3D PRINTABLE MULTILAYER RF INTEGRATED SYSTEM

Graduate Students: Xiaoju Yu(1), Min Liang(1), Corey Shemelya(2)
Faculty Advisor: Ryan Wicker(3), Eric MacDonald(2) and Hao Xin* (1)
(1) Electrical and Computer Engineering Dept., University of Arizona, Tucson, AZ, USA
(2) Dept. of Electrical Engineering, University of Texas at El Paso, El Paso, TX, USA
(3) Dept. of Mechanical Engineering, University of Texas at El Paso, El Paso, TX, USA

ABSTRACT

In this work, a 3D-printable multilayer phased array system is designed to demonstrate the applicability of additive manufacturing technique combining dielectric and conductor processes at room temperature for RF systems. Phased array systems normally include feeding networks, antennas, and active components such as switches, phase shifters and amplifiers. To make the integrated system compact, the array system here uses multilayer structure that can fully utilize the 3D space. The vertical interconnections between layers are carefully designed to reduce the loss between layers. Simulated results show good impedance matching and high-directive scanning beam. This multilayer phased array will finally be 3D printed by integrating thermal / ultrasound wire mesh embedding method (for metal) and fused-deposition-modeling technique (for dielectric).

Key Words:
3D print, Multi-layer, Phased Array, Vertical Interconnection

INTRODUCTION

Additive manufacturing (AM), which refers to layer-by-layer automatic printing techniques for 3D objects of arbitrary shape, is a potentially promising technique to manufacture multilayer RF components / systems. In order to achieve high conductivity comparable to regular metal, the 3D printed components using conductive ink [1] requires high temperature metal sintering process which may induce deformation or damage of the dielectric substrate and prevent potential integration of RF devices. We have proposed a novel low-cost 3D printing technique in fabricating functional RF components at room temperature but still maintaining good electromagnetic performance [2-3]. In this work, a 3D printable multilayer phased array system that fully utilize 3D space is designed to demonstrate the applicability of the printing techniques for RF system integration.

Phased array systems, which are commonly used to achieve high gain and electronic beam steering, normally consists of many RF components including power feeding networks, antennas, and active components such as phase shifters and amplifiers. To make the integrated system compact, the phased array in this work is designed using multilayer structure that can fully utilize the 3D space. The multilayer structure, in addition, enables the flexibility to add more functionality by increasing the total structure thickness while keeping the footprint size unchanged. The multilayer phased array needs to be carefully designed to have low loss in the vertical transitions.

MULTILAYER PHASED ARRAY DESIGN

The proposed multilayer phased array (operating at 3.5 GHz) is designed as shown in Fig. 1. It consists of three layers: a 1 to 4 Wilkinson divider at the bottom layer; four voltage controlled phase shifters mounted on grounded CPW at the center layer; and four patch antennas at the top layer. The coax to stripline and stripline to grounded coplanar waveguide (CPW) vertical interconnections are optimized to reduce transmission loss between layers. Good isolation between layers is achieved by inserting a ground between adjacent layers. This multilayer phased array structure, in the near future, will be 3D printed. The metal part will be realized using thermal / ultrasound wire mesh embedding [4-5] and the dielectric part will be printed using fused deposition modeling technique [6]. Polycarbonate (PC) – one of the most common printable thermoplastic and that has dielectric constant of 2.7 and loss tangent of 0.005 is used for each layer's substrate. The thermoplastic printing accuracy in thickness is about 0.4 mm, and therefore, the dielectric substrate should be thick enough to make sure that the fabrication error will not influence the performance much. To have good performance margin, here the total thickness is designed to be 21 mm and the smallest thickness for each layer is set to be 3 mm. The details about the design of important parts of the phased array system is discussed in the following. All models are built and simulated in ANSYS HFSS software [7].

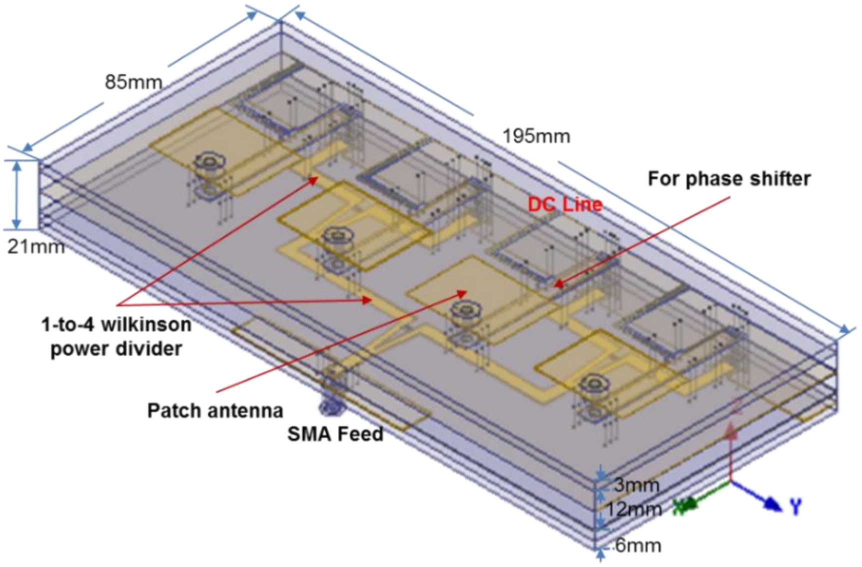

Figure 1. 3D printable three-layer phased array schematic

The top layer is a 4-patch antenna array with substrate thickness of 3 mm. The patch is designed to work at 3.5 GHz with size of 23.36 × 31.07 mm^2. The patch array is fed by the grounded CPW at the center layer using probe feeding. At the center layer, DC bias lines for voltage controlled phase shifters are included on the grounded CPW. The grounded CPW has signal trace width of 4.3 mm, gap width of 1 mm, and total substrate thickness of 12mm. The material loss will introduce loss for the grounded CPW at the level of 3.13 dB per meter at 3.5 GHz. Some through substrate vias are added along the CPW to ensure that only CPW mode is supported in the frequency band of interest. The bottom layer is a 1-to-4 Wilkinson power divider realized using stripline. The line width and dielectric substrate thickness are set to be 4 mm and 6 mm respectively to get 50-Ohm characteristic impedance. The stripline insertion loss from material is 2.88 dB per meter at 3.5 GHz. Some important interconnections design between layers are shown in the following.

A. Coax to Stripline Vertical Transition Design

Figure 2 shows the schematic of coax to stripline vertical interconnection. The principle is to transit coax to CPW, then to stripline. The coaxial connector is a SMA with extended center pin that touches the upper CPW trace. The CPW is optimized to reduce impedance mismatch. Vias are required along the CPW to reduce radiation loss and remove unwanted modes. Figure 3 shows that the simulated vertical interconnection has a reflection coefficient lower than -22 dB and insertion loss smaller than 0.3 dB in the frequency band of interest.

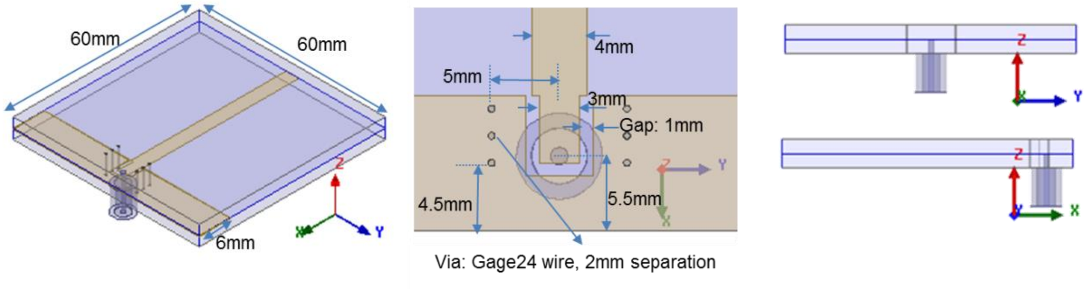

Figure 2. The coax to stripline vertical interconnection schematic: (from left to right) whole view, enlarged top view, and side view.

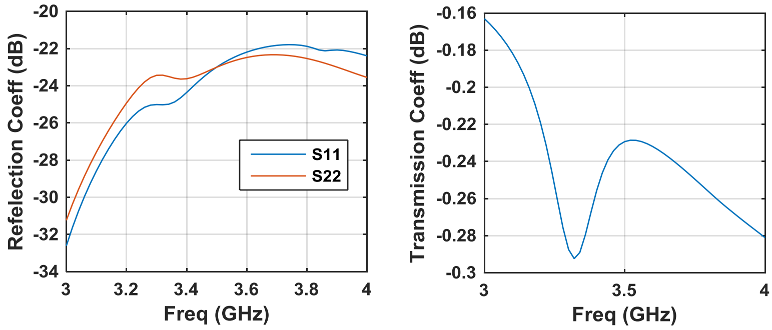

Figure 3. The simulated reflection and transmission coefficients of the vertical interconnection from coax to stripline.

B. Stripline to Grounded CPW Transition Design

Figure 4 shows the schematic of stripline to grounded CPW interconnection. The stripline width is 4 mm and the grounded CPW signal trace width is 4.3 mm with gap width 1 mm. The principle of the interconnection is to transit stripline to CPW at the same layer first, then to the grounded CPW on the upper layer. The lower layer stripline conducting strip is connected to the upper layer grounded CPW center conductor using via. Vias connecting all grounds at different layer are also required and optimized to reduce loss. Figure 5 shows that the simulated reflection coefficient and insertion loss of the designed interconnection is lower than -17.5 dB and 0.25 dB respectively in the frequency band of interest.

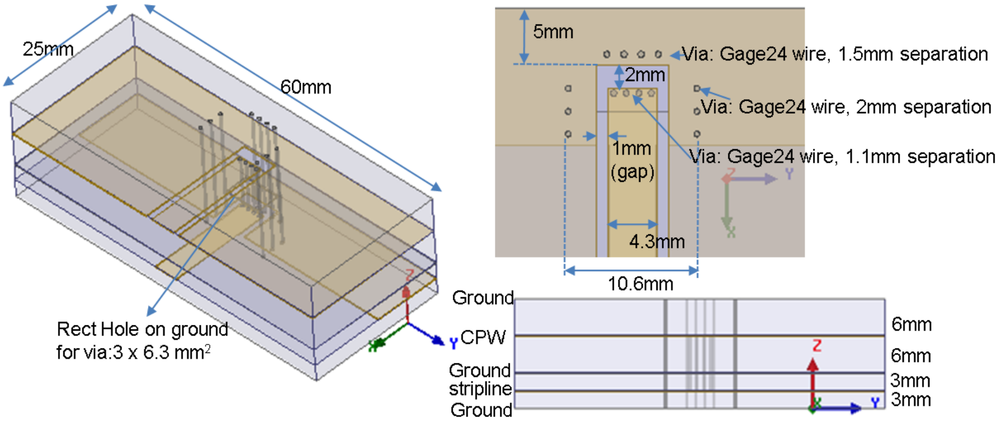

Figure 4. The stripline to grounded CPW transition schematic: whole view, enlarged top view, and front view.

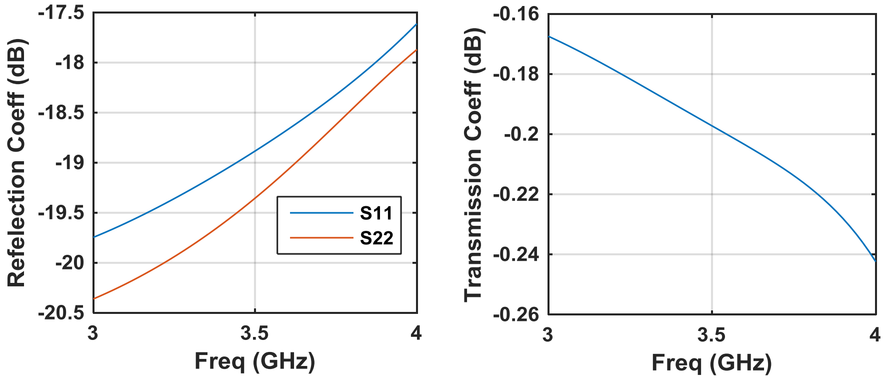

Figure 5. The simulated reflection and transmission coefficients of the stripline to grounded CPW transition.

MULTILAYER PHASED ARRAY SYSTEM PERFORMANCE SIMULATION

The simulated results for the whole phased array system shown in Fig. 1 is plotted in Fig. 6. It is demonstrated that the array system has reflection coefficient smaller than -10 dB from 3.44 GHz to 3.56 GHz and a high directive beam in broadside as expected with peak gain of 10.76 dB at 3.5 GHz. At 3.5 GHz, the array system achieves a radiation efficiency of 76%. The 1.2 dB loss comes from the vertical transitions and the material losses.

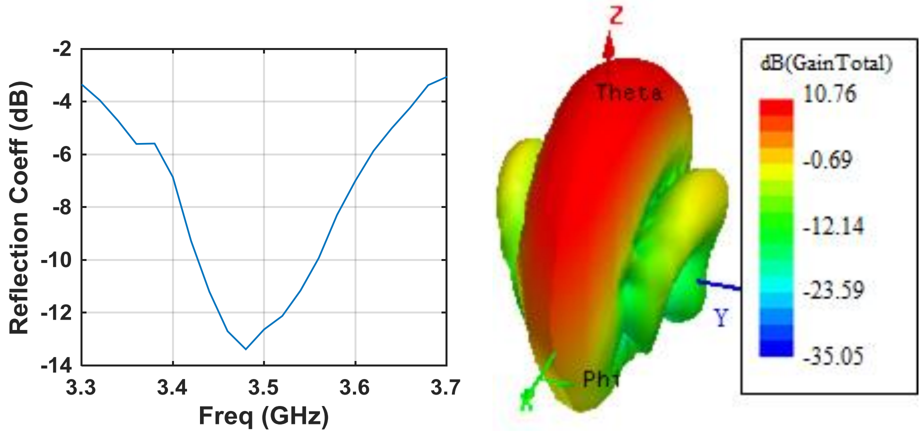

Figure 6. Simulated reflection coefficient and array gain of the 4-patch array at 3.5 GHz.

CONCLUSION

A 3D printable compact three-layer phased array operating at 3.5 GHz is designed. Low loss vertical interconnections are obtained. The simulated results of the whole system show a reflection coefficient smaller than -10 dB at the working frequency and a high directional beam achieved at expected direction. The radiation efficiency for the whole array system is 76%. Next, this multilayer phased array will be 3D printed at room temperature using thermal / ultrasound wire mesh embedding for the metal part and fused deposition modeling technique for the dielectric part. The phase shifter chips can be mounted into pre-designed pockets first and then soldered onto the printed grounded CPW. Alternatively, the pins of the phase shifter chips can be directly connected to the CPW conductors using laser weld.

ACKNOWLEDGEMENT

The research presented here was conducted by The University of Arizona and The University of Texas at El Paso within the W.M. Keck Center for 3D Innovation (Keck Center). Through funding from the State of Texas Emerging Technology Fund, the Keck Center recently expanded to over 13,000 sq. ft., housing state-of-the-art facilities and equipment for additive manufacturing processes, materials, and applications. Specifically, this research was supported by funding from National Science Foundation under Award 0925220 and 1408271, the National Aeronautics and Space Administration under grant number NNX13AR17A, the Intelligence Community Postdoctoral Research Fellowship Program under grant no. 2012-12071000005, as well as the state of Arizona under TRIF.

This project was supported by a grant from the Intelligence Community Postdoctoral Research Fellowship Program through funding from the Office of the Director of National Intelligence. All statements of fact, opinion, or analysis expressed are those of the author and do not reflect the official positions or views of the Intelligence Community or any other U.S. Government agency. Nothing in the contents should be construed as asserting or implying U.S.

Government authentication of information or Intelligence Community endorsement of the author’s views.

REFERENCES

[1] J. J. Adams, E. B. Duoss, T. F. Malkowski, M. J. Motala, B. Y. Ahn, R. G. Nuzzo, J. T. Bernhard and J. A. Lewis, “Conformal Printing of Electrically Small Antennas on Three-Dimensional Surfaces” Adv. Mater., Vol. 23, pp. 1335–1340, 2011..

[2] M. Liang, C. Shemelya, E. MacDonald, R. Wicker and H. Xin, “Fabrication of microwave patch antenna using additive manufacturing technique” Radio Science Meeting, USNC-URSI, 2014.

[3] M. Liang, X. Yu, Xiaoju Yu, C. Shemelya, E. MacDonald and H. Xin, " 3D Printed Multilayer Microstrip Line Structure with Vertical Transition toward Integrated Systems," Microwave Symposium Digest (IMS), 2015 IEEE MTT-S International, May 2015.

[4] A. J. Lopes, E. MacDonald and R. B. Wicker, “Integrating stereolithography and direct print technologies for 3D structural electronics fabrication” Rapid Prototyping Journal, vol. 18 pp. 129-143, 2012.

[5] T. W. Turpin and R. Baktur, “Meshed Patch Antennas Integrated on Solar Cells,” Antennas and Wireless Propagation Letters, vol. 8, pp. 693-696, 2009.

[6] http://www.stratasys.com/3d-printers/technology/fdm-technology

[7] ANSYS HFSS version 2014, Ansys Inc., 2014