Integration of a 4x8 Antenna Array with a Reconfigurable 2-bit Phase Shifter using RF MEMS Switches on Multilayer Organic Substrates

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Introduction

As water is a crucial factor for sustaining life, the study of its distribution around the globe has also been a great importance. Satellites have been deployed with antennas operating at 14 GHz to observe the rainfall. In the past, high-gain parabolic reflectors have been used frequently for space missions with a cost of low efficiency, large size, heavy weight, and difficulty in deploying. In order to overcome these troubles, microstrip arrays antenna have been developed. Though they have higher insertion loss, meaning less efficiency, they will be significantly lighter, smaller, and simpler [1], [2]. Recently, NASA has been collaborating with Georgia Institute of Technology to develop advanced, low cost, light weight, and large surface area antennas that can be deployed in space. Previous works show multi-functional small arrays [3], [4], but the size has been limited, and the possibility of expanding the structure is small.

In this paper, Liquid Crystal Polymer (LCP) is used as the substrate, which enables the fabrication of a flexible, low cost, and light weight antenna. Using LCP, an attempt to expand from the previous works has been accomplished by constructing a 4x8 antenna array made of two 4x4 sections being fed with a reconfigurable 2-bit phase shifter. Each reconfigurable phase shifter is enabled by eight RF MEMS switches and the two 2-bit phase shifter together, allow a 6° phase shift in the final design.

Antenna Design

The unit design is based on a 4x4 antenna array. We can see in Fig. 1, the S11 response of a 4x4 array. The resonance is at a frequency about 13.9 GHz shown by the line corresponding to thick foam and the measurements match the simulation results. The thick foam (~2 inches) was placed on the patches to facilitate the measurements when positioning the probes, and did not interfere with the free-space results as the relative permittivity is very close to 1. In order to verify that the resonance indeed represents radiation that takes place and does not originate from anywhere along the feed network or the slots, the patch layer was attached to a thick metal plane. With the metal plane on top of the patches, the reflection coefficient was measured (Fig. 1). The results showed a cancellation of the occurring resonance which verifies that the radiating elements are the metal

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patches. Each unit 4x4 contains a 2-bit reconfigurable phase shifter operated with RF MEMS switches as shown in Fig. 2. The different layers will be described in a paragraph below.

Next, two 4x4 antenna arrays are joined together with a corporate feed network to form a 4x8 array structure. The corporate feed network design allows the possibility of expanding the array, only limited by the conduction loss. The total length of each possible path in the phase shifter differs by 90° phase difference and the measured loss is less than 0.5 dB per bit. This particular phase was chosen to serve as the foundation of the proof of concept that beam steering actually takes place while all microwave components have been fabricated directly on LCP without using any other substrate or procedure. The 90° path differences between the two 4x4 units can steer the beam by 6°. There is a trade off between the number of phase shifters used and its bits. Having more phase shifters and more bits would allow a finer tuning in the beam steering and the side lobes would decrease. On the other hand, the increase in numbers adds more loss and adds to the complexity of the structure, leading to a system more prone to errors. Therefore, considering the number of bias lines and the size of the phase shifter when the array is expanded, it is optimal to minimize the number of phase shifters while operating at an acceptable level of side lobes, or less than -10 dB, and a sufficient coarse tuning.

The substrate material for the fabricated prototype is LCP ($\varepsilon_r \sim 2.95$) and multiple layers are bonded as seen in Fig. 2. At the top, there are 4x4 antenna patches with 3 µm thick copper metallization on a 10 mils LCP layer. Beneath this layer, there are 3 µm thick copper coupling slots again with 4 mils of LCP beneath it. At the very bottom, the feed line and phase shifter with the MEMS are fabricated. Due to the nature of the difference in melting points of two different types of LCP, the bonding is possible with thermal compression bonding. In this process, only one layer melts and as it cools, the other layers are adhered as the melted layer solidifies. The final dimension of the 4x8 antenna is approximately 8x5 cm^2 as shown in Fig. 3.

Results

Initially, a hard-wired 4x8 array was fabricated and measured in order to fine-tune the design frequency before the integration of MEMS. The deviation from the design frequency was found to be only 0.7%, thus, allowing for the subsequent integration of the MEMS switches. Figs. 4 and 5 show the simulation results of the radiation patterns of the prototype. In Fig. 4, the E-field is plotted for an antenna that has zero phase shift difference between its two 4x4 sub-arrays. As expected, the beam is centered at 0°. Giving one 4x4 unit array a 90° phase shift compared to the other unit array, leads to a 6˚ phase shift in the beam itself as shown in Fig. 5.

Conclusion and Future Work

An extremely light-weight, low-cost, flexible, and deployable antenna array that includes the ability to steer the beam has been shown. With a 4x8 array and having 2-bit phase shifters for each 4x4 unit, a 6° phase shift was achieved. More phase steps can be achieved by using additional path lengths in the reconfigurable system while tighter packing of the phase shifters can enable much larger tilt angles for the array. Future work will include the verification of all simulation results initially by measurements of ‘hard-wired’ circuits and then measurements of the RF MEMS reconfigurable system with beam-scanning functionality. These measurement results will be presented in the symposium.

References:

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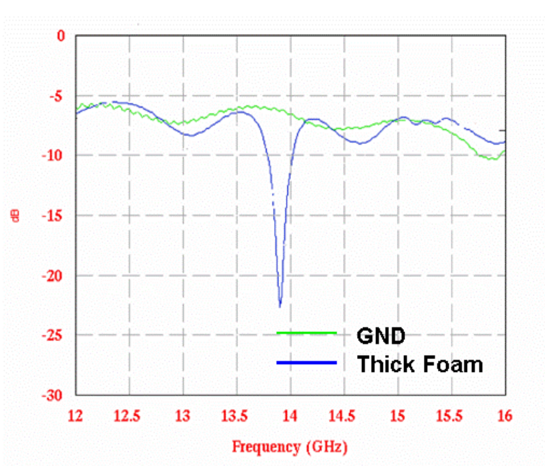

Fig. 1. 4x4 antenna array measured mounted on metal (GND) and mounted on thick foam (~3 inches).

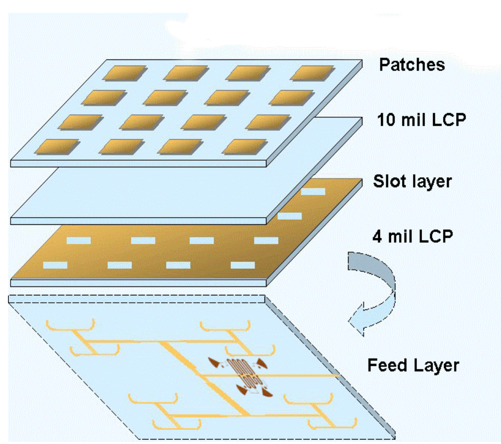

Fig. 2. 3-D architecture of the 4x4 patch antenna array on multilayer LCP substrate. The feed layer faces the bottom.

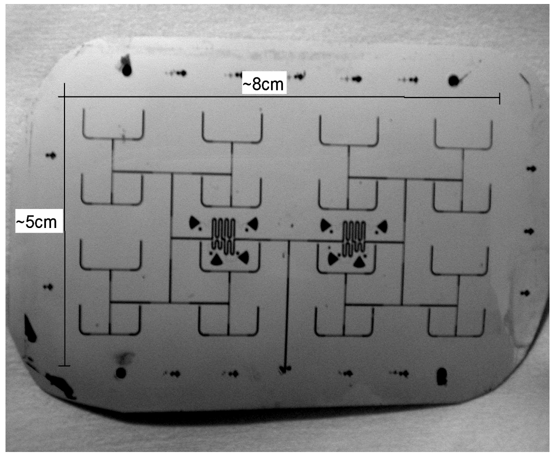

Fig. 3. Fabricated 4x8 "hard-wired" antenna array with its alignment marks.

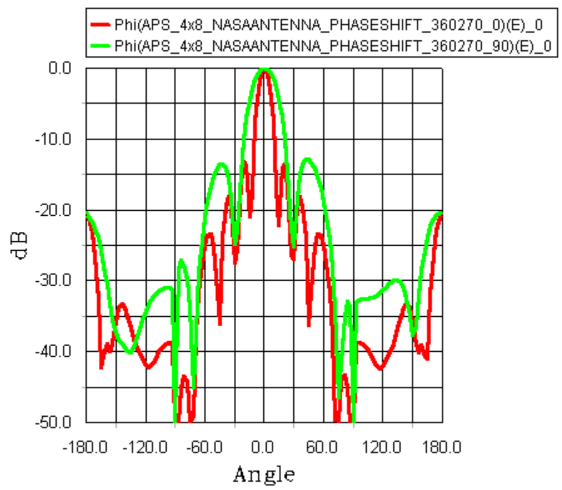

Fig. 4. E-field plotted with the 4x8 array having no phase variation. The red line is with φ = 0° and the green line is with φ = 90°

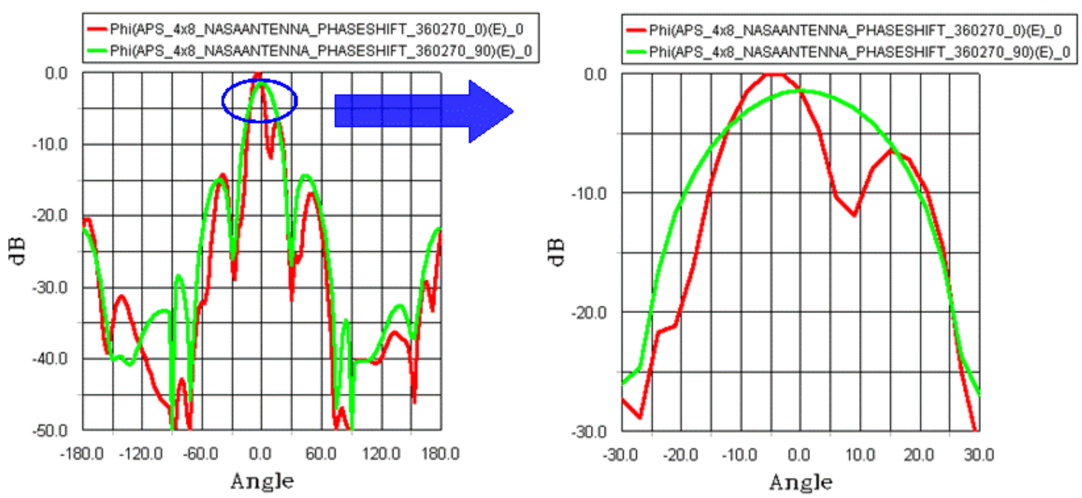

Fig. 5. E-field plotted with the 4x8 array having a 90° phase variation shows a 6° beam steering. The red line is with φ = 0° and the green line is with φ = 90°.