HIGH-RESOLUTION ADAPTIVE NULLING PERFORMANCE FOR A LIGHTWEIGHT AGILE EHF MULTIPLE BEAM ANTENNA*

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ABSTRACT

The design, fabrication and measured performance of a lightweight high-resolution adaptive nulling EHF multiple beam antenna (MBA) are addressed. A 127-beam MBA and a four-channel RF nulling network operating over the 43.5 to 45.5 GHz band are used to adaptively null a jammer in anechoic chamber measurements. Lightweight feed horns connected to waveguide transmission lines controlled by ferrite switches are used to select beam positions from the 127-beam MBA. The MBA is designed to provide independent coverage for three communications system users while providing pattern discrimination or nulling of multiple jammers located within 0.1° of the user. Cancellation greater than 30 dB when operating in a wide-band mode is experimentally demonstrated.

INTRODUCTION

Future geosynchronous extremely-high frequency (EHF) communications satellite uplink antennas may require high-resolution adaptive nulling capability to provide sufficient pattern gain to desired users while maintaining pattern nulls on interference sources in close proximity to the users. High resolution is achieved by using an adaptive antenna with a large electrical diameter which produces narrow nulls [1,2]. For the case of a high-resolution single filled-aperture multiple beam antenna (MBA), the required number of beams can be excessive for uniform pattern coverage. A distributed multi-aperture multiple beam antenna with highly-overlapped beams can provide the desired resolution with fewer beams and hence a corresponding decrease in weight and complexity [3-6].

High nulling resolution is important for low, medium, and high data rate communications system users. Figure 1 depicts the field of view from a communications satellite where there are multiple users and a single jammer that is located approximately 90 km from a user. This distance gives an angular spread between the jammer and user of about 0.1°. Multiple beams are necessary to provide simultaneous coverage areas. These beams are repositioned rapidly to provide time-division multiple access capability. User terminals can be located within a given theater or may be scattered globally. The uplink performance can be significantly enhanced with adaptive nulling and, in this study, 30 dB or more of adaptive nulling is desired.

*This work was sponsored by the Department of the Air Force under contract F19628-95-C-0002.

In this paper, the measured adaptive nulling performance of a lightweight EHF (43.5 – 45.5 GHz) 127-beam multi-aperture multiple beam antenna is investigated. The antenna achieves high resolution adaptive nulling by means of a distributed multiple aperture design. Figure 2 depicts the interlaced beam pattern of a seven-lens 127-beam MBA. With the thinned MBA approach, adjacent beams are highly overlapped and are generated from different apertures. Each collimating lens feeds two switch trees which provides a total of fourteen channels that are fed into the nulling processor. Fixed delay lines in each channel are used to remove dispersion introduced by the distributed lenses. In the nulling processor, eleven of the fourteen channels are used to provide adaptive nulling degrees of freedom, The nulling processor produces three independent user beams. These user beams can be configured to cover a 1.5° theater for many users while simultaneously servicing two independent users at arbitrary positions over the Earth's field-of-view.

Details of the MBA design and construction are given in the next section. The nulling weight network and nulling algorithm used for anechoic chamber tests are then discussed. Adaptive antenna pattern nulling measurements with a four-channel RF nulling weight network and CW interference source are described. A nulling angular resolution of approximately 0.1° is demonstrated with the four-channel test bed.

MBA DESIGN AND CONSTRUCTION

A layout for the 127-beam MBA is shown in Figure 3. The total mass of the assembled antenna, including the switch trees, is 25.3 kg. With the multi-aperture MBA design, seven individual multiple beam antennas are located on a hexagonal lattice having a spacing of 61 cm between apertures. The 61 cm aperture spacing was chosen, by means of a computer simulation model, to provide the desired nulling resolution of 0.1° such that the adapted antenna gain recovers to within −15 dB of the peak beam gain. The center aperture is a 19-beam multiple beam antenna and the six surrounding apertures have 18 beams per aperture. The desired minimum gain for three independent beams covering a 1.5° theater diameter is assumed to be 31 dBi. The peak gain of each beam was desired to be approximately 37.0 dBi which requires a lens with diameter 20.3 cm assuming a 60-percent efficiency. The half-power beamwidth of each of the 127 beams is approximately 2.5° and the 6-dB beamwidth is approximately 3.4° which satisfies the 1.5° theater diameter. The 127 beams are highly-overlapped (−1.3 dB relative to the beam peak) and spaced at 1.6° intervals to fully cover the Earth's field-of-view from geosynchronous altitude.

Each of the seven MBAs has a mass of approximately 2.8 kg and each is comprised of a right-hand circularly-polarized (RHCP) conical horn feed cluster illuminating a 20.3-cm diameter Rexolite lens (relative dielectric constant ϵ_r=2.54). The front (Earth-side) and back (feed-side) surfaces of each lens are waffled to reduce mismatch losses. The feed-side lens surface is zoned into two flat surfaces to reduce the lens mass. The F/D for each lens is 1.5. The MBAs are mounted in a lightweight aluminum structure and final alignment of the individual MBAs is achieved with measurement of the beam peak positions and subsequent correction with mechanical shims.

A lightweight switch tree waveguide beamformer is used to select two receive beams from each distributed aperture for a total of fourteen simultaneous receive beams. The RF switch structure and the switch drive electronics were manufactured by Electromagnetic Sciences, Inc. The switch trees utilize a 4:1 switch tree as the basic building block. The insertion loss for a 4:1 switch tree is approximately 0.5 dB and the isolation is approximately 50 dB to any off port. The switching speed is less than 1 μsec. A lightweight switch tree structure is achieved by using flangeless waveguide interconnects, thin-wall electroformed waveguide, and ferrite switches. A sketch of an 18:2 switch tree that feeds one of the 18-beam MBAs, is shown in Figure 4. This switch tree is composed of an 8:1 switch tree and a 10:1 switch tree. The total mass of the switch tree including waveguide, electronics, brackets and miscellaneous hardware is 666 g. The eighteen waveguide input flanges are mounted on a thin aluminum spherical feed horn plate that has a mass of 286 g.

The feed horns are made of electroformed copper with a gold finish and have a rectangular (WR22) to circular waveguide transition section (1.27 cm long), followed by a uniform circular waveguide section (0.686 cm diameter, 3.175 cm long) containing a dielectric-vane polarizer which generates the desired RHCP signal and a resistive card to reduce undesired LHCP (cross-polarized) signals. To obtain the desired illumination of the MBA lens, a thin-wall Rexolite tube is mounted in the circular waveguide feed aperture of each conical horn. The effect of the dielectric tube is to narrow the beam pattern from the conical horn which reduces the lens spillover and improves antenna efficiency. The conical feed horn diameter is 2.1 cm and the Rexolite tube with wall thickness 0.254 mm and diameter 0.64 cm extends 5.1 cm from the feed horn aperture. The total length of the feed horn, including the dielectric tube and brass flange, is 12.55 cm. The effective axial length of the conical horn is 3.9 cm. The theoretical far-field gain [2] of one of these 15° flare-angle conical horns, without the Rexolite tube, is approximately 18.5 dBi at 44.5 GHz. With the Rexolite tube, the measured boresight gain is approximately 20.9 dBi at 44.5 GHz. The feed horns have a measured axial ratio at boresight of approximately 0.5 dB (maximum) over the 43.5 to 45.5 GHz band. A typical radiation pattern at 44.5 GHz of one of the feed horns is shown in Figure 5, where the half power beamwidth is 18°. The mass of one of the feed horns is approximately 8 g.

NULLING WEIGHT NETWORK/ALGORITHM

The test bed RF nulling weight network consists of four rectangular waveguide transmission lines with four pairs of mechanically adjustable attenuators and phase shifters. Waveguide shims were used to accurately match the line lengths of the four rectangular waveguide transmission lines. The attenuators and phase shifters are set with an accuracy that enables a cancellation of 40 dB in bench tests with a jammer simulator. In this paper, we will not attempt to describe the implementation of adaptive nulling weights or weight control algorithms which could be used for an operational satellite communications system. Note: Optical nulling weights are currently under investigation for high data rate communications antenna applications [7].

In the anechoic chamber tests, adaptive weight control is determined by the sample matrix inversion (SMI) algorithm [8] operating in an open-loop mode. The jammer covariance matrix for four beams is obtained by measuring the received signal at five equally-spaced frequencies across the 2 GHz nulling bandwidth, and then computing the frequency-averaged cross-correlations between channels. The quiescent weight vector is chosen to have unity amplitude on one of the beams with the three remaining beam weights set to zero. The adaptive weights are computed from the product of the covariance matrix inverse and the quiescent weight vector. The adaptive weights are accurately applied by utilizing calibration data obtained from bench tests of the RF nulling weight network.

MEASURED RESULTS

A compact range reflector system, with a 2 m quiet zone, is used in the anechoic chamber measurements. A measured radiation pattern cut, over ±4.5° for the center beam of the center lens is shown in Figure 6. The measured half-power beamwidth is 2.5° and the first sidelobe is approximately −24 dB.

Jammer angle of arrival is simulated by mechanically rotating the 127-beam MBA to the desired angle and measuring the jammer signal vector. The output signals from four of the MBA beams are fed into the four-channel RF nulling weight network. A 4 x 4 jammer covariance matrix was computed from the signals measured in the four RF nulling channels.

In the nulling experiments four adjacent beams were selected, by using the ferrite switches in the switch tree, as depicted in Figure 7. The quiescent conditions have one beam turned on. The jammer is positioned at AZ=−0.40°, EL=0.85°. Figure 8 is an azimuth cut through the jammer elevation angle before and after adaptive nulling. The amplitude ripple in the adapted pattern is expected due to interference between the highly overlapped beams. The increase in gain by approximately 6 dB over the quiescent pattern is expected and is attributed to the highly overlapped beams. Figure 9 shows the null depth as a function of frequency. A cancellation of greater than 30 dB is observed over most of the 2 GHz nulling bandwidth. Further details of the adaptive nulling results are contained in [4,9].

CONCLUSION

This paper has described the design, construction, and measured performance of a lightweight high-resolution adaptive nulling EHF (43.5-45.5 GHz) multiple beam antenna. The 127-beam MBA consists of seven individual MBAs located on a distributed hexagonal lattice. The beam selection is achieved with a ferrite switch tree which allows for a total of fourteen simultaneous beams. Adaptive nulling measurements were performed with a four-channel RF nulling weight network and a single jammer. A nulling resolution of 0.1° and a wide-band cancellation of greater than 30 dB has been experimentally demonstrated.

ACKNOWLEDGEMENT

Numerous individuals at Lincoln Laboratory contributed to this effort. The author wishes to express his gratitude to B.M. Potts and W.C. Cummings for developing the 127-beam MBA concept, to A.R. Dion for developing the MBA lenses, to J. C. Lee for developing the feed horns, to D. C. Weikle for developing the RF nulling weight network, to L.W. Rispin for conducting and documenting many of the antenna measurements, to D.S. Besse for software support, and to R. J. Burns for organizing the measurements.

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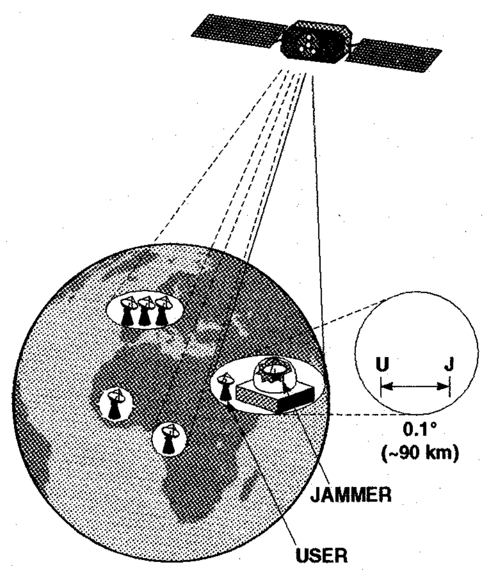

Figure 1: Desired nulling resolution for a geosynchronous communications satellite.

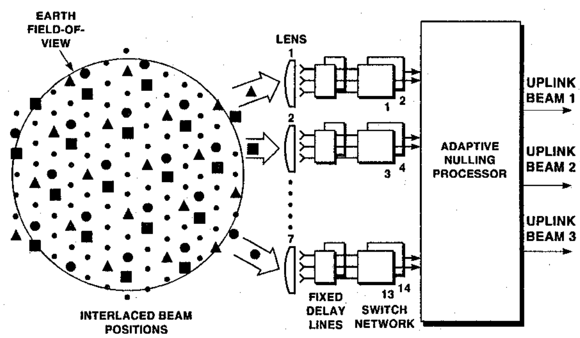

Figure 2: Interlaced beams and switch network for a seven-lens 127-beam adaptive nulling MBA.

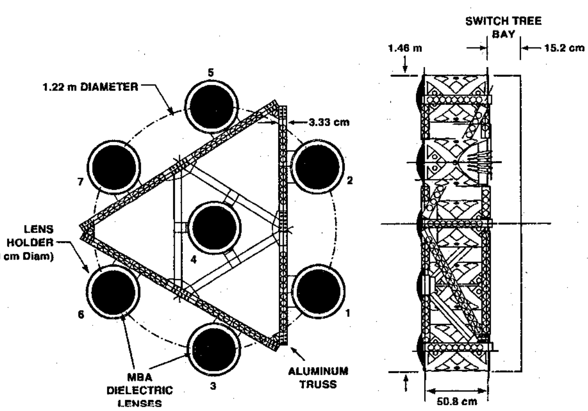

Figure 3: Layout for seven lenses in the lightweight 127-beam MBA.

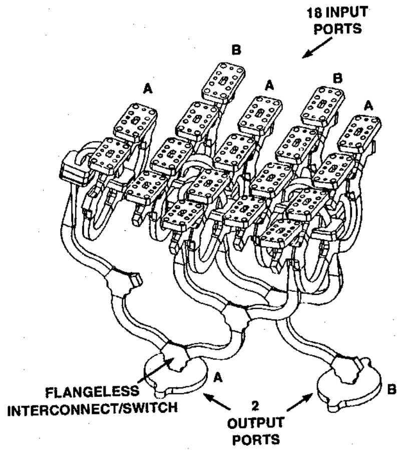

Figure 4: Three-dimensional view of an 18:2 switch tree used in the 127-beam MBA.

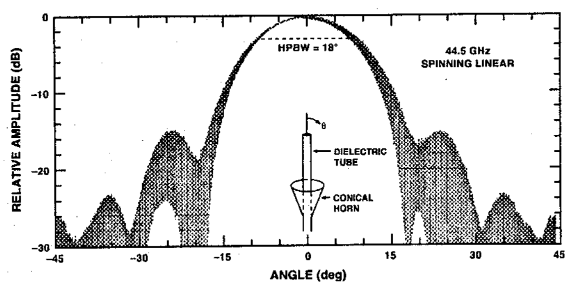

Figure 5: Measured radiation pattern for a feed horn used in the 127-beam MBA.

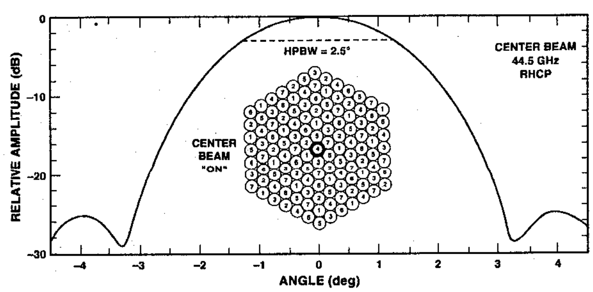

Figure 6: Measured radiation pattern for the center beam of the 127-beam MBA.

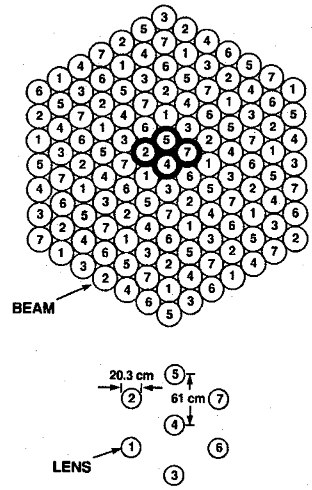

Figure 7: Layout of the 127 beams with the four beams (indicated by the heavy-line circles) used in the anechoic chamber adaptive nulling measurements.

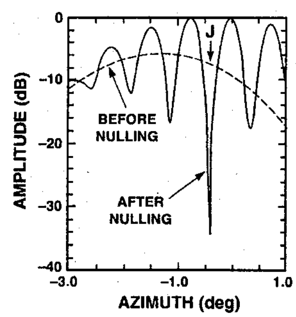

Figure 8: Comparison of quiescent and adapted radiation patterns measured for the 127-beam MBA.

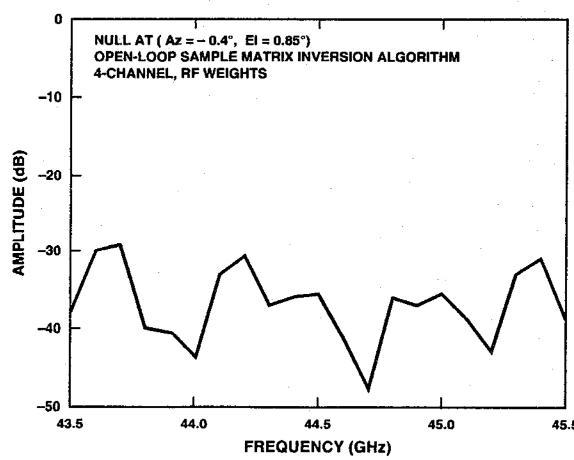

Figure 9: Measured adaptive null depth versus frequency for a single jammer.