Active Antennas for Commercial and Military Communications Satellites – A Review

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Abstract: Active antennas have been in use in communications satellites for decades. The antenna configurations include array-fed reflectors, multiple-beam lenses and direct radiating phased arrays. The active feedings of the antennas include single amplifier per radiating element and matrix power amplifiers shared between clusters of radiating elements. This paper reviews the combinations of antenna configurations and active feedings as applied to different satellite systems. The miniaturization of active and beam forming components using MMIC technology are also addressed. The examples presented in this paper scan four decades of development at all frequency bands from L- to Ka-bands. The applications cover commercial and military systems with multiple spot beams, cellular mobile systems, broadband systems and dynamic high-power high-capacity systems.

1. Introduction

Present and future communications satellites for both commercial and military applications require considerable flexibility in order to use the limited power and bandwidth resources efficiently. Broadband applications are among the services that are envisioned for future satellite systems and flexibility is also required for such applications. Flexibilities include forming multiple beams, sharing power between beams, rapidly reconfiguring and re-pointing the beams, high reliability and compensation for component failures. These requirements make active antennas with distributed and shared power amplifiers the preferred choice over conventional passive antennas with separate amplifiers per transponder or separate amplifiers per beam. Advances in monolithic microwave integrated circuits (MMIC) and other miniaturization technologies allowed the realization of lightweight, power efficient and flexible active antennas for satellite applications.

The active antenna can be either a direct radiating phased array, a phased array feeding a reflector or lens system, or a matrix-amplifier-fed reflector or lens antenna. The direct radiating phased array may be a potential candidate when the required apertures are not prohibitive. Appropriate dual reflector and lens optic designs can be considered for providing array magnification when the array size may encounter packaging difficulties. A smaller size array may be used in conjunction with lens or unfurlable reflector systems to produce a potentially lightweight antenna with performance equivalent to that of a direct radiating array.

A number of successful designs for active arrays found their ways into commercial and military satellite systems, and more are being considered for future satellites. The following sections review some of those designs.

2. Matrix Amplifiers in AMSC, Inmarsat-3, ETS-VI and ARTEMIS Satellites

Among the commercial satellites that use power sharing between the beams through matrix amplifiers are Inmarsat-3, AMSC, ARTEMIS at L-band and ETS-VI at S-band [1]. Inmarsat-3 generates 7 spot beams using a 22-element cup helix feed array and 22 SSPAs distributed among four 4X4 matrices and one 6X6 matrix. The total power of the each individual matrix is routed to any combination of the beams. AMSC (or MSAT) uses two matrix power amplifiers to feed 6 beams independently. Each of the two matrices has the flexibility of directing all of its RF power into a single beam, while at the same time loading each of the SSPAs equally to minimize intermodulation noise. ETS-VI uses a similar concept, while in ARTEMIS the shared amplifiers are sandwiched between a beam forming network and a Butler matrix.

3. IRIDIUM Main Mission Antenna

One of the earliest uses of direct radiating active phased arrays onboard satellites was the IRIDIUM main mission antenna, operating at L-band [2]. Three arrays, each generating 16 optimized shaped beams, are deployed on each of 66 satellites in the low-Earth-orbiting constellation. Each array consists of over 100 lightweight patch radiators, each of which is driven by a T/R module. An optimized beamforming network
provides the excitation for the array. The array maintains a high G/T in receive operation and an efficient EIRP generation for transmit operation. The T/R modules use high-efficiency linear pseudomorphic high-electron mobility transistors (PHEMT). Five different module sizes are provided for peak RF output power operation at the T/R modules for high efficiency. The array deployment on the spacecraft is designed for efficient thermal radiation.

4. **Globalstar Phased Array Antennas**
The Globalstar system has a constellation of 48 low-Earth-orbiting satellites. The communication antennas are located at the Earth-facing deck of the satellite, and consist of multibeam active L-band receive and S-band transmit phased arrays [3]. The transmit array employs 91 elements arranged in a hexagonal aperture, while the receive array uses 61 elements in a similarly shaped aperture. Each antenna generates 16 simultaneous circularly polarized beams using phase-only equal-amplitude beamforming. The radiating elements are fed with modules containing a SSPA and a bandpass filter. Equal amplitudes eliminate phase errors associated with different input levels to the SSPAs. Unlike the deployed array panels in the Iridium satellites that allow for direct thermal radiation, Globalstar transmit modules are mounted on a solid Beryllium heat sink integrated with heat pipes, and along with external radiation panels complete the thermal control system.

5. **Skybridge Ku-Band Antenna**
Skybridge is a Ku-band low Earth orbiting satellite system for high data rate wideband applications [4]. The system uses 80 satellites, each providing 18 beams. A hybrid mechanical/electronic design is used for scanning and zooming functions of the transmit and receive antennas. The scanning is performed mechanically by an elevation over azimuth antenna pointing mechanism. The zooming is achieved by reconfigurable direct radiating arrays (DRA). The receive DRA uses active MMIC to obtain the optimum G/T, while the transmit DRA uses ferrite components to reduce losses. Amplitude only control is used for the beam forming.

6. **STENTOR Active Antenna**
The STENTOR is an experimental satellite that uses a Ku-band active antenna to realize three functions [5]: a single carrier hopping beam TDMA-standard mode, a multicarrier 3-beam mode with low intermodulation levels, and in-flight antenna calibration capability. The antenna uses 48 radiating elements and 48 SSPAs. A beamforming matrix connects the three beam inputs to the 48 amplifiers. Thermal control system transfers the heat dissipation to the spacecraft radiating surfaces. It is composed of a nominal thermal control that uses capillary pumped loop technology, and a redundant thermal control hardware that makes use of variable conductance heat pipes.

7. **Ka-Band Active Antennas**
The use of Ka-band for satellite communications presented a promise for achieving wideband operation. Development programs focused on the active modules for phased arrays [6]. The module is a subarray that is used as the building block for the full array. It consists of three layers: radiating element layer, device layer and signal distribution layer. The microstrip patch radiating elements are embedded in cavities formed in the module housing to provide low resistance thermal paths for heat dissipation. The cavity-backed construction also provides good bandwidth and scan angle performance. The device layer consists of MMIC power amplifiers and phase shifters. The signal distribution layer consists of a multilayer of RF, DC and logic distribution network. Commercial programs were envisioned for Ka-band use. An example is the Teledesic system [7] that uses a number of active phased arrays on board the large number of satellites in the low Earth orbit constellation. The military applications use commercial Ka-band satellite communication systems as well as US Department of Defense systems, such as the Global Broadcast System, to address its wideband communication needs. In addition to these existing systems, future plans include Gapfiller satellites, which will have a high-capacity two-way Ka-band capability to support mobile and tactical personnel. These will form the Interim Wideband System, which will eventually give way to the Advanced Wideband System. Presently, the US Army is developing an electronically scanned antenna that will support high data rate communications through a satellite link [8]. This multifunctional antenna is wideband in
operation and consists of four layers: radiating patch antenna elements, amplifiers for transmit and receive, beamformers in the form of a Rotman lens, and a switch matrix. A distinction between this and other phased array implementations is the ability to support multiple beams simultaneously over large bandwidths while maintaining a low insertion loss. As such, it becomes possible for this antenna system to act as a conduit from which satellite information can be relayed directly to other nodes in a battlefield environment.

8. **DSCS Lens Antenna**

The Defense Satellite Communications System operates at SHF frequencies and consists of 3 receive and 5 transmit antennas [9]. The receive antenna system has two earth coverage horns and one steerable 61-beam nulling lens antenna. The transmitter system has two earth coverage horns, one high gain parabolic gimbaled dish and two steerable 19-beam waveguide-lens antennas. The uplink and downlink beam forming networks allow the reconfiguration of the pattern in orbit by use of ferrite phase shifters integrated with the spacecraft’s waveguide lens antenna.

9. **MILSTAR Antennas**

The Milstar I satellites carry a secure, robust low-data-rate (LDR) communications payload, and a crosslink payload that allows the satellites to communicate globally without using a ground station. The Milstar II satellites extend the communications capabilities to higher data rates by adding a medium-data-rate (MDR) payload. The Milstar I and II satellites are fully interoperable for LDR communications and crosslinks. The MDR antenna consists of eight narrow spot beam antennas: two narrow spot beams with nulling capabilities (nuller antennas) and six distributed user coverage antennas, each supporting two-way communications. The uplink/downlink frequency is 44/20 GHz. The crosslink payload provides V-band (60 GHz) data communications between Milstar satellites for both the MDR and LDR payloads. The payload includes modulation and demodulation of the data, upconversion, amplification for transmission and downconversion.

10. **Conclusion**

The use of active antennas in communications satellites offers flexibility in coverage, multiple beam generation, beam switching and routing, wideband operation, increased capacity and overall efficiency. Direct radiating phased arrays, as well as reflector and lens systems fed with matrix amplifiers and other active feed arrays have been implemented on a number of commercial and military programs. The technological advances in this area have been helped by the significant evolutions in the miniaturization of integrated and solid state circuits. MMIC components and SSPAs have become the mainstay in modern satellite systems. The examples presented in this paper are only representatives of what has been implemented. Numerous other examples exist.

11. **References**


