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LIGHT WEIGHT MIMO PHASED ARRAYS WITH BEAM STEERING CAPABILITIES USING RF MEMS

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ABSTRACT

A conceptual design of a MIMO Phased antenna array on Liquid Crystal Polymer (LCP) is introduced. Because of the properties of the substrate, the overall design is comparably light weight and semi-flexible to previous MIMO designs. Each input output unit array is capable of steering the beam ±6° in a 1-D space. This beam steer is enabled with the use of a 2-bit reconfigurable phase shifter using RF MEMS. The building blocks of a single input and output has been simulated to prove the concept. In addition, the array can be expanded to beam steer in a 2-D space for each individual unit. Overall, the entire system will be capable of having the beam steering function in multiple directions.

I. INTRODUCTION

Multi Input Multi Output (MIMO) systems have attracted much attention due to the advantages of increased channel capacity. Previous studies [1, 2] have shown that MIMO systems can support much more capacity within the same bandwidth. However, a simple MIMO system may be bulky and heavy due to the need to space the antennas a few wave-lengths apart for uncorrelated channels. In order to overcome these special requirements, phased arrays have been studied [3]. The phased arrays save much more space and add the function of being able to steer the beam when needed. In addition, further study has been done to show that directional antennas can provide more system capacity with the trade off of complexity [4, 5].

In this paper, a complex MIMO system that uses a phased array for beam steer has been designed. The design not only takes the special advantage of phased arrays, but also uses microstrip patches for the antennas that further reduce the overall size compared to conventional arrays. In addition, the design uses a light weight substrate (LCP) for a smaller and lighter system. The individual structures that are brought together to form the whole system is a 4x8 antenna array. For each of these 4x8 arrays, the antenna patches are aperture coupled through a corporate feed network that can easily be expanded for a larger structure that has more functions. The feed network also includes two 2-bit reconfigurable phase shifters that use RF MEMS switches for steering the individual beams.

II. OVERVIEW

As can be seen in Fig. 1 the MIMO system consists of multiple antenna arrays in different planes in space. The operating frequency of the antenna is 14 GHz. Each individual beam can be steered for a total of 12°, while facing different directions in the 3-D plane. The feed will consist of multiple lines to control each antenna array separately. The outputs maybe turned on or off with the MEMS switches and can steer each beam to optimize the directivity in the desired direction.

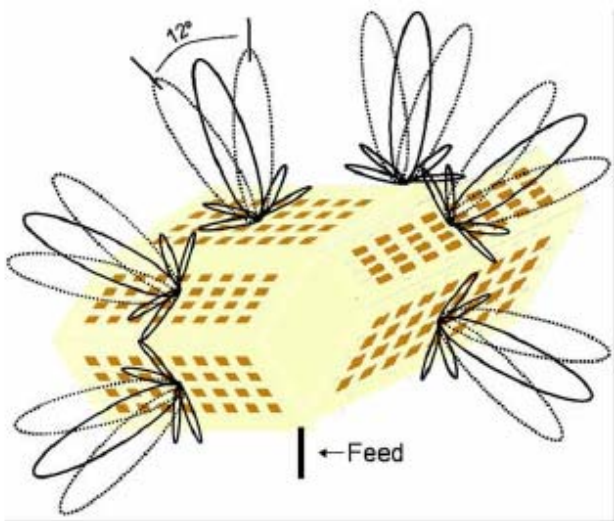

Figure 1: Conceptual design of the overall MIMO phased array antenna with the individual beam steering capability.

The antennas are microstrip antenna arrays that are fed by way of aperture coupling. The substrate material is LCP that provides great electrical properties as well as physical properties. Electrically, the material gives great high frequency characteristics and low loss (δ = 0.003). In addition, the material is flexible, light weight, and resistant to moisture. These great properties enable the making of a light weight, semi-flexible MIMO system comparable to previous designs.

III. ARRAY UNITS

The overall MIMO system can be divided into sub-units consisting of single inputs and single outputs. Each sub-unit is a 4x8 antenna array that includes two 2-bit phase shifters and 16 MEMS switches. This is the smallest functional unit because it is the smallest unit that can steer the beam. The 4x8 array is a sum of two 4x4 antenna arrays that has one 2-bit phase shifter. First, the 4x4 array will be analyzed to better understand the structure of the basic unit of the 4x8 array.

A. 4x4 Array Units

In order to show the concept of the entire MIMO antenna system, the smallest repeated array structure of a 4x4 array has been analyzed. Each 4x4 array unit has a 2-bit

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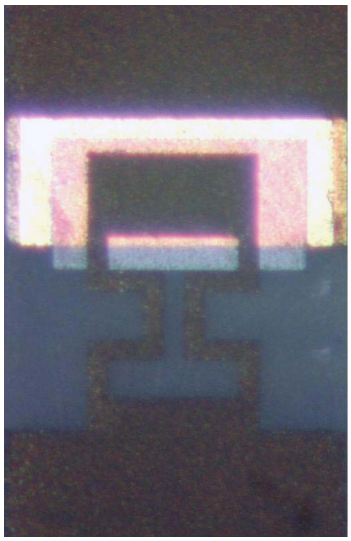

Figure 2: Cantilever structured capacitive RF MEMS Switch.

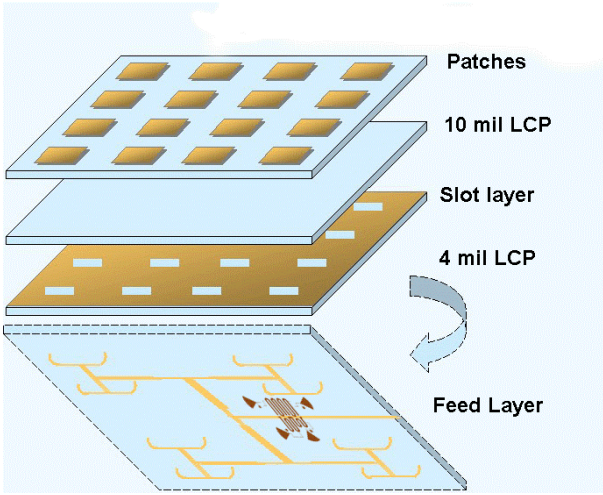

Figure 3: 3-D architecture of the 4x4 patch antenna array on multilayer LCP substrate. The feed layer faces the bottom.

reconfigurable phase shifter that is enabled with RF MEMS switches. As shown in Fig. 2, the MEMS devices are capacitive cantilever switches and they are electro-statically actuated with a voltage of 40 V. The total length of each possible path in the phase shifter differs by 90° phase difference (e.g. 0°, 90°, 180°, 270°) 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 RF MEMS switches were used to select the different path lengths as well as turning the entire circuit on and off.

The substrate material for the fabricated prototype is LCP ($\varepsilon_r = 2.95$) and multiple layers are bonded as seen in Fig. 3. At the top, there are 4x4 antenna patches with 3µm 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 with gold. 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 is cooled, the other layers are adhered as the melted layer solidifies.

B. Basic System Units

The basic building block for the overall system is a 4x8 antenna array. 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 90° path difference 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,

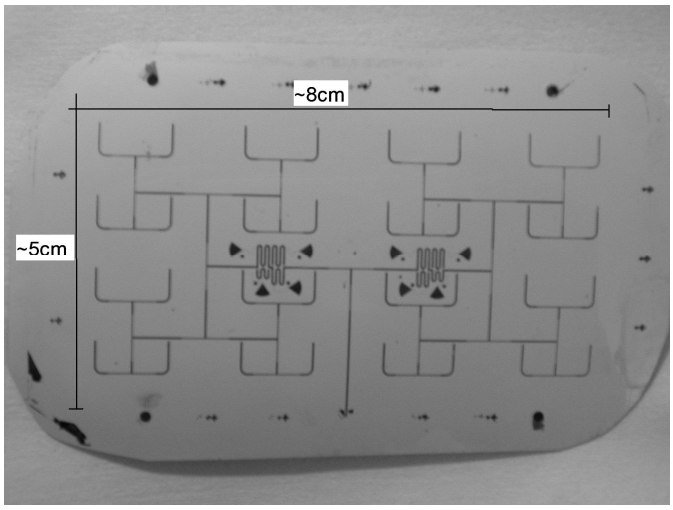

Figure 4: Fabricated 4x8 “hard-wired” antenna array with its alignment marks.

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 final dimension of the 4x8 antenna is approximately 8x5 cm^2 as shown in Fig. 4.

Each input will control a 4x8 system unit so that the beam can be steered in a one dimensional space. The input must also carry DC information for actuating the right MEMS switch for the desired output. Further expansion of the array is possible for increased functionality. For example, in order to control a system unit beam in two dimensions, we will need to expand the array to an 8x8 array. This can be easily designed with the corporate feed network. In addition, a larger array will give better directivity and can suppress the side lobe levels as well.

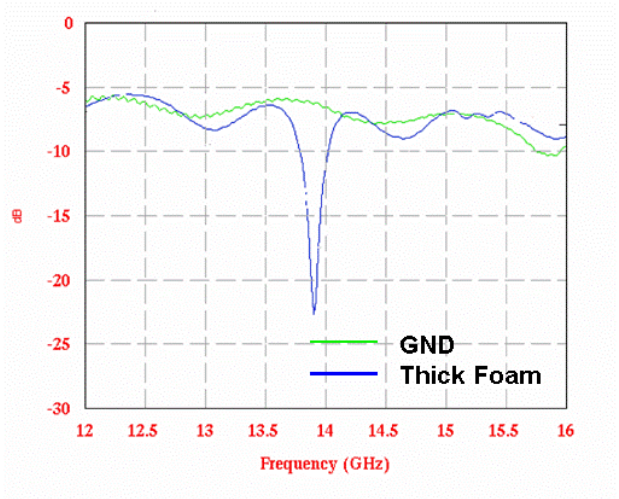

Figure 5: 4x4 antenna array measured mounted on metal (GND) and mounted on thick foam (≈ 2 inches).

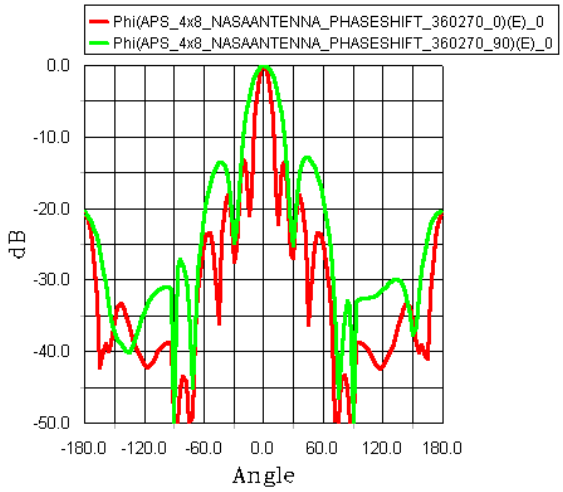

Figure 6: The E-field plotted with the 4x8 array having no phase variation. The red line is with $\phi = 0°$ and the green line is with $\phi = 90°$.

IV. Measurements and Results

The S11 response of a 4x4 array is shown in Fig. 5. The resonance is at a frequency of 13.9 GHz shown by the line corresponding to thick foam. As expected, 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. 5). The results showed a cancellation of the occurring resonance which verifies that the radiating elements are the metal patches. The majority of the loss in the figure is from conductor loss as the corporate feed network introduces long lengths of transmission lines.

Next, 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. Fig. 6 and Fig. 7 show the simulation results of the radiation patterns of the prototype. Fig. 6 shows the E-field that has no variation as the two 4x4 array units have the same phase. However, Fig. 7 shows a 6° beam steer when a 90° phase difference has been applied.

V. Conclusion

The concept of developing a MIMO system with each individual output beam to steer 6 degrees in a 1-D space has been shown. The individual units are aperture fed 4x8 antenna arrays that includes two 2-bit reconfigurable phase shifters enabled by RF MEMS. In the 3-D space, each unit will be placed in different angles planes so that it will be possible to transmit and receive in multiple directions while also steering the beam for optimum directivity in the desired direction. In addition, the possibility of expanding the array so that the beam can be steered in two directions also exists because of the corporate feed network design. Future work would be to show the complete integration of the MEMS switches for the phase shifters and to show multiple 4x8 array units working in sync.

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