in place for mechanical integrity.
3. Marker Beacon Canoe Antenna – The next Cobham CI 102 Marker Beacon antenna is designed for use with the modern and high sensitivity marker beacon receivers using RF at 75 MHz, shown in **Figure 8 (C).** This antenna is designed **s**mall and with assembly enclosed in an injection-molded radome, which is impervious to the tough environments typical of the underside of an aircraft. In this way, it is skydrol and rain erosion resistant and DC grounded to minimize accumulation of precipitation static. The antenna can be installed on single and twin-engine piston aircraft for applications of this antenna design.

6. Integrated Antennas Systems

The modern aircraft integrated antenna systems is combination between radio communication, navigation and weather antennas.

6.1. Navigation, Weather and Sirius Radio Antenna Systems

1. VHF/GPS Antenna – The Cobham CI-2680-201 VHF/GPS in a single antenna, illustrated in **Figure 9 (A).** Thus, the dual function high-speed antenna is covering RF band for VHF 118 - 137 MHz and GPS 1575.42 MHz with 17.0 dB gain and can be installed on single and twin engine piston aircraft including some light turbine and light jets. This aircraft antenna provides 80 dB of VHF harmonic suppression allowing antenna to offer VHF and GPS in one radome without in-line filters. It is designed for use with Garmin GPS panel mount receiver units requiring 17.0 dB gains.
2. VHF/GPS/XM Antenna – The Cobham CI 2728-410 ComDat VHF/GPS/XM Weather antenna frequencies covered at VHF 118 - 137 MHz, GPS 1575.4 (±3) MHz and XM 2332.5 - 2345.0 MHz, shown in **Figure 9 (B).** This antenna design has triple function VHF/GPS/XM specifically designed to meet the GPS WAAS Gamma 3 specifications required by the Garmin G1000 system. Enables primary navigation using GPS WAAS, including terminal navigation and approach to landing. XM Weather antenna is designed for low gain systems such as the Garmin GDL-69/69A or Heads Up systems with shorter coax runs. This antenna can be installed on single and twin-engine piston aircraft and light turbine and light jet aircraft.

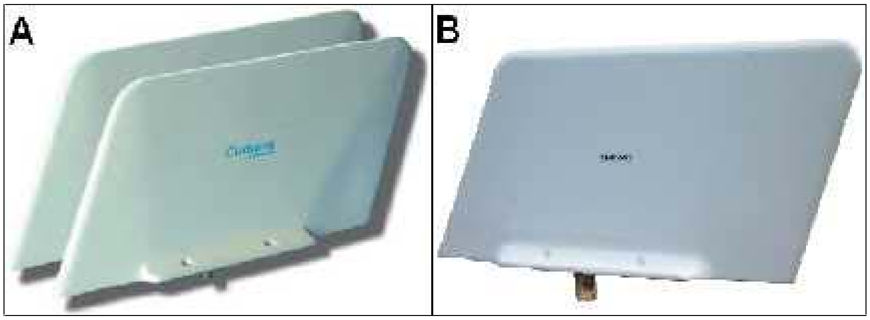

Figure 10. Multipurpose Antennas – Courtesy of Prospects: by Cobham/Verdant **[07, 10]**

3. VHF/XM Antenna – The Cobham CI-2680-216 VHF/XM multifunction is modern antenna model designed for high-speed aircraft using frequencies at VHF 118 - 137 MHz and XM 2332.5 - 2345.0 with 30 - 34dB gain, illustrated in **Figure 9 (C).** This antenna is exact match of common teardrop footprint and is perfect to add XM weather data to a standalone VHF mounted antenna. The VHF harmonic suppression also protects co-located stand-alone GPS antennas, allowing for more antennas in less total area. It is applicable for twins and light turbine and jet aircraft and for single and twin-engine piston aircraft **[01, 02, 07]**.

6.2. Antenna Systems for VHF/UHF VOR ILS/LOC/GS

1. VHF/UHF VOR ILS/LOC/GS Two Blades Antennas – The Cobham CI 120-G/S set of aircraft navigation antenna provides optimum VOR performance when used for airplane area navigation, covering frequencies at 108 - 118 MHz for VOR/LOC and 329 - 335 MHz for GS, shown in **Figure 10 (A).** Antenna system is qualified for use on single engine, twin, business jet aircraft including helicopter, and provides glide slope reception capability. Complete set includes a pair (2) of blades, each with single BNC connector output, two coax interconnect cables and a signal combiner output providing for a single cable run to the avionics installation.

2. VHF/UHF, VOR, ILS/LOC/GS Blade Antennas – The Verdant Telemetry model JH 85 VOR/ILS/LOC and GS is navigation antenna designed for military as well as for commercial application, using frequencies at 108 - 118 MHz for VOR/LOC and 329 - 335 MHz for GS, illustrated in **Figure 10 (B).** The low profile lightweight antenna is designed to withstand extreme environmental conditions. The antenna is suitable for Helicopters as well as High performance Jets. A set includes a pair (2) of blades, each with single TNC connector [**07, 10**].

7. Conclusion

The purpose of this research effort was to determine existing and in development phase miniaturized antenna array for GPS and other applications that can be used to provide reception enhancements. The majority of presented airborne antennas have been already applied onboard aircraft and some of them are in testing phase. In general, the important performances of all described antennas are to achieve reduced size and weight. In particular, the low profile of the antenna plate makes it suitable for other applications such as vehicle, loco, ships, military aircraft, missile/rocket and manpack solutions. All these antennas were designed to meet harsh environmental and other requirements, making it also suitable for marine and arctic applications.

8. References

[01] Chen X., "Antennas for Global Navigation Satellite Systems", Wiley, Chichester, 2012.
[02] Rama B., "GPS/GNSS Antennas", Artech House, London, 2013.
[03] Brown A. and Others, "Miniaturized GPS Antenna Array and Test Results", NAVSYS Corporation, Colorado Springs, US, 2014 [www.navsys.com].
[04] u-blox, "PAM and CAM Antennas", u-blox AG, Thalwil, Switzerland, 2014 [www.u-blox.com].
[05] Alpha, "725 N A1A and G.top Gms-u1LP Antennas", Alpha Micro Components Inc, Basingstok, UK, 2014 [www.alphamicro.net].
[06] PCTEL, **"**Airborne Antennas", PCTEL, Inc., Bloomingdale, US, 2014 [www.pctel.com].
[07] Cobham, "Airborne GNSS/Integrated Antennas", Cobham, Wimborne, UK, 2014 [www.cobham.com].
[08] Trimble, "Aircraft GNSS Antennas", Trimble Ltd, Sunyvale, US, 2014 [www.trimble.com].
[09] Sensor, "Aircraft GNSS Antennas", Sensor Systems, Inc., Chatsworth, US, 2014 [www.sensorantennas.com].
[10] Verdant, "Multipurpose Airborne Antennas", Verdant Telemetry & Antenna Systems Pvt. Ltd., Cochin, India, 2014 [www.verdanttelemetry.com].