Characterization of Liquid Metal Antenna Using T-Section Bandpass Filter for Voltage Conversion

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Abstract **– This study describes the design and implementation of voltage conversion from the resonant frequency of the Liquid Metal Antenna as the input. The application of the dipole liquid metal antenna as a possible sensor for displacement, when embedded on the concrete surface, is observed, and to record the data, a circuit is designed to convert the resonant frequency into voltage pulses. The circuitry consists of a harmonic termination matching network that serves two purposes: (1) for impedance matching and (2) for harmonic suppression and is based on the stub matching concept for transmission lines and microstrip filters, a two-diode configuration half-wave rectifier which uses Schottky Diode HSMS-2850 for low-power applications, a t-section bandpass filter, and a voltage multiplier. The design and simulation were made using Keysight's Advanced Design System 2016 and the results are compared to the actual data using the Computer Application which is transmitted by the Wireless Sensor Network via Zigbee Technology. The experiment shows that the behavior of the antenna's length compared to the average output voltage is inversely proportional both to the simulated and actual data. It is also important to consider that the resonant frequency of the Liquid Metal Antenna varies, therefore, there is no direct comparison of values between the values of the antenna's length, output resonant frequency, and average output voltage, except for the relationship and behavior.**

Keywords **– Liquid Metal Antenna, Resonant Frequency, Harmonic Termination Matching Network, T-Section Bandpass Filter**

I. Introduction

The implementation of Structural Health Monitoring in the Philippines is important since it is in the Pacific Ring of Fire, therefore, a frequent earthquake occurs and when overlooked, unforeseen disasters may happen, and one of the many reasons is the risk of structural failure. With the advancement of technology, the implementation of Structural Health Monitoring was also improved, and this includes the use of strain gauges, sensor nodes, and automated monitoring [1].

The Characterization of the Liquid Metal Antenna as a feasible sensor for displacement, when embedded in the concrete beam was proven due to its flexibility and self-healing properties [2]. Liquid Metal Antenna is a promising technology that may be a replacement for a strain gauge, which is one of the many sensors used in Structural Health Monitoring Systems. To implement such technology, a sensing unit circuitry would be designed and fabricated. The output of the Liquid Metal Antenna is the resonant frequency and has been proven that the behavior of the antenna's resonant frequency with the displacement is inversely proportional [2]. Taking into consideration the input, the circuitry shall be designed in such a way that the resonant frequency would be converted into voltage pulses, which will be read by the computer application via Wireless Sensor Network that uses Zigbee Technology.

This experimental study will focus on the behavior of the liquid metal antenna's displacement with the output voltage, and the capability of the designed circuitry to convert the resonant frequency into voltage pulses to acquire data. The design of the circuit will be based on the implementation of an RF-DC Converter Circuit [3]. The Liquid Metal Antenna to be used for this study will be fabricated using Soft Lithography, and the output resonant frequency shall be measured using NanoVNA. Keysight's Advanced Design System will be used for the design and simulation of the circuitry.

II. Methodology

The data gathering of the system consists of the simulation and the actual data. The design and simulation will use Keysight's Advanced Design System. For the actual data, a Structural Health Monitoring System is constructed, where the strain sensor will be the Liquid Metal Antenna, the designed circuitry for acquiring resonant frequency then converting it into voltage pulses, and a Wireless Sensor Network that will transmit the voltage pulses data to a computer application via Zigbee Technology.

A. Liquid Metal Antenna Fabrication Design

The Liquid Metal Antenna is fabricated as a half-wave dipole antenna that would react to every strain induced onto it by stretching. The study in [4] had found an alternative way of using a photoresist in performing soft lithography with the use of readily available materials. On the other hand, study [5] had done a systematic way of performing soft lithography to fabricate LMA as a pressure sensor. Consequently, the strategies of these two studies would be combined to fabricate the LMA that would be utilized by this system. The following tools and equipment that would be needed are: glass slides, electrical tape, stainless steel scalpel, polystyrene petri dish, oven, polydimethylsiloxane (PDMS) & curing agent (Sylgard 184, Dow Corning), Eutectic Gallium Indium (EGaIn) liquid metal, coring tool, tweezers, and gloves and eye protection glasses.

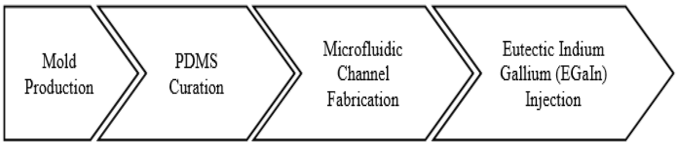

Figure 1. LMA Fabrication Procedure

The actual length of a half-wave dipole antenna would be only 95% of the electrical length due to its capacitance effect. For the LMA designed to have a frequency of 800 MHz:

$$PDMS\ \epsilon r = 2.67$$

$$f = 800\ MHz$$

$$l = \frac{\lambda}{2} = \frac{cVf}{2f}$$

$$L = 0.95l$$

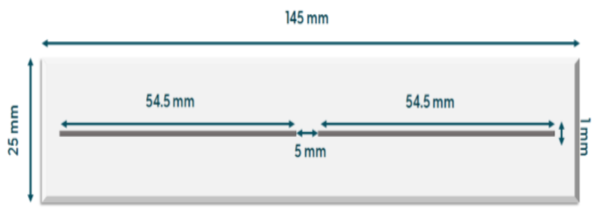

Figure 2. LMA Design

B. Design and Simulation

The design of the sensing unit circuitry is based on the design made by Au & Seo [6] and Schauwecker [7] which takes the concept of an RF-DC circuit. Figure 1 shows the block diagram of the sensing unit circuitry which will be fabricated for testing and compared to the simulated data.

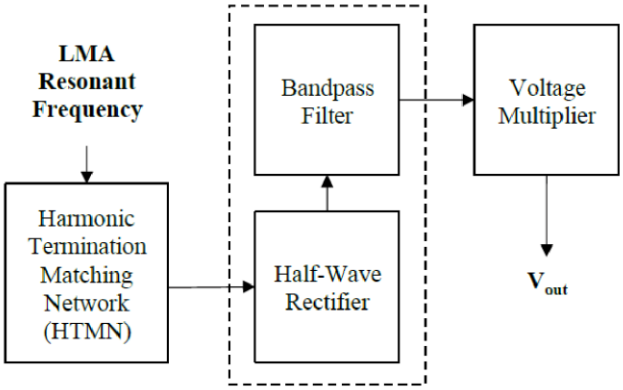

Figure 3. Sensing Unit Block Diagram

The construction of the HTMN utilizes the *Line Calculation* feature of Keysight's Advanced Design System for the dimensions of the stubs depending on the frequency, impedance, and substrate used. The frequency implemented in this design of HTMN is 590 MHz since this is the average measured resonant frequency of the fabricated liquid metal antenna, tested using the NanoVNA. A two-diode configuration half-wave rectifier is implemented for the design with HSMS-2850 Schottky diodes used, which is suitable for low-power applications. A T-Section bandpass filter is designed whose computations were based on [7].

$$f_c = \sqrt{f_L f_H}$$

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$$C_1 = \frac{f_H - f_L}{4\pi f_H f_L Z_0} \qquad C_2 = \frac{1}{\pi Z_0 (f_H - f_L)}$$

$$L_1 = \frac{Z_0}{\pi (f_H - f_L)} \qquad L_2 = \frac{Z_0 (f_H - f_L)}{4\pi f_H f_L}$$

For the fabrication of the circuitry, it will be implemented with surface surface-mounted components since the input system operates at the microwave frequency range. For the substrate, this study will use FR4 substrate since the measured resonant frequency would not exceed 1GHz which will be lossy when exceeded the said frequency [8].

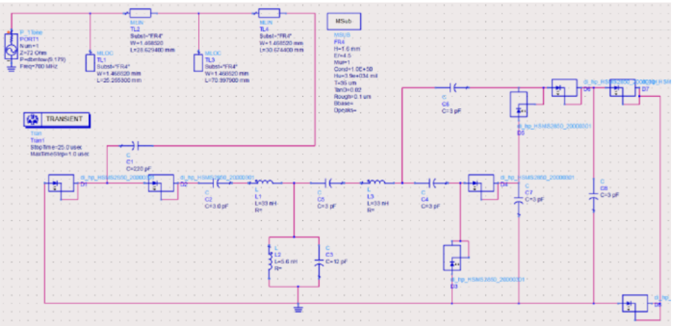

Figure 4. Sensing Unit Design on Keysight's Advanced Design System Software

The designed circuitry layout for fabrication is made using KiCAD Electronic Design Automation Software. The Gerber files were rendered and sent with the assistance of the Department of Science and Technology – Electronic Development Production Center (DOST – EPDC) for the fabrication service for Surface Mount Technology (SMT) circuits.

Figure 5. Sensing Unit Design

C. Structural Health Monitoring System Prototype

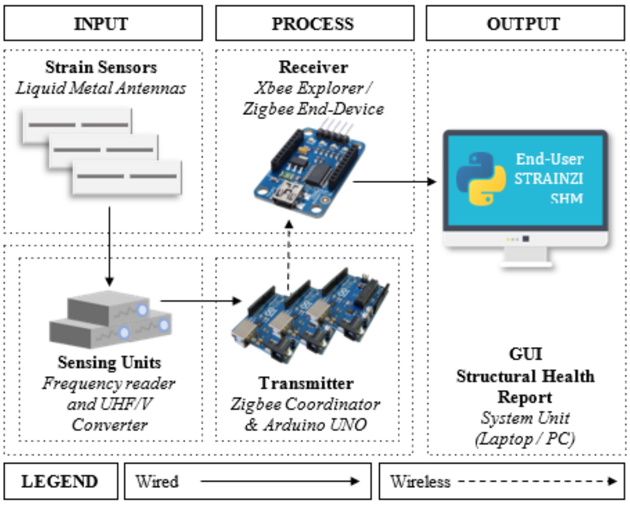

Figure 6. System Architecture of the Structural Health Monitoring System

The prototype system of the study is shown in Figure 3. It consists of wired and wireless connections between devices for the input and output. The system consists of three parts: (1) the input system, (2) data processing, and (3) the output system. The input system includes the liquid metal antenna which will be subject to displacement as the sensor of the system and the sensing unit which will be designed to convert resonant frequency into voltage pulses. The processing system includes the Wireless Sensor Network which will transmit the converted voltage data to the output system which will be the computer application of the system. The computer application shows the voltage pulses detected by the system in a timeline manner.

III. Results And Discussion

The data analysis for this study was categorized and presented into two sections: 1) Simulation Data and 2) System Prototype Data. The data were collected and interpreted in response to the objective of the study for the feasibility and behavior of the liquid metal antenna as a displacement sensor for the implementation of a Structural Health Monitoring system. This also included the justification of data in case no statistical results were to be found.

A. Simulation Data

To test the output voltage of the designed circuit, it is simulated under varying frequencies from 800 MHz to 100 MHz with an increment of 10 MHz in between. Figure 4 shows the plotted data gathered from the simulation.

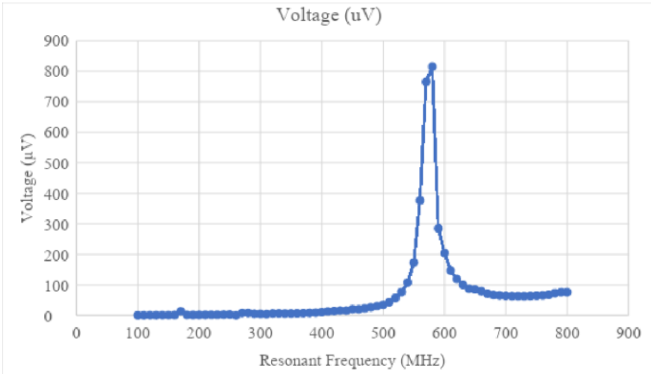

Figure 7. Plotted Data of Sensing Unit Simulation

There is a positive spiked of data recorded in 590 MHz, this was due to the design of the Harmonic Termination Matching Network since it was designed for the 590 MHz frequency, which is the average measured resonant frequency of the fabricated liquid metal antenna that is tested and used for this study. In addition, the highest recorded voltage data from the simulation is 816 µV. As observed from the data gathered, there is a direct relationship between the resonant frequency and the output voltage, with an outlier existing from the designed resonant frequency.

B. System Prototype Data

It was found in the previous study regarding the inversely proportional behavior of the liquid metal antenna in terms of the displacement and resonant frequency [2]. To determine the behavior of the antenna about the average output voltage, three antennas were subject to test by elongating the antenna and recording the average output voltage through the system prototype.

From the recorded and gathered data, figure 5 shows the behavior of the voltage in terms of the antenna's elongation. There is an inverse relationship between the length of the antenna and the average output voltage of the system. When there is strain applied to the antenna, it is expected that there is a decrease in output voltage that will be read by the system

Table 1. Average Output Voltage in terms of Length of the LMA

LMA Length (mm)	**V_{ave} (μV)**		
	Sensor Node 1	**Sensor Node 2**	**Sensor Node 2**
145	19.9070855	19.794	25.41156541
147	19.90485475	19.760	25.54884716
149	19.91605632	19.791	25.39134457
151	19.80921379	19.691	25.37948902
153	19.72771662	19.712	25.20596096
155	19.66395942	19.710	25.20019999
157	19.56963315	19.697	25.14344618
159	19.46050595	19.703	25.16131366

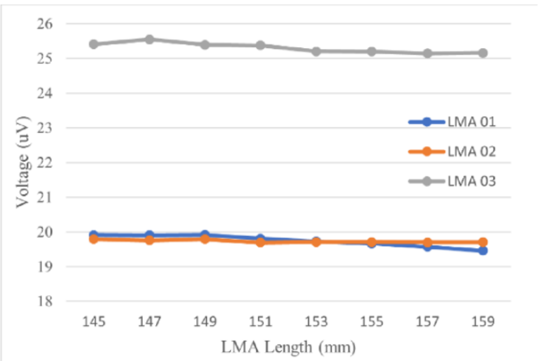

Figure 8. Graphical Representation of the Acquired Average Output Voltage of the System vs Length of the Liquid Metal Antenna

IV. Conclusion

Based on the results of the study, the following conclusions were drawn, the behavior of the length of the liquid metal antenna with the resonant frequency is inversely proportional, and the behavior of the length of the liquid metal antenna with the average output voltage is inversely proportional, therefore, there is a direct proportionality with the behavior of the resonant frequency of the liquid metal antenna and the average output voltage from the designed sensing unit circuitry. There is no direct simulation with the resonant frequency and the expected output of the system since the frequency of the fabricated Liquid Metal Antenna varies, and from the simulation system used, there is no direct simulation where the input can be Liquid Metal Antenna. The proposed prototype system, with the Liquid Metal Antenna as the sensor, is capable of reading displacement based on the experimental setup performed.

V. Recommendations

To further improve the study, future researchers may consider developing a circuitry where the system yields DC Voltage rather than voltage pulses for easier and direct data readings. It is also advisable to consider other wireless mediums for data gathering. This study is advisable to coordinate with other engineering disciplines, especially with Civil Engineers.

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