Development of mm-Wave Dual-Frequency Multilayer Antenna Arrays on Liquid Crystal Polymer (LCP) Substrate

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I. Introduction

Microstrip patch antennas are very popular radiating elements due to their low profile, lightweight, low-cost characteristics and their compatibility with MMICs [1]. Moreover dual-frequency antenna arrays, required by many radar and contemporary communication systems, have gained considerable interest [2]. Dual-frequency arrays often necessitate a multilayer architecture not only to realize a compact implementation but also to control the radiation pattern characteristics of the individual arrays and prevent cross-coupling, blockage and edge diffraction effects.

Although low temperature co-fired ceramic (LTCC) technology is very suitable for multilayer realizations of microwave circuits such as filters and other passives, they are not ideal for antenna implementations. Antennas using high index materials such as LTCC result in pronounced surface wave excitation that can limit the impedance bandwidth, reduce the efficiency, and degrade the radiation pattern [3]. One solution is to use micro-machined or suspended patch antennas [4] albeit with increased fabrication cost and complexity. A soft-and-hard surface (SHS) structure can also be used to improve the radiation pattern [5]. Another alternative is to use a hybrid integration scheme wherein different dielectric media can be integrated to control the effective index [6]. However such multilayer structures formed by integrating different materials are subjected to greater stresses due to coefficient of temperature expansion (CTE) mismatches. Mechanical and thermal problems are inherent in those designs due to material incompatibilities.

Liquid crystal polymer (LCP), with a unique combination of characteristics and good mm-wave performance [7], offers an excellent solution to the aforementioned problem. Its low dielectric constant, engineered CTE and low loss in tandem with its vertical integration capabilities make it a choice material for the development of multilayer antenna arrays [8]. In this paper, the development of 2x2 aperture coupled antenna arrays operating at 14 and 35 GHz have been reported. Phase shifters and MEMS switches can be introduced to allow beam scanning and to switch polarizations.

II. Antenna Array Design

The top and side view of the multilayer antenna array architecture operating at 14 and 35 GHz is shown in Fig 1. The 14 GHz patches are placed on the top layer with a substrate thickness of 14 mils. The 35 GHz patches are embedded on a lower layer with a 5 mil thick substrate. Such an arrangement was chosen to minimize cross polarization at 35 GHz. The positioning of the array elements is optimized to reduce side lobes while minimizing blockage effects. An aperture-coupled feeding mechanism is used for both arrays to reduce parasitic radiation from the feed network. The feed network is located on a 4 mil LCP layer beneath the ground plane. The 2x2 array at each frequency consists of two linear sub-arrays (two 1x2 arrays) that are serially fed. A corporate feed network is employed to connect the linear sub-arrays. The feed network is optimized to ensure in-phase feeding of all the elements. It is also designed in such a manner that the polarization of the antenna elements can be switched with the help of a MEMS switch. The polarization directions here are at 45^0 and 135^0 as opposed to the conventional x-y directions. As a first modeling step, the switching of polarizations is controlled by the presence of hardwired perfect short and open conditions simulated by a continuous feedline and an unloaded 200 μm gap respectively. EMPicasso, a method-of-moments (MoM) based frequency domain 2.5D solver has been used for design and simulations.

III. LCP Multilayer Fabrication and Measurement Results

The availability of two types of LCP material that have different melting temperature facilitates the realization of multilayer structures. The type-I LCP with high melting temperature (315 ^{0}C) is used as the core layer while the type-II LCP with low melting temperature (290 ^{0}C) is used as the bond layer. The individual layers of the design were first fabricated on type-I LCP substrate using photolithographic process. They were then bonded together to produce the multilayer LCP structure. Alignment of the layers was performed using laser-drilled holes with positional accuracy of 25 μm or better. Such accuracy is required as the resonance behavior of the array is very sensitive to the relative positioning of the slots and the patch elements. Several experiments were performed to optimize the temperature profile and the tool pressure to achieve reliable bonding while preventing shrinkage, formation of bubbles and melting of core layers.

The return loss measurements were carried out with a vector network analyzer using a 2.4 mm coaxial-to-microstrip connector. A short, open, load and thru (SOLT) calibration was performed with the end of the coaxial cable fixed as the reference plane. Fig 2 shows the simulated and measured return loss of the 14 GHz array while the feed network of the 35 GHz array was left open circuited. Excellent agreement with the simulation results has been achieved. The impedance characteristics of the 14 GHz array are summarized in table I. Fig 3 shows the simulated and measured return loss of the 35 GHz array while the 14

GHz array was treated as a parasitic element. While measuring the 35 GHz array, launching problems were identified between the coaxial connector and the microstrip feed. Gating method is used, therefore, to measure the return loss. Since the array cannot be completely isolated from the launcher, only the resonant frequency was accurately determined. The impedance characteristics at 35 GHz are summarized in table II.

IV. Conclusion

The development of mm-wave dual frequency antenna arrays has been presented in multilayer LCP technology. Two 2x2 arrays operating at 14 and 35 GHz respectively have been designed and their impedance characteristics have been validated with measurements. These arrays can be integrated with 3D modules containing integrated circuits, filters and embedded passives to realize a complete System-on-Package (SOP) based RF front end.

References

[1] K. R. Carver, J. W. Mink, “Microstrip antenna technology,” IEEE Trans. Antennas and Propagation, vol. 29, pp. 2-24, Jan. 1981.

[2] S.D. Targonski, D.M. Pozar, “Dual-band dual polarized printed antenna element,” Electronic Letters, Vol. 34, No. 23, pp. 2193-2194, Nov. 1998

[3] Daniel H. Schaubert, K. Sigfrid Yngvesson, “Experimental study of a microstrip array on high permittivity substrate,” IEEE Trans. Antennas and Propagation, Vol. 34, No. 1, Jan 1986.

[4] Ioannis Papapolymerou, Rhonda Franklin Drayton, Linda P.B. Katehi, “Micromachined Patch Antennas,” IEEE Trans. Antennas and Propagation, Vol. 46, No. 2, Feb 1998.

[5] R.L.Li, G.DeJean, J.Papapolymerou, J.Laskar and M.M.Tentzeris, “Radiation-Pattern improvement of patch antennas on a large-size substrate using a compact soft surface structure and its realization on LTCC multilayer technology”, IEEE Transactions on Antennas and Propagation, Vol.53, No.1, pp.200-208, January 2005.

[6] J. Granholm, N. Skou, "Dual-frequency, dual-polarization microstrip antenna array development for high-resolution, airborne SAR," Proc. IEEE Asia-Pacific Microwave conference, pp. 17-20, Dec. 2000.

[7] D.C. Thompson, O. Tantot, H. Jallageas, G.E. Ponchak, M.M. Tentzeris, J. Papapolymerou, "Characterization of Liquid Crystal Polymer (LCP) Material and Transmission Lines on LCP Substrates from 30-110 GHz," IEEE Transactions on Microwave Theory and Techniques, vol. 52, No. 4, pp. 1343-1352, April 2004.

[8] G. Dejean, R. Bairasvasubramanian, D. Thompson, G.E. Ponchak, M.M. Tentzeris, J. Papapolymerou, “Liquid Crystal Polymer (LCP): A new organic material for the development of multilayer dual frequency/ dual polarization flexible antenna arrays”, accepted for publication in Antennas and Wireless Propagation letters.

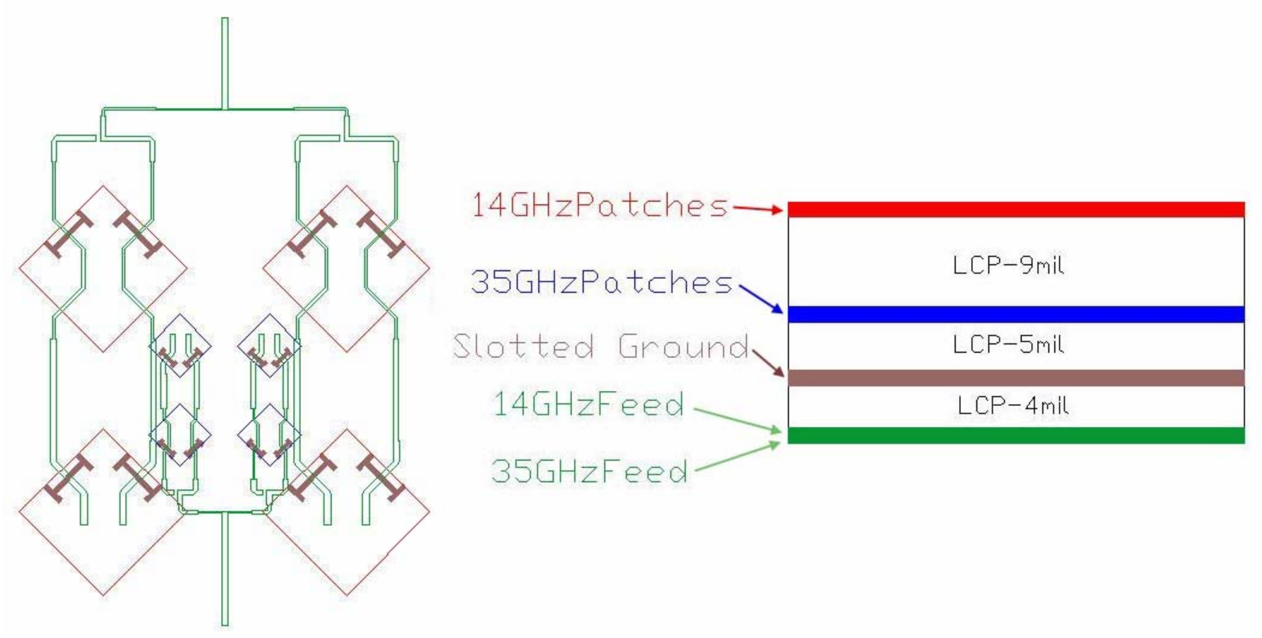

Fig. 1. Series-Fed Aperture Coupled Dual frequency Array, [L] Top View, [R] Side View

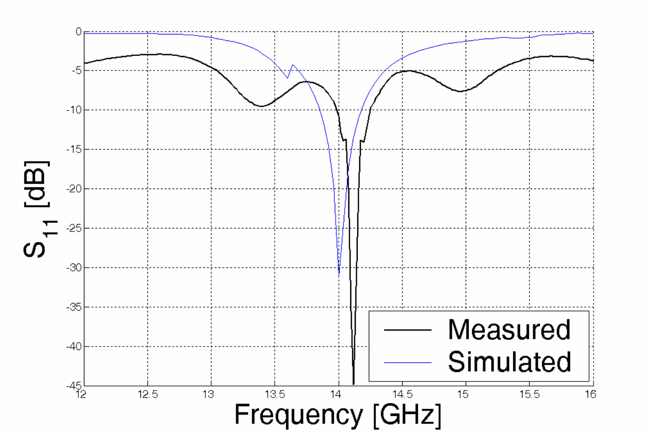

Fig. 2. Return Loss of the 14 GHz Array

Table I – Impedance Characteristics of the 14 GHz Array

Attribute	Simulation	Measurement
Resonant Frequency	14 GHz	14.1 GHz
Return Loss	-30 dB	-45 dB
% Bandwidth	2%	1.8%

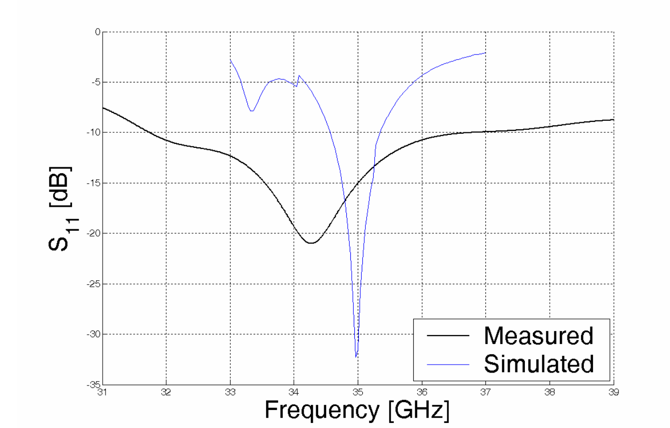

Fig. 3. Return Loss of the 35 GHz Array

Table II – Impedance Characteristics of the 35 GHz Array

Attribute	Simulation	Measurement
Resonant Frequency	35 GHz	34.3 GHz
Return Loss	-32 dB	-21 dB
% Bandwidth	2.08%	--