Aperture-Coupled Thin-Membrane Microstrip Array Antenna for Beam Scanning Application*

John Huang, Gregory Sadowy, Chuck Derksen, Linda Del Castillo, Phil Smith, Jim Hoffman, Toshiro Hatake and Alina Moussessian
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109
John.huang@jpl.nasa.gov; alina.moussessian@jpl.nasa.gov

Abstract – A microstrip array using aperture-slot-coupling technique with very thin membranes has been developed at the L-band frequency for beam scanning application. This technology-demonstration array with 4 x 2 elements achieved a relatively wide bandwidth of 100 MHz (8%) and ±45° beam scan. Very narrow coupling slots were used with each having an aspect ratio of 160 (conventional slot aspect ratio is between 10 to 30) for coupling through very thin membrane (0.05mm thickness). This thin-membrane aperture-coupling technique allows the array antenna elements to be more easily integrated with transmit/receive amplifier (T/R) and phase shifter modules. This paper addresses only the radiator portion of the array. The array and active components will be presented in a separate paper.

Introduction – Electronic beam scanning phased array antenna with very large apertures (10m to 100m dimensions) will provide a wide range of radar capabilities for NASA's future Earth science missions. For these very large arrays, the antenna mass, volume and cost will be prohibitive if the technology relies on previous rigid-panel phased arrays, such as the SIR-C antenna [1]. Previously developed membrane-based deployable passive array antennas [2,3] provided a means to reduce mass, launch-vehicle stowage volume, and overall cost compared to rigid antenna systems. However, to realize beam-scanning capability with thin-membrane-mounted active components, one of the challenges is to develop a proper excitation technique for feeding a thin-membrane patch array having the ability to integrate with the T/R modules. To avoid the use of many rigid coax feeding pins and associated solderings on thin membranes, aperture-coupling technique [4] is the ideal method for a large set of microstrip lines to feed a large array of microstrip patch elements. Previously developed inflatable L-band array antennas [3] used three layers of thin membranes as sketched in Fig. 1. These three layers, at the low microwave frequency of L-band, are separated with relatively large empty spaces – 0.64cm and 1.27cm. A previous paper [5] presented a new approach where only two thin-membrane layers were used for a single patch element. This paper gives the same approach for a 4x2 array with beam scanning results. With this approach, as shown in Fig. 2, the top layer has both the microstrip lines and the slotted ground plane, while the bottom layer has only the patch elements. On the top layer, the microstrip lines are separated from the slotted ground plane via a thin membrane substrate (0.05mm). This approach allows easier integration with the membrane-based T/R modules where a single-layer co-planar waveguide (CPW) or microstrip transmission-line system is used [6]. This two-layer approach also allows the large-aperture antenna to be more easily rolled up with a smaller stowage volume than the previous three-layer system.

Antenna Design – Fig. 3 shows the photo for a single aperture-coupled membrane patch element with the left picture showing the bottom layer and the right picture showing the top patch layer. It can be observed that the coupling slot is very thin. It has dimensions of 79.5mm by 0.48mm with a length-to-width ratio of 160. The 4x2 array uses this same element design with linear polarization and E-field parallel to the long dimension of the array. Two 4x2 arrays were fabricated and tested with one being a passive array and the other an active array. The active array

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is identical to the passive array except it has T/R modules integrated between the aperture coupling slots and the power divider. Fig. 4 gives a front view of the 4x2 array, where the elements spacing is 15.24cm (0.64 λ_o) in both vertical and horizontal planes. This spacing is selected to accommodate the T/R-module-required real estate while allowing the beam to scan to a relatively wide angle of 45°. Each patch is a square with a dimension of 8.89cm and has a resonant frequency centered at 1.26 GHz. The array of elements is fed by a corporate microstrip power divider system with uniform amplitude distribution. The two membrane layers are each a 0.05mm-thick polyimide material (Pyralux ^{TM}) having a relative dielectric constant of 3.4. On each membrane the deposited copper is 5 micron thick. Both membranes are supported and tensioned by a framed catenary system to maintain the required membrane flatness (< 5mm rms) and membrane spacing (1.27cm).

Calculation and Measurement Results – The measured input return loss of the 4x2 passive array is given in Fig. 5 where it shows that the –10dB return-loss bandwidth is about 100MHz (8%) with a deep resonance occurring at 1.26 GHz. Due to the relative high loss material of the polyimide membrane substrate, the corporate power divider incurred a 2.5 dB insertion loss. The passive array achieved a measured gain of 12.1 dB (include the power divider loss). Both calculated and measured two-principal-plane radiation patterns at 1.26 GHz are shown in Fig. 6. The calculation was done by the moment-method-based Ensemble software. For the active array, the 4-bit phase shifters were adjusted for the main beam to scan to 15°, 30°, and 45° in the E-plane of the array. Both calculated and measured patterns for these three scanned beam positions are shown in Figs. 7,8 and 9, respectively. The calculations agree well with that measured. The 45° scanned beam has a significant drop in gain of about 3.0 dB. This is because, in order to achieve wide bandwidth with a relatively thick air substrate, the element pattern [5] formed a relatively narrow beam of ±42° which suppresses the array 45° scanned beam. In addition, due to the element spacing of 0.64 λ_o, the grating lobe starts to form, which further reduces the main beam gain. Nevertheless, the 4x2 active array has successfully demonstrated that the membrane-based beam scanning array is very feasible.

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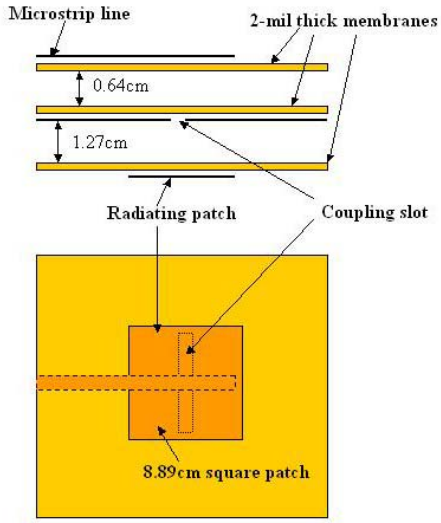


Figure 1. Previous 3-layer approach.

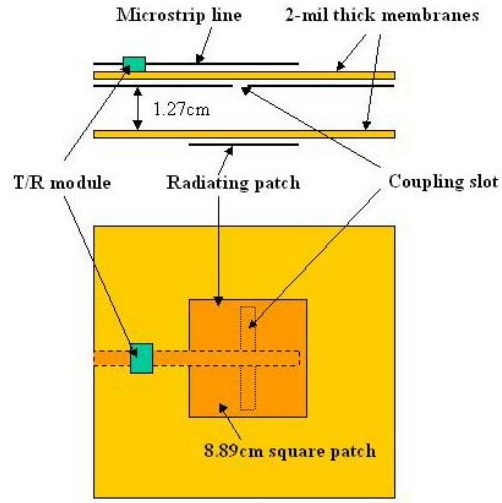


Figure 2. Current 2-layer approach

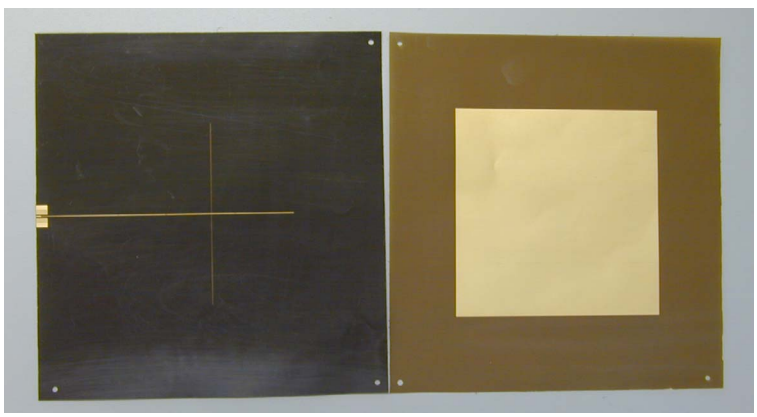
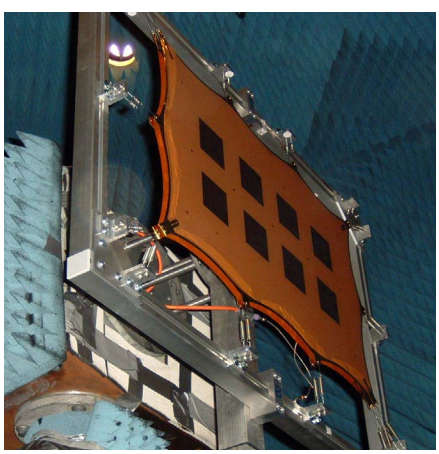


Figure 3. Photo of the single patch element with two separated membrane layers



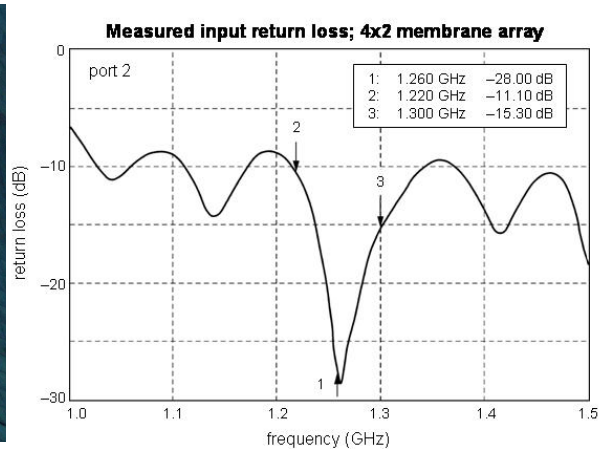


Figure 4. Photo of the 4x2 membrane array

Figure 5. Measured input return loss

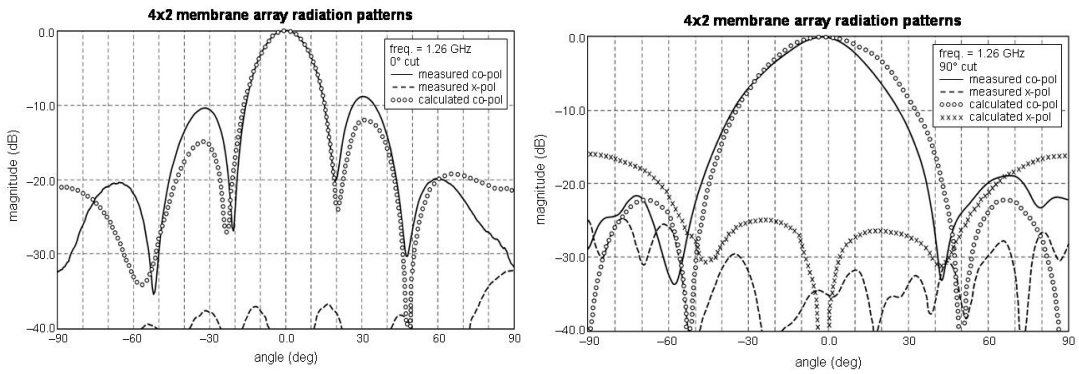


Figure 6. Two-principal-plane patterns of the 4x2 passive array

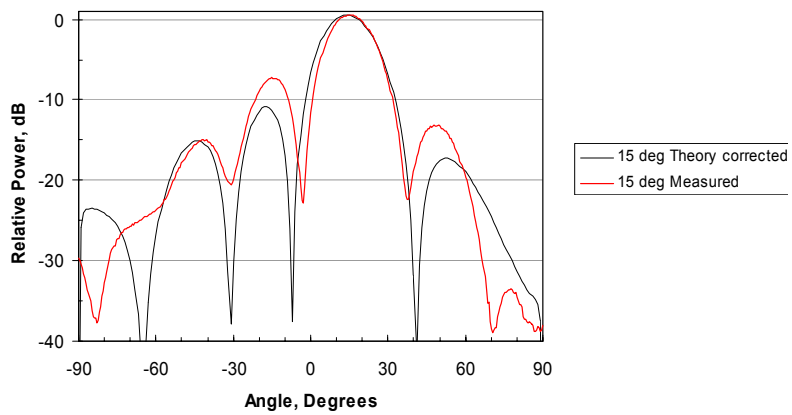


Figure 7. 15° scanned pattern of the 4x2 active array

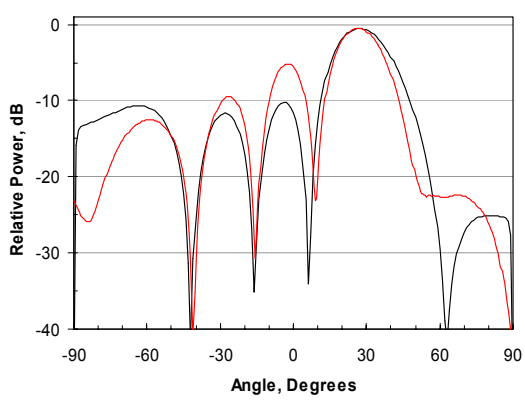


Figure 8. 30° scanned pattern

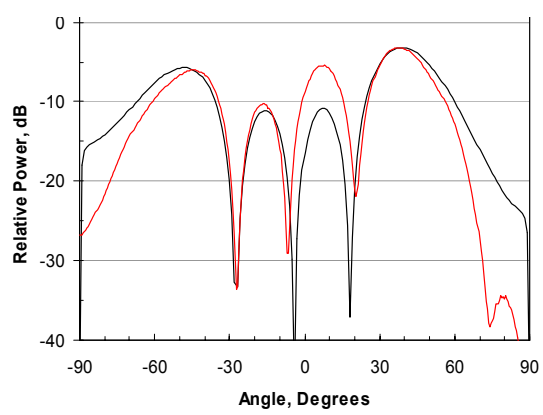


Figure 9. 45° scanned pattern