An 8x8 Lightweight Flexible Multilayer Antenna Array

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Introduction

Multilayer integration has become a key technology driver to optimize the compactness in a design. One application that can benefit from the multilayer approach is large antenna arrays. Antenna arrays have the advantage of high directivity and gain, which are essential for military and space applications. For these applications, the size of the array can increase very quickly and multilayer configurations can help decrease the overall size. By separating the elements of the antenna array from the feed network and active components in the system to different layers, the compactness of the design can be maximized. Furthermore, a reduction in overall size in a single layer can give rise to coupling between the feeding and the radiating elements. Again, the multilayer approach can help eliminate this problem by incorporating an embedded ground plane. Previous papers have shown multilayer flexible antenna arrays with embedded ground plane, which also includes slots for the coupling between the feeding elements and radiating elements [1]. In addition, integration of a phase shifter to make a compact reconfigurable antenna array and a 'stitching' technique to expand an array beyond available fabrication limits have been explored [2-3].

In this paper, a lightweight 8x8 antenna designed on a Liquid Crystal Polymer (LCP) is presented. Using via hole technology, a multilayer approach for integration of RF front end components has been successfully achieved. Additionally, the flexibility of the antenna is demonstrated as the antenna pattern is measured while wrapping it on the surface of a cylindrical Styrofoam.

Antenna Design

The antenna design is based on 4x8 sub-arrays on an LCP substrate at 14 GHz. Two sub-arrays are connected using vias on a separate layer, which is termed as 'stitching' a layer. Figure 1 shows the layout of the 'stitched' 8x8 antenna array. The antenna feed is shown on the right hand side, where an RF probe is used to feed the array. With 250 μm wide and 125 μm deep via holes, the signal is connected to the feed line of each 4x8 sub-array. The embedded feed line layer includes $\lambda/4$ impedance transformers for each junction and a 'hard-wired' phase shifter set with 0° of phase shift. The phase shifters are preliminary designs for the MEMS enabled phase shifters and the switches are replaced with simple short circuited lines representing ideal switches. The ground is embedded 100 μm above the feed lines, which also includes slots for the signal to couple to the

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patches. The patches are 0.52λ apart and 250 microns above the ground. The overall size is 8.7 cm by 8.6 cm (Figure 1). The antennas were fabricated using multi-layer LCP processing technology with laser ablated and electroplated vias to accomplish vertical interconnections.

Results

The S_{11} measurement is shown in Figure 2. The resonance is at 13.8 GHz which is shifted 200 MHz from the design frequency due to fabrication tolerances and alignment. When a metal plate is placed in the vicinity of the patches, the resonance disappears; therefore, the resonance in the measurement represents the radiation from the patches. Figure 3 shows the measured gain and pattern measurement data. As the phase shifters are set to 0° phase shift, the maximum lies in the broadside as expected. The ideal antenna gain can be estimated with the equation

$$G = \varepsilon_{ap} \frac{4\pi}{\lambda^2} A_p = \varepsilon_{ap} \frac{4\pi}{\lambda^2} L_x L_y = \varepsilon_{ap} \frac{4\pi}{\lambda^2} \left(\sqrt{N} d\right)\left(\sqrt{N} d\right) = \varepsilon_{ap} \frac{4\pi}{\lambda^2} N d^2 \qquad [4]$$

where ε_{ap} is the efficiency, A_p is the area of the aperture, N is the number of elements, and d is the antenna spacing. Then the ideal gain is 23.4 dB, which is 6.5 dB more than the measured gain of 16.9 dB. The main source of the loss is the long corporate feed network. The microstrip line adds about 0.25 dB/cm and the signal path is approximately 14 cm, accounting for 3.5 dB of loss. The remaining 3 dB of loss is attributed to mismatch arising from fabrication tolerances, small losses in the T-junctions, and possible radiation from the slots. In addition, the vias and the landing pads are sources for the loss as well.

The 8x8 antenna is mounted on a cylindrical Styrofoam with a radius of 6.5 cm as shown in Figure 4. Two measurements are made with one having the patches facing the center of the cylinder, and the other facing outward away from the center of the cylinder. The measured patterns are shown in Figure 5. The Hco patterns in both cases show a broadened pattern with degradation in the gain and the maximum approximately 50° away from the broadside. Similar results and solutions to correct these effects of conformed antennas have been reported [5-6]. The results in Figure 5 show that the antenna array operates correctly while being flexed and can be designed as a conformal antenna.

Conclusion

A lightweight flexible multilayer 8x8 antenna array has been designed, fabricated, and measured. The results show 16.9 dB of gain with the loss originating mainly from the line loss of the corporate feed network. Using via hole technology, 'stitching' of two 4x8 sub-arrays have been achieved with minimal RF performance degradation. In addition, the array has been measured on a cylinder with a radius of 6.5 cm as a verification of its flexibility and the results show negligible performance change due to mechanical distortion.

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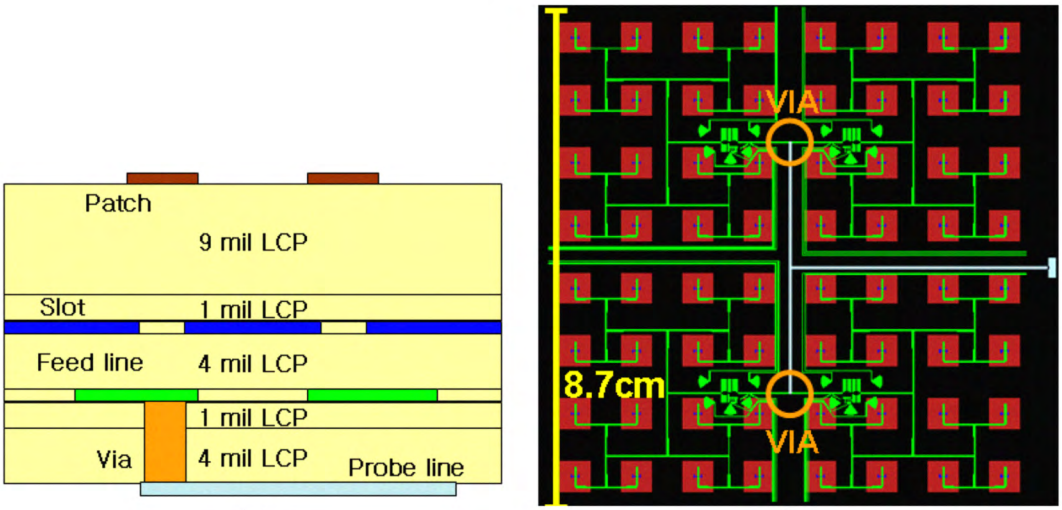

(a) (b)

Figure 1. Design and layout of 8x8 array (a) vertical view (b) top view

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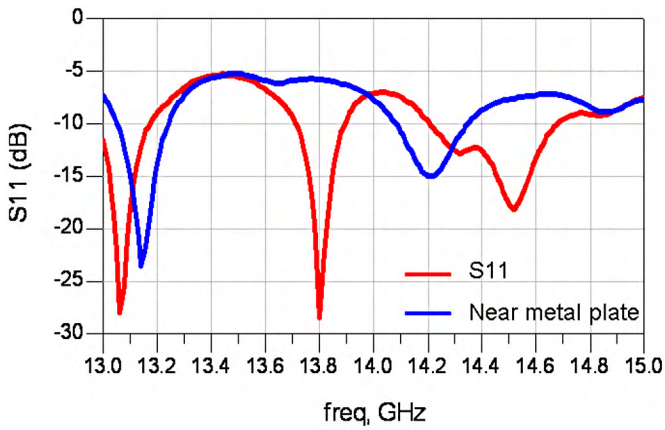


Figure 2. S_{11} measurement including a metal plate in the vicinity of the patches.

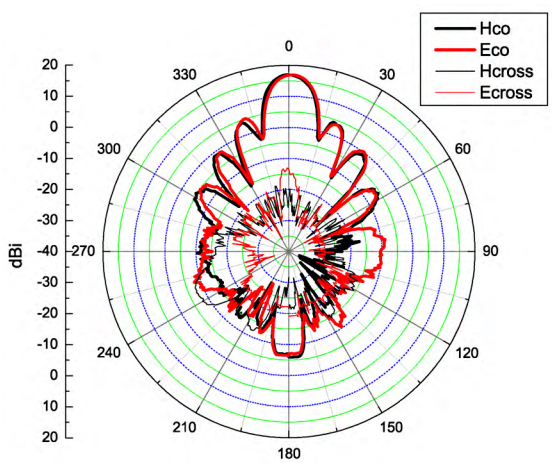


Figure 3. Pattern measurements of 8x8 with 'Hard-wired' phase shifters.

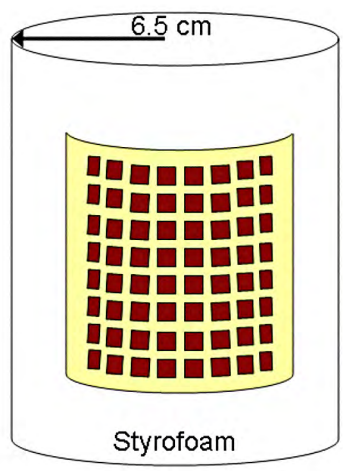
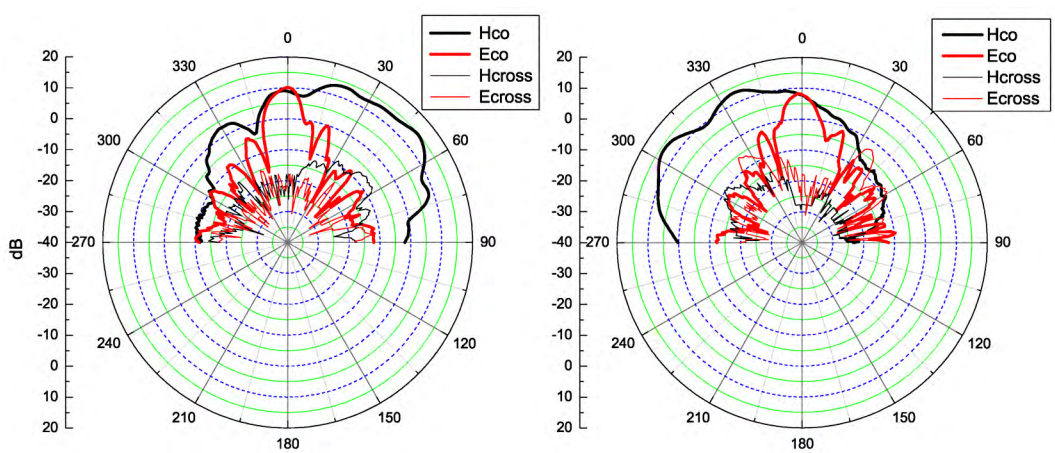


Figure 4. 8x8 array on a 6.5 cm radius curvature.



(a) (b)

Figure 5. Pattern measurements of antenna on a 6.5 cm radius curvature with the patches facing (a) inward and (b) outward.

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