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Design and Types of Array Mobile Satellite Antennas (MSA)

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ABSTRACT

This paper outlines the state-of-art of Array Mobile Satellite Antennas (MSA) and describes their designs, benefits and specific impacts in Mobile Satellite Communications (MSC). 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 and other Geostationary Earth Orbit (GEO) and Non-GEO current and forthcoming MSC 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.

Mobile Satellite Antennas (MSA) systems are the most essential component of any wireless and satellite communication system. Signal distances are greater because Geostationary Earth Satellites (GEO) is located at higher altitudes. As a result, route loss increases and signal power levels decrease. Mobile Satellite Communication (MSC), such as for maritime, land (road and rail) are becoming increasingly popular in today's modern MSC system.

In order to effectively cover the required operational bands, the future MSA structures must fulfill multi-band or wideband standards and provide better transmission and propagation effect. In fact, the succcesful and effective design of the antenna array doubles exponentially as the number of operating frequency bands increases, while the mobile antenna array must be compact enough to be effectively positioned within the satellite propagation channels.

Thus, antenna array design problems double exponentially as the number of operating frequency bands increases. Moreover, the antenna array must be compact enough to be positioned efficiently within the MSC networks. In today's development technologies, there is more bandwidth necessary to send and receive more information, thus increasing bandwidth and reduced, and in such a way, antenna array size is a hot topic of study. Due to its low-profile construction and smaller size, microstrip patch array antennas are becoming increasingly desirable in satellite applications.

As a result, MSA systems are fully compatible with built-in antennas in portable devices such as mobile telephony, mobile satellite TV, mobile satellite technology, satellite broad-

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band etc. With satellites, antenna chompcakes for tracking and communication must be narrow and conformal and are widely used. Patch antennas made of microstrip. Their main advantages are light weight and minimum size volumes, as well as a low-profile antenna with a planar arrangement.

Therefore, the different MSA parameters such as directivity, gain and bandwidth can be extremely poor, according to previous abalizes and research. On that plan, were taken intensive attempts to build an antenna for satellite applications, with array elements added in either a parallel or series arrangement. Consequently, a microstrip antenna was selected as the array element and used in a 2x4 array configuration. In addition, various array topologies such as cross-slot, cross-dipole and other arrays are recognized due to their high directivity and increased signal-to-noise ratio.

2. Types of Mobile Satellite Antennas (MSA).

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

1. Shipborne MSA - The different types of shipborne MSA for Maritime Mobile Satellite Communications (MMSC) were developed for installation on board ocean-going ships and inland sailing vessels, on sea platforms and other offshore infrastructures. These antennas must have strong and rugged constructions, with corresponding mechanical and electrical particulars. The Inmarsat Ship Earth Station (SES) is the inheritor of the first generation of MSA, while where developed many other standards, using the third and fourth of Inmarsat satellite constellation.

2. Vehicleborne MSA- This 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).

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

4. Transportable MSA - Inmarsat developed special transceiving satellite antennas, which can be integrated into mobile Transportable Earth Stations (TES) of Inmarsat-B, C, M, mini-M and Broadband terminals.

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

6. Other Types of MSA - The other solutions for MSA are as follows: receiving broadcast radio and TV MSA, Global Navigation Satellite Systems (GNSS) MSA and transceiving broadband MSA, Digital Video Broadcasting - Return Channel via Satellite (DVB-RCS) MSA and MSA for Communications, Navigation and Surveillance (CNS) equipment.

3. Basic Array Antenna.

Several different type of antenna can be arrayed in space to make a directional pattern or one with a desired radiation pattern. This type of integrated and combined antenna is called an array antenna consisting in more than two elements, such as microstrip, cross-slot, cross-dipole, helixes or other wire elements and is suitable for MSC. Each element of array is excited by equal amplitude and phase and its radiation pattern is fixed.

3.1. Microstrip Array Antenna (MAA).

The type of MAA is a nine-element flat antenna, disposed in three lines spaced at 94 mm, namely about a half wavelength at 1.6/1.5 GHz and whose antenna volume is about 300 x 300 x 10 mm, see **Figure 1 (A).** As shown in this figure, the element arrangements of the MAA solutions are 3 x 3 rows square arrays in order to obtain similar radiation patterns in different cut planes. The MAA beam scanning is performed by controlling four-bit variable phase shifters attached to each antenna element. This type of antenna is very applicable for the MES Inmarsat-M and the Inmarsat-Aero standard.

3.2. Cross-Slot Array Antenna (XSA).

The XSA antenna is a 16-element solution with 97 mm spacing and their volume is about 560 x 560 x 20 mm, shown in **Figure 1 (Left)**). Evident is the element arrangement of the XSA, which is a modified 4 x 4 square array in order to obtain similar radiation patterns in different cut planes.

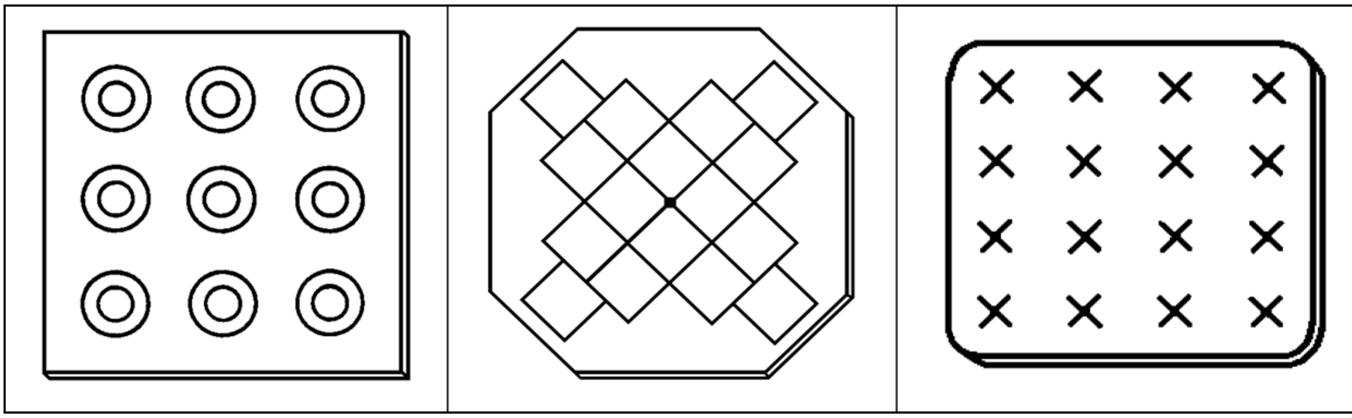
3.3. Cross-Dipole Array Antenna.

This antenna is composed of 16 crossed-dipoles fed in phase with a peak gain of 17 dBi and with the feeding circuit behind the radiating aperture, shown in **Figure 1 (Middle).** The main electrical characteristics of this antenna are: gain is 15 to 17 dBi with peak RHCP transmit; axial ratio has a value of 0.7 dB; beam width of 3 dB is -34^o; terminal G/T is –9.5 dBK and EIRP terminal value is 32 dBW. Otherwise, the antenna system consists in a stabilization mechanism for tracking, flat antenna array, diplexer, HPA and LNA, which are all protected by a plastic radome. Stabilization of the antenna is obtained by a single-wheel gyroscope, when the azimuth pointing is controlled by the output from the ship's gyrocompass. Similar to the previous two models, this antenna is also suitable for maritime and aeronautical applications.

4. Four-Element Array Antennas.

There have been several four-element antenna models developed, such as Yagi-Uda, Quad-Helix and four elements SBF array.

Figure 1: Microstrip, Cross-Slot and Dipole Array Antennas.



Source: Author.

4.1. Yagi-Uda Crossed-Dipole Array Antenna.

This array antenna has been developed for use on board ships and is protected with a radome, shown in **Figure 2 (Right)**. The feeder of this antenna is a simple formation of four in-line crossed-dipoles fixed in the middle of the reflector. This endfire array has circular polarization and the gain is between 8 and 15 dBi.

4.2. Quad-Helix Array Antenna.

The quad-helix array antenna is composed of four identical two-turn helical wire antennas in the shape of a square and whose elements are oriented in the manner illustrated in **Figure 2 (Left)**.

According to previous studies, the effect of mutual coupling between each element of this antenna is not negligible and this mutual coupling mainly degrades the axial ratio. The axial ratio of a single helical antenna is about 1 dB but this value is degraded to about 4.5 dB in the case of the array antenna with array spacing of 0.7λ. However, the best properties of antenna gain and axial ratio can be obtained at a rim height of about 0.25λ. The antenna gain is improved by 0,4 dB and the axial ratio is also improved by 3.5 dB, compared to that of the quad-helix array antenna without rims.

he performance characteristics of this small antenna are essentially, gain is about 13 dB (HPBW is 38^o) and aperture efficiency is about 100%. It appears that this type of helix-integrated antenna is also well suited for the shipborne Inmarsat-M standards.

4.3. Four-Element SBF Array.

This antenna is developed on the basis of a conventional SBF antenna as an integrated array with four SBF elements, see **Figure 2 (Right)**. The antenna provides high aperture efficiency, circular polarization and almost high-performance gain between 18 and 20 dBi. Because of the high gain characteristics, this array is very suitable for maritime applications as a shipborne antenna.

5. Spiral Array Antenna.

Directional antennas for Land Mobile Satellite Communications (LMSC) have been expected to provide voice and HSD links not only for long haul tracks but also for private cars. From that point of view, cost is an important factor to be taken into account in designing antenna systems. In the early stage of LMSC, a mechanical steering antenna system was considered the best candidate for vehicles, however, it will be replaced by a phased array antenna in the near future because it has many attractive advantages, such as low profile, high-speed tracking and potential low cost.

The mechanical steering antenna with eight spiral elements and with adopted closed loop tracking method gives about 15 dBi in system gain, shown in **Figure 3 (Left)**. The antenna is 30 cm in radius, 35 cm in height and 1.5 kg in weight. The array consists in 2 x 4 spiral elements and it forms a fan beam with a half-power beam width of 21^o in the azimuth and 39^o in the elevation plane at L-band. Its peak gain is about 15 dBi, including the feeder losses, and is suitable to track the satellite for MSC, because elevation angles to the satellite are not as varied as those of the azimuth angles. In effect, the antenna beam direction can be shifted in two azimuth directions, from the E or W side, by switching the pin diode phase shifters. Consequently, the difference between the received signals in both directions is used to drive the antenna system towards the satellite. The beam-shifting angle is set to approximately 4^o.

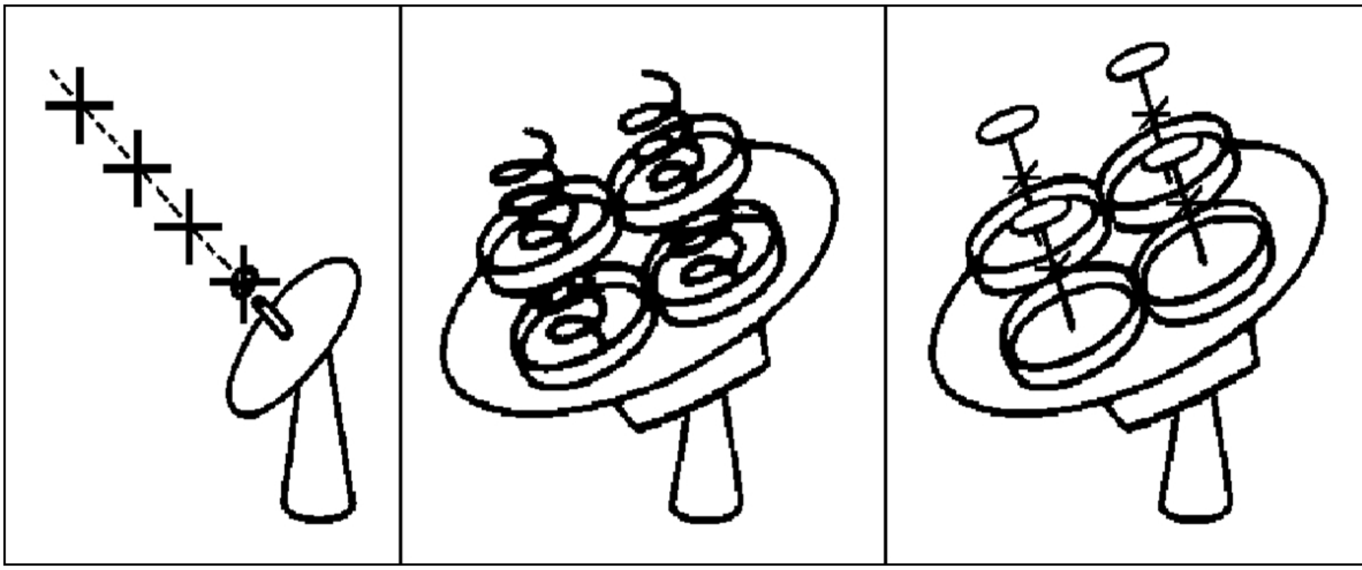
6. Patch Array Antennas.

The main feature of the future MSC will be portability, which means that a person can directly access the satellite to establish a link using a very small TES transceiver with antenna system. Even in the present Inmarsat L-band system, great efforts have been made to develop transportable and portable terminals with corresponding antennas.

6.1. Two-Patch Array Antenna.

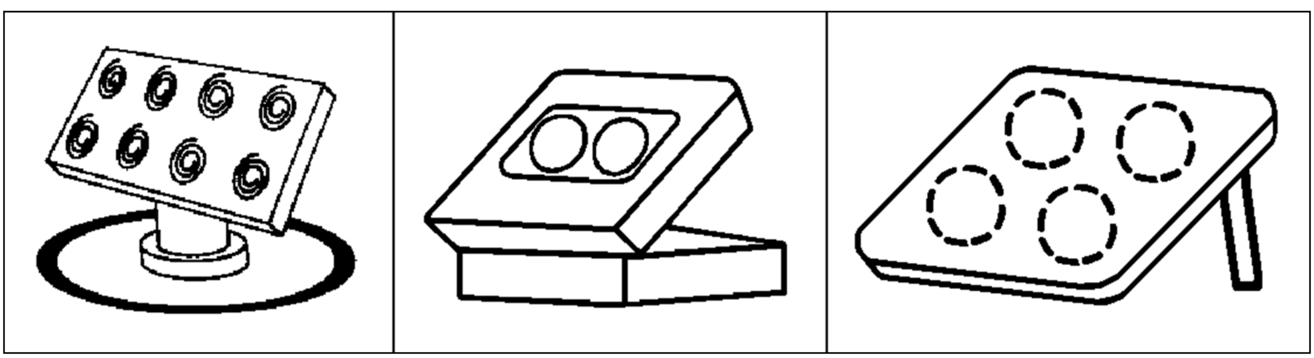
This antenna for TES and briefcase portable terminals is developed in the Inmarsat and ETS-V programs, see **Figure**

Figure 2: Types of Four-Element Array Antennas.



Source: Author.

Figure 3: Types of Spiral, Two and Four-Patch Array Antennas.



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3 (Middle). This antenna has two microstrip patch elements (one for Rx and another for Tx), gain is 6 dBi, EIRP is 6 dBW and G/T is –21 dBK. The reason for adopting separate Rx and Tx antennas is to eliminate a diplexer, which is too large and heavy for a compact and lightweight terminal. The antenna beam width on the lid is wide enough to point to a satellite by manual tracking. Two microstrip patch array antennas mounted on the lid of the briefcase TES transceiver for low-speed data transmission serves the Inmarsat and ETS-V TES terminals.

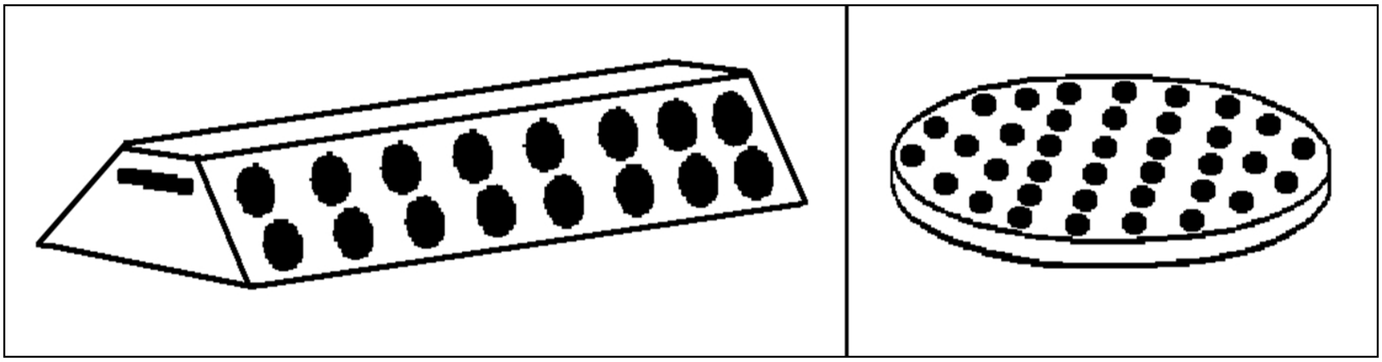
6.2. Four-Patch Array Antenna.

Several four-element patch array transportable antennas were developed for universal Inmarsat-C and other TES terminals. On the other hand, JPL and NASA designed similar L-band types of mobile antennas, mainly for LMSC for regional utilities in the placecountry-regionUSA. These include a mechanically steered, tilted 1 x 4 patch array and two electrically steered planar-phase array antennas. Otherwise, the mechanically steered four-square patch arrays can be fixed in one line, similar to two-patch array, or can have the shape of a four-circular patch array manually steered antenna, which arrangement is shown in **Figure 3 (Right).**

All three of these medium-gain antennas feature beams that are narrow in azimuth angle, hence, they require azimuth steering to keep the beam pointed toward the desired satellite as a mobile changes its azimuth orientation. They provide 9 to 12 dBi gain, reject multipath signals outside their beam pattern and allow two satellites separated by 30^o in a GEO arc to reuse the same frequency to cover the continental US region.

A dither-tracking four-element, circular, polarized array for Aeronautical Mobile Satellite Communications (AMSC)/MSAT terminals has been designed, 10.16 cm high, 50.8 cm in diameter, with 20 – 60° elevation coverage and with a minimum of 10 dBi gain. This antenna employs a kind of closed-loop for tracking the satellite in azimuth. The rotating antenna platform is mounted on the fixed platform that includes the motor drive and pointing system hardware.

Figure 4: Types of Aeronautical and Maritime Phased-Array Antennas.



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7. Phased Array Antenna.

Phased array antennas were developed for maritime, land and aeronautical applications to provide a design for a thin antenna that can be installed on land vehicles and aircraft. Otherwise, these mobile antennas were developed initially for aircraft and are well known for their complexity and high cost. As a result, emphasis was placed on the selection of manufacturing techniques, materials and component types, in addition to meeting the RF and pointing requirements and keeping the cost down.

As mentioned previously, the radiation pattern of an array antenna is fixed, however, the radiation pattern can be scanned in space by controlling the phase of the exciting current in each element of the array. This type of antenna is called a phased array antenna, which has many advantages in terms of MSC applications such as compactness, light weight, high-speed tracking performance and potentially, low cost.

7.1. Airborne Phased-Array Antenna.

A directional medium-gain antenna is considered a key technology in AMSC. This type of antenna was developed and tested by CRL for the ETS-V program. At the same time, Inmarsat approved all aeronautical antenna standards for installations on board commercial and military aircraft. Taking account of the electrical and mechanical requirements of AMSC, a phased array with low-profile antenna elements was chosen for a directional main antenna, while a microstrip antenna was chosen as an antenna element because of its very low profile, very light weight and mechanical strength, which satisfy the requirements for airborne antenna.

However, one disadvantage is the very narrow frequency bandwidth, usually 2 to 3%. The antenna adopted is a two-frequency resonant element because it provides a compact array and a simple feed line configuration. On the other hand, this type of antenna has very poor axial ratio values. The problem was overcome by using the sequential-array technique, where a thin substrate with high dielectric constant is used over a wide frequency bandwidth with excellent axial ratios. The microstrip phased-array antenna is mounted on top of the fuselage and has two planes with 16 circular patch elements, 2 of which are in elevation and 8 in azimuth, see **Figure 4 (Left).** In practice, the required coverage angles are as narrow as +20^o, so the beams are not steered in elevation directions and the array plane is set at 65^o to the horizon in order to optimize the beam coverage on the flight routes.

Thus, by controlling eight 4-bit digital phase shifters, the antenna beam scans in a 4^o step with +60^o with respect to a line perpendicular to the axis of the aircraft. In addition, a step track method was adopted to track the satellite. Therefore, this array has the following characteristics: 2 L-band Tx and Rx frequencies; polarization is LHCP; gain is 14.7 dBi for Tx and 13.5 dBi for Rx; EIRP is about 30 dBW, G/T –10.8 dBK, the axial ratio is about 2 dB, volume is 760 (l) x 320 (w) x 180 (h) mm and the weight is 18 kg.

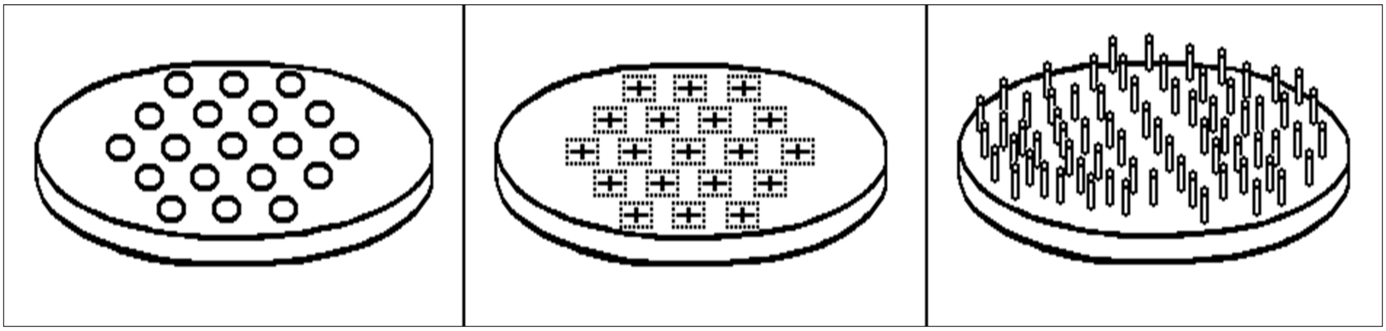
7.2. Shipborne Phased-Array Antenna.

The new shipborne phased-array antenna for MMSC has been developed for utilization on board big ocean-going vessels. Besides other directional types of shipborne antenna, this unit is designed to serve as Above Deck Equipment (AD)E of the Nera F77 transceiver or other brand SES for new Inmarsat Fleet 77 service. The Nera F77 antenna is a mechanically steered circular disc with 32 low-profile radiating elements arranged in two circles with 16 and 12 elements and 4 elements are located in the middle of the disc, which is illustrated in **Figure 4 (Right).** The ADE unit can be mounted on a mast or directly on the deck and is covered by a radome. The dimensions of antenna mast mount are 180 x 132 cm with a weight of 65 kg and deck-mounted antennas are 108 x 91 cm and 50 kg in weight. The gain of the antenna is about 15 dBi in both transmission satellite links.

7.3. Vehicleborne Breadboard Phased-Array Antenna.

The breadboard mobile phased-array antennas have been developed in the USA to meet the L-band frequency requirements, 20^o to 60^o elevation and full 360^o azimuth angles of special coverage, gain of 10 dBi above 30^o in elevation and 8 dBi at 20^o in elevation, half-power bandwidth of 25^o in azimuth and 35^o in elevation, anti-satellite signal isolation of 20 dB between two GEO separated by circa 35^o and beam pointing accuracy of +5^o.

Figure 5: Types of Breadboard Phased and Adaptive Array Antennas.



Source: Author.

This antenna with all the radiated elements, hybrids, diode phase shifters, pin diode drivers and power/combiner driver (except diplexer) can be mounted on the roof of a land vehicle cabin. Thus, based on the research experiments of the airborne phased-array antenna, a new phased-array car antenna has been proposed by Communications Research Laboratory (CRL). The antenna was installed on a test van and tracks the ETS-V satellite at an elevation angle of 47^o. The receiving signal from the satellite was almost constant except for shadowing and blocking effects. The gain of this antenna is 10 and 18 dBi for elevations of 30^o and 90^o, respectively, the system temperature is about 200^oK, axial ratio is 4 dB for 30^o of elevation, the volume is 60 x 4 cm and weight is 5 kg.

Two phased-array antennas were developed for LMSC: Ball and Teledyne designs illustrated in **Figure 5 (Left and Middle)**, respectively. Each antenna consists in 19 low-profile radiating elements, with 18 3-bit diode phase shifters. The Ball model uses dual resonant stacked circular microstrip elements to cover both the Tx and Rx bands, while the Teledyne model employs stripling crossed-slot radiators.

For the antenna's beam-pointing system, the initial acquisition of the satellite is accomplished by a full azimuth search for the strongest received signal. An angular rate sensor is used to establish an inertial reference point when the acquisition is performed while the mobile is turning.

Tests show that the antenna can acquire a reference pilot signal in two seconds from a random spatial position. After the desired satellite signal has been acquired, the antenna tracks the satellite by a closed-loop sequential lobbing technique. In the event of severe signal fade due to shadowing, the sequential lobbing can no longer function properly. In this case, the open-loop angular rate sensor takes over the pointing for a 10 sec period, until the sensor drifts away. This antenna with all the radiated elements, hybrids, diode phase shifters, pin diode drivers and power/combiner driver (except diplexer) can be mounted on the roof of a land vehicle cabin. Thus, based on the research experiments of the airborne phased-array antenna, a new phased-array car antenna has been proposed by CRL. The antenna was installed on a test van and tracks the ETS-V satellite at an elevation angle of 47^o. The receiving signal from the satellite was almost constant except for shadowing and blocking effects. The gain of this antenna is 10 and 18 dBi for elevations of 30^o and 90^o, respectively, the system temperature is about 200^oK, axial ratio is 4 dB for 30^o of elevation, the volume is 60 x 4 cm and weight is 5 kg.

8. Adaptive Array Antennas.

The antenna for the MSAT program of LMSC was developed by the Canadian CRC. Linearly and circularly polarized arrays with gain values of 9–11 dBi and 10–13 dBi, respectively, have been designed and evaluated in trials using the ex-Marecs-B satellite. Both antennas use L-band with spatial coverage of 15^o to 50^o elevation and 360^o azimuth angles. The satellite tracking is initially acquired with a closed-loop method of stepping through 16 azimuth beam positions and selecting the beam with the strongest signal. In the event that the signal falls below a given threshold, the acquisition sequence is again initiated until the signal is required. The speed of operation is determined by the terminal C/N_0 ratio and the value of S/N requirements in the control loop bandwidth, which takes 0.1 sec to acquire the satellite after an initial phase look. Satellite Tracking is performed by periodically switching on either side of the current beam position, selecting the beam with the strongest signal. A number of algorithms have been devised to minimize any perturbation of the communications signal to less than 1% of the time. The main characteristics of this type of antenna are as follows: operating RF is from 1.530 to 1.660 GHz; spatial coverage is 15^o to 50^o elevation and 360^o azimuth; gain is 9 to 11 dBi for linear and 10 to 13 dBi for circular model and the size of both models is about 61 cm diameter, while the linear is 6.3 cm and circular is 20.3 cm high, respectively. The maximum phase transients in azimuth can be kept to less than ± 10^o over the required angular coverage and operating frequency band.

1. Linearly Polarized Adaptive Array Antenna – This antenna consists essentially in a driven quarter-wave monopole surrounded by concentric rings of parasitic elements all mounted on a ground plane of finite size. The parasitic elements are connected to the ground through pin diodes. With the application of suitable biasing voltages, the desired parasitic elements can be activated and made highly reflective.

The directivity and pointing of the antenna beam can be controlled both in the elevation and azimuth planes using high-speed digital switching techniques. The use of a circular polarizer in the linearly polarized design can realize an increase in gain at the expense of an increase in antenna height. The polarizer has an elliptical cross-section, a diameter of 40 cm and a height of20 cm. It consists in a number of conformal scattering matrices to achieve the 90^o differential phase shift between two orthogonal polarizations. Part of a five-ring linearly polarized antenna is shown in **Figure 5 (Right).** This linearly polarized adaptive array antenna incorporates sufficient electronics to control the radiation patterns and pointing on command. It is designed to serve MSAT and AMSC transceivers and to be mounted on the metallic roof of a vehicle, where the effective ground plane can significantly enhance antenna gain at low elevation angles.

2. Circularly Polarized Adaptive Array Antenna – This type of adaptive array is similar to linear adaptive array and hence, is obtained by adding the linearly polarized array.

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.

References.

[1] Aragón-Zavala A. at al, "Antennas and Propagation for Wireless Communication", John Wiley, Chichester, 2008.

[2] Calcutt D. & Tetley L. "Satellite Communications: Principles/Applications", Edward Arnold, London, 1994.

[3] Evans B.G., "Satellite Communication Systems", IEE, London, 1991.

[4] Fujimoto K. & James J.R. "Mobile Antenna Systems Handbook", Artech House, Boston, 1994.

[5] Gallagher B. "Never Beyond Reach", Book, Inmarsat, London, 1989.

[6] Mukhopadhyay M, "Adaptive Array Antenna for Mobile and Satellite Communication", Createspace Independent Publishing Platf, Scotts Valley, California, US, 2016.

[7] Inmarsat, "Inmarsat Aeronautical Services Reference Manual", Inmarsat, London, 1995.

[8] Inmarsat, "Inmarsat Maritime Communications Manual", Issue 4, Inmarsat, London, 2002.

[9] Group of Authors, "Saturn 3 standard-A Installation / Operator' Manuals", EB, Nesbru, 1986.

[10] Huurdeman A.A., "Guide to Telecommunications Transmission Systems", Artech House, Boston-London, 1997.

[11] Ilcev D. S. "Global Mobile Satellite Communications for Maritime, Land and Aeronautical Applications", Springer, Boston, 2005.

[12] Law E.P. "Shipboard Antennas", Artech, 1983.

[13] Maral G. & others, "Satellite Communications Systems", John Wiley, Chichester, 1994.

[14] Ohmory S., Wakana. H & Kawase S. "placeMobile Satellite Communications", Artech House, Boston, 1998.