IMPLEMENTATION OF A LOW COST, LIGHTWEIGHT X-BAND ANTENNA WITH INTEGRATED SiGe RF ELECTRONICS

Chad E. Patterson[1], Tushar K. Thrivikraman, Ana M. Yepes, Swapan K. Bhattacharya, John D. Cressler, and John Papapolymerou

School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332
[1]cpatterson@gatech.edu

SUMMARY

This paper presents an organic, lightweight X-band antenna array with integrated silicon germanium (SiGe) low noise amplifiers (LNA) and 3-bit phase shifters (PS). The SiGe LNAs and PSs were successfully integrated onto an 8x1 lightweight antenna stack-up utilizing a multilayer liquid crystal polymer (LCP) substrate. Successful comparisons of the measured and simulated results verify a working antenna array with a return loss of around 10 dB across the frequency band of 9.25 GHz - 9.75 GHz. A comparison of radiation patterns for the 8x1 antenna with integrated SiGe LNA and the 8x1 antenna with integrated SiGe LNA and PS show a 16 dB and 25 dB increase in gain, respectively. The ultimate goal is to develop an airborne X-band radar capable of a beam steering of at least ±40° through utilization of low power highly integrated SiGe electronics on a low cost multi-layer organic platform. This paper represents the first successful demonstration of a building block prototype (i.e., a fully integrated, high gain X-band antenna with SiGe LNAs and SiGe phase shifters) that can be expanded to a complete active phased array for remote sensing applications in X-band.

1. INTRODUCTION

Rapid growth in the field of wireless communications and the consistent need for high-performance circuitry at lower costs have made the integration of RF circuits in a large processing format increasingly attractive. The use of Liquid Crystal Polymer (LCP) as a substrate-level integrated platform offers high performance at frequencies extending well into the millimeter wave band [1-3]. In addition, its inherent properties allow it to be processed using standard techniques compatible with printed circuit board manufacturing at lower cost [2]. Furthermore, incorporation of highly functional low power 0.13 μm BiCMOS SiGe circuits on LCP makes this technology [4-5] niche and uniquely positioned compared to other technologies available in the literature [6-7]. It has been successfully shown that the integration of SiGe with radar systems is a viable low cost solution [6]. The potential for several integrated functions on a single chip that offers high performance at lower costs keeps this technology in high demand. Recently, a research group incorporated 0.35 μm SiGe technologies with microstrip antennas for a radiometer application yielding good performance at reduced costs compared to other MMIC technologies [7]. The work in [7] reveals the enormous potential for application of SiGe circuits in radar applications, but to date a fully integrated multilayer antenna with a demonstrated phase shifting capability in X-band has not been achieved. Furthermore, the active components in the present work utilize for the first time state-of-the-art 0.13 μm BiCMOS SiGe technology.

The present research is the first to successfully integrate a SiGe X-band low noise amplifier and phase shifter onto a functioning three dimensional organic antenna array. The ultimate goal is to demonstrate an X-band radar on a lightweight organic platform by integrating low cost SiGe electronics for remote sensing of snow and cold-land processes in X-band.

To accomplish this task, first an 8x1 antenna array is presented with a fully integrated SiGe LNA and SiGe PS in an all LCP organic platform. The 8x1 array is intended to serve as a building block for the realization of an 8x8 high gain antenna on a flexible large format low cost organic substrate with a high degree of beam steering capability through the incorporation of phase shifters and T/R switches.

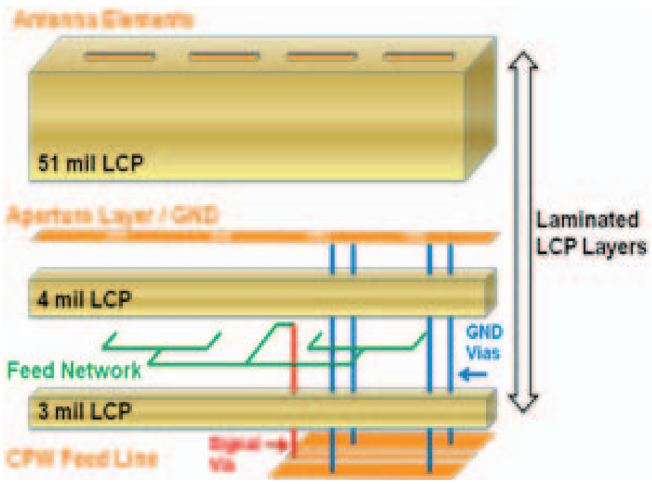

Fig. 1. Stack up of multi-layer LCP 8x1 antenna array. Only 4 antenna elements are shown in the top layer.

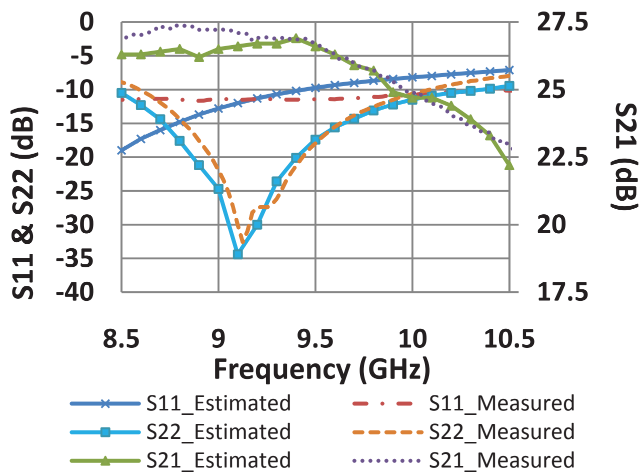

Fig. 2. Comparison of measured and simulated S-parameters for LNA and PS packaged on LCP.

II. ANTENNA ARRAY OVERVIEW

An 8x1 antenna array was designed for operation at 9.5 GHz with a minimum bandwidth of 500 MHz. It is an aperture coupled microstrip patch antenna fabricated on 3850 Liquid Crystal Polymer (LCP). It utilizes eight microstrip patches spaced $0.855\lambda_o$ apart and uniformly fed in parallel. The stack up of the antenna is shown in Figure 1. This design utilizes three LCP layers consisting of 3 mil (2 mil core plus 1 mil bondply), 4 mil, and 51 mil (50 mil core plus 1 mil bondply) thicknesses. On top of the stack there are eight microstrip antenna elements measuring 11.09 mm x 7.71 mm and are spaced 27 mm apart. The aperture layer contains eight slots measuring 5 mm x 0.5 mm and centered directly below each patch element. The total length of the 8x1 array is 20 cm. The feed network is embedded in the LCP and fed through a signal via from the bottom layer. This is to allow additional room for packaging components on the bottom metallization layer. The CPW feed line is a 50-ohm co-planar line on the bottom layer consisting of a 410 µm wide signal line, 100 µm gap and 2680 µm wide ground lines. This antenna design was modeled using Ansoft High Frequency Structure Simulator (HFSS). The return loss and far-field patterns were simulated and optimized for the design frequency and required bandwidth. The design clearly makes a return loss better than 10 dB across the 500 MHz bandwidth. The gain was simulated at 9.5 GHz and found to be 9 dBi.

III. SiGe CHIP PACKAGING AND INTEGRATION

In order to scan the beam of the antenna array and maintain a large antenna gain, individual SiGe low noise amplifiers (LNA) and phase shifters (PS) were incorporated. Details of the LNA and PS are discussed in [8] and [9], respectively. Each component was first packaged individually on LCP and characterized. Details of the packaged LNA characterization are reported in [5]. Once a packaging scheme was successfully implemented, both were packaged in series on LCP and measured. The effective S-parameters of the packaged LNA and PS were estimated by using those acquired from the individually packaged circuits and using ADS to simulate them in series. The measured and simulated S-parameters are shown in Figure 2. It is seen that the measurements match very closely with the simulated results. The packaged LNA and PS are predicted to add about 26 dB of gain to the antenna array. Additionally, a comparison of measured phase shift for the unpackaged and packaged SiGe PS shows minimal deviation for each bit of the circuit.

IV. ANTENNA MEASUREMENTS

After fabrication of both the LNA integrated antenna and the LNA/PS integrated antenna, SMA connectors were attached to the inputs. The S-parameters of the antennas were measured using an Agilent PNA and showed a return loss around 10 dB across the desired frequency band.

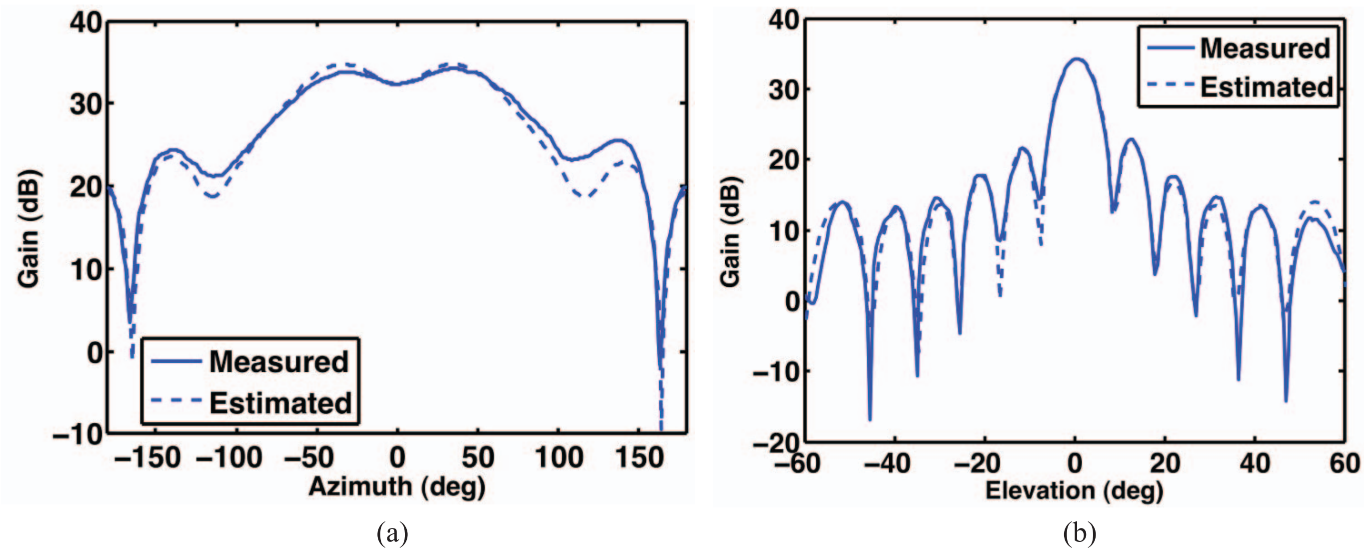

Fig. 3. Comparison of estimated and measured radiation patterns at 9.5 GHz for the 8x1 array with integrated LNA and PS for both azimuth and elevation cuts. An LNA and PS gain of 26 dB are added in the simulation results for comparison with the measured data.

An anechoic chamber was used to measure the radiation patterns from 8.5 to 10.5 GHz for the 8x1 with LNA as well as each phase state for the 8x1 with LNA and PS. Each antenna was mounted on a stand vertically and placed in the near-field of an X-band rectangular waveguide antenna. A cylindrical scan was used to accommodate the broad beamwidth in the azimuth direction. After completion of the radiation patterns, the broadside gain was measured over the frequency band. This data was compiled with the near-field data and transformed to the far-field. Plots of the measured E and H planes taken at 9.5 GHz are compared with results simulated in HFSS. The data from the pattern measurements is plotted in Figure 3. The estimated radiation patterns for the antennas use the results for the simulated baseline antenna adjusted by the predicted additional gain (16 dB and 26 dB) for the packaged LNA and packaged LNA and PS. The measured active gain of the 8x1 with LNA and the 8x1 with LNA and PS was approximately 25 dBi and 34 dBi, respectively. In addition, the side lobes were within -10 to -13 dB with respect to the peaks. For both antennas, the location of peaks and nulls correspond very well and the max gain is within 1.0 dB of the estimated results. Surface roughness of LCP, misalignment tolerance during fabrication, and loss contributed by the vias and connectors are attributed to any deviation from simulation. The gain of each antenna was plotted over frequency. The gains did not deviate more than 1 dB within the 500 MHz bandwidth of the center frequency (9.5 GHz). Measured and simulated beamwidth at the central 9.5 GHz is shown in Table 1. Simulated results of the passive antenna are, as expected, very similar to the results of the measured active antennas.

Table 1. Simulated vs Measured Beamwidth @ 9.5 GHz

Antenna	Elevation	Azimuth
Simulated 8x1 passive	7°	114°
Meas 8x1 w/ LNA	8°	121°
Meas 8x1 w/ LNA + PS @ 0 deg	7.5°	128°

V. CONCLUSION

SiGe LNAs and PSs were successfully integrated onto an 8x1 antenna array fabricated using multilayer organic materials. The measured return loss and radiation patterns were in excellent agreement with the simulated results. The packaged LNA and PS supplied an additional 25 dB of gain over the 9 dBi of the passive antenna. This is the first demonstration of such a lightweight antenna array in X-band built with low cost PCB fabrication technologies and Si-based RF electronics for remote sensing applications.

VI. ACKNOWLEDGMENTS

The authors would like to thank the assistance of Greg Hampton, Glenn Hopkins, Vic Tripp, Chris Bailey, Bill Wilson, Brian Hudson and Ted Heath of the Georgia Tech Research Institute for help in antenna pattern measurements. The authors would also like to thank Metro Circuits, in Rochester, NY, for fabrication of the antennas. This work was supported by NASA under grant #NNX08AN22G.

REFERENCES

[1] E. C. Culbertson, "A new laminate material for high performance PCBs: liquid crystal polymer copper clad films," *in Proc. 45th Electronic Components and Technology Conference*, 1995, pp. 520-523.

[2] A. Geise, U. Strohmaier, A. F. Jacob, "Investigations of transmission lines and resonant structures on flexed liquid crystal polymer (LCP) substrates up to 67 GHz," *39th European Microwave Conference*, Rome, 2009, pp. 735-738.

[3] N. Kingsley, D. E. Anagnostou, M. M. Tentzeris, J. Papapolymerou, "RF MEMS sequentially reconfigurable Sierpinski antenna on a flexible organic substrate with novel dc-biasing technique," *Journal of Microelectromechanical Systems*, vol. 16, pp. 1185-1192, October 2007.

[4] J.D. Cressler (Editor), Silicon Heterostructure Handbook – Materials, Fabrication, Devices, Circuits, and Applications of SiGe and Si Strained-Layer Epitaxy, CRC Press, 2006.

[5] C. E. Patterson, A. M. Yepes, T. K. Thrivikraman, S. K. Bhattacharya, J. D. Cressler, and J. Papapolymerou, "A lightweight X-band organic antenna array with integrated SiGe amplifier," *IEEE Radio &Wireless Symposium.*, pp. 84-87, January 2010.

[6] N. Billstrom, K. Axelsson, B. Lumetzverger, "X-band sub-antenna for low cost AESA radars," *in 39th European Microwave Conference*, Rome, 2009, pp. 910-913.

[7] M. Borgarino, A. Polemi, A. Mazzanti, "Low-cost microwave radiometer front-end for industrial applications," in IEEE Trans. on Microwave Theory & Tech., vol. 57, pp. 3011-3018, December 2009.

[8] W.-M. L. Kuo, Q. Liang, J. D. Cressler, and M. A. Mitchell, "An X-Band SiGe LNA with 1.36 dB mean noise figure for monolithic phased array transmit/receive radar modules," in IEEE RFIC Symp. Dig., 2006, pp. 498-501.

[9] T. K. Thrivikraman, W.-M. L. Kuo, J. D. Cressler, "A two-channel, ultra-low-power, SiGe BiCMOS receiver front-end for X-band phased array radars," IEEE BCTM, 2009, pp. 43-46.