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A DISTRIBUTED ARRAY ANTENNA SYSTEM

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ABSTRACT

The Space Station communication system will use microwave frequency radio links to carry digitized information from sender to receiver. The ability of the antenna system to meet stringent requirements on coverage zones, multiple users, and reliability will play an important part in the overall multiple access communication system. This paper will describe the configuration of a multibeam conformal phased array antenna and the individual microwave integrated components incorporated into this antenna system.

INTRODUCTION

One of the antenna systems proposed for the Space Station multiple access communication system is based on the use of a multibeam conformal phased array. This multibeam conformal array will allow communications from the Space Station to several simultaneous external users through one antenna structure. The system itself is a five-channel, full duplex, Ku-band, frequency-division multiple access scheme. The implementation of the multibeam antenna involves the design of the microwave components such as low noise amplifiers, high power amplifiers, phase shifters, filters, etc., and the integration of these components into the antenna structure.

SYSTEM DESCRIPTION

Figure 1 shows the antenna system configuration and its major functional blocks. The intermediate frequency/radio frequency (IF/RF) translation block will provide the frequency conversion of the communication distribution system, used throughout the internal structure, to the carrier frequencies used for communicating to external vehicles. The element selection block must direct the signal path of the appropriate channel into the elements determined to be active for that channel. For this function to be implemented, some initial information as to the user's location must be given to the system. This information would then determine which elements in the array should be active for that user. Tracking of the user after this initial placement may then be handled by the array itself, and appropriate switching (on/off) of elements based on new coordinates may be done. The beam-forming network is then used to control the pattern of the active array. In essence, it electronically steers the peak and/or nulls of the array pattern to a specific scan angle. Also embedded in the beam-forming block is a summing network which will multiplex all channels into each of the array elements. This implies then that any given element may be active for more than one channel simultaneously.

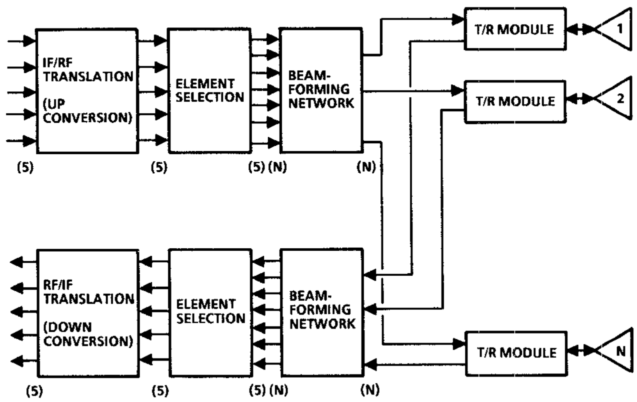

Figure 1.- System configuration.

Perhaps the most crucial block to the system performance is the transmit/receive (T/R) module. It is the T/R module which sets the transmit power level and the receiver noise figure. Each of the prior functional blocks can be located apart from the antenna site; however, the T/R module must be colocated at the array to achieve optimum performance. Therefore, the T/R modules are mechanically integrated to the individual antenna elements.

ARRAY DESIGN

The first step in determining the antenna gain/pattern and the subsequent array configuration is deciding the coverage zone needs. This specific antenna system is required to serve the users located in the midzone region of the multiple access network. The midzone region extends from 200 m to 185 km from the Space Station structure with varying scan angle requirements for given distances.

Figure 2 shows a pictorial representation of the gain/coverage requirement. The first region of interest encompasses a sphere that extends from 200 m to 1 km away from the structure. In this region, the elevation angle can vary up to ± 180° and the scan

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angle (the angle from the velocity vector) can vary up to ±90°. Users in this region may require telemetry and command information (low data rate) or high resolution television (high data rate). The second region of interest encompasses a disc shape that extends from 1 km to 37 km out from the structure. This region requires an elevation angle variation of ± 180° but a scan angle variation of only ± 20°. Again, users in this region may require telemetry and command or high resolution television. The final sector of interest is a rectangular region which extends from 37 km to 185 km along the velocity vector and is 74 km high by 18 km thick. In this region, users only require low data rate telemetry and command information.

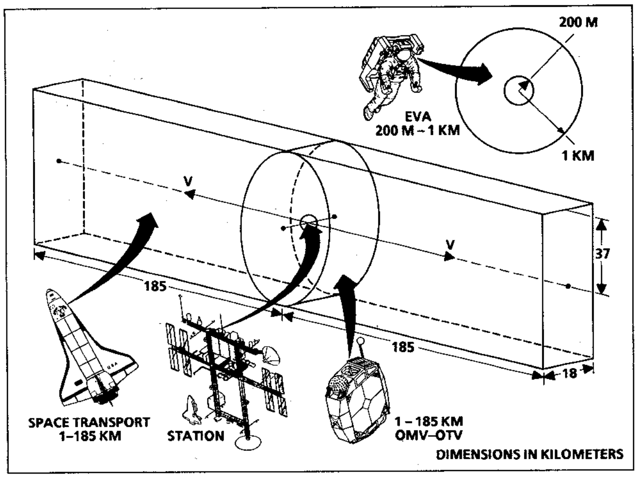

Figure 2.- Coverage zones.

The most stringent requirement on the array design is the spherical antenna coverage zone. However, the most stringent link margin for the system is the farthest distance requirement of 185 km. By blending the requirements of each coverage zone with the required effective isotropic radiated powers (EIRP's) and link margins, a gain taper can be determined on the array to allow spherical close-in antenna coverage with maximized array gain in the velocity vector (orbital plane) direction. Such a gain taper is shown in figure 3, where a somewhat constant gain is maintained within 20° of the orbital plane, with a decreasing gain rolloff at 90° from the orbital plane.

Interest in spherical arrays for achieving spherical or hemispherical antenna coverage is based on the natural ability of spherical arrays to provide uniform pattern and gain over wide angular regions. Other array configurations, such as planar arrays, suffer from beam degradation as the beam is steered over wide angular regions. Cylindrical or conical arrays can reduce beam variations in elevation but still suffer beam variations in the scan angle direction. Figure 4 shows a predicted gain versus scan angle plot of a spherical and a cylindrical array. Therefore, an array of elements conforming to a spherical pattern can be used for hemispherical coverage, provided the array is large in terms of wavelength. In addition, the individual elements may be tilted toward the velocity vector to maximize the contribution of the elements in that

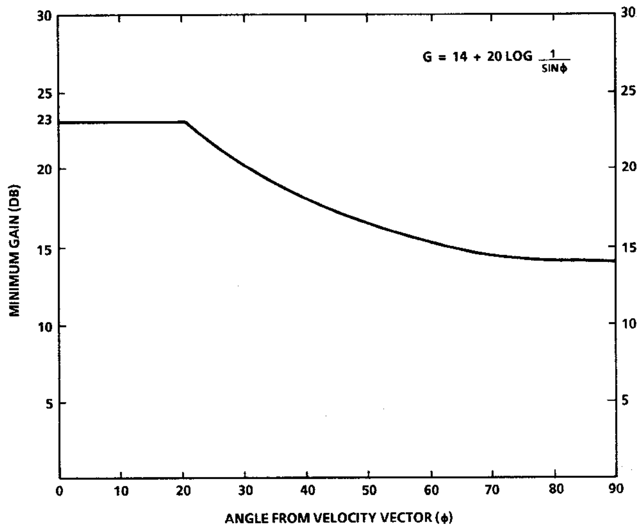

Figure 3.- Array gain taper.

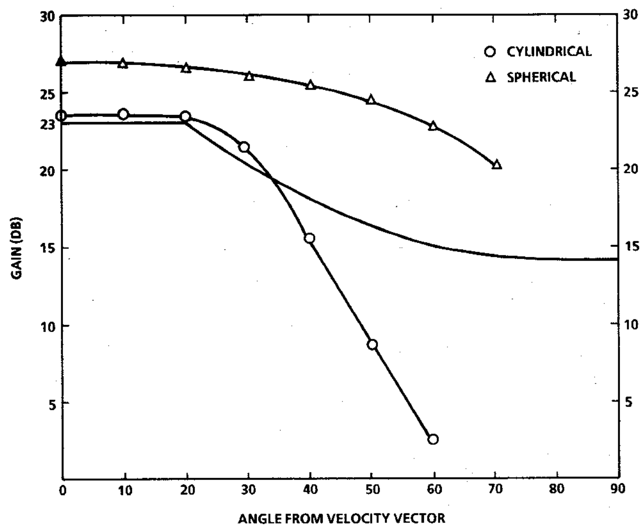

Figure 4.- Spherical and cylindrical comparison.

direction with a corresponding decrease in contribution toward the scan angle direction.

The overall gain of the array antenna is a function of the individual element gain and the total number of elements in the array:

$$G_{ARRAY} = G_{\substack{IND.\\ELEM.}} + 10 \log N \quad (1)$$

where:

G_{ARRAY} = Gain of the array

$G_{\substack{IND.\\ELEM.}}$ = Gain of identical elements in the array

N = Total number of elements in the array

Therefore, for a desired array gain, incorporating individual high gain elements results in a fewer number of elements for the array. However, the real benefit in this reduction of elements is the corresponding decrease in components. Recent interest in array development has been in terms of microwave monolithic circuits integrated into an array of microstrip patch antennas. Typically, these patch antennas have gains ranging from 0 dBi to 6 dBi at Ku-band frequencies. Thus, an array of 23 dBi would require 100 elements (3 dBi). As a contrast to this, using elements of 8 dBi gain would require an array of only 32 elements. This threefold decrease in elements and active components is extremely beneficial to the reliability of the system.

In this array application, the elements are waveguide horns with gains of approximately 8.5 dBi and beamwidths of 58°. The integration of this waveguide component to the T/R module is done via a fine-line waveguide-to-microstrip transition. This technique allows an end launch into the waveguide assembly for a more desirable mechanical configuration. Figure 5 shows a picture of the transition/element assembly and the corresponding measured input impedance. Figure 6 shows the measured antenna pattern of a gold-plated aluminum assembly.

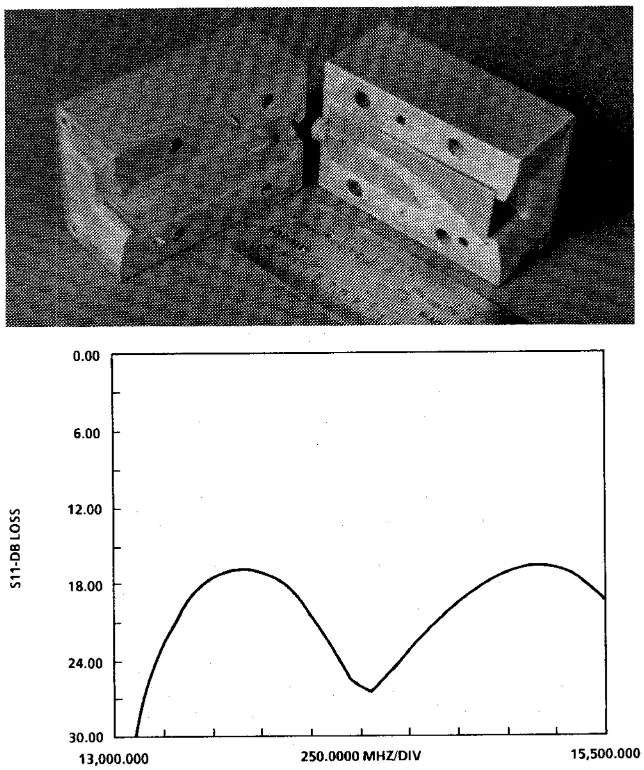

Figure 5.- Transition/horn element.

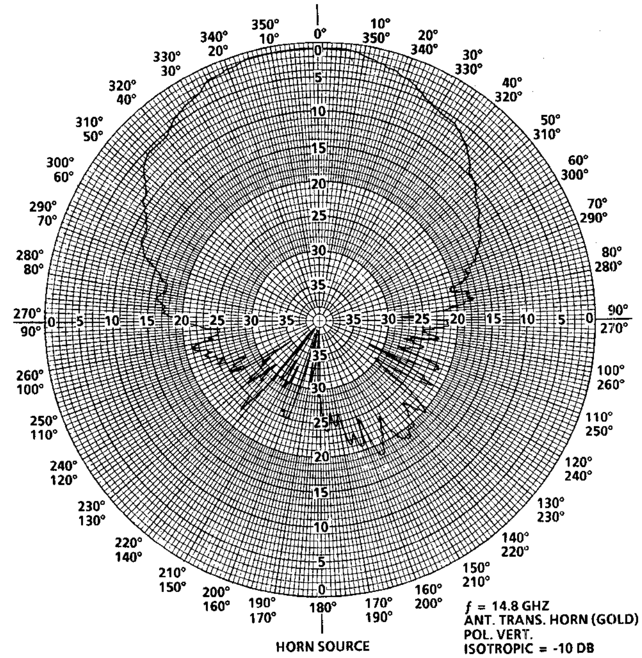

Figure 6.- Transition horn antenna pattern.

MICROWAVE COMPONENT DESIGNS

As was stated previously, the need to colocate the T/R module at the antenna site for optimum performance is a critical requirement. However, it is this mechanical integration of the element and T/R module which drives the complexity and performance of the array. The overall size of the T/R module determines the size of the sphere and the spacing between the elements. A block diagram of the T/R module is shown in figure 7 along with gain levels of individual stages. It is intended that the final version of such a unit would be a combination of microwave monolithic integrated circuits (MMIC's) and hybrid micropack assemblies. The MMIC technology would reduce cost and space requirements versus a completely hybrid approach.

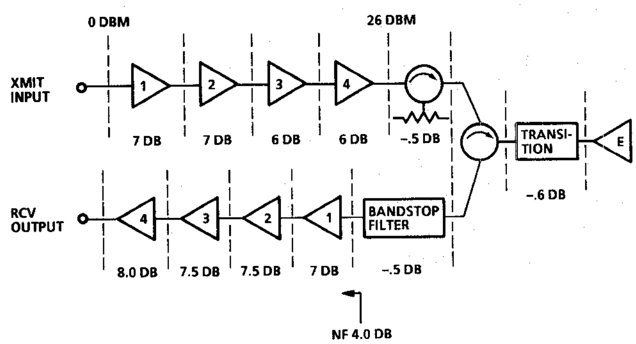

Figure 7.- T/R module block diagram.

The system must maintain full duplex capability through one antenna structure which requires separate transmit and receive frequencies and necessitates the use of a diplexer at the antenna port. This can be done simply with a circulator. To make certain the high level transmit signal leaking through the circulator is below a satisfactory level, a high Q (low-loss) bandstop filter is incorporated in front of the low noise amplifier. This filter must have minimal insertion loss in the receive band because of noise figure degradation. The receive amplifier gain and noise figure set the system noise figure and dynamic range. The current design incorporates a 0.3-μ packaged GaAs Fet device in a four-stage amplifier. Typical measured performance of the individual stages is shown in figure 8. The use of a packaged device at these frequencies does limit the bandwidth and require innovative mounting and lead placements, but the advantages of quick assembly and added reliability of a protected hermetically sealed device are beneficial for narrow-band applications. The best performance has been achieved by inverting the package and mounting it between the input and output matching networks. Individual lead attachment must be made as close to the package entrance as possible (especially the source bypass connection).

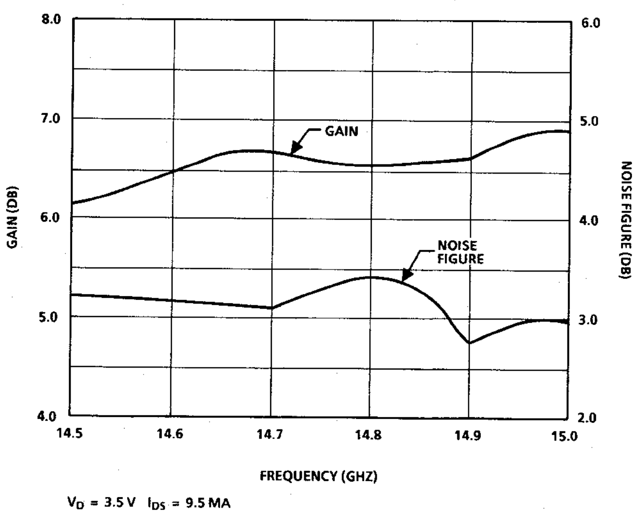

Figure 8.- Typical single-stage LNA performance.

The high power amplifier (HPA) output level is used to set the EIRP of the system. The current design incorporates a four-stage amplifier comprised of internally matched flange packages. Bias and direct current isolation components are added externally to these packages. Figure 9 shows the typical performance of a two-stage amplifier. The complete four-stage amplifier has a gain of 26 dB and ranges in efficiency between 18 percent and 28 percent, depending on the number of channels active in that element. The typical output for a single channel is 0.25 W.

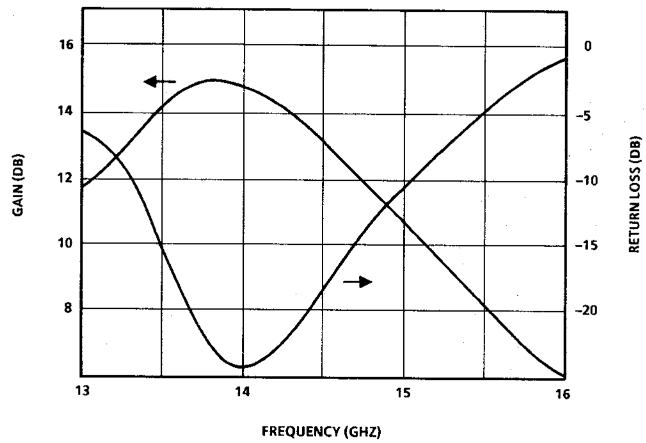

Figure 9.- Typical two-stage HPA performance.

CONCLUSION

The system configuration and array design for a full-duplex multibeam antenna has been presented. This communication antenna system utilizes a spherical conformal array, high gain elements, one complete array for both transmit and receive, and independent channel beam-forming to meet the gain/coverage requirements of the proposed Space Station multiple access system.

ACKNOWLEDGEMENTS

This work has been performed under the sponsorship of the National Aeronautics and Space Administration (NASA) Johnson Space Center, Houston, Texas, contract number NAS 9-15800. The authors wish to thank Dr. G. Raffoul and J. R. Carl for assistance in the antenna analysis and array design and W. Cope for assistance in assembly and testing of the microwave components.

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