Structurally Embedded Vascular Antenna Arrays ($SEVA^2$) in both Multi-Layer and Complex Curved Composites

Gregory H. Huff, Amrita Bal, and Darren Hartl
Texas A&M University
College Station, TX, 77843
prof.ghuff@gmail.com

Jeffery W. Baur, Geoffrey J. Frank, David Phillips, Thao Gibson, and Daniel Rapking
Air Force Research Lab (AFRL/RXCC)
WBAFB, OH, 45433

***Abstract*—Recent advances in structurally embedded vascular antennas (SEVAs) have demonstrated the ability to integrate microfluidic-enabled electromagnetically-tunable reconfigurable antennas into planar epoxy-filled quartz fiber composite panels. Reconfiguration of these antennas has been enabled by the pressure-driven flow of a liquid metal alloy within the patterned microchannels. These are embedded into the composite using novel sacrificial materials, additive manufacturing, and post-processing fabrication techniques. The wide tunability, radiation pattern stability, and repeatability of these structures have been demonstrated, and now the deployment of these fabrication techniques to develop aerodynamically efficient composite shapes makes SEVA attractive for agile aircraft antenna. This paper will highlight the composite fabrication of a multi-element SEVA, or Structurally Embedded Antenna Array ($SEVA^2$), within a complex curved article that resembles an aircraft leading-edge. It includes a summary of the design and operation of the structure as a phased array of physically-reconfigurable antennas. These frequency-agile antennas can also be interconnected to form larger contiguous reconfigurable antenna structures that extend the range of electromagnetic tunability and/or provide other operational modalities.**

***Keywords*— Computational Design, Composite Manufacturing, Aerospace Structures, Materials, Analytics, Simulation, Automation**

I. Introduction

Liquid metal, GaIn alloy has been used extensively in the design of antennas in the recent years. It's applicability in the design of patch, monopole and slot antenna has been demonstrated. Researches in structurally integrated antennas have open ways for study in material sciences and various fabrication technologies. Frequency reconfigurable antennas has also been investigated using various electronically controlled mechanisms like reed switches, RF PIN diodes and varactors, dielectric fluids, GaAs FET switch and ferroic materials. Liquid metal has been used in the design of antenna arrays to achieve beam steering

This paper aims to present advances in materials and fabrication technologies to design multilayer structure. This also explains design and fabrication of curved composite resembling section of wing in an airplane. The structurally integrated antenna arrays (SEVA2) have shown promising results in achieving frequency reconfiguration and beam steering. Liquid metal (EGaIn) has been used in SEVA2 to form an electromagnetically connected structure to achieve desired properties. This paper discusses the design and operation of multilayer and multi-element SEVA2 first. It then provides a discussion on the measurement of impedance and radiation pattern for dual-layer and curved SEVA2 structure respectively. This is followed by acknowledgments and references.

II. Design

A. Design and Operation of Dual-layer SEVA2

Fig. 1 shows CAD model of SEVA2 with parallel strip feed network. Increasing sinusoidal meandering will be referred as SEVA-RLα2 and the linear embedded vascular structure will be referred as SEVA-RLα30. The names of the two-different meandering with different α are discussed in the following sections. SEVA-RLα2 and SEVA-RLα30 are placed in parallel along z-axis, connected to the same feed. Both the substrates are mechanically fixated by drilling visually aligned holes and are threaded together with nylon screws. This section discusses the feed network, antenna design and frequency reconfigurability of the structure.

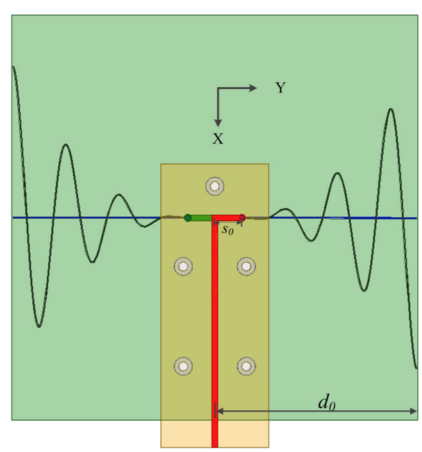

Fig 1. CAD model of multilayer $SEVA^2$ with parallel strip feed network

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B. *Design and Operation of SEVA2 on Complex Curved Composite*

Fig. 2 shows the CAD model of SEVA2 on the complex curved composite with its curved parallel strip feed network. The feed structure is an anti-podal dipole fed by a parallel-strip feed line on a 20 mil thick Duroid 5880 substrate. This "soft" substrate was chosen so it could be formed to the curvature of the composite. A more detailed physical description of this feed structure is explained in [1]. The hollow vias at the end of antipodal dipoles on feed are aligned with the vias on the composite using a close-fitting needle. The vias are soldered to the printed feed structure and sealed to the holed in the composite using a silicone-based epoxy. This process ensures an airtight passage for the flow of liquid metal. Adhesive is deposited along the perimeter of each feed network and pressed with a mandrel during curing to ensure mechanical rigidity.

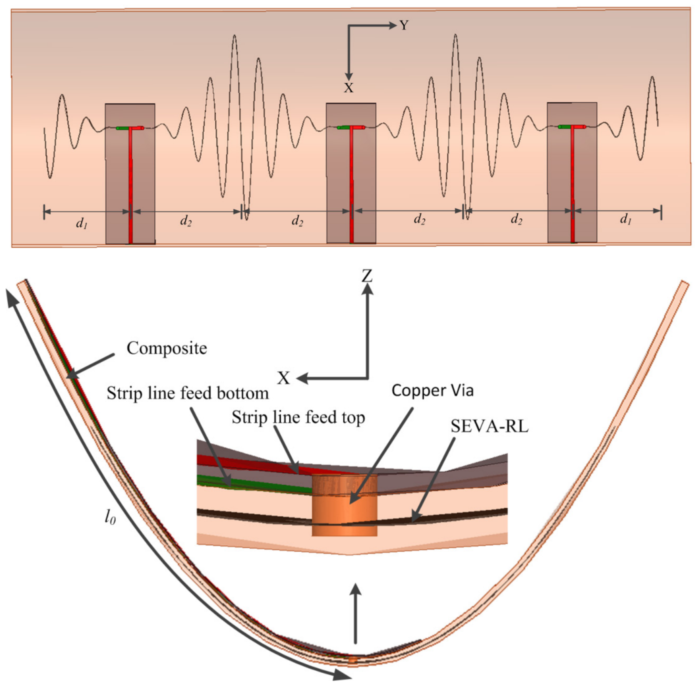
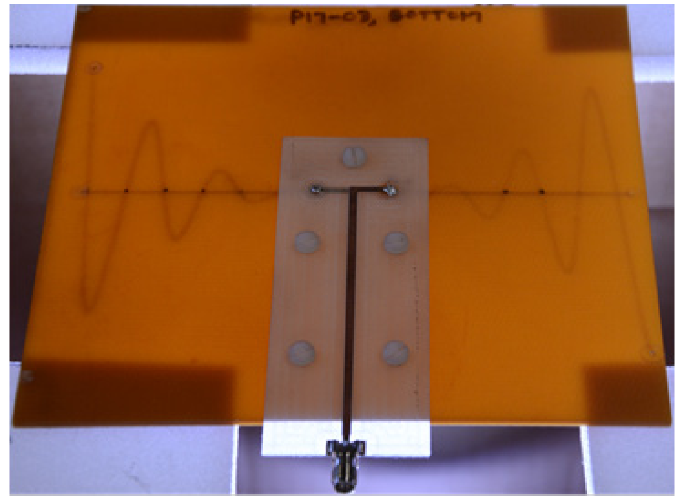


Fig. 2 Top view of CAD model of curved composite SEVA^2 with all three elements (top). Side view of CAD model (bottom).

III. Experiment

Prior to experiments the microchannels in each antenna configuration are filled with the low-loss low-dielectric heat transfer fluid Fluorinert FC-70 Electronic Liquid. This is closely matched to the dielectric properties of the substrate and serves as both a barrier fluid to prevent oxidation of the liquid metal alloy EGaIn and a pushing fluid for the pressure-driven displacement if the metallic fluid. An appropriately tipped syringe is then used to flow the liquid metal into the channels. Once the appropriate amount of liquid metal is flowed into the microchannel the outlet is sealed using a temporary thermal adhesive. Fig. 3 shows the fabricated multi-layer SEVA2 and Fig. 4 shows the simulated and measured input reflection coefficient in dB for two of the antenna states. This topology provides additional tuning capabilities from the two constituent antenna topologies embedded into the structure. Fig. 5 shows a picture of the fabricated SEVA2 on a curved composite.



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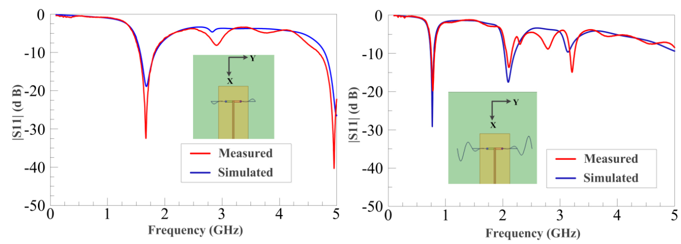

Fig. 5 Measured and simulated log-magnitude of the input reflection coefficient (|S11| [dB]) for two configurations of the multi-layer SEVA2.

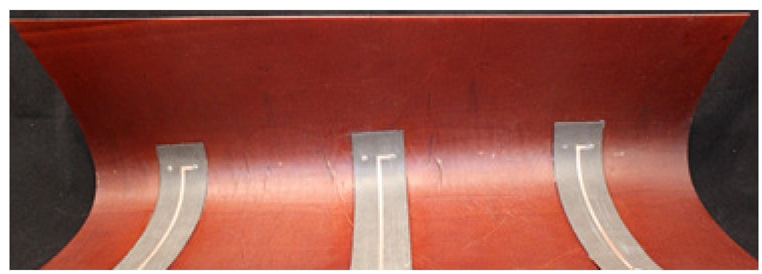

Fig. 5 Fabricated model of curved composite SEVA2 with 3 elements.

IV. Summary

The design and performance of two SEVA^{2}s have been presented. This highlights the ability to fabricate reconfigurable antenna topologies that are multi-layer and conformal to complex curved surfaces. Preliminary measurement campaigns have indicated the potential of these new antenna topologies as candidates for complex and pragmatic antenna morphologies.

V. Aknowledgements

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References

[1] G. H. Huff, H. Pan, D. J. Hartl, G. J. Frank, R. L. Bradford, and J. W. Baur, "A Physically Reconfigurable Structurally Embedded Vascular Antenna," IEEE Trans. Antennas Propagat., vol. 65, no. 5, May 2017.