Recent Advances in the Development of a Lightweight, Flexible 16x16 Antenna Array with RF MEMS Shifters at 14 GHz

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***Abstract*-This paper presents recent advances towards the development of a lightweight, flexible 256-element antenna array utilizing RF MEMS phase shifters. The antenna array is being developed using the 3-D System-on-a-Package (SOP) RF front end technology, where several organic layers are stacked up together. Passive and active circuits, as well as MEMS devices, can be embedded in this 3-D stack up providing space savings without compromising the performance. The antenna array is fabricated using low cost Liquid Crystal Polymer (LCP) substrate that shows flexibility and has excellent electrical performance up to 110 GHz. The results of a 2x2 integrated sub-array module with RF MEMS phase shifters and embedded amplifier on LCP operating at 14 GHz are presented in this paper. In addition, a stitching technique using low loss vias for the development of multilayer integrated 4x8 sub-arrays and the entire 16x16 array at 14 GHz has been explored.**

I. INTRODUCTION

Phased array antennas are critical components for automobile collision avoidance radar, military radar, and space communication systems as they provide the advantage of high directivity and gain. However, the antenna system requires the integration of several components such as amplifiers, phase shifters, and RF power distribution networks. In addition, practical implementation of these phased array antennas with MMICs and RF MEMS phase shifters have been hampered by the high cost of packaging and integration of the system [1–2]. Furthermore, developing a reliable multi-layer process technology remains as a challenge. In an attempt to tackle these existing challenges all at once, a 3-D System-on-a-Package (SOP) approach has been developed using a low cost, light weight, flexible LCP substrate [3–4].

Taking advantage of the excellent electrical properties of LCP [5], research toward developing a light weight, flexible 256-element antenna array utilizing RF MEMS phase shifters has been in progress at the Georgia Institute of Technology. Passives and active components, as well MEMS switches, are integrated in a 3-D stack up to save real estate. In addition to saving space, the embedded multi-layer stack up maximizes the isolation between components and layers as it carries an embedded ground plane. Both approaches of coupling between layers and using via technology are implemented in the designs.

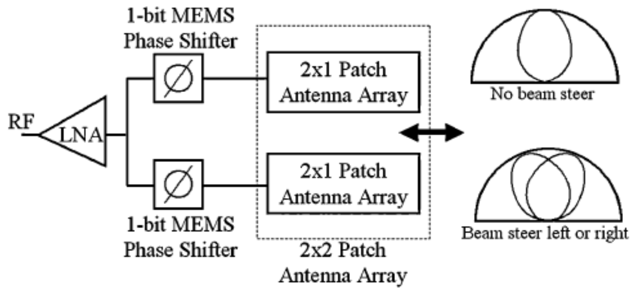


Fig. 1. Block diagram for a receive-mode phased array antenna.

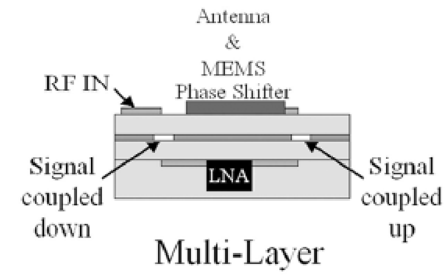


Fig. 2. Multi-layer implementation of the antenna array.

In this paper, recent advances toward the development of a 256-element antenna array are reported. This includes the integration of a 2x2 multi-layer antenna array that includes a MEMS phase shifter and an embedded amplifier [6]. Also, a stitching technique is shown that utilizes via technology to expand a unit array creating a larger array beyond fabrication limitations [7].

II. INTEGRATED 2X2 ARRAY

A. Design

Fig. 1 shows the block diagram of a 2x2 antenna array with a 1 bit MEMS phase shifter that will allow steering the beam in a single axis. Fig. 2 shows the multi-layer stack up that enhances the compactness of the overall system compared to a single layer configuration. The 2x2 patch array was designed to minimize distance between the patches which minimizes the array size and the side lobe. The degree of beam steering was correlated with the phase shift and the magnitude of the side lobes using ADS Momentum Software. The simulation results show a phase shift of 30^{o} will be

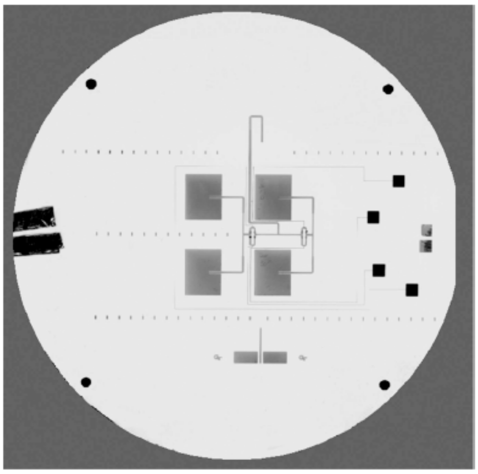


Fig. 3. Fabricated 2x2 multi-layer antenna array.

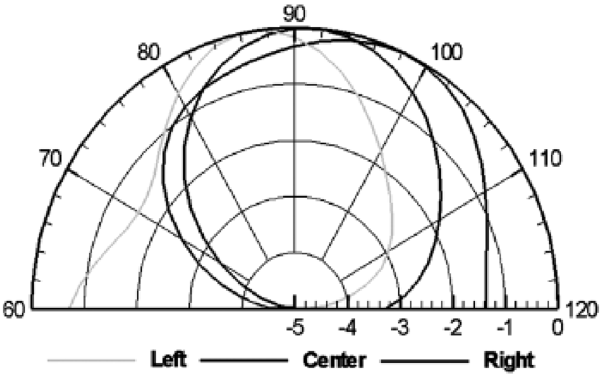


Fig. 4. Measured antenna pattern showing the beam steering. Data has been normalized.

required for maximum beam steering at a minimum of 15 dB or better side lobe level. The phase shift was achieved using RF MEMS switches, which have an on-state insertion loss of 0.20 dB and an off-state isolation of more than 30 dB at 14 GHz. The input signal is fed through a microstrip line that splits twice at T-junctions before reaching the patches. Quarter-wave transformers are used to maintain a 50 ohms impedance throughout the feed network. A K*u* LNA from Raytheon was embedded inside the multi-layer construction.

B. Results

Fig. 3 shows the top layer of the fabricated antenna array with the antenna patches and the RF MEMS enabled phase shifters in the feed line. Fig. 4 shows the measured antenna pattern in different phase states, showing the beam steer of the antenna. The results show that by integrating MEMS switches in a patch antenna array, a 12^{o} beam steer can be achieved. In addition, the fabricated antennas showed stability over a moderate flexing of the LCP substrate.

III. Expandable Array

A. Design

Fig. 5 shows an 8x8 antenna array layout with a 4 inch circle drawn as well. This figure shows it would be difficult to

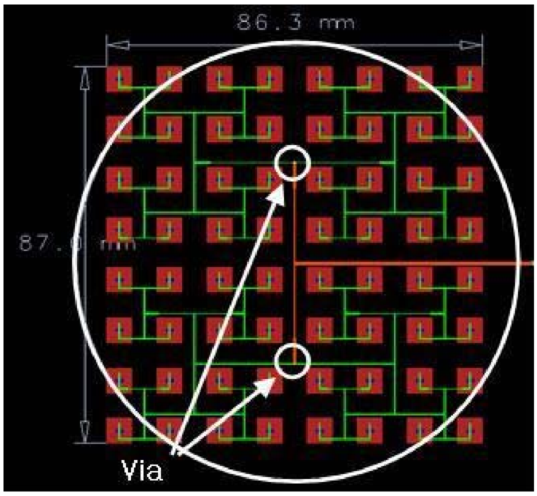


Fig. 5. Two 4x8 antennas “stitched” together to form an 8x8 array. The circle denotes the fabrication size limit of 4 inches

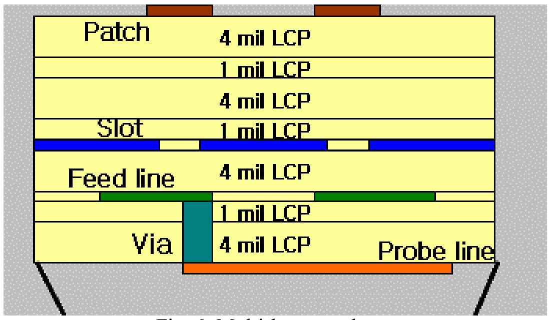
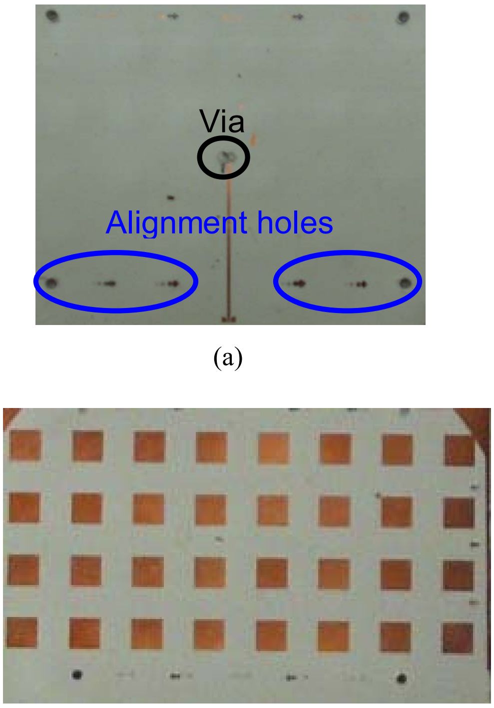


Fig. 6. Multi-layer stack up.

fabricate an 8x8 antenna array with a 4 inch processing capability. However, this is enabled with a stitching technique that utilizes via technology. Two unit 4x8 antenna arrays are connected in a separate layer with vias. It is possible to process bigger sample sizes, but at the cost of yield and non-uniformity across the sample. Also, with larger samples, the guaranteed minimum feature size becomes larger than desired and again, it may not be uniform. The overall stack up is shown in Fig. 6. The antenna uses approximately the half wave microstrip patches that are separated by 0.46λ. Two 4 mil LCP and two 1 mil LCP layers are bonded for a 10 mil separation between the patch layer and slot layer. The slot layer provides coupling from the feed line layer to the patch layer, allowing simplification of the overall connection between the patch and feed line. In addition, the slot layer acts as the microstrip ground for all of the other layers and electrically isolates the top half from the bottom half. The feed line uses a symmetric corporate feeding network that eases the process of expanding the array, and is limited only by the conduction loss as the size increases. At each junction, an impedance transformer is used to effectively match the impedance of each output for the signal to split in half. At the bottom, there is the probe line layer where the measurement probe or SMA connector can be attached. A 250 µm via makes the connection from the probe line layer to the feed line layer.



(a)

(b)

Fig. 7. Fabricated sample (a) top probe layer (b) bottom patch layer.

B. Results

Fig. 7 shows the top and bottom of the fabricated antenna. This fabricated antenna is tested with a vector network analyzer for the S11 measurements. A coaxial connector has been used to connect the sample and the input from the analyzer. The measurement result is shown in Fig.8 with comparison to the simulated measurements. The resonance is clear at 13.9 GHz with a S11 value of -19.1 dB. In order to verify the resonance is the actual radiation, a metal plate is placed in the vicinity of the patch layer, covering all the patches, and we observed the resonance disappear. The overall loss is slightly higher than the simulated response which can be due to fabrication tolerances, such as over-etching and misalignment discussed previously, and the metal quality of the copper lines. In addition, since the calibration was done using a short, open, and load (SOL) calibration technique, this does not account for the connector loss and the transition loss expected to be at least 0.3 dB at 14 GHz. Also, the bandwidth is slightly larger than the simulated response which is due to some additional loss in the overall antenna assembly including the connector. Fig.9 shows the probe measurement of the S11 response using TRL calibration for the 8x8 array. Again, when putting a metal plate close to the patches, it is clear that the resonance disappears, verifying the radiation. The resonance is at 13.78 GHz with a S11 value of -32 dB.

IV. Conclusion

In this paper, two different systems are assembled to show the integration possibilities of a 3-D SOP approach using LCP. First a 2x2 antenna array that includes a LNA and phase shifters enabled with RF MEMS shows a maximum beam

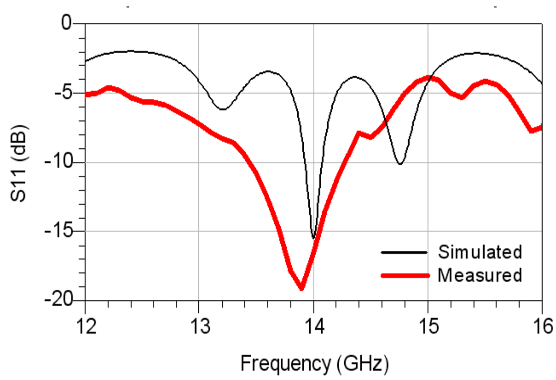


Fig. 8. Measured and simulated 4x8 array S11 response.

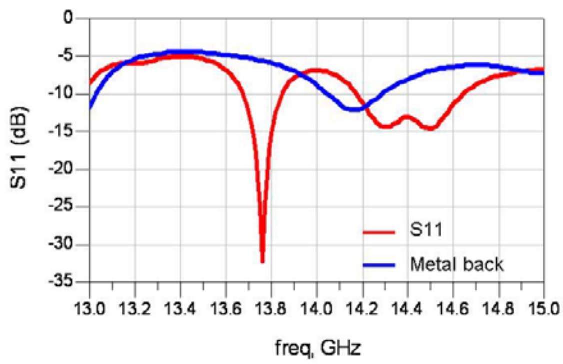


Fig. 9. Measured 8x8 array S11 response.

steer of 12°. In addition, an integration technology that utilizes vias to expand a unit array is shown. Secondly, using a 4x8 antenna array as a unit array, an 8x8 antenna array has been fabricated and the S11 response is presented. Both of these systems show that a low cost, light weight, and flexible 256-element array integrated in a multi-layer stack up is made possible with the development of a 3D LCP processing technology.

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