Low Cost 3D-printed Monopole Fluid Antenna

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***Abstract*— Low cost 3D printed monopole fluid antenna is investigated. The PDMS container of the seawater is fabricated by 3D printing technology for reducing cost and complexity. The design parameters of the antenna have been studied for efficiency improvement. The achieved peak efficiency is about 70% at 2.75 GHz, and the impedance bandwidth is about 67%. Stable radiation patterns are demonstrated across the operating bandwidth. The radiation mechanism of the antenna has been explained.**

***Keywords*— monopole, fluid antenna, efficiency, 3D printing, PDMS**

I. INTRODUCTION

Fluid antennas have attracted attention. Conductive fluid, no matter metal fluid or ionised liquid, has no defined shape; therefore it is possible to create the desirable shape of a fluid antenna for different wireless environment. Recently, a military grade seawater antenna operating at the UHF band is reported [1][2]. The seawater antenna can establish a two-way communication with stations 50 km away. The length and width of the fluid beam can be adjusted to determine the operating frequency and bandwidth respectively. Beam-scanning liquid metal antenna discussed in [3] demonstrates the possibility of accessing multiple base stations using fluid antennas. By adjusting the air pressure inside the low cost 3D-printed plastic panel, microfluidic system has been proven effective in changing the shape of fluid in sub-millimetre scale inside biosensor chips. A dual function design integrating solar panel with water patch antenna is reported in [4].

The conductivity of ionised water, such as seawater, is around 4.7 S/m, so one of the main concerns of using ionised water for fluid antenna is efficiency. The efficiency of a monopole seawater antenna has been discussed in [5][6], a dielectric layer was inserted between the ground and seawater monopole to improve the efficiency of the antenna to about 60%. It is desirable to further improve the efficiency for practical wireless applications.

Another concern of fluid antenna is the container design; the fabrication of leakage proof container needs special consideration. 3D-printer technology is one of the best methods for fast and low leakage fabrication. Moreover, researchers have high freedom in creating new shapes for fluid antennas.

Motivated by the above opportunity, this paper proposes to utilise low cost 3D-printed technology to design high efficiency monopole fluid antennas. CST microwave studio 2015 was used in the simulation [7].

II. ANTENNA GEOMETRY

The cross-sectioned geometry of the 3D-printed monopole fluid antenna is shown in Fig. 1. The antenna consists of three main parts, 1) a ground plane, 2) a circular tube containing the seawater, and 3) a coaxial feed probe. The size of the ground plane (L×W×h) is 30×30×0.1 mm^3. Stereolithography based 3D printer technology was used to fabricate the Polydimethylsiloxane (PDMS) circular tube. PDMS is a low cost commercially available silicone based rubber with dielectric constant (ε_r) equals 2.8 and loss tangent (tan δ) equals 0.001. The dielectric constant and conductivity of the seawater inside the PDMS cylinder are 81 and 4.7 S/m respectively. The feeding probe is a 50Ω coaxial cable with the centre conductor contacting the seawater as shown in Fig. 1. The other dimensions of the antenna have been tabulated in TABLE I.

TABLE I DETAILED DIMENSIONS OF THE 3D-PRINTED MONOPOLE FLUID ANTENNA

Parameters	**Symbols**	**Dimensions (mm)**
Thickness of the tube	h_{tube}	0.5
Inner radius of the tube	r_{tube}	5.5
Height of the tube base	y_{base}	5.4
Height of the probe from the top of the tube base	y_{probe}	2
Height of the tube from the top of the tube base	y_{tube}	30
Height of seawater from the top of the tube base	y_{water}	25

The container for ionised water is built using standard Clear Resin with Form 1+ Formlabs 3D printer. An experiment was set to measure the parameters of the Clear Resin provided by Formlabs. The dielectric probe that was used is Agilent 85070E Dielectric Probe Kit. Fig. 2 shows dielectric constant and loss tangent measurements. The dielectric constant goes from 2.3 down to 1.6, decreasing in frequency. While the loss tangent is mainly constant around 0.05.

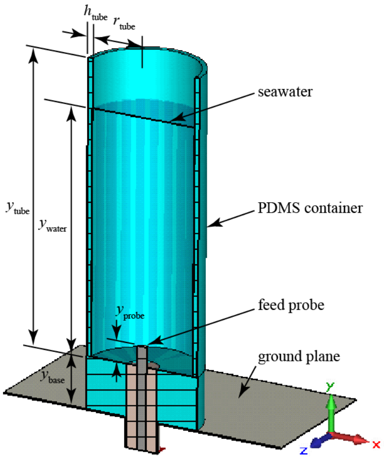


Fig. 1. Cross sectioned geometry of the 3D-printed antenna

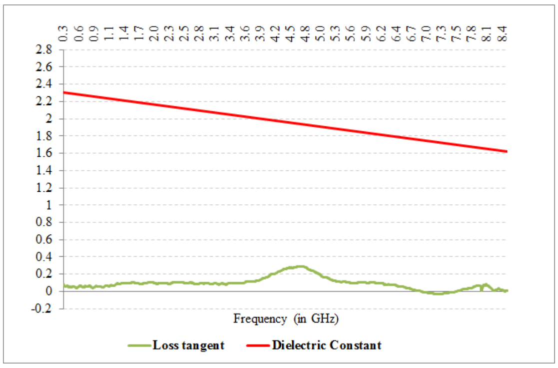


Fig. 2. Loss tangent and dielectric constant measurements of 3D printing material

III. RESULTS AND DISCUSSION

The simulated S_{11} of the monopole fluid antenna is shown in Fig. 3. It can be observed that the operating bandwidth is between 2.29 to 4.58 GHz, the impedance bandwidth is about 67%. As shown in Fig. 4, three resonances, at 2.75 GHz, 4 GHz and 5 GHz, can be identified inside the operating frequency band. In order to understand the corresponding parameter for each resonance, the H-field distribution of the antenna at 2.75 GHz and 4.75 GHz are plotted in Fig. 5. It can be observed that at 2.75 GHz, the energy is mainly radiated from the saltwater, while at 4.75 GHz, the radiation come from the higher order mode of the saltwater and the feed probe. Such observation agrees with the resonances shown in Fig. 4. Fortunately, as the radiation mechanisms at the three resonances are similar, it does not deteriorate the radiation patterns across the whole operating bandwidth. Donut-shaped radiation patterns of the antenna can be observed across the band. Radiation patterns at 2.75 GHz and 4.75 GHz are shown in **Fig. 6.** Moreover, the maximum gain of the monopole is about 0.4 dB which mainly contributed by the fundamental mode of the seawater tube. The peak efficiency of the antenna is about 70% at 2.75 GHz and it drops to 40% at 4.75 GHz. This also explains the lower gain obtained at the higher frequency range.

In the study, it is observed that the base of the PDMS tube and the length of the feed probe play critical role in determining the efficiency. As the impedance of the antenna can be optimized by adjusting the height of the PDMS tube base, while the length of the feed probe will control the level of energy coupling to the seawater. In a preliminary study about the length of feed probe shows that the efficiency can be improved by proper selected probe length. Nevertheless, these two parameters should be carefully optimized for high efficiency. A parametric study will be presented in the final paper. Moreover, the experimental results will be provided in the presentation.

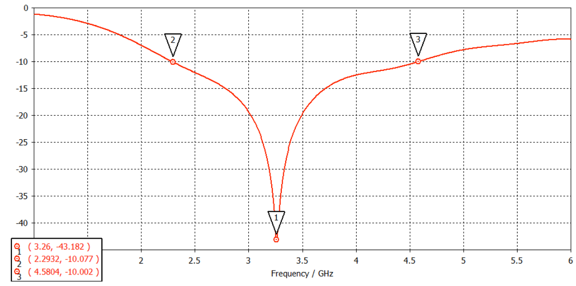


Fig. 3. S_{11} of the proposed 3D-printed monopole fluid antenna

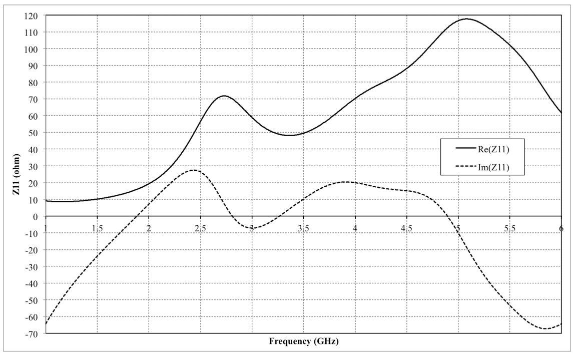
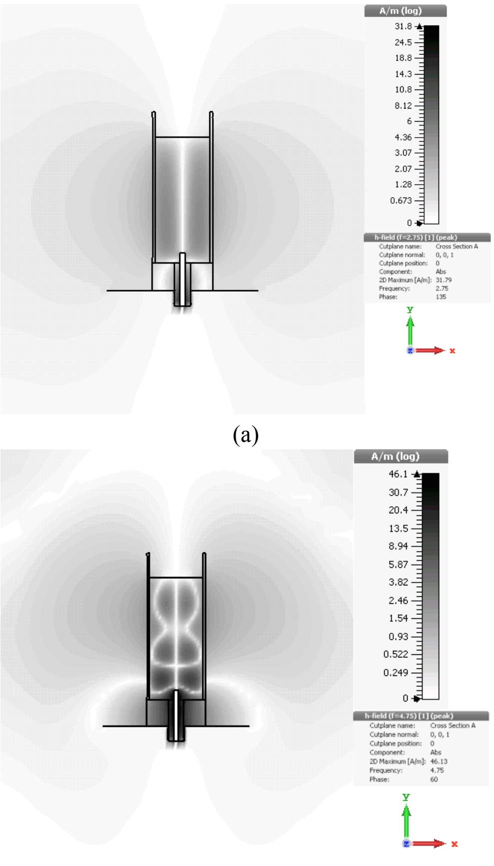


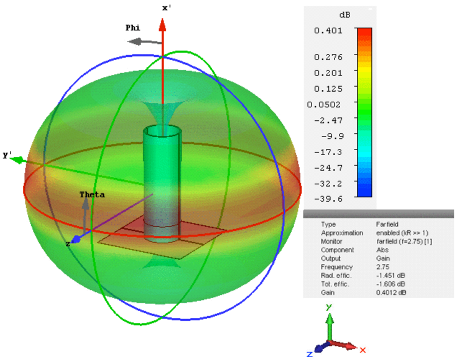
Fig. 4. Z_{11} of the proposed 3D-printed monopole fluid antenna



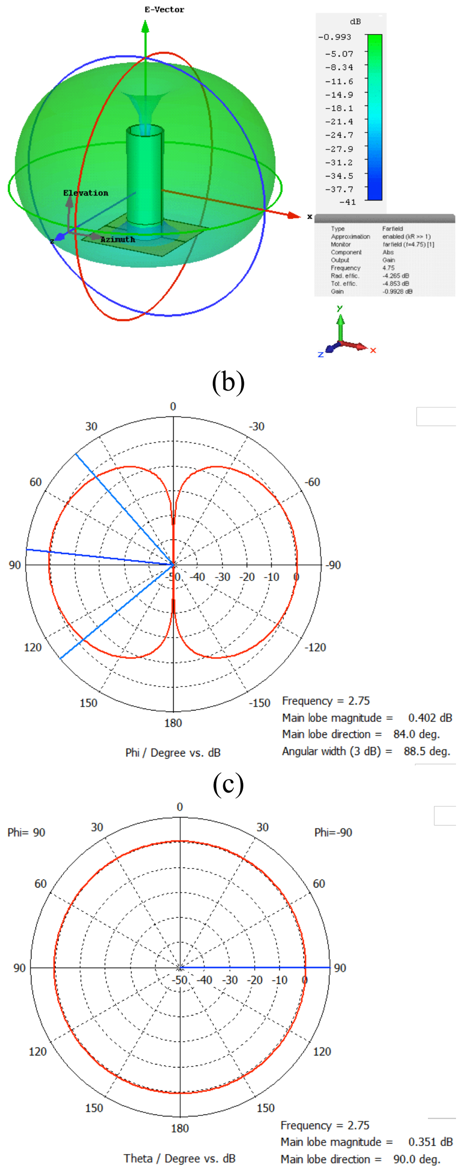
(a)

(b)

Fig. 5. H-field distribution of the monopole fluid antenna at (a) 2.75 GHz and (b) 4.75 GHz



(a)



(b)

(c)

(d)

Fig. 6. Radiation patterns 3D-printed monopole fluid antenna (a) 3D at 2.75 GHz, (b) 3D at 4.75 GHz, (c) E-plane at 2.75 GHz, and (d) H-plane at 2.75 GHz

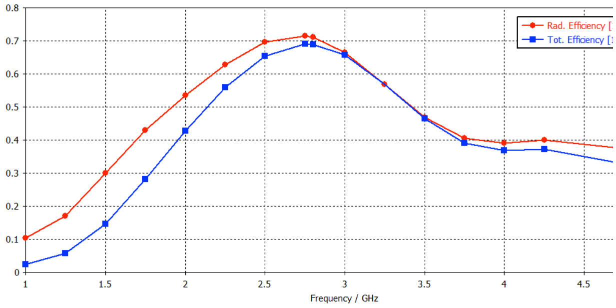


Fig. 7. Efficiencies of the proposed 3D-printed monopole fluid antenna

IV. CONCLUSION

The preliminary study of a low cost 3D-printed monopole fluid antenna has been presented. Reasonable impedance bandwidth of 67% has been achieved and the peak efficiency is about 70%. The radiation pattern of the antenna is stable across the operating bandwidth. Detailed study of the feed probe length and tube base height should be done to improve the efficiency at high frequency.

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