Thin-Membrane Aperture-Coupled L-Band Patch Antenna

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Abstract – A microstrip line on very thin membrane substrate (0.05mm) is slot-coupled through a thick air substrate (12.7mm) to excite an L-band radiating patch element. It achieved a relatively wide bandwidth of 100 MHz (8%). Very narrow coupling slot is used with aspect ratio of 160 (conventional slot aspect ratio is between 10 to 30). This new feed design makes the thin-membrane or inflatable array antenna technology more practical. It reduces the number of thin-membrane layers required for a dual-pol wide-band inflatable array from three layers in a previous design to two layers. In addition, this technology allows the thin-membrane array antenna elements to be readily integrated with thin-membrane-mounted transmit/receive (T/R) modules.

Introduction – Electronic beam scanning phased array antennas with very large apertures ($100m^2$ to $900m^2$) will provide a wide range of radar capabilities for NASA's Earth science remote sensing applications. Future Earth science missions will require very high-gain antennas placed in high orbits, such as medium or geosynchronous Earth orbits (MEO or GEO). For these very large arrays, the radar mass, volume and cost will be prohibitive if the antenna technology relies on previous rigid-panel phased arrays, such as the one used for the SIR-C program [1]. Membrane-based deployable antennas [2, 3] provide a means to reduce mass, launch-vehicle stowage volume, and overall cost compared to rigid radar antenna systems. However, prior to realizing thin-membrane phased arrays in space, many challenges must be overcome. One of the component challenges is to develop the proper excitation technique for feeding a thin-membrane patch radiator, which can also be integrated with 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. The bottom layer has the microstrip lines, which excite the top layer patch elements through the slots located in the middle ground-plane layer. These three layers, at the low microwave frequency of L-band, are separated with relatively large empty spaces – 0.64cm and 1.27cm, respectively. This paper addresses a new approach where only two thin-membrane layers are possible. The bottom layer has both the microstrip lines and the slotted ground plane, while the top layer has only the patch elements. 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) transmission line system is used [5]. This two-layer approach also allows the large-aperture antenna to be more easily rolled up with a smaller stowage volume.[1]

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Antenna Design – Fig. 1 is a sketch that illustrates the two-layer thin-membrane aperture-coupled design for a single L-band patch element. The L-band square patch is 8.89cm on each side and is supported on a 0.05mm-thick polyimide thin membrane (Pyralux^{TM} with a relative dielectric constant of 3.4). This patch is separated from the ground plane by 1.27cm. The feeding microstrip line is 50 ohm with 0.12mm width and is separated from the ground plane by the same 0.05mm-thick polyimide membrane. The aperture-coupling slot, etched in the ground plane, is 0.48mm wide and 79.5mm long. In order to have maximum coupling, the microstrip line extends beyond the slot center by a length of 36mm, which is about a quarter of an effective-wavelength long. The other end of the microstrip line is transformed to a 50-ohm co-planar waveguide (CPW) line for T/R module integration. The plated-through vias on the CPW are used to suppress the possible generation of parallel-plate modes. It can be observed that this antenna consists of only two thin-membrane layers. As shown in a photo in Fig. 2, one layer has the patch and the other has the microstrip line and coupling slot. Note that the slot width is very narrow and is only about 10 times the substrate membrane thickness and 4 times the microstrip line width. The slot has a length-to-width ratio of about 160. With such a large aspect ratio and narrow width, the slot can still effectively couple energy to the patch and achieve a relatively wide impedance bandwidth of 100 MHz (8%).

Calculation and Test Results – The measured antenna input return loss is given in Fig. 3 where it shows that the -10dB return-loss bandwidth is about 100 MHz (8%) and agrees very well with that calculated by the moment-method-based Ensemble software. The measured and calculated radiation patterns at the center frequency of 1.26GHz are shown in Fig. 4 for both E-plane and H-plane cuts. The agreement between the calculated and measured results is very good within the angular region of ±90°. Since the calculations assume infinite ground plane, no backward radiation is shown. The measured patterns also show very little backward radiation. This is due to the blockage from the mounting structure located at the back of the antenna. The peak cross-pol level of -20dB shown in the measured results is significantly higher than the calculated results of below -40dB (not high enough to be seen in the plots). This is because the actual antenna has a very small ground plane (see Fig. 2) that results in strong edge diffractions in both polarizations. The measured peak antenna gain at the center frequency of 1.26GHz is 6.93 dBi. The gain variation across the 100 MHz band is very stable and is given in the table below. The measured radiation patterns also show similar performance across this band.

Frequency (GHz)	1.18	1.24	1.26	1.28
Measured gain (dBi)	6.85	6.64	6.93	7.03

Summary – A two-layer, thin-membrane, aperture-coupled microstrip antenna has been successfully developed at the relatively low microwave frequency of L-band. This two-layer design allows integration with membrane mountable T/R modules for future thin-membrane phased array application.

References:

1. R. L. Jordan, B. L. Huneycutt and M. Werner, "The SIR-C/X-SAR synthetic aperture radar system," IEEE Trans. Geoscience and Remote Sensing, Vol. 33, pp. 829-839, July 1995.
2. J. Huang, M. Lou, and E. Caro, "Super-low-mass spaceborne SAR array concepts," IEEE AP-S/URSI Symp., pp. 1288-1291, July 1997.

3. J. Huang, "The development of inflatable array antennas," IEEE Antennas Propag. Magazine, feature article, vol. 43, pp. 44-50, Aug. 2001.
4. D. M. Pozar, "Microstrip antenna aperture-coupled to a microstripline," Electronics Letters, vol. 21, pp. 49-50, Jan. 1985.
5. A. Moussessian, et al., "Transmit/receive membranes for large aperture scanning phased arrays," Earth Science Technology Conference (ESTC), College Park, MD, June 2003.

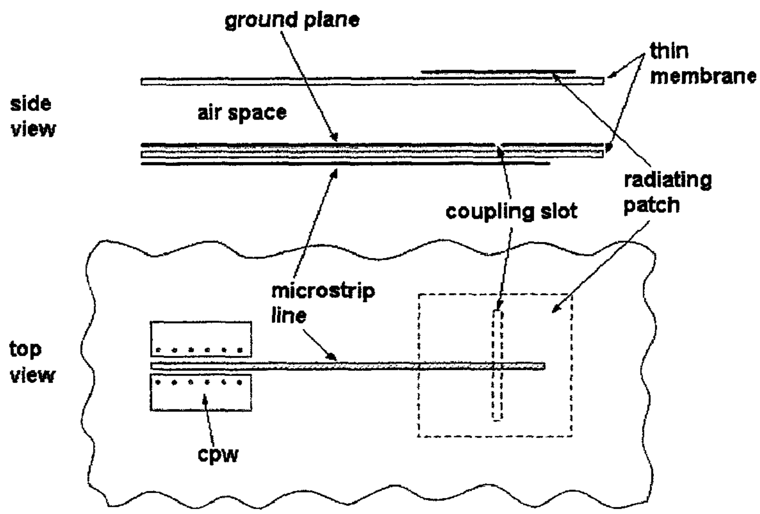

Figure 1. Configuration of thin-membrane aperture-coupled microstrip antenna. The T/R module will be connected to the CPW side of the feed.

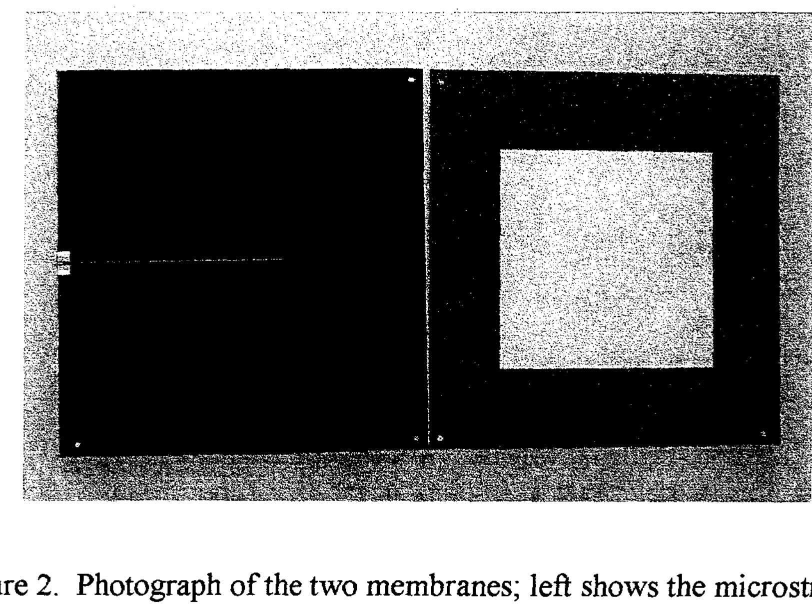

Figure 2. Photograph of the two membranes; left shows the microstrip line and the aperture-coupling slot, right shows the L-band patch. The aperture slot is on the back side of the membrane and is nearly visible through the thin layer of polyimide.

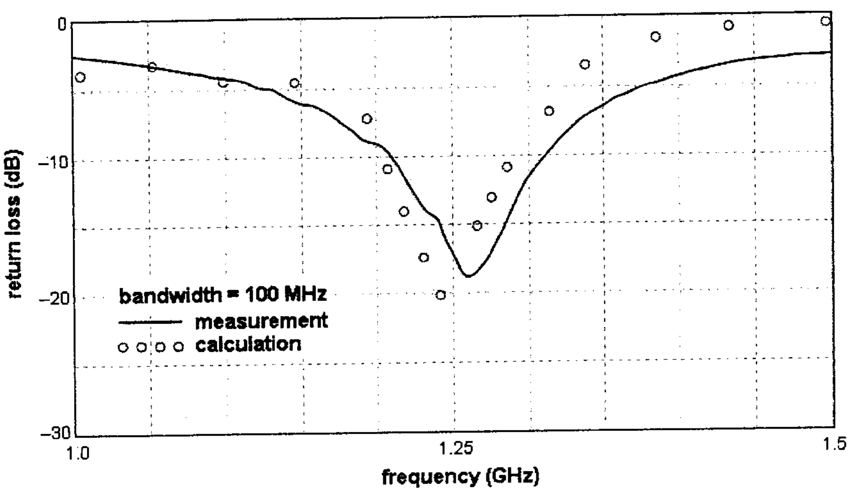

Figure 3. Measured and calculated input return loss.

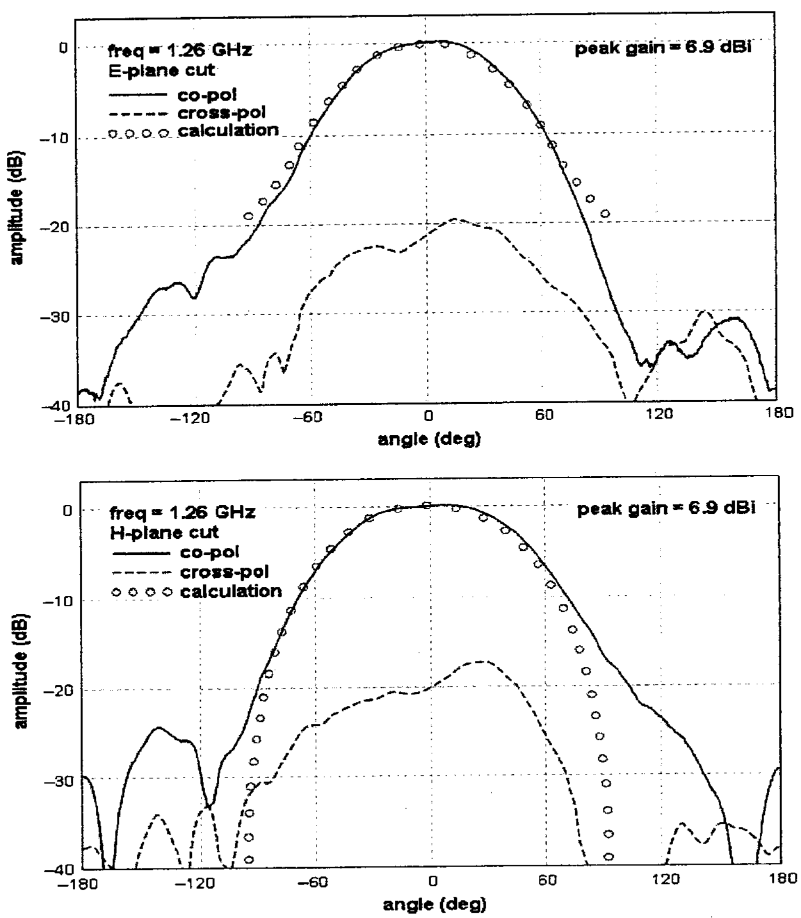

Figure 4. Measured and calculated E-plane (top) and H-plane (bottom) radiation patterns.