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System Aspects of Active Phased Arrays¹

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1. Introduction

Demands in satellite communication systems for large number of spot beams with high beam-to-beam isolation and the need for flexibility in steering the beams impose requirements that are easier met with active phased arrays. The advances in MMIC and digital technologies played a major role in realizing these arrays for such systems. However, the added requirements and active array characteristics introduce a set of transmission impairments in the satellite link that did not necessarily exist in the conventional reflector-based satellite systems.

The design of the antennas for multiple beam communication systems depends on the beam definition, which in turn is a function of the system capacity and projected traffic patterns. Several systems require a large number of fixed narrow spot beams to cover the service area. A single reflector with a large number of feeds may provide such coverage. However, if the scanning loss is excessive due to the large number of beams scanned in one direction, multiple reflectors may be required. Alternatively, single or multiple phased arrays may be used. The phased array may have lower scan loss and a single phased array can handle a large number of beams. The phased array solution also offers higher reliability due to the use of the beam former versus the switching arrangement in a focal-region-fed reflector antenna. For a small number of beams at a time, a microwave beam former represents a simple and attractive solution, while if the number of beams is large a digital beam former is a more viable alternative. In many applications the choice between the microwave and the digital beam formers becomes a system issue.

Active phased arrays can also meet high flexibility requirements that have become the feature of several satellite communications systems. Among the flexibility requirements are the ability to form multiple beams, provide power sharing among beams through distributed amplification, and rapidly reconfigure and/or repoint the beams. The

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requirements also include high reliability and the ability to readjust the feed or array coefficients to compensate for component failures. The conventional drawbacks of active antennas pertaining to mass, non-uniformity of performance of a large number of elements, and reliability have been largely overcome by the advances in monolithic microwave integrated circuits (MMICs), printed-circuit antennas and digital beam forming networks. The MMICs allow the beam-forming network, which may include signal-conditioning circuitry such as MMIC phase shifters and attenuators, to be incorporated in a lightweight transmission medium. The resulting antenna configurations have the potential for dramatic reductions in mass while providing increased efficiency, flexibility, and capacity. Similar features apply also to digital beam formers.

The satellite industry conducted evolutionary research and development programs to assess the feasibility of implementing MMIC-driven active phased-array antennas in high-capacity communications systems. A number of advanced concepts employing active phased arrays have been investigated. Among the early developments are Ku-band and X-band arrays that were sponsored by INTELSAT, COMSAT Corporation and the US Air Force (Zaghloul et al., 1994), (Zaghloul, 1996). Another array was also developed at COMSAT Laboratories at C-band to produce eight simultaneous and independently shaped and steerable beams. Extensive development was performed in parallel at Lockheed Martin Commercial Satellite Systems and accomplished high level of integration in active phased arrays (Jacomb & Lier, 2000). The design uses modular concepts to increase the design flexibility and afford efficient in-orbit operation using MMIC components and high-efficiency SSPAs. The characteristics of the communications systems that use phased arrays have been measured and analyzed to show the effects of the array's signal formation mechanisms on the transmission parameters. The following section reviews some of the reported development of these active phased arrays. The transmission impairment mechanisms associated with such systems are subsequently addressed. Other and similar characterizations of the transmission mechanisms, interference parameters and bit error analyses were reported (Maalouf et al., 1998), (Purdy & Lier, 2000), (Lier & Maalouf, 2003), (Maalouf & Lier, 2004). Of special interest is the analysis of intermodulation components that result from multi-carrier operation of active phased arrays (Sandrin, 1973), (Lier & Charrette, 2005). A reliability model to support the design of active phased arrays in satellite communications systems was also reported (Ruggieri, 1997).

2. Early Developments of Active Phased Arrays for Satellite Systems

2.1 Ku-Band Active Phased Array

The first example is a Ku-band array that consists of 24 active radiating elements, each equipped with an ortho-mode transducer (OMT) for dual-linear polarization (Zaghloul et al., 1994). Figure 1 shows a block diagram of the array components and Figure 2 shows the array assembly. The radiating elements are dual-linearly polarized square horns of 3λ aperture each; a size chosen to reduce the number of elements in the overall aperture, reduce the mutual couplings between the elements, and eliminate the grating lobes within the $\pm 9^\circ$ field of view of the geostationary satellite.

To form a number of simultaneous and independent beams, a beam-forming matrix (BFM) is used. Directly behind each element is a 2-W Solid-State Power Amplifier (SSPA). The SSPAs are located in separate housings that are mechanically cooled by a liquid cooling loop. The outputs of the amplifiers are probe coupled to the input of the OMTs. The inputs

to the amplifiers are connected to the respective outputs of the BFM, which is capable of forming four simultaneous beams. Each beam is independently steerable through the use of digital phase shifters located in the BFM. The logic circuitry necessary to drive and store the respective states of the phase shifters is also located within the BFM. The SSPA and BFM designs both make extensive use of MMICs. Phase-matched RF cables provide the signal path from the outputs of the BFM to the inputs of the amplifiers.

The BFM consists of four 1-to-24-way power dividers and 24 four-way power combiners. Each transmission path in the BFM consists of an MMIC 5-bit phase-shifter module, input and output distribution networks. A total of 96 MMIC phase-shifter modules are located in the BFM housing. A modular architecture was selected for implementation of the MMIC-populated BFM in the form of 4-input, 8-output shelves, corresponding to the four beams and eight elements, respectively. The three shelves are identical in assembly and performance. Each shelf shown in Figure 3 contains four 1-to-8-way dividers, eight 4-to-1-way combiners, thirty-two MMIC phase-shifter modules and associated control electronics. Four 1-to-3-way dividers distribute the signals for each beam to the three shelves. The input plane of the BFM shelf contains four eight-way Wilkinson dividers and MMIC phase shifter modules. The MMIC phase-shifters are assembled on separate carriers for individual testing. The output plane of the BFM shelf also contains the phase-shifter driver and level-shifter electronics that are mounted on multilayer alumina boards. The ground plane in the middle serves as an RF and DC ground and also provides isolation between input and output planes.

Fig. 1. Block diagram of multiple-beam active phased array

Fig. 2. Ku-band Active Phased Array

Fig. 3. 4x8 Shelf in Ku-band BFM

This design approach for the BFM provides several advantages including modularity, reproducible assembly and performance. Broadband Wilkinson dividers and combiners provide inherently good amplitude and phase balance between the paths. Furthermore, path-to-path insertion loss variations can be minimized by the appropriate selection of MMIC phase shifter modules so that low loss phase shifters are matched with high loss paths, and vice versa.

The power amplifier design combines MMIC and quasi-monolithic technology to achieve optimum DC-to-RF conversion and linearity, while simultaneously meeting output power

and size requirements. The amplifiers are designed to be integrated directly in back of the array to minimize total output losses.

2.2 X-Band High-Power Active Phased Array

A study performed at COMSAT Laboratories addressed a set of requirements for a future DSCS system (Zaghloul, 1996). A key antenna specification is to transmit four beams simultaneously. These beams are to be shaped and steered independently, and can range in size from the minimum of 2° to the full earth coverage of 17° . An EIRP of 50 dBW is required for the 2° beams, and the overall antenna mass and DC power consumption are to be minimized with goals of 200 lb. and 400 Watts, respectively.

Fig. 4. Demonstration X-band array for DSCS system

A proof-of-concept array was developed as a subarray of such an antenna, and aims at demonstrating the most critical components required of a full-up active array antenna. This demonstration array, shown in Figure 4, utilized a total of eight radiating elements to form two independently steerable and reconfigurable beams. A key component developed for the program is the Beam Forming Matrix (BFM) whose function is to shape and steer the beams. The BFM implements modular MMIC technology in its phase shifters and attenuators which provide highly repeatable and uniform performance that is critical for this application. The lightweight radiating elements are composed of scalar ring horns and pin-polarizers that together provide high polarization purity required in a dual-polarization system should that option be exercised. Another key development is the highly efficient 2 Watt power amplifiers which are positioned within the transmit modules behind each radiating element.

2.3 C-Band Multiple-Beam Active Phased Array

The linearly polarized Ku-band array described above demonstrated the concept of active phased arrays for communications systems. It used large pyramidal horns as the radiating elements. One of the most desirable features, which have to be achieved, is lightweight. Because the size of the array can be large, especially at lower frequencies, the need for compact, lightweight radiating elements became paramount. The next array in this development series used printed-circuit patch radiators in order to achieve this goal. The array, shown in Figure 5, was designed at C-band (3.6-4.2 GHz) and featured printed-circuit radiators, a highly modular approach for the beam-forming matrix as well as for the active aperture, and an integrated thermal control system (Zaghloul et al., 1994). The array consists of 69 electromagnetically coupled patch (EMCP) elements, each producing two orthogonal circular polarizations. The elements are fed with 2-Watt SSPAs that are integrated in the array structure. The BFM provides independent control of eight simultaneous beams.

Fig. 5. C-Band active phased array

The array active elements demonstrate a high level of integration. The integrated element includes the EMCP radiating element, redundant SSPAs, MMIC gain blocks, redundancy switches, and monitoring circuit at the SSPA output. The SSPA consists of a high-efficiency power amplifier preceded by multistage MMIC preamplifiers and an MMIC linearizer to predistort the signal such that high linearity is achieved simultaneously with the required efficiency.

The active array is controlled by an 8X69 BFM, which consists of nine 8x8, shelves and accommodates up to eight beams connected to a maximum of 72 elements. For the 69-element array, three outputs are match terminated. The modular architecture of the Ku-band BFM described above has been further enhanced by implementing the C-band BFM shelf with eight 1x8 BFM modules. Each of these modules is realized by modular MMIC packages, each containing phase and amplitude control elements and associated digital control for each BFM cross point. This additional modularity further offers improved design flexibility for larger size BFMs, ease of repair and reduced manufacturing costs. The 8 x 8

shelf, shown in Figure 6, is composed of eight 1x8 BFM modules on the topside and eight 8-way power combiners on the bottom surface. Each 1x8 BFM module is an independently testable unit and includes the control circuits for eight MMIC packages and also provides the RF signal paths from the top to the bottom of the BFM shelf. Each 1x8 module consists of an eight-way power divider, eight MMIC packages and the digital control circuits. The most basic building block of the BFM is the MMIC package, shown in Figure 7, which contains an MMIC 5-bit phase-shifter, a 5-bit MMIC attenuator and three digital control ICs. This MMIC package can be individually tested and hermetically sealed to provide a rugged design.

Fig. 6. 8 X 8 Shelf in C-band BFM

Fig. 7. Basic C-band MMIC module

3. Evaluation of Transmission Parameters

This section presents evaluations of three transmission parameters through analysis and/or measurements: radiation patterns of intermodulation products, bit error ratios and co-channel interference between beams.

3.1 Far-field radiation pattern measurements of intermodulation products

Intermodulation products (IMP) result from the nonlinearities in the power amplifiers that are used in the active phased arrays. The distributed amplifiers are shared between all channels that are transmitted through all elements in the array. Due to the periodicity of the array structure and the nature of the intermodulation product generation, the location of such undesired and interference-like radiation can be predicted. The intermodulation products generated by a pair of carriers whose frequencies are f_1 and f_2 form distinctive beams with peak positions that are the vector sums of the carriers' positions. The frequency of the intermodulation product is defined by:

$$f_{third} = 2 * f_2 - f_1$$

The direction of the intermodulation product beam can be predicted by (Sandrin, 1973):

$$\bar{k}_{third} = 2 * \bar{k}_2 - \bar{k}_1$$

where:

$$\bar{k} = 2\pi \frac{d}{\lambda} (\cos \varphi \sin \theta \hat{x} + \sin \varphi \sin \theta \hat{y})$$

is the direction vector of the beam. The levels of the intermodulation products can be estimated knowing the nonlinear input/output characteristics of the amplifiers. The nonlinearities are represented in Bessel function expansion series that leads to power level evaluations (Fuenzalida et al., 1994). Typical amplifier characteristics are shown in Figure 8. The output power levels are plotted against the input back-off (IBO). The IBO is the back-off of the amplifier total input power level that corresponds to the output back-off (OBO), which is defined as the ratio of the peak single-carrier output power to the total multi-carrier output power at the operating point.

Multiple-beam intermodulation measurements for the 24-element Ku-band array described above, and shown in Figures 1 and 2, were performed in an anechoic chamber, where the antenna under test operated in transmit mode at relatively high power levels. Array control, measurement control, and data collection proceeded in essentially the same manner as during regular single carrier pattern measurements (Ekelman et al., 1994). The signal sources were composed of a synthesizer driving a 20-Watt Traveling Wave Tube Amplifier (TWTA) through a band-pass filter and 10-dB directional coupler. Three input signals were coupled off at the BFM inputs, and drive levels were continually monitored for the duration of the measurement. The drive level for all carriers was 33 dBm so as to provide the maximum drive into the SSPA's without incurring gain compression at the phase shifters in the BFM. Carrier frequencies and beam locations were chosen as shown in Figure 9 and Table 1, and designated as frequencies a, b and c.

Fig. 8. Transfer characteristics of SSPA models

Signal Type	Frequency (GHz)	Generator Polynomial	Location (Θ°, Φ°)
IMP	11.67	$2 \bullet a - c$	$(0^\circ, 4^\circ)$
IMP	11.72	$a + b - c$	$(4^\circ, 4^\circ)$
IMP	11.77	$2 \bullet b - c$	$(8^\circ, 4^\circ)$
IMP	11.80	$2 \bullet a - b$	$(-4^\circ, 0^\circ)$
Carrier	11.85	a	$(0^\circ, 0^\circ)$
Carrier	11.90	b	$(4^\circ, 0^\circ)$
IMP	11.95	$2 \bullet b - a$	$(8^\circ, 0^\circ)$
IMP	11.98	$c + a - b$	$(-4^\circ, 4^\circ)$
Carrier	12.03	c	$(0^\circ, 4^\circ)$
IMP	12.08	$b + c - a$	$(4^\circ, 4^\circ)$
IMP	12.16	$2 \bullet c - b$	$(-4^\circ, 8^\circ)$
IMP	12.21	$2 \bullet c - a$	$(0^\circ, 8^\circ)$

Table 1 Carrier and Intermodulation Parameters

Fig. 9. Radiation far field intermodulation contours, Top: predicted, Bottom: measured

Predicted third order IMP locations are shown in Figure 9 (top). Pattern contours were measured at the 3 carrier frequencies and the 9 in-band 3rd-order IMP frequencies, and are shown in Figure 9 (bottom). The carrier and intermodulation component locations are listed in Table 1. Measured pattern contours demonstrate that the predicted patterns are accurate in regard to the beam shapes and locations.

3.2 Bit-Error Ratio Measurements

Fig. 10. BER for single carrier

The bit-error ratio (BER) measurements of the same Ku-band active phased array described above were performed under different operating conditions: single channel and multi-channel operations at different power levels in one beam with and without traffic loading in a different beam (Kohls et al., 1995). In order to simulate the traffic loading represented in multitude of populated signal channels, a single white noise source was connected to one of the BFM input ports. The noise-loading beam was scanned to a position isolated from the beam under test. When in operation, the drive level of the noise-loading channel was maintained at a level equivalent to a fully populated transponder bank. At such a drive level, it is possible to observe the effects of driving the SSPA's into saturation.

The purpose of the single channel measurements is to assess independently the impact of noise loading and carrier input drive level on BER performance. Figure 10 shows the results of the single channel measurements where four operating conditions are investigated: the desired carrier at -3.0, 0.0, and +8.4 input back-off (IBO) levels with no noise loading, and the desired carrier at +8.4-dB IBO in the existence of a noise loading at a level of +0.7-dB IBO. The dotted line indicates the theoretical BER limit for a QPSK signal. The changes in the BER characteristics as the channel drive level is increased indicate the degradation that is attributable to the non-linear distortion effects as the SSPA's are driven towards saturation. The difference between the curves with and without the noise loading indicates that the degradation is primarily attributable to carrier suppression as most of the available SSPA power is expended in the loading channel. As the traffic or the number of carriers represented by the noise loading increase, the relative level of the carrier under test decreases within the available SSPA power. This causes the carrier suppression and the corresponding degradation in the BER performance. The same degradation due to non-linear distortion is still present in the unloaded case, as in the +0.0-dB back-off case, but the impact is secondary by comparison.

The purpose of the multi-channel measurements is to assess the impact of adjacent channel interference on BER performance, while the adjacent-channel beam is either in the same location as, or scanned away from, the desired-channel beam. It is also the purpose of the multi-channel measurements to assess the impact of co-channel interference on BER performance, while the co-channel interferer beam is scanned away from the desired-channel beam. All multi-channel measurements were performed with and without noise loading. Figure 11 shows the results of one set of multiple channel measurements. In this case, the BER of the desired channel was measured with the desired channel set at a +8.4-dB IBO drive level. The BER was then re-measured after the addition of the interfering channel, which was also set at a +8.4-dB back-off drive level. Finally, the desired channel BER was measured with the addition of the noise-loading channel, which was set to +1.5-dB back off. Similar to the single channel case, the most degradation occurs due to the carrier suppression as a result of the noise loading.

Fig. 11. BER for a carrier with on-axis adjacent channel interferer

3.3 Co-Channel Beam Interference

In cellular satellite communication systems employing multiple beam antennas, mutual interference among beams operating at the same frequency can be severe especially for systems that use a large number of beams. The co-channel interference depends on the coverage requirements, antenna performance for both user terminals and satellite payload, and user traffic within each cell. The carrier-to-interference ratio (CIR), which is the ratio of the power levels of the desired signal and the aggregate interference, is used to quantify this effect. Multiple parameters affect the CIR, some of which are readily predictable from the

system parameters (such as the total number of co-channel beams, and their separation), while the others need to be determined by statistical means (such as the antenna pointing error and user traffic).

Fig. 12. Satellite antenna pattern used in interference calculations

Fig. 13. Example of simulation for uplink interference

The downlink CIR is measured at the user terminal and is a function of the payload antenna characteristics and the location of the user terminal within the beam. The uplink CIR is measured at the payload and is a function of the user traffic within all co-channel beams at a

given time, as well as their locations within the beam (Kilic et al., 1999; Chhabra, et al., 2005; Chhabra et al., 2009). To demonstrate these interferences, array patterns for the satellite antenna are assumed based on large apertures consistent with the cell size. Designs similar to the ones described above can be used with the aperture distribution optimized to minimize the interference. In the results to follow, the pattern shown in Figure 12 was used to represent the relative gain function of all cellular satellite beams in a cellular low-altitude system. The pattern is based on an actual satellite antenna design provided by a satellite manufacturer. The figure shows the location of the co-channel interference beams for a hexagonal cellular system with a frequency re-use pattern of $N = 7$. The antenna pattern can be optimized further to position the pattern nulls at the center of the interfering cells.

Fig. 14. Example of simulation for downlink interference

Figure 13 demonstrates a statistical histogram for the uplink CIR for two cases where the number of frequency segments in the frequency re-use pattern N is 7 and 13, respectively. The uplink CIR is calculated hundreds of times with uniform statistical distribution of the interfering users within the co-channel beams. The number of times the CIR falls within certain range (# of occurrences) is recorded for different ranges and the results constitute the statistical histogram. As the number of frequency segments increases, the number of interfering beams that use the same frequency segment decreases, leading to higher levels of CIR. Figure 14 shows the downlink CIR levels at different beams that are identified in an ascending order starting from the coverage center. All users in these examples are assumed to be located at the beam center. As Figure 13 suggests, the uplink CIR can vary as much as 12 dB for $N = 7$ and 6 dB for $N = 13$, depending on the user traffic within each beam. The downlink CIR, on the other hand, is more stable due the fact that all co-channel interferers are always on. However, depending on the location of the beam in the coverage area, the variation in downlink CIR can be as much as 5 dB as the simulation for the case shown in Figure 14 indicates.

4. Conclusion

Active phased arrays provide significant advantages in satellite communications systems that require the generation of a large number of beams. The advantages include the flexibility in generating the beams, sharing of power between beams and achieving a large

number of frequencies re-use. These advantages come at a cost at the system level performance that has to be studied and can be minimized. The system-level performance of active phased arrays, which employ distributed amplifiers across the array aperture can be accessed through measurements and computer simulation. The primary parameter in identifying the goodness of the system is the BER, which is a function of the net carrier to noise and interference ratio (CNIR).

In a multiple beam phased array system, intermodulation products and co-channel interference are two key contributors to the degradation of the CNIR. The far-field intermodulation radiation follows certain patterns, which can be predicted using software tools that are verifiable by measurements. The intermodulation radiation degrades the CNIR if it falls within certain frequency bands in the directions of the beams that use those bands. Judicial choices of the operating frequencies and associated beams can reduce or mitigate such degradation.

The two components of the co-channel interferences, downlink and uplink, are functions of both deterministic parameters of the system, such as the total number of beams, antenna performance and frequency re-use scheme, as well as stochastic parameters, such as the traffic pattern, location and equipment pointing errors of the users. While these effects can cause significant variations in the co-channel CIR, the system can be designed based on the worst-case predictions in order to offer higher levels of margin.

An associated phenomenon is the BER degradation due to carrier suppression as a result of traffic loading. This exceeds the degradation that results from driving the desired channel in the non-linear region of the amplifier or at saturation. It also exceeds the degradation that results from adjacent channel or co-channel interference. This type of BER degradation can be controlled by proper loading of the satellite channels.

5. References

- Chhabra, S.; Zaghloul, A.I. & Kilic, O. (2005). Co-Channel Interference in Satellite-Based Cellular Communication Systems, *Proceedings of the URSI General Assembly*, New Delhi, India, October 2005.
- Chhabra, S.; Kilic, O. & Zaghloul, A.I. (2009). *Co-Channel Interference in Satellite Links Utilizing Frequency Reuse*, VDM Publisher, ISBN 978-3-639-17714-5, Saarbrücken, Germany.
- Ekelman, E.P.; Kohls, E.C.; Zaghloul, A.I. & Assal, F.T. (1994). Measured Performance of a Ku-Band Multibeam High-Power Phased-Array, *Proceedings of the IEEE International Symposium on Antennas and Propagation*, pp. 844-847, Seattle, Washington, June 1994.
- Fuenzalida, J.C., Shimbo, O. & Cook, W.L. (1973). Time-Domain Analysis of Intermodulation Effects Caused by Nonlinear Amplifiers, *COMSAT Technical Review*, 1973.
- Jacomb-Hood, A. & Lier, E. (1999). Multibeam Active Phased Arrays for Communications Satellites, *IEEE Microwave Magazine*, pp. 40-47, December 2000.
- Kilic, O.; Zaghloul, A.I.; Thai, M. & Nguyen, L. (1999). Beam Interference Modeling in Cellular Satellite Communication Systems, *Proceedings of the URSI General Assembly*, Toronto, Canada, 1999.

- Kohls, E.; Ekelman, E.; Zaghloul, A.I. & Assal, F. (1995). Intermodulation and BER Performance of a Ku-Band High Power Active Phased Array, *Proceedings of the IEEE International Symposium on Antennas and Propagation*, pp. 1404-1408, Newport Beach, California, June 1995.
- Lier, E.; Purdy, D. & Maalouf, K. (2003). Study of Deployed and Modular Active Phased Array Multibeam Satellite Antennas, *IEEE Antennas and Propagation Magazine*, vol. AP-45, no. 5, pp. 34-45, October 2003.
- Lier, E. & Cherrette, A. (2005). An Intermodulation Suppression Technique for Transmit Active Phased Array Satellite Antennas with Multiple Shaped Beams, *IEEE Transactions on Antennas and Propagation*, vol. AP-53, no. 5, pp. 1853-1858, May 2005.
- Maalouf, K.; Gaus, Jr., R.; Sowelam, S. & Jacomb-Hood, A. (1998). Error Rate Estimation in a Multi-Channel Active Phased Array," *Proceedings of the IEEE International Conference on Communications*, pp. 402-406, June 1998.
- Maalouf, K. & Lier, E. (2004). Theoretical and Experimental Study of Interference in Multibeam Active Phased Array Transmit Antenna for Satellite Communications, *IEEE Transactions on Antennas and Propagation*, vol. AP-52, no. 2, pp. 578-592, February 2004.
- Purdy, D. & Lier, E. (2000). "EIRP and C/I Analysis of Multibeam Active Phased Array Transmit Antennas for Communication Satellites," *Proceedings of the IEEE International Conference on Phased Array Systems and Technology*, Dana Point, CA, pp. 203-206, May 2000.
- Ruggieri, M. (1997). A (Design-Oriented) Reliability Model for Active Phased Arrays in Satellite Communication Systems, *IEEE Aerospace and Electronic Systems Magazine*, vol. 12, no. 10, pp. 23-29, October 1997.
- Sandrin, W. (1973). Spatial Distribution of Intermodulation Products in Active Phased Array Antennas, *IEEE Transactions on Antennas and Propagation*, vol. AP-26, no. 6, pp. 864-868, November 1973.
- Zaghloul, A.I.; Gupta, R.K.; Assal, F.T.; Martin, J.E. & Wernek, S.B. (1994). Active Phased-Array Development at C- and Ku-Band, *Proceedings of the 15th AIAA International Communications Satellite Systems Conference*, pp. 1683-1691, San Diego, California, February - March, 1994.
- Zaghloul, A.I. (1996). X-Band Active Transmit Phased Array, *US Air Force Report*, RL-TR-96-164, September 1996.

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