Reconfigurable Diode-Based and Liquid Metal Antenna for 5 GHz Wi-Fi

Jonathan Lundquist, Lauren Linkous, and Erdem Topsakal
Virginia Commonwealth University, Richmond, VA 23284, USA
(lundquistjd@vcu.edu)

Abstract—**In this paper we present a reconfigurable planar antenna, tuned via PIN diode switching and liquid metal input impedance tuning. PIN diodes are used as switches to electrically add or remove radiating elements from the structure, while the liquid metal Eutectic Gallium Indium in a printed Formlabs Flex 80A resin tube is used to change the length of stub for impedance tuning at the input. A continuous tunable band across the entire 5G Wi-Fi spectrum is achieved in simulation. A gain of approximately 4 dB was achieved across the entire 5 GHz Wi-Fi spectrum.**

Keywords—reconfigurable; liquid metal; PIN diodes; tunable

I. Introduction

Reconfigurable antennas capable of providing acceptable gain and input impedance for several configurable frequencies are becoming an important part of designing for a future where network congestion and high data transmission rates are the status quo. Network congestion is an important problem for crowded venues at popular events, and can be a critical challenge for those providing and seeking emergency services in these situations. Reconfigurable antennas are a good solution to actively diffuse some of the network traffic. These antennas generally fall into the categories of pattern reconfigurable antennas, polarization reconfigurable antennas, tunable antennas, or some combination thereof. Tunable antennas are designed primarily with the goal of modifying the antenna's operating frequency band to meet the demands of the communications network [1].

A common method of achieving tunability is by using solid-state switching to effectively add or remove elements to the antenna structure. The response time for this reconfiguration is on the order of nanoseconds. In these types of tunable antennas PIN diodes are switched on or off to connect or disconnect elements from the RF current path. While the speed of reconfiguration is a significant advantage, tunability of these antennas occurs in discrete bands and is not continuous [1].

By contrast, liquid metal antennas tend to be the compliment where this dynamic is concerned. Liquid metals can be used to continuously modify the conductor length of an antenna, thereby allowing for a continuous range of tunability [2]. Despite the advantage of being continuously tunable, liquid metal antennas have a much slower reconfiguration speed due to their mechanical operation, which is on the order of milliseconds instead of nanoseconds.

This work aims to achieve a synergy between these two switching methods, using solid-state switching to achieve large band jumps, while precise tuning is conducted via a Eutectic Gallium Indium (EGaIn) stub. The idea being to allow the liquid metal EGaIn to provide the continuous tuning in a particular band, while PIN diode switching is used to jump bands or maintain antenna gain by adding or removing planar elements.

II. Design and Simulation

In order to achieve a continuously tunable structure, an EGaIn tunable stub is set inside of a Formlabs Flex 80A resin printed half-tube and semi-spherical reservoir. The permittivity as a function of frequency for the Flex 80A resin can be found in [3]. Control of the level of EGaIn in the tube is regulated by compression of the reservoir by a plate made of Formlabs Rigid 10K resin. This low loss, firm resin, comprised predominantly of glass, has a permittivity of 3.3 [4]. The actuator plate pressure is controlled by metal embedded pieces and electromagnets placed on the opposite side of an FR-4 board on which all components are situated.

Figure 4 shows the layout of components. The RF input is designed for 50 Ohms and feeds into the reservoir, which also contacts the DC input line for diode actuation and the radiating patch structures. DC current is used to turn on and off diodes that connect the radiating elements. This current is isolated from RF via surface mount inductors.

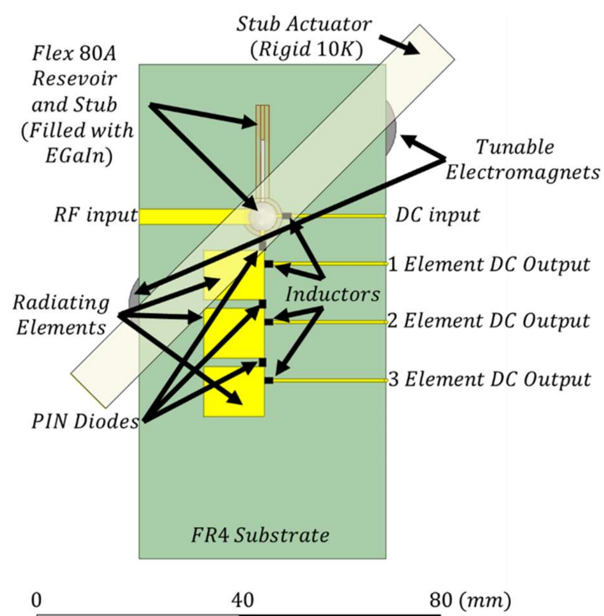

Figure 1. Antenna Design and Board Layout.

Simulation was performed in Ansys HFSS using parametric sweeps to find optimal dimensions and configurations for operation in the 5 GHz Wi-Fi band. Configurations consisted of "on" and "off" diode states and varying stub lengths of EGaIn. Lumped elements were simulated using lumped impedances on sheets with the same size as the component footprint. Diodes were simulated in both the on and off state depending on the configuration being simulated.

III. Simulated Results

Simulated results for S_{11} for the lower frequency 2 and 3 element configurations can be seen in Figure 2, and simulated results for the higher frequency 1 element configuration can be seen in Figure 3. Table I provides a summary of simulated gain for 4.5, 5, 5.5, 6, and 6.5 GHz in the optimal configuration.

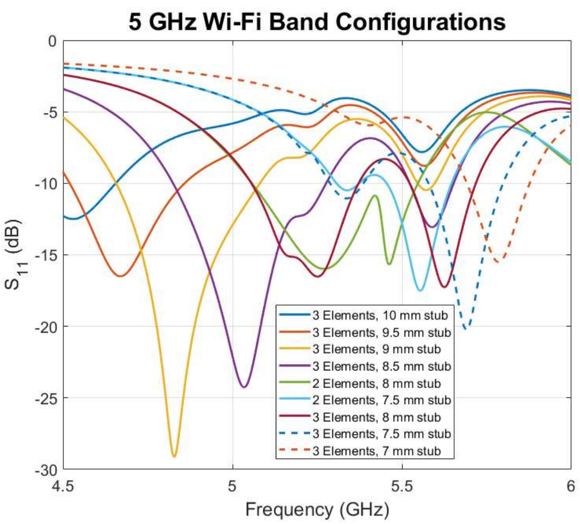

Figure 2. Simulated S_{11} for 2 and 3 Element Configurations.

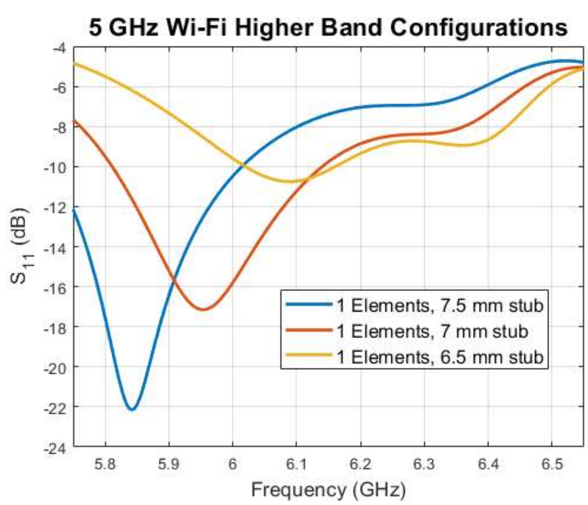

Figure 3. Simulated S_{11} for 1 Element Configuration.

Table I. Simulated Gain at Solution Frequencies

Frequency (GHz)	4.5	5	5.5	6	6.5
Gain (dB)	4.16	4.91	4.31	3.74	2.83

IV. Discussion

Simulated S_{11} and gain are presented for frequencies ranging from 4.5 to 6.5 GHz. The simulated results show a continuous configurable band starting from 4.5 GHz up to 6.17 GHz, covering the entire 5 GHz Wi-Fi band. With all diodes on (3 active elements), the EGaIn stub is capable of tuning continuously from 4.5 GHz to 5.39 GHz and again from 5.65 GHz to 5.88 GHz. With two diodes on (2 active elements), the range from 5.39 GHz to 5.65 GHz can be continuously tuned, and with 1 diode on (1 active element) frequencies from 5.88 GHz to 6.17 GHz can be continuously tuned. All of the configurable states work with a stub length between 6.5 and 10 mm, allowing for minimal force to be applied to the reservoir, and allowing for at least 1 cm of empty tube space to prevent liquid metal spillage. While the gain fluctuates some between configurations it largely remains approximately 4 dB from 4.5 GHz to 6 GHz. These results show that a relatively consistent gain can be achieved over a continuous band of tunability using the combination PIN diode switching and liquid metal tuning.

V. Conclusion

The speed afforded by solid-state switching like PIN diodes allows for rapid switching in the upper half of the tunable band where stub lengths are all near 7.5 mm. The continuously tunable liquid metal stub allows for access to the entire 5 GHz Wi-Fi spectrum, while maintaining a gain of approximately 4 dB. The speed of reconfiguration and wide continuous range of frequencies can help provide improved communication for congested environments like concert venues, sports arenas and other crowded areas. This could help emergency services communicate effectively to assist people in need in these congested environments.

References

[1] S. P. Lavadiya, V. Sorathiya, S. Kanzariya, et al. "Low profile multiband microstrip patch antenna with frequency reconfigurable feature using PIN diode for S, C, X, and Ku band applications," *Int J Commun Syst*. 35, 9, 5141. 2022. doi:10.1002/dac.5141

[2] X. Geng, Y. Zhang and A. Wang, "A Reconfigurable Dual-Band Liquid Metal Antenna for 5G Terminals," *2021 IEEE 4th International Conference on Electronics Technology (ICET)*, Chengdu, China, 2021, pp. 664-667, doi: 10.1109/ICET51757.2021.9450926.

[3] M. A. Acar, O. Furkan Sezgen, O. K. Erden and S. Dumanli, "3D Miniaturization Method and its Application to a Wearable Vivaldi Antenna," *2022 3rd URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC)*, Gran Canaria, Spain, 2022, pp. 1-4, doi: 10.23919/AT-AP-RASC54737.2022.9814402.

[4] J. D. Lundquist, L. Linkous, U. Hasni and E. Topsakal, "Indirect Applications of Additive Manufacturing for Antennas," in *IEEE Open Journal of Antennas and Propagation*, vol. 4, pp. 434-445, 2023, doi: 10.1109/OJAP.2023.326569