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A MICROSTRIP ARRAY FEED FOR MSAT SPACECRAFT REFLECTOR ANTENNA

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ABSTRACT

An L-band circularly polarized microstrip array antenna with relatively wide bandwidth has been developed. The array has seven subarrays which form a single cluster as part of a large overlapping cluster reflector feed array. Each of the seven subarrays consists of four uniquely arranged linearly polarized microstrip elements. A 7.5% impedance (VSWR <1.5) as well as axial ratio (<1 dB) bandwidths have been achieved by employing a relatively thick honeycomb substrate with special impedance matching feed probes.

INTRODUCTION

Very large multiple-beam satellite reflector antennas in the 20 to 55 meter range have been planned for the future U.S. Land Mobile Satellite Systems (LMSS)[1]. From 40 to 90 contiguous beams covering Continental United States (CONUS) are to be generated from overlapping cluster feed arrays[2] with diameters of up to 6 meters. A structure of this size should have the capability of being folded and stowed in the satellite launching vehicle. Consequently, the feed array should be low in profile and light in weight. An earlier experimental feed array to demonstrate the feasibility of generating contiguous beams by using the overlapping cluster feed concept was successfully developed and tested[3]. In that feed array, relatively narrowband microstrip patches were used in order to reduce the complexity of the experiment.

This paper describes the development of a new array which has a relatively broadband performance sufficient to cover the bandwidth requirements of the Land Mobile Satellite System. To meet the light weight requirement of the system and to cover both downlink frequencies (1545 to 1559 MHz) and uplink frequencies (1646 to 1660 MHz), the microstrip antenna with a half-inch thick honeycomb-supported substrate has been selected. Since a half-inch (0.07 wavelength) substrate is relatively thick for microstrip radiators, four feed probes are required[4] per single element to suppress the undesired higher order modes and thus to generate acceptable circular polarization (c.p.) across the total bandwidth. For a large array, such a single-patch four-probe feed system would increase the complexity of an already complex feed beam-forming network, and will make it heavier and more prone to RF losses.

In a previous paper[5] the theoretical background was presented for obtaining a circularly polarized array from single-probe fed linearly polarized patch elements. The c.p. is achieved by having a basic 2 x 2 subarray with specific orientation and phase arrangement for the feed elements. As shown in Figure 1, the feed elements' angular orientation as well as phase are arranged in the 0^{o}, 90^{o}, 180^{o}, 270^{o} fashion. With such a system, not only is the feed complexity reduced, but also the bandwidth performance is improved. To demonstrate the concept, a single cluster array composed of seven subarrays with 28 single-feed linearly polarized patches has been constructed and tested.

HARDWARE DESCRIPTION AND RESULTS

The overlapping cluster array concept can be demonstrated by 2 clusters of arrays as shown in Figure 2. The two large circles represent the arrays to generate two contiguous beams, and each small circle is a sub-array consisting of four microstrip patches. The array that has been constructed and tested is one of the large circles and has a total of 28 microstrip patches. Dimensions of this array are illustrated in Figure 3. The relatively sparse element spacing is a result of the overlapping cluster arrangement for optimum reflector illumination with a minimum number of elements in the array. The array has an amplitude taper so that the reflector is illuminated with proper edge taper required for achieving low sidelobe levels. Each of the 7 subarrays are fed by a stripline 4-way hybrid power divider so that 0^{o}, 90^{o}, 180^{o}, 270^{o} feeding phases for the elements can be realized.

The fabricated array is illustrated in Figure 4 where the placement of the feed probes in the 4 patches of each subarray is similar to that shown in Figure 1. Since the honey-comb supported microstrip substrate is relatively thick, it generates a large amount of surface waves which cause significant mutual coupling between subarrays. These surface waves and the consequent mutual coupling effect cause asymmetry in the field components and degrade the c.p. performance. Introduction of metallic baffles between the subarrays can block out most of the surface waves and thus reduce the mutual coupling between subarrays. It is found that one-inch tall metallic baffles are required between all the subarrays to bring the on-axis axial ratio from 3 dB to less than 1 dB. Within each subarray, however, due to the 0^{o}, 90^{o}, 180^{o}, 270^{o} element orientation and phase arrangement, most of the unwanted field components caused by surface waves are cancelled and field symmetry is preserved.

In feeding a microstrip antenna with a thick substrate, generally a large inductance occurs around the feed probe. Normally, an impedance matching circuit can be etched prior to each feed probe for tuning out the probe inductance. This, however, introduces complexity and additional loss to the hybrid circuit. Furthermore, there may not be enough real estate available on the hybrid circuit board layer to accommodate the matching circuits and, consequently, an additional layer of circuit board may be needed. To reduce this complexity, a tear-drop shaped probe has been used to effectively tune out the inductance and provide 7.5% bandwidth. The tear-drop shape introduces an appropriate amount of capacitance to cancel the undesired inductance and provide a gradual change of the field from the coaxial line into the thick microstrip antenna substrate.

The measured radiation patterns of the array shown in Figures 3 and 4 are illustrated in Figure 5. These patterns are produced by a spinning-linear-dipole technique to demonstrate the c.p. quality of the array. Figure 5(a) is the pattern measured at 1545 MHz for $\phi = 45^o$ plane cut, while Figure 5(b) is measured at 1660 MHz. Patterns measured at other plane cuts will be presented in the conference. The worst axial ratio on the main beam peak is less than 0.8 dB for both frequencies. The main beam of the array is rather symmetrical, and its 10 dB beamwidths for $\phi = 0^o$, 45^o, and 90^o planes are nearly equal. The main beam below 10 dB and the sidelobes, however, are different for various cuts. The design goal was to achieve circular symmetry of the main beam down to 15 dB from the peak. A reflector with edge taper of this level will produce better than 30 dB sidelobe levels. Because of the inherent circular asymmetry of the 7-subarray feed, perfect symmetry for the feed pattern in all the cuts is hardly feasible.

The relatively high feed array sidelobe levels are a consequence of the relatively large separation of the subarrays (1.5 and 1.3 wavelengths in 0^o and 90^o plane) imposed by the overlapping cluster requirement of the contiguous multibeam system[2]. These high sidelobes will result in large spill-over past the reflector edge and hence lower reflector efficiency when compared with a gain optimized reflector. A complete three dimensional pattern integration shows that the relatively high sidelobes encountered here will only contribute to less than 0.3 dB of gain loss.

CONCLUSION

A circularly polarized feed array for a spacecraft reflector antenna has been constructed by using linearly polarized microstrip elements. The array achieved an axial ratio better than 0.8 dB at the pattern peak and better than 3 dB down to 20 degrees from the peak, across a 7.5% frequency bandwidth. A tear-drop shaped feed probe is used to achieve wideband input impedance matching for the relatively thick microstrip substrate. Due to the success of this experimental study, a circularly polarized microstrip array can have a simplified feed mechanism, reduced RF loss in the feed circuit, and improved radiation performance over a wide frequency bandwidth. It is expected that 10 to 15 percent bandwidth can be achieved by using the same technique if the substrate thickness is further increased.

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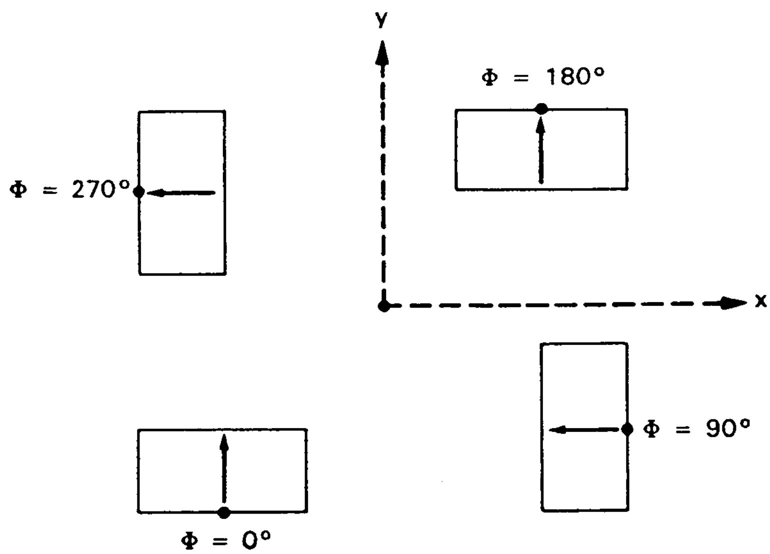

Figure 1. **Square grid 2 x 2 subarray of 4 identical lineary polarized microstrip elements that together generate C.P. The heavy dot on each patch indicates the feed location and ∅ indicates the feed phase. Arrows are E-field polarization directions.**

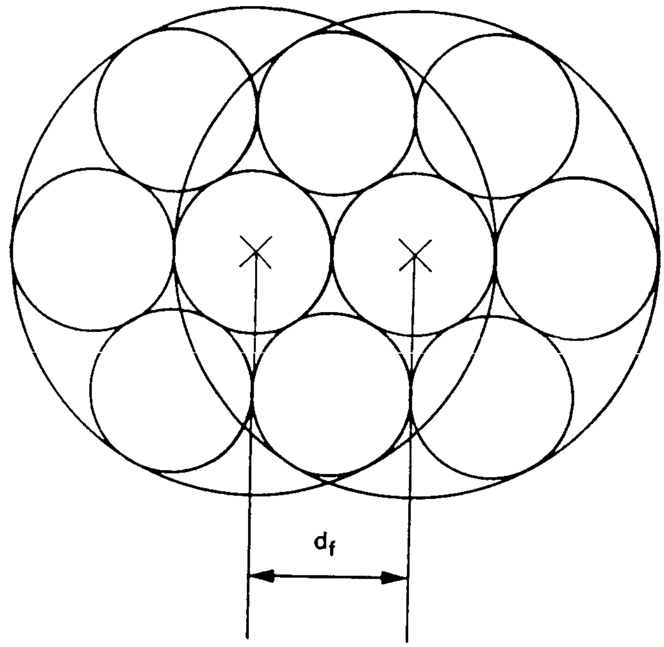

Figure 2. Two overlapping 7-subarray cluster feeds. d_f is separation distance between any two adjacent subarrays and between two cluster feeds.

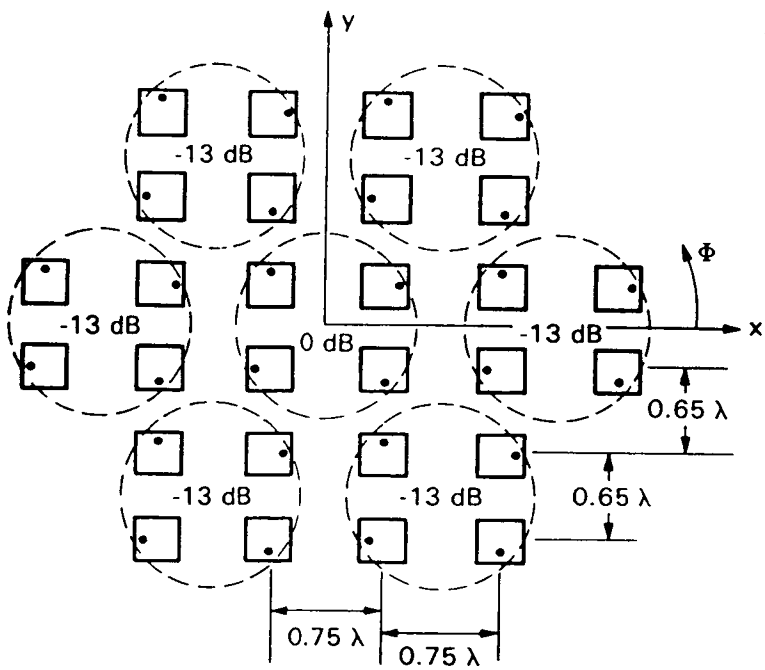

Figure 3. 7-subarray single cluster feed with 28 **microstrip** patches.

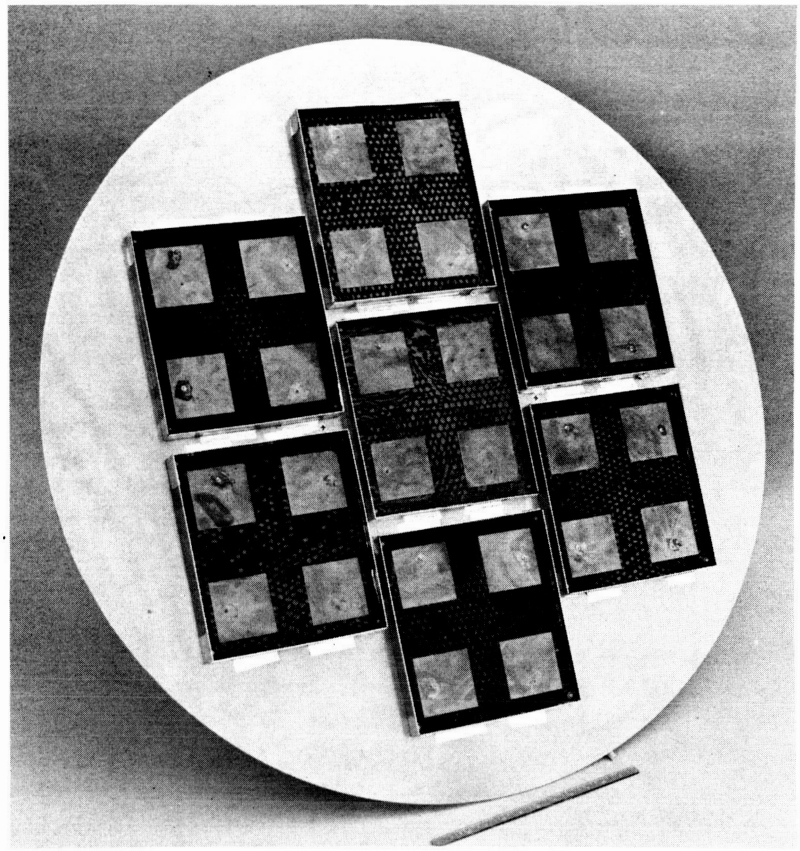

Figure 4. Constructed 7-subarray single cluster feed with 28 microstrip patches. Each subarray is enclosed by 1.0-inch tall aluminum baffles.

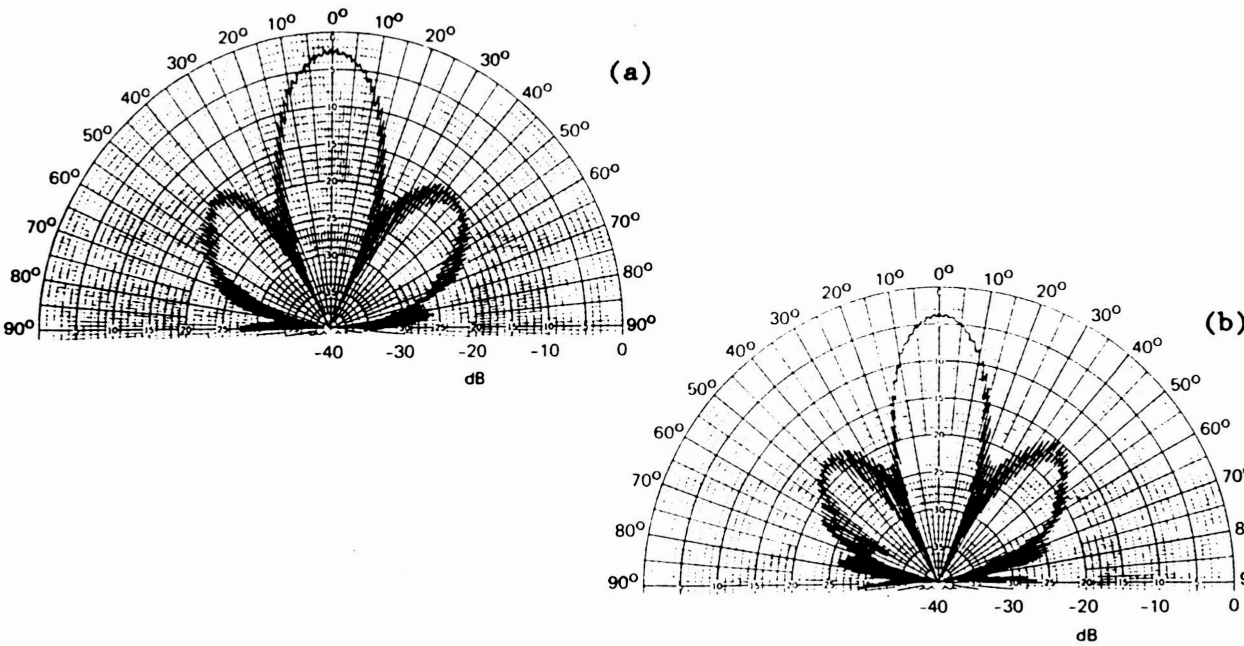

Figure 5. Measured array patterns at $\phi = 45^{\circ}$ plane cut for: (a) frequency = 1.54 GHz and (b) frequency = 1.66 GHz.