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Design and Types of Wire Mobile Satellite Antennas (MSA)

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ABSTRACT

This paper describes wire Mobile Satellite Antenna (MSA) as the most important part in Mobile Satellite Communications (MSC) systems. Antenna transforms electrical signals into radio waves and vice versa, and the MSA systems are of various kinds and having different characteristics according to the need of signal transmission and reception. In this paper is described outlines the state-of-art of wire MSA and describes their designs, types, benefits and specific impacts in MSC systems. In many respects the MSA infrastructures currently available for MSC constitute the weakest links of the system. If the mobile antenna has a high gain, it has to track the satellite, following both mobiles and satellite orbital motions. Namely, sometimes this is difficult and expensive to synchronize. Therefore, if the vehicular antenna has low gain, it does not need to perform tracking but the capacity of the communications link is limited. In general, according to the transmission direction, there are three types of MSA: **1)** transmitting and receiving or so-called transceiving, as a part of all types of Mobile Earth Station (MES); **2)** only receiving is part of the special Inmarsat EGC receiver and **3)** only transmitting is built in satellite beacon antennas for maritime, land and aeronautical applications. On the other hand, all MSA are classified into omnidirectional and directional tracking antennas. The Inmarsat, Eutelsat, ESA, Cospas-Sarsat, Iridium, Globalstar, ICO, Orbcomm, ACeS, Thuraya, Insat, O3b and other GEO and Non-GEO current and forthcoming mobile satellite operators have conducted research on all network segments, including different types of MSA and their future development and improvements. The Engineering Test Satellite-V (ETS/V) experiments conducted in placecountry-regionJapan for the transmission of voice, video and different data rate digital communications between ships, land vehicles and aircraft were successful. Moreover, a test of low-speed data transmission by using briefcase-size transportable equipment, onto which two small printed antennas were mounted, was among the experiments.

1. Introduction.

Existing Mobile Satellite Antenna Systems (MSA) represent one of the most important components for the development of any radio (wireless) and satellite communication system. When using some Geostationary Earth Orbit (GEO) satellites, such as Inmarsat, Thuraya, Insat and other MSC networks, MSC devices with MSA are located at greater distances, about metricconverterProductID36,000 km36,000 km, in which case, due to the increase in distance, route loss increases and signal strength levels decrease.

As for Non-GEO satellite networks, such as Iridium, Globalstar, Orbcomm and other MSC networks, are located at smaller distances of about metricconverterProductID1,000 km1,000 km, so MSC devices with MSA achieve a higher signal level and due to the reduced distance, route loss is reduced.

All GEO and Non-GEO MSC networks, such as maritime, land (road and rail) are becoming increasingly popular in today's modern MSC system. To effectively cover the required operational bands, future MSA structures must meet multiband or broadband standards and provide better transmission and propagation effects. In fact, successful and efficient antenna array design doubles exponentially as the number of operating frequency bands increases, while a mobile antenna array must be compact enough to be effectively positioned within satellite

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propagation channels.

In MSC systems, it is very important to carry out an adequate design and selection of wire antennas used in MSC networks, and describes the major properties of specific antenna types. These are unloaded forms, in which the parameters are controlled by changes to the geometry, forms containing passive loads, whose effect is to modify the current distribution and radiation properties, and antennas containing active devices that are used either for altering the current distributions, or for matching or amplification.

The selection of an antenna type for MSC systems requirement is considered, and the synthesis and optimization methods are described as well. Numerical analysis methods are compared to show their relative strengths and weaknesses. Most MSC wire antennas have been evolved from the basic dipole and straight wire types.

Changes in the geometry and the addition of passive loadings have led to improved gain, greater bandwidth, and reduction in size and these factors can be traded off against one another. Active loads offer still more flexibility, but to date commercially produced forms have been nonintegrated, the electronics are only being used for matching and amplification.

2. Types of Mobile Satellite Antennas (MSA) Systems.

In particular, taking in consideration the kind of mobiles, the antenna systems for MSC can be classified into shipborne, vehicleborne, airborne, transportable, MSA for personal satellite terminals and other types.

2.1. Shipborne MSA Systems.

The different types of shipborne satellite antenna systems were developed for installation on board ocean-going ships and inland sailing vessels, on sea platforms and other offshore infrastructures. In general, these antennas must have strong and rugged constructions, with corresponding mechanical and electrical particulars. The Inmarsat-A Ship Earth Station (SES) is the inheritor of the first generation of Marisat and was the first Inmarsat operating standard of Maritime MSC (MMSC). In fact, this analog standard started in 1982 to use Inmarsat standard-A transceiving MSA known as Above Deck Equipment (ADU) and recently is not in use any more. In the meantime Inmarsat-C and EGC were developed with small omnidirectional antennas. In addition, Inmarsat-B digital standard started to be in service on ships at the end of 1993, using the second generation of Inmarsat satellite constellation. This standard is compatible with Inmarsat-A and uses the same antenna specification.

After employing more powerful third generation of constellation, the Inmarsat system developed Inmarsat-M, mini-M, and D+ standards with special shipborne antenna systems. Since 2003 were developed three new Inmarsat standards known as Fleet-33, Fleet-55 and Fleet-77 using special tracking MSA. In 2007 was presented new Inmarsat standard known as Fleet-Broadband using special broadband MSA via fourth generation of spacecraft Inmarsat-4.

All MSC antennas are transceiving antennas, except for the Inmarsat-EGC receiver, which can use a receiving antenna only. On the other hand, the Cospas-Sarsat system developed shipborne EPIRB, with small built in UHF antennas. Thus, rugged MSA with added-value system functions compatible with shipborne operation for Inmarsat, Iridium, Globalstar and other systems and compact antennas for small lifeboat operation are some of the fascinating requirements for shipborne antenna designers of in the future.

2.2. Vehicleborne MSA Systems.

The vehicleborne transceiving MSA were developed for installation on road and rail vehicles, such as trucks, trailers, buses, cars and trains. The Inmarsat-C, D+, M, mini-M, broadband and other MSA are used onboard Vehicle Earth Station (VES). Similar to the maritime application, the Cospas-Sarsat system has developed personal or vehicleborne PLB handheld satellite beacons with small built in UHF band transmitting antennas.

2.3. Airborne MSA Systems.

The airborne MSA were developed for installation on board airplanes and helicopters known as Aeronautical Erath Station (AES). There are several types of low and high-gain airborne transceiving MSA for Inmarsat-C, H, H+, I, L, mini-M, Swift64, SwiftBroadband and other MSS.

Parallel to the maritime and land distress applications, the Cospas-Sarsat system developed airborne ELT satellite beacons with small built in UHF band transmitting antennas. Because of the high speed of aircraft, the aerodynamic constraints are significant and antennas for both radio and satellite systems must conform to minimum drag and reliability requirements.

2.4. Transportable MSA.

Inmarsat MSC network developed special transceiving satellite antenna systems, which can be integrated into mobile Transportable Earth Stations (TES) of Inmarsat-B, C, M, mini-M and all new Broadband terminals.

2.5. MSA for Personal Satellite Terminals.

The new GEO and Non-GEO MSC systems developed small satellite antennas for Global Mobile Personal Satellite Communications (GMPSC) terminals, such as handheld antennas, antennas for mobiles and roof antennas for indoor and outdoor satellite terminals. Some of these systems provide mobile tracking, so the tracking antenna has to be combined or integrated with the communications antenna.

2.6. Other Types of MSA.

The other solutions for MSA are receiving broadcast radio and TV MSA, receiving GNSS MSA, transceiving broadband MSA, transceiving DVB-RCS MSA and transceiving MSA for Communications, Navigation and Surveillance (CNS) equipment.

3. Wire Antennas.

The wire antenna systems are monosyllabic construction or combinations of elements, such as different shapes of wire spirals and helixes, dipoles and patches. These types of antennas have a very simple construction, with any reflector specified for medium-gain directional antennas and, with some modification, responds well to the demands of MSC applications.

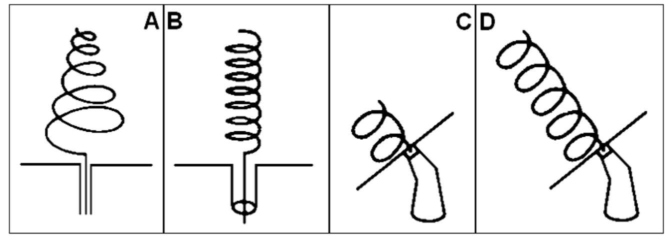
4. Helical Wire Antennas.

Since an axial mode helical antenna has good circular polarization characteristics over a wide frequency range, it has been put into practical use as a single wire antenna or as an array element. With respect to the structure, this antenna can be considered a compromise between the dipole and the loop antennas and the radiation mode varies with the pitch angle and the circumference of the helix. In particular, a helix with a pitch angle of 12 to 15^o and a circumference of about 1 λ, has a sharp directivity towards the axial direction of the antenna. This radiation mode is called the axial mode, which is the most important mode in helical antennas. Several studies have been carried out on the properties of the axial mode helical antenna with a finite reflector. The current induced on the helix is composed of four major waves, which are two rapidly attenuating waves and two uniform waves along the helical wire. These waves include the traveling wave and the reflected wave. Thus, in a conventional helical antenna, the uniform traveling wave will be dominant when the antenna length is fairly large, with typical versions such as a conical helix shown in **Figure 1 (A)** and a cylindrical helix in **Figure 1 (B).** A conical helix is interesting for L-band MSS enabling HPBW in the order of 100^o and circular polarization without hybrid gain of 4 to 7 dBi. Cylindrical antennas can be monofilar or multifilar, also suited for L-band MSS, while in a short-cut cylindrical helix antenna, the rapidly attenuating traveling wave will be dominant, especially in a two-turn (N = 2) helical antenna.

1. Conical Helix Antenna – This antenna can be regarded as a low-gain development of the cylindrical helix antenna and is suitable for wide-beam width applications with good efficiency. Thus, with suitable choices of cone angle and turn spacing, it is possible to achieve a beam width in the order of 100^o. This type of antenna can also achieve an input VSWR of 1.5:1 or better than 5% frequency bandwidth merely by incorporating a simple quarter-wavelength transformer. The typical size for an L-band application is in the order of 15 cm in length and the ground plane is about 20 cm in diameter. The resultant gain is approximately 4 to 7 dBi, which is between low and medium-gain requirements.

2. Two-Turn Cylindrical Helix Antenna – This antenna has two-turns of wires, forming a simple helical antenna solution with reflector, illustrated in **Figure 1 (C).** This model has relatively high antenna gain and excellent polarization characteristics for its size. Radiation patterns characteristically are calculated with respect to (E_0) and ($E_?$) planes. The gain of this antenna is 9 dBi and the axial ratio is about 1 dB, with reflector

Figure 1: Types of Helical Wire Antennas.



Source: Author.

diameter (d) around 1λ. Such types of antenna have comparatively high performance in spite of their small size and compact construction. From the above-mentioned considerations, a highly efficient antenna for the Inmarsat-M MES can be realized by applying this antenna to elements of an array antenna.

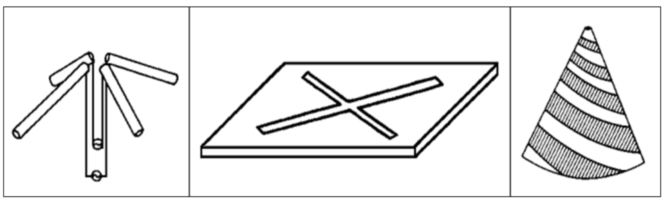
3. Five-Turn Cylindrical Helix Antenna – This antenna solution is illustrated in **Figure 1 (D).** The main electrical characteristics are: gain is 12.5 dBi of peak RHCP for Tx and 11.5 dBi for Rx; sidelobe level has value of about –13 dB; axial ratio is 3 dB; beam width of 3 dB has angle of –47^o; terminal G/T has –16 dBK and terminal EIRP has 29 dBW. This antenna solution is designed and developed by the European research institution ESTEC. In addition, stabilization of this antenna is obtained by gravity elevation on double-gimbaled suspension. The pendulum aligns itself with the vertical when not subject to other acceleration. However because the centre of rotation of the pendulum is distant from that of the ship pitch and roll movement induces horizontal acceleration to which the pendulum is sensitive. In order to limit perturbations, the resonant frequency of the pendulum must be low with respect to the excitation frequencies in pitch and roll and the damping (friction) must be minimum. Low resonance frequency is achieved by minimizing the distance between the centre of gravity of the rotating part and its centre of rotation. This also reduces torque due to horizontal acceleration but at the same time reduces the stabilizing torque due to gravity.

5. Inverted V-Form Cross Dipole Antenna.

The inverted V-type Crossed Dipole Antenna is an advanced circularly polarized antenna with tick V-elements, which is illustrated in **Figure 2 (Left).** Thus, the resonance of this antenna structure is obtained when the length is somewhat shorter than a free-space half wavelength. In such a way, as the thickness is increased, the resonant length is reduced. Circular polarization of antenna can be produced by a pair of orthogonally positioned dipoles driven in Quadrature phase with equal amplitudes. The crossed-dipole antenna arrangement cannot provide a good axial ratio off boresight because the radiation patterns for the straight dipole are different in both principal planes, called the H and E-planes. This shortcoming can be improved by modifying the straight dipoles to a no straight version, such as the V and U-forms.

The improved dipoles are called V and U-type dipoles. In fact, according to some conducted measurements, the U-type dipole provides better electrical performance than the V-type, though the V-type is simpler in mechanical structure and is less complex. The crossed-dipole can also produce circular polarization without using any external circuits, such as the hybrid component. Thus, the condition to excite the circularly polarized waves can be established by a balun and the self-phasing of four radiating elements. Two of the elements are at a 0^o phase angle and the other two are at an 180^o phase angle.

Figure 2: Types of Cross Dipole, Slot and Conical Wire Antenna Systems.



Source: Author.

The desired 90^o phase difference is obtained by designing the orthogonal elements such that one is larger relative to making it inductive, while the other is smaller to make it capacitive. This type of antenna is a good model for Ku-band aeronautical satellite communications.

6. Crossed-Slot Antenna.

These antennas are useful for L-band aeronautical satellite communications on high-speed aircraft because they are low profile in structure and suitable for a flush-mounting application, which is shown in **Figure 2 (Middle).** Thus, the slot antenna is circularly polarized and is complementary with the corresponding dipole antenna, so that the radiation pattern is the same as that for the horizontal dipole.There are only two differences: first is the property that the electric and magnetic fields are interchanged and second, is that the slot electric field component normal to the perfectly conducting sheet is discontinuous from one side of the sheet to the other because the direction of the field reverses.

In this case, the tangential component of the magnetic field is, likewise, discontinuous. This antenna can be also complementary with the corresponding crossed-dipole antenna, although the feeding method for the circular polarization is more complicated. On a model of this antenna known as a cavity-backed it needs one 90^o hybrid to produce the circular polarization. This feed technique is effective not only to suppress undesired coupling between the cross slots but also to match the input impedance over a wider frequency band.

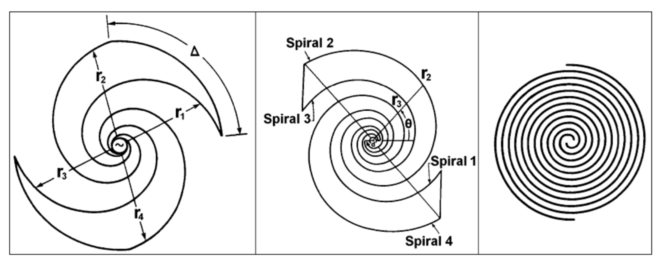
7. Conical Spiral Antenna.

This type of antenna has spiral wire elements on a cone with circular polarization and is suitable for L-band LMSC and GPS applications, while the bifilar version is also used in Ku-band satellite communications, see **Figure 2 (Right).** In comparison with a conical helix antenna, this type of antenna provides better performance and is more versatile, though the geometry is somewhat complex. Therefore, such an antenna is independent of frequency and its geometry can be presented mathematically in spherical coordinates (r, θ, Φ) as:

$$r = e^{a\Phi} g(\theta) \quad (1)$$

Where (a) and g(θ) are an arbitrary constant and angular function, respectively. Its radiation mechanism can be understood by regarding the two spirals as a transmission line. When two conductor arms are fed in antiphase at the cone apex, waves travel out from the feed point and propagate along the spirals without radiating until a resonant length has been traversed. Strong radiation occurs at that point and very little energy is reflected by the outer limits of the spiral. Conveniently, two conductor arms can also be fed directly at the centre point or apex from a coaxial cable bonded to one of the spiral arms without any external baluns because the spiral arm can itself act as a balun. In this case, a dummy cable may be bonded to another arm to maintain the symmetrical performance. If the width of arm is decreased to a narrow constant value, the arms can be formed by the cable alone.

Figure 3: Types of Spiral Wire Antenna Systems.



Source: Author.

8. Planar Spiral Antennas.

Cavity-backed planar spiral antennas are commonly divided into three main categories: equiangular, logarithmic and Archimedean spiral antennas. These types of antennas are well suited for flush mounting on aircraft for L to Ku-band satellite communications. In general, this antenna has been fed by using the external balun but it can also be fed at the centre point, or apex, from a coaxial cable bonded to one of the arms, without any external baluns, like the conical spiral antenna.

1. Equiangular Spiral Antenna – Its geometry corresponds to the special case of the conical spiral antenna, bifilar with logarithmic period, cavity-backed and can be obtained by substituting a $\pi/2$ into θ_0 to give:

$$r_1 = r_0 e^{a\Phi}; r_2 = r_0 e^{a(\Phi-\Delta)}; r_3 = r_0 e^{a(\Phi\pm\pi)}; r_4 = r_0 e^{a(\Phi-\Delta\pm\pi)} \quad (2)$$

This antenna needs no external hybrid circuits to produce circular polarization and the example shown in **Figure 3 (Left)** can radiate LHCP waves outward from the page and RHCP waves into the page when the pair of spirals is excited in antiphase at the centre.

Otherwise, according to experimental measurements, the axial ratio is near unity and the HPBW is in the order of 90^o over a decade bandwidth or even more. As for the input impedance the resistive part on the thickness of the antenna elements and thin elements lead to high impedance values.

This implies that the impedance depends on the arm width when the structure is planar. If the angular extent (Δ) is chosen to be 90^o, the geometries of the arm and the space between arms are identical, except for a rotation of 90^o around an axis. The structure is defined as self-complementary, just like the conical spiral antenna but it should be noted that the planar spiral antenna has a constant impedance of 60π [Ω] for the two arm configurations.

2. Logarithmic Spiral Antenna – This spiral bifilar antenna design with logarithmic period and cavity-backed, is shown in **Figure 3 (Midle)**, and can be presented mathematically by:

$$r_1 = a^{\Phi}; r_2 = a^{(\Phi-\Delta)}; r_3 = a^{(\Phi\pm\pi)}; r_4 = a^{(\Phi-\Delta\pm\pi)} \quad (3)$$

This antenna can radiate RHCP waves outward from the page and LHCP waves into the page without any external hybrid circuits, as a pair of spirals is excited with an antiphase at the centre.

3. Archimedean Spiral Antenna – The Archimedean spiral thin-wire bifilar cavity-backed antenna, shown in **Figure 3 (Right),** is another geometry of the planar spiral. This antenna has superior bandwidth properties when fully optimized and typically consists in a pair of thin wire arms, of which the geometry can be presented by:

$$r_1 = r_0\Phi; r_2 = r_0(\Phi - \pi) \quad (4)$$

This antenna also needs no external hybrid circuits to produce circular polarization and can radiate RHCP waves outward from the page and the LHCP waves into the page if the pair of thin wire arms is excited in antiphase at the centre.

It is a broadband antenna and has properties similar to the standard planar spiral antenna, although it is not theoretically a frequency independent structure. When placed in a quarter-wave cavity, this antenna can achieve near-octave bandwidth, even when the cavity consists in a metal-based cylinder without any absorber.

Thus, if an absorber-loaded cylinder is employed in the cavity, a greater-than decade bandwidth may be achieved, although about half the power is dissipated into heat by the absorber.

A typical Archimedean spiral antenna has an octave bandwidth for a VSWR less then 2, an axial ratio of less then 2 dB and a beam width of about 70^o, while a gain of 7 to 8 dBi is achieved without an absorber. The structure has several mechanical advantages: it is compact and fairly simple to construct and the spiral arms can be easily fed, using a suitable impendence-transforming balun.

Conclusions.

The modern design, configuration and characteristics of MSA are very important for implementing successful MSC and networks for all mobile applications. The good merit of antenna, physical and technical parameters are the prerequisite to provide compact and lightweight MSA for implementing in the harsh environments and very extreme operating temperatures.

The convenient MSA structure can be selected among the size of the network, location and environment where it is going to be used. In fact, will be also necessary to establish a compromise between these parameters constrained by the radiation characteristics of certain antenna type.

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