Future Trends: Satellite Communication Antennas – A Review

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Abstract - This paper describes the future trends in satellite communication antennas and the trend for ever-increasing capacity, flexibility and availability of service, as well as increasingly more affordable, more compact, lighter, and even more stylish. The implementation of PIM-free multiband antennas, Reconfigurable antennas and Active direct radiating Array (ADR) are reviewed. The goal has been to design smart antenna for satellite communications.

Keywords: Antennas, Satellite, Reconfigurable, Array, Multiband.

I. INTRODUCTION

Demands of the very latest satellite applications have meant that antenna designers have had to be extremely innovative when design their products. The first satellites used Omni-directional antennas, mainly due to the inability to stabilize the spacecraft. As stabilization techniques improved higher-gain antennas were utilized: horns, small reflectors, arrays, then larger solid reflectors, then even larger reflectors that require deployment, then mesh and membrane deployable. Integrating multiple functions into one antenna system also involves sub reflectors with frequency selective surfaces and feed arrays.

Future antenna technologies are organized into various categories below;

1.1 Increased Power Levels

The DC power capability of spacecraft platforms is always increasing as new solar array and battery technologies evolve and become more affordable. More power available on the satellite allows for ever improving link budgets, and payloads that fully use this capability become a necessity.

For satellite antennas this means a greater number of antennas on board (maintaining the thrust towards compact low-mass designs) and higher transmits (down-link) RF power levels with the consequent power handling issues. These include more challenging multifactor and Passive Inter Modulation (PIM) requirements as well as more efficient thermal management solutions.

Multipactor is an electron avalanche phenomenon that can be established in a vacuum between two surfaces when certain conditions are met, often meaning a relatively high voltage across a relatively small gap (measured in terms of the wavelength). This phenomenon can inflict serious permanent damage to the on-board equipment, and must, generally, be avoided. Meeting future Multipactor requirements will not solely hinge on developing new designs with higher threshold voltages. It will also necessitate a better understanding of the phenomenon in multi-carrier environments as is usually the case in communications satellites, more accurate modeling, more extensive testing facilities and a more pragmatic approach to the requirements specifications.

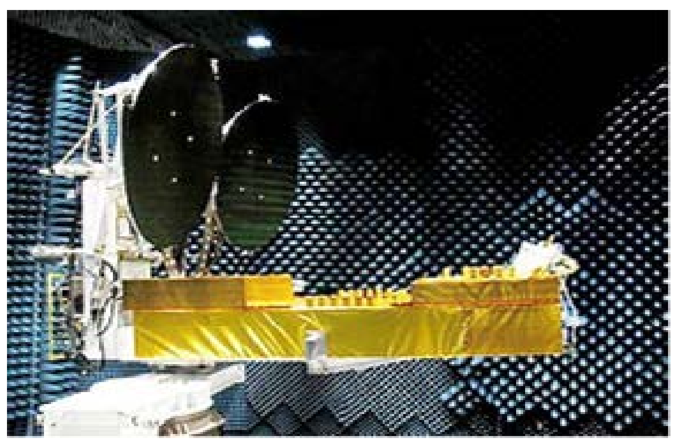

Fig 1.1 Multibeam Ka-band Antenna

Passive Inter Modulation occurs when multiple transmit RF carriers propagate in a non-linear medium, such as is obtained, for example, when dissimilar materials are put in physical contact with each other. The PIM products represent an undesired noise that interferes with the intended communications signals and might prevent the achievement of the required signal-to-noise levels. The challenge associated with PIM under higher power levels will be compounded by the extended operating frequency bands of future systems. Wider frequency bands enable the occurrence of lower order passive inter modulation products, generally implying a much stronger level for the PIM signals.

1.2 Wider Bands + V-Band

Higher capacity systems call for increased bandwidths, and since the level of difficulty when designing antennas increases with the bandwidth as a percentage of the center frequency, higher center frequencies are necessary. The Ka-band market is still growing, but higher frequencies such as V-band offer significant potential for increasing system capacity and is now starting to be exploited. The IEEE definition of V-band is 40 to 75 GHz, but for communications satellites this usually means transmit (down-link) signals in the range of 40-46 GHz and receive (up-link) signals in the range of 48-56 GHz.

Although the bandwidths as a percentage of the center frequency are generally lower at V-band, many other aspects are harder to achieve than at Ka-band (tighter manufacturing tolerances, higher RF losses, higher atmospheric propagation losses, much higher losses due to precipitation, and lower efficiency electronics, among others). Consequently, while the required V-band technological advancements are being pursued, cheaper Ka-band systems will continue to be preferred in the near future, as long as the frequency spectrum remains available. The first commercial use of V-Band may well be in gateway links for multibeam Ka-Band missions, replacing the currently used Ka-Band gateway links, and thus increasing the Ka-Band spectrum available for the user beams.

1.3 Combined Frequency Bands

As stated previously, satellite platforms are becoming increasingly more powerful, and their power/volume ratio is increasing. Consequently, missions are becoming limited by the real-estate available to mount antennas on a spacecraft. Combining antennas to save spacecraft real-estate and increase spacecraft revenues has become one of the trends, expected to last and intensify way into the future.

Combining Tx and Rx into the same antenna is already a prevalent feature of modern satellite designs, and this tendency will continue and strengthen in the future and will also lead to antennas combining more than one frequency band. The corresponding design challenges are already the object of many R&D projects around the world. The implementation of PIM-free multiband antennas will call for advanced low-loss multiplexer technologies such as the triplexers and quadruplexers that have been required on some recent programs.

1.4 Larger Reflectors

Ever increasing gain requirements will call for ever increasing antenna aperture sizes, which can be most efficiently achieved with reflector antenna configurations. Unfurlable mesh reflectors are commercially available, have already been used in many satellite missions and, although their price is high, they are currently the most practical means to implement these large aperture diameters.

The reflector diameter range covered by this technology is currently between 6m and 22m, although even larger reflectors will likely be available in the future. For Ku-band and higher frequency bands, the need for smaller diameters and for tight reflector surface tolerances has so far been fulfilled by solid reflector technology, often using Carbon Fiber Reinforced Plastic (CFRP) construction. Their size is currently limited, by the volume available inside the launch vehicle fairing, to about 3m in diameter.

High accuracy reflectors in the range of diameters between 3 and 6m have not yet been developed, and are likely to be required by future wideband multiple spot beam applications. Some additional folding and deployment may be required for the larger reflectors in this diameter range so as to fit within the allowable stowed envelope, once the spacecraft volume limit or the launch vehicle fairing dimensional limits are reached. In this case, the reflector may be built as several deployable solid parts rather than one single solid reflector structure. These larger solid reflectors may also incorporate semi-rigid parts into their construction.

1.5 Reconfigurable Antennas

The need for in-orbit re configurability has been gaining momentum in FSS/DBS communications satellites over the last few years. Operators would like to have the ability to reconfigure their spacecraft in orbit in order to cope with changing traffic requirements, or to be able to re-assign the spacecraft to cover a different service area or the same region from a different orbital location. These needs are accentuated by the long mission life of modern satellites, commonly reaching 15 years or more.

The market demands evolve substantially during that time and the original satellite configuration may no longer be optimal to meet them during the later stages of the mission. The design challenge is accentuated by the fact that, although operators are always keen on getting more flexibility, they do not necessarily want to pay substantially more, nor increase the risk profile of their program, in order to obtain this flexibility. Reconfiguring an existing satellite, if such capability has been built into the design from the start, is usually the most economical and less risky approach to meet evolving market demands.

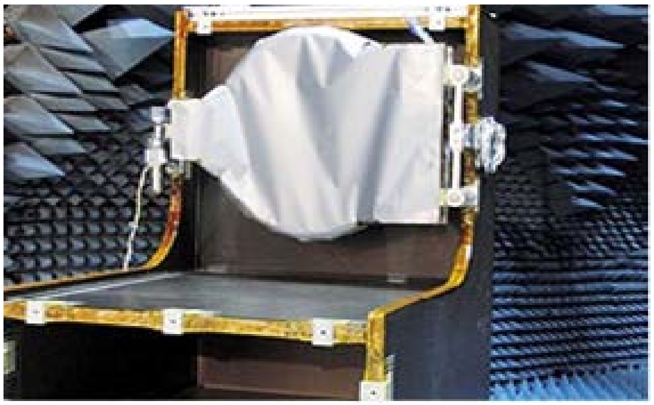

Fig 1.2 Mechanically Reconfigurable Antenna

Antennas can be reconfigured by mechanical means (whereby the original antenna configuration is typically modified by rotating, translating or mechanically changing the shape of a reflector or sub-reflector), by fully electronic means, or by using hybrid solutions that combine the two types of re configurability. Concepts using controllable reflect arrays have also been extensively studied and the technology may eventually become sufficiently mature for use in a commercial communications satellite.

1.6 Active Direct Radiating Array Technologies (DRA)

Active Direct Radiating Array (DRA) antennas offer the potential for unequalled coverage flexibility from space, with significant commercial returns. However, they currently have high complexity, risk, and cost, and consequently are often bypassed in favour of more established lower-cost technologies, such as reflector-based architectures. This is especially true for geo-stationary (GEO) satellites, where reflector antenna solutions offer unparalleled technological maturity and are therefore hard to displace for many of the existing and planned missions.

For Medium-altitude Earth Orbit (MEO) satellites, and especially for Low-altitude Earth Orbit (LEO) missions, active arrays have already become the solution of choice in cases where wide angles of scan and moderate gain levels are required, consistent with a limited number of radiating elements (typically in the order of one hundred elements). For GEO applications a much higher gain requirement would mean a much greater number of radiating elements; however the small scan angles involved from GEO allow for a greater inter-element separation and for the use of sparse array concepts so as to limit the number of elements and the number of active controls across the array aperture.

In order to decrease risk and cost, a modular approach to building the array, comprising highly integrated tiles (incorporating RF radiating elements, feed networks and amplifiers, as well as power and control signal distribution and also structural and thermal management functions), is a promising strategy that greatly advances the feasibility of GEO based active DRAs. Advances in enabling technologies, which may include semiconductor technologies leading to higher RF power levels and higher DC-to-RF power conversion efficiencies, alternative beam forming technologies such as optical beam forming, cheaper and highly integrated electronics, low-loss phase shifting technologies such as those using Micro Electro Mechanical Systems (MEMS) or others, and so on, will make active DRA solutions increasingly more attractive in the future.

Fig 1.3 Array Antenna in satellite

Future satellite communication systems will satisfy the commercial user by providing seamless connectivity anywhere, in any weather, with five nines (99.999%) service availability, high-throughput broadband services, and this will be made possible with reconfigurable satellite antenna systems that adapt on an hourly basis to the often geographically predictable changes in user demand.

Following this introduction is a literature review, then a discussion of trends, followed by a discussion of future challenges, and finally a summary conclusion.

II. LITERATURE SURVEY

The Space Antenna Handbook [1] covers many aspects of antennas for space applications. Reference [2] provides design information for a wide range of satcom services. Reference [3] is a comprehensive propagation guide above 1 GHz while [4] provides a thorough treatment of satellite communication systems engineering.

Reference [5] presents recent developments in multiple beam and reconfigurable antennas, [6] discusses advances in design concepts for ground station antennas, and [7] surveys advanced concepts for European spacecraft antennas. Recent advances in multi-beam array antennas are summarized in [8], [9].

The Iridium satellites make ex-tensive use of phased arrays [10], whereby each phased array development of a broadband and squint-free Ku-band phased array is detailed in [11]. In [12] the feasibility of Q-band is analysed through the definition of a novel simulation method of an aeronautical satellite multipath channel. Aircraft structural integration of Ku-band antennas is discussed in [13]. Uniquely low-profile satcom antennas are presented in [14]. A dual-polarized antenna is given in [15]. Helicopter satcom antennas are modeled in [16].

Reference [17] summarizes recent reflect array developments, including analysis and design techniques for single and dual reflector configurations, design procedures for contoured beams and bandwidth. Reference [18] simplifies the beam forming requirements for a class of phased array antennas and [19] addresses high data rate Ka-band mobile satcom. A Ka-band phased array with MEMS phase shifters is given in [20]. The Iridium satellites make extensive use of phased arrays [9].Design a novel and compact low profile MIMO microstrip antenna for C band and Ku band applications [20]. Design reflectarray antenna 29.5-30.5 GHz with multilayer PCB structure [21]

III. FUTURE CHALLENGES

3.1 Mesh Reflectivity

The challenge for future mesh antennas is to extend the operating frequency above Ka-band. A decade or so ago the mesh loss was about 0.5 dB loss at Ku-band (typically 10 OPI, i.e., 10 opening per inch). There are now designs available with up to 40 OPI and operate up to and beyond Ka band.

3.2 MIMO

The increased channel capacity that multiple-input and multiple-output (MIMO) techniques offer can be applied to satellite communication links; although, the ground antenna space diversity antennas must be placed farther apart to achieve the diversity than is required in terrestrial MIMO links, due to the relatively longer distances of the satellite space link. Since a requirement to have to place the ground antennas farther apart tends to reduce the practicality, the challenge is to find means by which to gain the increased channel capacity that MIMO provides with minimal ground antenna separation for the satellite link.

3.3 Arrays

Array bandwidth is typically limited by the fact that phase delay rather than time delay transmission lines are used as phase shifters for the array elements, which tends to limit array bandwidth to about a few percent. A challenge for the future is to find innovative ways to extend the useful array bandwidth with acceptable cost.

3.4 Multiplexer Integration

As integrated space antenna systems become more highly integrated with additional functionality, the need to development reflector antennas with multi-band feeds increases. This drives a need for higher-level multiplexing for multi-band feed horns. Integrating horns with tri- and quadruplexers can thereby lead to a more compact spacecraft. Polarization transformers; e.g., linear to circular, usually accomplished by a screen (such as ameander line polarizer) or with a waveguide orthomode transducer, also contribute significantly to the size and complexity of feed horn assemblies/networks.

3.5 Optical

The primary challenge for satellite optical antennas appears to be achieving sufficient accuracy with the laser pointing and tracking systems. An optical laser beam transmitted from Mars to Earth has at Earth a Gaussian beam waist only about the size of Earth [22], [23], which provides for very efficient power transfer; although, such a laser space link imposes very tight pointing accuracy requirements.

IV. CONCLUSION

This paper describes the different technique, methods and future challenges for designing a smart antenna for the satellite applications. From this it is concluded that it is to design an antenna which can be optimize the satellite communications.

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