Tunable SIW Filters Using Liquid Metal Actuation

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***Abstract*—This project demonstrated the potential of room temperature liquid metals such as Galinstan for tunable filter applications. Liquid metal tuning posts were incorporated into a substrate integrated waveguide (SIW) filter design to allow for continuous frequency tuning from 3 to 6 GHz center frequency tuning. Design of highly reconfigurable filters for bandwidth and shape tuning is also being investigated that could allow for either constant fractional bandwidth tuning from 2% to 7% or a constant absolute bandwidth tuning from 100 MHz to 200 MHz across the entire frequency tuning range.**

***Index Terms*—Liquid metal, Galinstan, tunable filter, reconfigurable filter, substrate integrated waveguide (SIW)**

I. Introduction

THE rising demands of modern wireless communication and radar applications call for systems capable of dynamic spectrum access. In order to accomplish this, future RF hardware will need to be highly reconfigurable. A key device in these adaptable systems will be tunable filters which allow for flexible response control which is important for efficient spectrum use. Work into tunable filters using MEMS, varactors, PIN diodes, and piezoelectric actuators has been done.

Development of room temperature liquid metals has sparked recent interest in the RF community for tunable component due to promising reversibility, repeatability, and power handling capabilities. Antennas, switches, and filter designs incorporating liquid metal are currently being explored ([1]-[3]). An SIW bandpass filter with discrete tuning states from liquid metal posts being filled in corners of the cavity was demonstrated in [4]. In [5], band-reconfigurable SIW bandpass filters using liquid metal were realized by designing liquid metal posts that control the allowable modes in the filter.

This work focuses on the design of continuous liquid metal tuning of SIW filters. Rather than allowing for only fully empty or fully shorted liquid metal post states like in [4] and [5], vias that allowed for variable capacitive loading of liquid metal are able to realize a continuous range of filter states.

II. Tuning Mechanism

Initial findings of this work were published in [6] at the 2019 International Microwave Symposium, and more details on the performance and structure of the full design can be found there. Some details of the tuning structure shown in Fig. 1 will be described here. A via is drilled through the substrate while maintaining the copper on the top side, except for a small air opening. The top copper is left intact to allow for most of the fields to be concentrated in the air gap of the structure rather than being primarily edge fields through the substrate, which would increase loss. A Teflon tube is used to deliver the liquid metal into the structure. A brass holding is soldered onto the bottom side of the substrate to hold Teflon tube while also enabling a better electrical connection between the liquid metal and the cavity walls.

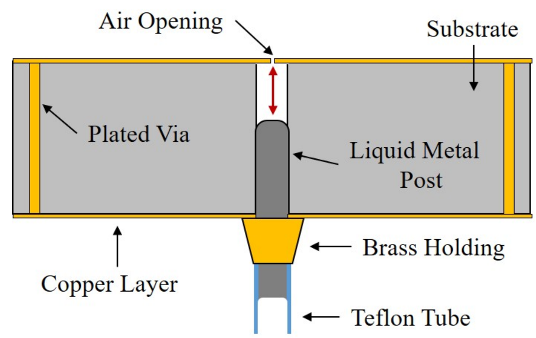

Fig. 1: Cross section of a liquid metal tuning post with a red double arrow indicating the capacitive air gap that is tuned.

The air gap between the liquid metal post and the top of the substrate can be continuously controlled by pneumatically pumping liquid metal into the via. By decreasing the size of the air gap, the increased capacitive loading of the structure will shift the resonant frequency of the structure down. Results of the resonant frequency tunability from 3 GHz to 6 GHz of a single square cavity resonator are reported in Fig. 2.

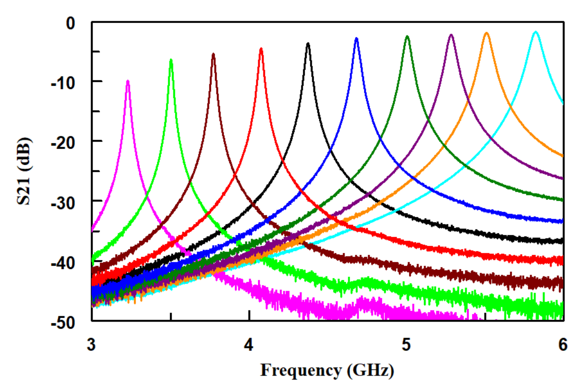

Fig. 2: Measured results of a single resonator with continuous liquid metal tuning.

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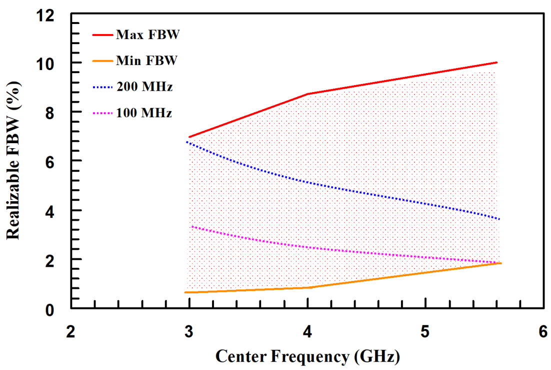


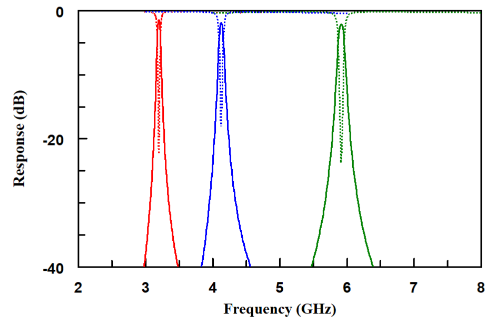
Fig. 3: FBW tuning space of the filter as a function of frequency for a Butterworth response. Constant absolute bandwidth curves are also plotted inside the FBW space of the filter.

III. Fully Reconfigurable Filter

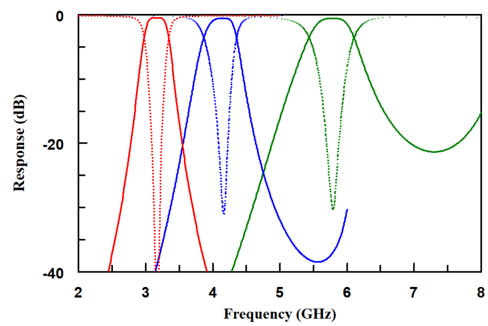
After investigating center frequency tuning, new work is being done on a fully reconfigurable filter design that allows for center frequency, bandwidth, and filter shape tuning. The same liquid metal tuning post is employed for center frequency tuning while exploring different liquid metal structures that can allow for continuous tuning of other filter characteristics. Preliminary simulated results of one design have shown promising amounts of filter reconfigurability.

The fully reconfigurable filter design can be tuned to a Butterworth response at different center frequencies over a continuous range of bandwidths as shown in Fig. 3. Note that over the entire tuning range of 3 GHz to 5.6 GHz, fractional bandwidths from 2% to 7% can be realized by the filter. Two constant absolute bandwidth curves are also plotted on the same graph to note the capability for constant absolute bandwidth tuning from 100 MHz to 200MHz.

Simulated filter responses are shown in Fig. 4 demonstrating this bandwidth tunability. This design work is still ongoing, but current progress has shown promising results that will hopefully be published in the near future.



(a) Narrowband Butterworth Response



(b) Wideband Butterworth Response

Fig. 4: Several tuned states demonstrating the center frequency and bandwidth tunability of the filter.

IV. Conclusion

A. Future career plans

The student has graduated his B.Sc. degree in Electrical Engineering and will be continuing his studies with the University of Oklahoma for his M.Sc. He plans on continuing his studies in microwave engineering and developing his work on liquid metal filters further. He is still considering different long-term goals but currently is planning to enter industry following his M.Sc. and return for his Ph.D. in the future.

B. Impression on MTT-S Sponsored Conference

He was able to attend the 2019 International Microwave Symposium in Boston where he presented work on his liquid metal filter design [6]. He was also awarded an honorary mention in the Three Minute Thesis Competition. He participated in various technical sessions, visited several booths in the Industry Exhibition, and made numerous new connections over the week. The experience of such an extensive conference has encouraged him to continue his career in the RF and Microwave community. He is thankful to MTT-S and will hopefully continue to contribute to the field throughout his M.Sc. studies and future career.

References

[1] A. M. Watson, K. Elassy, T. Leary, M. A. Rahman, A. Ohta, W. Shiroma, and C. E. Tabor, "Enabling reconfigurable all-liquid microcircuits via laplace barriers to control liquid metal," in *2019 IEEE MTT-S International Microwave Symposium (IMS)*, 2019, pp. 188–191.

[2] T. Palomo and G. Mumcu, "Microfluidically reconfigurable metallized plate loaded frequency-agile rf bandpass filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 1, pp. 158–165, 2016.

[3] G. J. Hayes, J. So, A. Qusba, M. D. Dickey, and G. Lazzi, "Flexible liquid metal alloy (egain) microstrip patch antenna," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 5, pp. 2151–2156, 2012.

[4] J. H. Dang, R. C. Gough, A. M. Morishita, A. T. Ohta, and W. A. Shiroma, "A tunable X-band substrate integrated waveguide cavity filter using reconfigurable liquid-metal perturbing posts," in *2015 IEEE MTT-S International Microwave Symposium (IMS)*, 2015, pp. 1–4.

[5] S. N. McClung, S. Saeedi, and H. H. Sigmarsson, "Band-reconfigurable filter with liquid metal actuation," *IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 6, pp. 3073–3080, 2018.

[6] A. H. Pham, S. Saeedi, and H. H. Sigmarsson, "Continuously-tunable substrate integrated waveguide bandpass filter actuated by liquid metal," in *2019 IEEE MTT-S International Microwave Symposium (IMS)*, 2019, pp. 21–23.