Analysis of Parasitic Effects of Sodium Hydroxide (NaOH) Electrolyte on Liquid-Metal Monopole Antennas

Jonathan T. Thews
Hume Center for National Security and Technology
Virginia Polytechnic Institute and State University
Blacksburg, Virginia, USA

Alan J. Michaels
Hume Center for National Security and Technology
Virginia Polytechnic Institute and State University
Blacksburg, Virginia, USA

Abstract—**Liquid metal alloys are being researched as a safe alternative to mercury in many different applications. One of these applications is using the liquid metal to form a reconfigurable antenna that allows changing frequency, beam steer, or polarization in real-time by injecting or retracting the liquid metal. Due to the formation of an oxidation layer on top of the liquid metal, researchers have been using an electrolyte to corrode this layer. This letter will analyze the effect this electrolyte has on the return loss of the antenna. Preliminary results show the electrolyte changes the effective length of the antenna, causing it to have a minimum return loss value at lower frequencies than predicted from the metal height alone.**

I. Introduction

Liquid metal alloys has been used in multiple cases as a safe alternative to mercury for liquid metal antennas. This revolutionary form of antenna allows the user to reconfigure the antenna in real-time to change frequency [1], beam steer [2], [3], or change polarization [4]. Two of the most common metal alloys used are eutectic gallium indium (EGaIn) and gallium, indium and tin (galinstan). Both of these metal allows are shown to produce a passivating oxidation layer when it comes in contact with oxygen. A layer of NaOH is often used to counteract this oxidation layer. This paper seeks to begin quantification of the parasitic RF performance effects caused by introducing this electrolyte to liquid metal monopole antennas.

II. Experimental Framework

This paper analyzes the effects of different heights of NaOH on the return loss of three different liquid metal monopole antennas. See [5] for diagrams of the individual monopole antennas and specifics of the measurement setup used in the tests.

The metal alloy used was eutectic gallium indiu. The eutectic point is the alloy composition at which the combined metals have the lowest melting point. For gallium-indium, this point is at 75.2% gallium and 24.8% indium, creating a melting point of 15° Celcius [6], which is lower than the independent melting points of both constituent metals (Ga:29.76°C, In:156.6°C), helping ensure the alloy's viability for use as a reasonably stable antenna at room temperature.

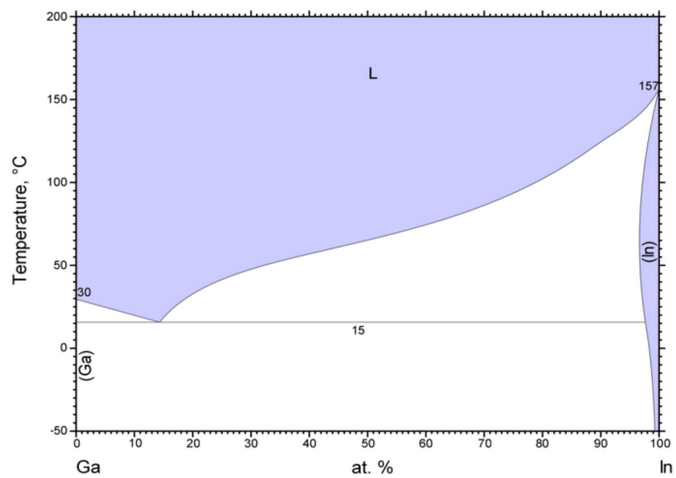

Fig. 1. Two Phase Diagram of Gallium and Indium [7]

This point is easily shown in the two-phase diagram (Fig. 1). The liquid metal and NaOH were injected separately into the monopole antenna tubing by the use of a 30 AWG gauge needle.

EGaIn has an electrical conductivity of $3.4 * 10^{6}$ S/m [1], and NaOH has a conductivity of about 18.1 S/m in a one molar solution [8]. While not significant compared to the conductivity of EGaIn, it can have some effects on the performance of the antenna based on how much NaOH is on top of the EGaIn. A one molar solution of sodium hydroxide (NaOH) was used to counteract the effect of the oxidation layer that forms where the liquid metal contacts oxygen. This oxidation layer forms almost instantly, but is a passivating layer [9], meaning it will grow to a certain thickness and then stop. This oxidation layer sticks to the inside of the tubing, making it difficult to determine/control the height of the antenna if any liquid metal was retracted. NaOH was used to counteract this skin layer because, according to the Pourbaix diagram, the skin layer can be removed at pH < 3 or pH > 10 [10], where 1M NaOH has a pH of 14. The NaOH counters this problem efficiently with a volume as small as one millimeter.

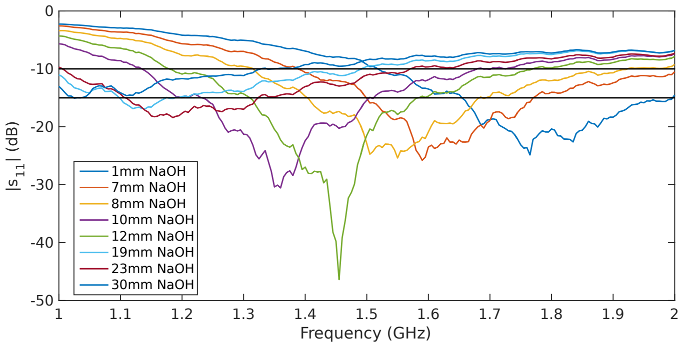

Fig. 2. Bottom fed: EGaIn length of 33mm

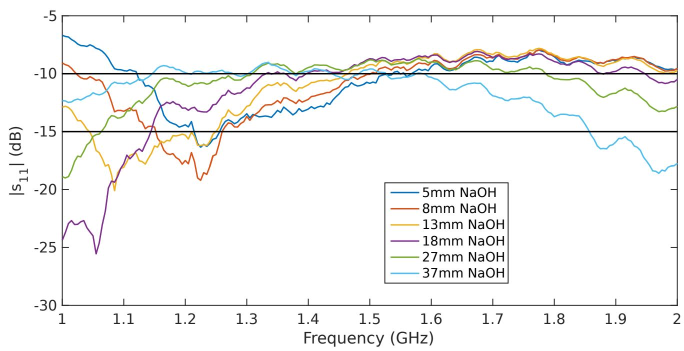

Fig. 3. Bottom fed with stub: EGaIn length of 41mm

III. Measured Effects

As can be seen in Figs. 2, 3, and 4, the amount of electrolyte on top of the liquid metal affects the return loss of the antenna. This means that the NaOH is effectively creating a longer antenna. In Fig. 2, the liquid metal antenna with 1mm of NaOH on top has a minimum s_{11} at $\approx$1.8 GHz, however when 30mm of NaOH is added on top of the same antenna, the minimum swings to $\approx$1.1 GHz. This shows that as the amount of NaOH on top of the EGaIn incrases, the effective length of the antenna also increases because the resonant frequency is decreasing. In Fig 3, the return loss stays relatively even at around -18 dB. When the NaOH height was increased to 37mm, there is a drop in return loss near 2GHz because this is very close to a half-wavelength monopole. With a EGaIn height of 41mm and a NaOH height of 37mm, the effective length of the antenna is 78mm, while a half-wavelength monopole at 2 GHz would be 75mm. The return loss remains at around -18dB even though the NaOH height is almost equal to the EGaIn height. Interestingly in Fig. 4, the larger amounts of NaOH on the antenna, the better the match of the antenna (the lower the return loss). This could be due to this specific feed inherently performing better at lower frequencies. So as the effective length of the antenna increased, the resonant frequency decreased. See [5] for the performance of each antenna feed type.

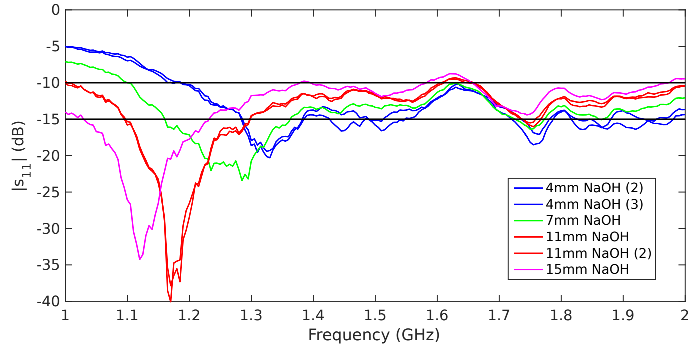

Fig. 4. Offset fed: EGaIn length of 46mm

IV. Conclusion

This paper has shown with a network analyzer that the amount of NaOH that is used to counteract the oxidation layer caused by the liquid metal has an effect on the effective length of the antenna. More tests are needed to analyze the effect the NaOH has on the radiating efficiency of the antennas, but from the figures in this paper, it is apparent that the NaOH has a potentially greater effect on the return loss of the antenna than would be expected by its conductivity alone.

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