Design and Fabrication of Stretchable Dipole Antenna for Use at 5GHz Frequency

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Abstract – *This paper presented a reconfigurable dipole antenna for use in wireless communication. The antenna comprises the liquid metal (mercury) injected into the microchannels, by employing soft lithography methods, microfluidic channels are fabricated with Polydimethylsiloxane. The antennas can resist mechanical deformation and return to their original position after the removal of applied stress. The initial length of the antenna is 2cm which can stretch up to 2.4cm. The resonant frequency and radiation patterns in E and H planes can be tuned by increasing the length of the dipole antenna. To validate the measured antenna, the resonant frequency and radiation patterns are compared with the results of the finite element methods software. Similar results are obtained. This antenna can be used in pressure-based sensors and sensors that can be installed on the body. Compared to other manufactured antennas, this antenna has a better gain at the central frequency of 5 GHz. The innovation of this research is the design and construction of a stretchable antenna with a higher gain than other similar antennas.*

Keywords: Stretchable dipole antenna, Microfluidic channel, Mercury Antenna, Resonant frequency

1. Introduction

Interest in the field of reconfigurable antenna has grown significant attention in the past decade[1-3]. These kinds of the antenna are capable of transmitting and receiving data in different communication environments and avoiding signal interference [4]. Furthermore, a reconfigurable antenna provides opportunities to communicate with several devices with different resonant frequencies. The conventional copper antenna is fabricated by etching rigid sheets to the proper designs [5]. These antennas are not suitable for flexible electronics. Due to the application of the antenna on non-planar surface or bending and stretching them, flexible electronics is desirable. Different types of frequency reconfigurable antennas use methods such as PIN diodes [6-8], varactor diodes, ferroelectric varactors, fluidic [9-15] and microelectromechanical systems (MEMS) switches [16-20]. Besides the declared methods, flexible substrates such as polymers and organic semiconductors are grabbed attention in the fields of the reconfigurable antenna [21]. The first method to fabricate flexible antenna is punching a sheet of metal between flexible substrates such as Polydimethylsiloxane. Polydimethylsiloxane (PDMS) has recently been used as a supporting substrate for making flexible antennas. The field densities inside the polymer are low. Therefore, PDMS is a suitable option for dipole antennas [9]. The soft lithography technique is another method to fabricate desired stretchable antenna [22]. There are two approaches to fabricate flexible antenna; the first one is chemical etching and plating the sheet of the metal deposited on the flexible substrate. This method can make flexible antennas by patterning metal on a flexible substrate [23]. Soft lithography method is utilized as a second approach.

We present an approach to producing a frequency reconfigurable dipole antenna. Solid metal is replaced by liquid metal in this project. Hg, which is liquid at room temperature used as a liquid metal to fill the microchannels. Utilizing liquid metal provides the opportunities for the device to stretch and bend into the

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appropriate design. Moreover, UV adhesives are used as a photoresist which is available, cost-effective, transparent, and easy to fabricate, instead of rather expensive photoresists such as SU-8. Frequency resonance and radiation pattern of simulated and measured antenna, which depends on the electrical length of the dipoles arm, are investigated.

2. DESIGN

The presented stretchable antenna is demonstrated in Fig.1. These kinds of antenna consist of two conductive channels separated by a gap. Due to the simplicity of the structure, half wave dipole antenna is chosen to fabricate. The dipole antennas comprise two equal linear branches separated by a small gap. Electrical signals are applied through a coaxial cable, balun [24] and 3 mm SMA connector. In the presented design, both the width, and thickness of the branches are 1 mm (Eq.2), the initial length of them is 1cm and the width of substrate is 7 mm.

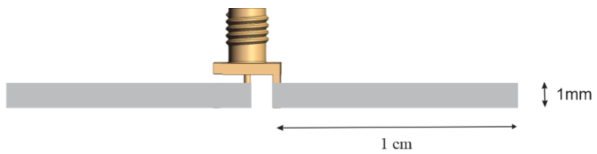


Figure 1. layout of dipole antenna that the length, height and width of the antenna are 1cm, 1mm and 1mm, respectively

3. FABRICATION METHOD

Microchannels were created as branches of the antenna. Soft lithography is a typical process for fabricating the microchannel (Fig.2) [25]. Microscopic glass slides are used as substrates for the master mold. UV adhesive is used as the negative photoresist. The thickness of the resist is dependent on the spinning speed of the spin coater. The resist is spun at the speed of 500 rpm for 10 s to obtain a thin thickness (1 mm). UV adhesive is commercially available, cost-effective, transparent, and easy to fabricate.

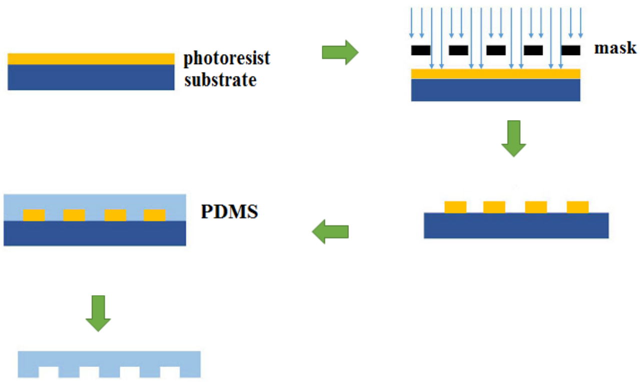


Figure 2. The procedure of soft lithography which contain fabrication of antenna mold and PDMS microchannel

Channels were designed by CAD software and connected to the maskless lithography system to transfer the layout to the substrate. After the exposure, the substrate developed in the Isopropyl Alcohol (IPA) for 30 s. After mold fabrication, the master mold is filled with polydimethylsiloxane (PDMS). 10:1 mixture of liquid prepolymer and a cross-linking agent was poured into the molds. Then put them in the vacuum chamber, and remove the bubbles. The material is then cured at 90°C for around two hours in the oven to obtain an elastomeric duplication of the mold. The top side of the channel was peeled off the molds. The bottom part of the antenna is fabricated by the same procedure by the molds without structures. To improve the adhesion of the PDMS layers, both layers were placed in the oxygen plasma chamber for 20 seconds, then bonded them under the pressure for about 30 min in the oven. SMA connector was punched between the channels to apply the signals. We use Hg as a conductive part of the antenna. For the comparison, the electrical conductivity of mercury is 106 S/cm, while the conductivity of copper at room temperature is 6×106 S/cm. Liquid metal (Hg) injecting elastomeric microfluidic channels [13]. The final device is demonstrated in fig.3.

Figure 3. stretchable fabricated dipole antenna

4. NUMERICAL SIMULATION

The characteristic of the antenna is studied by COMSOL Multiphysics software. COMSOL is utilizing the Finite Element Method (FEM) to solve the problems. In this antenna, the wavelength is 6 cm, and no material degradation and oxidation were assumed. The electromagnetic waves module was employed to evaluate the procedure (Eq1).

$$\frac{1}{\mu_r}\vec{\nabla}(\times\vec{\nabla}\times\vec{E}) - K_0^2(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0})\vec{E} = 0 \qquad (1)$$

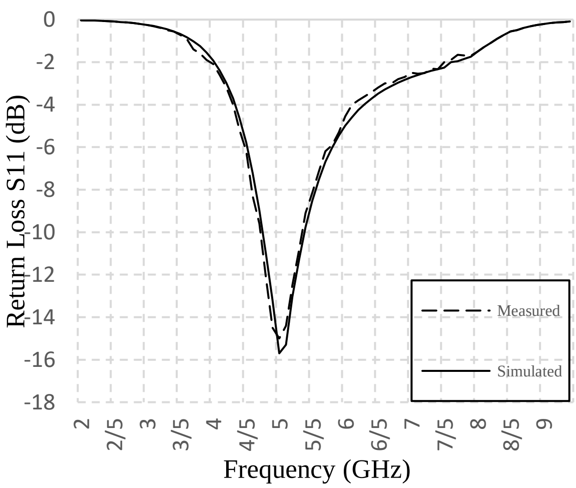
In the above equation, μ_r, ε_r, and σ are relative permeability, permittivity, and electrical conductivity, respectively. The wave number of free spaces is K_0.

5. RESULTS AND DISCUSSION

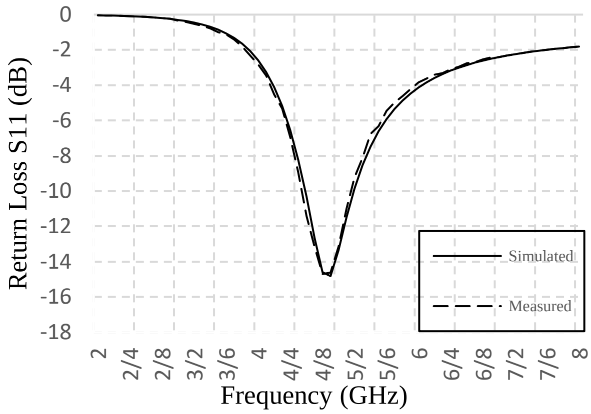
Under strain, the characterization of the antenna is investigated. The antenna is characterized in the free space (l=2 cm) and stretching position (l=2.4 cm). Fig.4 shows the measured and simulated S11 of the antenna with 2 and 2.4 cm length and their resonance frequency. We measured three different properties of the antenna (resonant frequency and radiation pattern), the antenna resonance frequency shift, due to the different lengths of the branches. A network analyzer is used to measure the reflection coefficient in various frequencies. Port impedance matching is found near the 5 GHz for the non-strain antenna in simulated and measured reflection coefficient. According to the Eq (2) [26], the guided wavelength of this dipole antenna decreases by increasing the effective dielectric constant the antenna. As observed in figure 4a the bandwidth of the antenna is from 4.75GHz to 5.4GHz.

$$\lambda_g = \lambda_0 \times \frac{1}{\sqrt{\varepsilon_{eff}}} \qquad (2)$$

Where λ_g is the guided wavelength, λ_0 is the free space wavelength, and ε_{eff} is the effective dielectric constant of PDMS. The resonance frequency of the antenna shifted downwards in both the simulated and fabricated antenna. Figure 4a and 4b compared the non-stretched and stretched devices for both numerical and simulated antenna, respectively. There is a decent agreement between our measurement and simulated antenna. According to the Fig.4, the reconfigurable antenna could be used as a strain sensor.



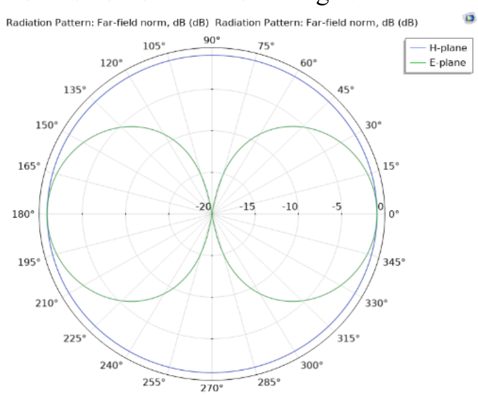
(a)



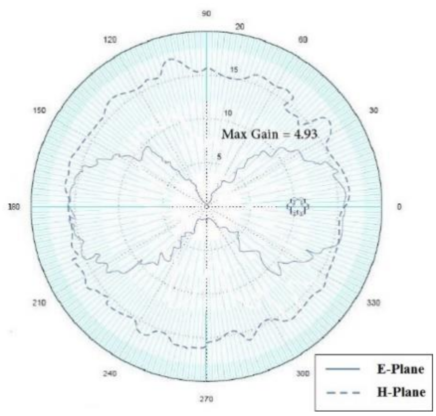
(b)

Figure 4. Simulated and measured Return Loss in various frequency. a) the resonant frequency of the non-stretched antenna is 5.1GHz (total length is 2 cm) b) 4.9GHz is resonant frequency of stretched antenna (total length is 2.4 cm)

Radiation patterns of the antenna with original size and stretched channel at the resonant frequency are shown in Fig5. As expected for the dipole antenna, the measured antenna in E-field has two peaks and two nulls of radiation, although the H-field has a circular radiation pattern. The measured maximum gain at center frequency is 4.98 for the non-strain antenna Fig.5.



(a)



(b)

Figure. 5 a) Simulated and b) Measured radiation patterned in E and H planes

Table 1 shows the simulated and measured values of antenna gain in stretched and non-stretched states. As can be seen, the gain is better at 4.9 GHz frequency due to good matching in stretched mode.

Table 1. Simulated and measured Gain

Freq	State	Gain (dB)	
		Simulated	Measured*
5.1GHz	Non-Stretched	5	4.91
	Stretched	4.5	4.45
4.9GHz	Non-Stretched	4.9	4.88
	Stretched	4.9	4.86

*Measurements were made in stretched state at maximum tension (20% stretch).

Table 2 shows the comparison of the antenna presented in this article and other articles. As can be seen, at 5 GHz frequency, the antenna introduced in this article has a better gain than other antennas.

6. Conclusion

The flexible reconfigurable antenna is deformable and durable. Furthermore, the fluidic antennas are mechanically tunable and sensitive to strain. Lithography is utilized to make the mold with UV adhesive, and the soft lithography approaches fulfill the fabrication process of the dipole antenna. By injecting fluid metal into the channels, a mechanically tunable antenna was fabricated. Radiation pattern and resonant frequency are obtained by COMSOL Multiphysics. The resonant frequency of the non-stretched antenna was obtained about 5GHz and by increasing the length of the antenna the resonance frequency can be tuned from near 5.1 to 4.8 GHz. The measured device is in excellent agreement with Numerical simulation. Consequently, the devices provide the opportunity to improve sensing or wireless communication.

Table 2. Stretchable Antenna patterning techniques based on printing/direct writing fabrication methods Abbreviations

Pattern technique	Antenna type	Radiation/Substrate Materia	Frequency	Antenna Gain
Liquid material in replica molded microfluidic channel [9]	Dipole	EGaIn/PDMS	1910–1990 MHz	-
PDMS microchannel glued to LCP substrate and liquid material [27]	Monopole	Mercury/PDMS & LCP	~1.2 – 5 GHz	2.4 @ 5GHz
Pressure sintering of liquid material nanoparticle [25]	Dipole	EGaIn nanopoarticle /PDMS	~2 -3 GHz	-
This paper	Dipole	Mercury/PDMS	4.75-5.4 GHz	4.9 @ 5GHz

7. References

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