SAFE EUROPE 2004

H R SMITH GROUP OF COMPANIES

THE VITAL LINK

Presented
by
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INTRODUCTION

1. A common feature in most avionic systems designed to enhance the safety of flight is the need to propagate radio frequency (RF) energy efficiently between different aircraft and between aircraft and ground installations. This is true for the simplest radio voice communication system and for significantly more complex systems that facilitate navigation and essential safety functions, including search and rescue. Underpinning the ability to communicate efficiently is the supporting RF antenna system that not only launches and detects electromagnetic energy, but also permits measurements essential to for the delivery of accurate navigation for situational awareness and search and rescue applications.

AIM

2. The Aim of this Paper is to illustrate the vital part that radio frequency antennas provide in communication and navigation systems that aid the effectiveness and safety of flight, including search and rescue missions, and to explain some recent developments in this field.

WIRELESS COMMUNICATION

3. The concept of wireless communications is hardly new – we have had commercial radio and television for many decades and, more recently, the advent of digital technology has brought significant improvements in the quality and volume of information that can be communicated. Furthermore, the increasing use of communications satellites has enhanced the distribution and accessibility of information to provide truly global coverage and fidelity of unparalleled quality. Not surprisingly, these commercial developments have been mirrored by significant advances in the capability and performance of avionic systems which also benefit from the ability to exchange and share data rapidly and in high volumes.

4. Essential to this communication process is the radio frequency (RF) antenna. The antenna has to convert electrical energy delivered along a conductive cable into a self-sustaining electromagnetic (EM) wave capable of propagating through a near-vacuum. At the receiving unit, another antenna has also to detect and convert into an electrical signal the EM wave which itself will have been dispersed and therefore significantly attenuated by its journey, possibly over many ten's of miles.

5. A basic but nevertheless very efficient omni-directional antenna is the 'dipole', so-named because of its dual radiating rod-like elements. The most efficient dipole design is a ½ wave dipole with elements that together measure in length one half of the wavelength of

the radiated electromagnetic wave that it produces - in simple mathematical terms wavelength = c (speed of propagation) / frequency. Not only does the ½ wave dipole provide the smallest practicable antenna size, its electrical performance offers the best bandwidth (ie operating frequency range) and matching (ie lowest variation in impedance with frequency). Therefore, despite its relative simplicity, the dipole remains to this day one of the fundamental building blocks of many antenna systems. However, a problem arises with the dipole for use in airborne applications due to its size. For example, half a wavelength at a signal frequency of 30 MHz (the lower end of the Tactical VHF communications frequency band) is 5 metres while at 300 MHz (mid-way along the airborne UHF communications band) a half wavelength measures 0.5 metres. Clearly, the dipole's size makes it an impractical choice for many airborne communication applications, while its physical characteristics also constitute a rather poor aerodynamic structure, especially for high-speed platforms with limited antenna real-estate. Consequently, an alternative approach was needed for air vehicles and this was provided by the monopole antenna.

6. A monopole is effectively one half of a dipole fed from an unbalanced source in which the ground is bonded to the aircraft's conductive surface. Providing a good, even bond is achieved with a suitable conductive-sealing gasket, this provides a 'ground plane' which allows the metallic skin to act as reflective surface, effectively mirroring the active monopole element. The effect of the ground plane is to create a virtual element which, together with the active monopole element, delivers almost the same antenna performance characteristics efficiency as a true dipole. Most importantly, the monopole is much easier to configure mechanically (usually in the form of an aerodynamic blade) for airborne installations, while its overall size (¼ wavelength equates to 25 cms at 300 MHz) becomes a much more practical proposition for installation on commercial and military aircraft. Add some RF specialist engineering techniques and antennas of practicable physical shape and size can be manufactured to cover the full range of communications frequencies. It is therefore the monopole antenna, characterised by its omni-directional azimuth coverage and relatively high elevation beam-width that provides the basis for a wide range of airborne communication antenna systems

7. **Conductive Sealing Gaskets.** Clearly, the performance of the monopole antenna and its ground plane depends on the creation of a sound electrical bond between the antenna base and the parent airframe. Although a metal-to-metal bond could arguably be achieved without a gasket, only three points of contact are invariably achieved which, in turn, allows the formation of RF 'hot spots' and unwanted circulating currents in the antenna base-plate. In addition, it is important to preserve the integrity of the electrical bond by preventing the ingress of moisture, salt water and spray, and the potentially damaging effect of contaminants like fuel and hydraulic oil. The H R Smith Group has therefore developed a unique range of easily installed conductive-sealing gaskets which ensure the long-term integrity and performance of their antennas regardless of operating environment.

LOCATING & HOMING

8. Whilst for most communications applications, omni-directionality is a desirable feature, locating and homing applications on the other hand - particularly with an omni-directional radiating emergency beacon - require a coverage pattern that varies in azimuth to enable relative bearing between the SAR aircraft and a transmitting beacon to be sensed electronically. One method for achieving directionality is to use a vertical loop antenna which features similar coverage to that of a dipole but the azimuth and elevation patterns are effectively reversed. The amplitude of the received signal at a loop antenna loop antenna

therefore varies with changing direction of the transmitting source. Although this process provides azimuth bearing sensitivity, the antenna's symmetrical pattern causes fore/aft directional ambiguity. This ambiguity can however be resolved by adding an omni-directional dipole 'sense' antenna. The combined polar coverage of the directional and sense antennas creates a cardioid pattern featuring a single null precisely at the zero degree azimuth error. Similar, though less perfect cardioid coverage can be achieved with dual dipole antennas; however, the shape of the pattern is very frequency dependent, and consequently separate sets of antennas are required for homing onto each different terrestrial distress frequency – 121.5; 156.8; and 243 MHz. Given also that homing systems are increasingly required to include the COSPAS-SARSAT satellite distress frequency (406 MHz), such installations involve almost impractical levels of antenna real-estate and cost.

9. **Phase Comparison Homing.** An alternative means of providing directionality for homing is the system of 'phase comparison'. A phase comparison system offers a more compact solution for SAR operations because only two wide-band antennas positioned only 30 cm apart can cover the entire range of international distress frequencies (121.5 MHz up to 406 MHz) without any ambiguity in phase occurring. Here the homing system effectively measures the path difference or relative phase of the incident RF energy at the two antennas and by this means determines the extent to which the signal source is displaced from the aircraft's centreline, assuming the antennas are positioned equidistantly either side of the aircraft's longitudinal axis. The Techtest Series 406 homer applies this technology in a stand-alone line-replaceable unit which uniquely offers homing on all distress frequencies, including 406 MHz with just one pair of wide-band antennas

10. **Limitations of Analogue Homing.** Notwithstanding the quality of the airborne homing system, mission effectiveness depends also on a number of additional external factors which include the quality and power of the beacons transmitted waveform; the coverage and efficiency of the beacon's antenna; and the effect of the Earth's curvature on line-of-sight communications. Typically, at a range of 50 nm, an aircraft has to fly at an altitude of 1000 ft ASL for the signal from a transmitting emergency beacon at sea level to be visible. In addition, it is difficult to discriminate between multiple transmitting beacons in close proximity, and in bad weather or at night, the absence of ranging information creates difficulty in determining whether the beacon has been reached or over-flown, especially if the survivor is unable to communicate with the SAR crew. This situation can be further exacerbated by most beacons' relatively poor coverage at high elevation angles.

TOWARDS A DIGITAL LOCATING

11. The introduction of the digitally encoded COSPAS-SARSAT emergency distress frequency (406 MHz) created an opportunity for significant improvements in the effectiveness of SAR operations compared with the use of traditional analogue homing techniques. The encoded distress signal not only enabled the emergency beacon to be uniquely identified, but 'Location' protocols also allowed latitude and longitude information to be inserted in the data message. Such positional data is typically derived from on-board GPS systems or, in the case of the latest Techtest emergency locator transmitters and beacons, from integral, stand-alone GPS receivers. Clearly, the primary aim of this data signal is to provide information for the rescue authorities via the COSPAS-SARSAT satellite system. However, by incorporating a digital 406 MHz message decoder in an airborne homing system, the SAR aircraft is able not only to identify the source of the distress transmission for itself but, with a location protocol beacon, also determine that beacon's position by decoding the latitude and longitude information embedded in the 406 MHz

message. This capability gives the SAR aircraft complete autonomy of operation and reduces inevitable data latency associated with the distribution of information across the COSPAS-SARSAT communications network.

12. Current development hardware displays the beacon's position co-ordinates in alphanumeric form on an integral indicator, together with the beacons ID and time. Additional beacons may be displayed using a simple scroll mechanism, thereby eliminating problems of multiple beacon discrimination associated with traditional distress frequencies. This positional information can also be compared with on-board navigation data to calculate relative position of the beacon in relation to the SAR aircraft. In turn the pilot can be given a range and heading to steer directly towards the emergency transmitter. Once a beacon position has been determined, the SAR aircraft is able to fly on an intercept heading without maintaining continuous line-of-sight visibility of the beacon, thereby providing added protection in hostile environments. The 406 MHz data decode function therefore effectively provides a covert, single-pass rescue capability while overcoming many of the limitations of analogue homing.

13. **Dual Function Homer-Decoder.** It is important to note, however, that that the accuracy of COSPAS-SARSAT encoded position co-ordinates varies significantly depending on the type of protocol used. Typically, 'long message' Location Protocols offer the greatest accuracy (to within approximately 125 metres), whereas the short message versions of these protocols offer significantly poorer accuracy; notionally 3 ½ to 30 km. Thus, it is essential to take account of the variations in positional accuracy and to initiate a transition from the data decode mode to a terminal homing mode at a suitable point in the mission. This point in the mission has to be decided on the basis of a realistic assessment of when the decoded data is likely to mislead rather than assist the SAR aircraft in its task. A systematic method of alerting the SAR crew and facilitating a transition from using decoded digital data to analogue homing is essential if a SAR mission is to benefit from the respective advantages of these operating modes and achieve the quickest possible transit to the point of visual acquisition and rescue. Accordingly, it is seen as essential that a practical system retains analogue homing functionality alongside 406 MHz message decode to provide a seamless and appropriately timed transition from data to analogue modes. In addition, it is important to remember that many emergency transmitters do not have a location capability; consequently, SAR operations involving 'non-location' beacons have to depend on traditional analogue homing techniques, aided by COSPAS-SARSAT Doppler location. Current development effort is therefore directed towards delivering a dual-function, stand-alone 'Decoder-Homer' system.

14. **Flexibility of Installation & Use**. In developing a dual function Homer-Decoder, appropriate interfaces are being included to facilitate integration with on-board or man-portable electronic map displays. Like its Series 406 predecessor, the unit is being designed for ease on installation and flexibility of operation featuring a rapid role-fit capability and easily interpreted displays which will enable any aircraft potentially to contribute effectively to a SAR emergency. In short, the Homer-Decoder will close the digital data loop and maximise the availability of information to the SAR crew.

WIDEBAND WIRELESS NETWORKS

15. We have seen how the combined use of direct RF measurement using specially configured antennas and digital data communications can be used to enhance the effectiveness of SAR missions. Not surprisingly, precisely the same concepts are now

providing much more accurate position measuring and situational awareness capability for a much wider range of applications.

16. One such system called Wideband-Wireless network (WWN) is the result of a joint development initiative by Electronic Warfare & Network Systems (EWNS), DRS Technologies and the HR Smith Group. In WWN, direct measurements of relative range, range-rate and bearing, together with exchanged digital navigation vectors allows a complete three-dimensional dynamic picture to be constructed by all participating aircraft within a 100 mile range. WWN's advanced radio frequency waveform not only provides very high data capacity, but also provides secure communications through the use of spread spectrum, adaptive power management and frequency hopping. Further development of WWN is directed to ground vehicles and man-portable applications, effectively extending the network to ground forces, including un-manned vehicles. Of course, line-of-sight constraints remain applicable, but with the integration of this technology across a wide range of airborne and ground platforms, it is possible to exchange important tactical information covertly throughout the command chain.

17. **WWN Antennas.** Unlike traditional communications and navigation systems, WWN operates in a much higher frequency band ranging from 3,100 to 3,600 MHz. At these frequencies, one wavelength measures just 10 cm, or a ¼ wavelength = 2.5 cm. At these smaller wavelengths, is possible to design more compact and efficient antennas. Moreover, it is possible to produce 'high aperture' devices using reflective secondary radiating elements or surfaces to produce highly focussed beam shapes suitable for very accurate angle measurement in support of airborne situational awareness applications. These improvements in aperture and, hence, directionality paved the way for novel developments in antenna technology that would have been wholly impracticable at lower frequencies. For WWN, these developments took the form of a small, low-profile directional antenna which is electronically switched to measure relative azimuth to 2 degrees accuracy. The antenna uses amplitude measurement techniques and compares the relative signal level received in adjacent lobes.

18. **Situational Awareness.** Situational awareness in a combat environment reduces to three basic questions: what is my location; where is the enemy; and where are any friendly forces? WWN provides a highly accurate low-latency solution to these questions be they related to air vehicles, ground platforms or foot soldiers. Once the system has identified enemy locations and those of non-participating friendly forces, these data can be shared over the network to the benefit of all participating friendly forces, automatically measuring their precise relative locations. The network provides commanders with a picture of the tactical situation and a means of direct communication, including the exchange of digital imagery.

19. **Augmenting TERPROM.** The BAE Systems terrain avoidance system, TERPROM, uses radar altimeter measurements to compare the elevation profile of the ground that the aircraft is over-flying with a Digital Terrain Elevation Database (DTED). In this way, TERPROM establishes the location of the aircraft in relation to the DTED to produce terrain avoidance advisories. However, when flying over water (or very flat terrain) errors can accumulate (normally at the rate of inertial drift) with the loss of a measurable ground reference. EWNS are therefore working with BAE Systems to integrate WWN as a means of sharing navigation data so that aircraft with a good terrain reference will be able to assist in achieving taughter navigations solutions for aircraft that may be subject to inertial drift – a process termed co-operative navigation.

20. **Proactive CSAR**. Finally, to return to the theme of Search and Rescue, downed military aircrew usually adopt evasive tactics to avoid capture, rather than actively engage with the enemy. In a typical CSAR scenario, a man-portable WWN beacon would allow downed aircrew to play a positive and proactive role not only in their own rescue but also in gathering important tactical information relating perhaps to enemy installations and potential threats to rescue forces. Indeed, we envisage that equipped with man-portable WWN and laser ranging binoculars, survivors could play a central role in Close Air Support operations by relaying details of enemy installations while simultaneously enhancing the safety of the rescue mission. SAR aircraft and rescue teams dropped to assist a survivor would also have accurate positional data and stealthy communications with operational commanders. The application of advance digital wireless networks and their supporting antennas is therefore considered to offer potentially significant improvements in CSAR capability.

CONCLUSION

21. Radio frequency antennas provide an essential function in almost all airborne communications and navigation applications; however, designing antennas for airborne applications poses special problems in terms of size, aerodynamic characteristics and limited real estate. For Search and Rescue operations it is also essential that antenna arrays provide an unambiguous means of sensing direction in order that the SAR aircraft may home successfully onto a transmitting emergency beacon. A number of analogue homing technologies are available but phase comparison systems continue to offer the most compact and cost-effective analogue homing solution.

22. More recently, the advent of the digital 406 MHz distress signal with satellite-aided detection and locating, allowed the digital transmission of positional latitude and longitude derived typically from GPS receivers. Incorporating a suitable 406 MHz decoder into a SAR aircraft therefore offered a means of delivering near real-time location information to SAR crews. However, because the accuracy and existence of such location protocol beacons cannot be guaranteed, a hybrid system of digital and analogue locating is needed to cover all eventualities. Current Techtest development efforts are therefore directed towards delivering a dual ‘Homer-Decoder’ system to support future SAR operations.

23. The combined use of wireless data transfer and direct measurement has been expanded significantly in the evolution of Wide-band Wireless Network (WWN) technology where complementary developments in antenna design have enabled the production of a highly accurate, low latency, self-organizing situational awareness system capable of locating and tracking platforms and individuals with minimal probability of unwanted detection.

23. Advances in capability, air safety and SAR effectiveness have been possible only though concurrent developments in antenna design and efficiency. Indeed, antennas continue to play a pivotal role in avionic system developments and, as such, provide the ‘Vital Link’ in airborne communication and navigation systems, including those used in support of search and rescue operations.

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March 2004