

Design and Validation of Water Based Dense Dielectric Patch Antenna (DDPA) for Microwave Communication around Frequency of 1GHz

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Abstract

Liquid antennas are distinct types of antennas that have been widely used due to their low profile, reconfigurable, and tunable features with steering abilities. In this paper, a low profile, high directivity, and good efficiency reconfigurable Water-Dense Dielectric Patch Antenna (DDPA) fed by the coaxial probe is presented. Distilled water becomes lossy above 1 GHz frequency, so it is best suitable for lower-frequency applications. A thick substrate between the water patch and the ground plane is used. An impedance bandwidth of 7% with a maximum gain of 7.78 dBi, and radiation efficiency up to 71 % is obtained. This antenna can operate over the 967 to 1038 MHz band without a reduction in radiation efficiency. Simulated results are presented to validate the new design in both CST microwave studio and ANSYS HFSS which are the best simulating software for antenna designing. The comparison shows that the new antenna has a more compact size, and simpler structure, and is suitable for low-frequency applications.

Index Terms: ANSYS HFSS, Coaxial Feed, CST Microwave Studio, Dense Dielectric Patch Antenna, Reconfigurable.

I. INTRODUCTION

An Antenna is a fundamental component in any wireless communication system. Since the first display of wireless communication, research to find better antennas for communication is underway. We have witnessed the migration from large, heavy metal antennas to seamless patch antennas in the recent past. The development of smart and low-profile antennas with better radiation performance has enabled to achieve, compact communication devices which led to the revolution in smart handheld communication devices. Characteristics of radiating material and the shape of the antenna are fundamental parameters that determine the performance of the antenna in a particular frequency range. Initially, liquid antennas were conceived to use the conduction property of some liquid metals along with their unique property of reshaping. Mercury was the first liquid metal for such trials to exploit its conductive characteristics and radiation behavior for its functioning as an antenna. However, there are serious concerns about its highly toxic nature and explosive tendency in electronic circuitry [1]. Due to some attractive features of liquid antenna, which include reshaping, reconfigurations, and withstanding the mechanical stresses, strains, and twists; liquid antennas are gaining significant interest from researchers. Besides mercury, there are other materials that have been tried to be used as antenna. Such materials include Eutectic

Gallium Indium (EGaIn) [2], liquid crystal [3], and some water-based formations [4].

Liquid antennas can be classified into two major types; metallic and non-metallic. Based on the composition of the dielectric, the latter type is further classified into water and non-water-based compositions. In most cases, the liquids are contained in a dielectric container which is fed with electronic signals of different frequencies and are radiated for wireless communication. The difference in conductivity and radiation performance amongst different liquids determine their suitability for practical use. In liquid antennas, the cost of liquid and its safe use in electronic equipment has also been an important factor for their consideration [5].

Water-based antennas are a unique type of liquid antenna and have a great demand in recent years. They use water as a transmitting and receiving medium for signals [6]. Mainly, two water types are used for developing antennas; saline water and pure water. A huge number of water monopoles can be developed by saline water. Saline water is used as a conducting fluid in antenna design while pure water can be used as a dielectric to form a dielectric resonator antenna [7].

Water antennas have interesting characteristics such as [8]:

- Water has high electric permittivity. Therefore, using water as a dielectric helps to reduce its size by a factor of $\sqrt{\epsilon_r}$.

- The shape of such antennas can be easily changed hence increased flexibility in of design process.
- The resonating frequency of water-based antennas is proportional to the thickness of the water composition.
- Low profile, lesser cost, and easily accessible.

The result in [9] shows that the operating principle of water-based Dense Dielectric Patch Antenna (DDPA) is similar to conventional patch antennas.

Besides the significance of liquid antennas, this form of antennas does have some challenges in the form of implementation. The fabrication process of liquid antennas requires a mechanical arrangement to pump liquid for reconfiguration. This process is a bit slower as compared to electronic reconfigurations adopted for conventional non-liquid antennas. Moreover, in liquid antennas, there is a requirement for a liquid holder and a sustainable leakproof mechanism. Liquid in antennas may vary its chemical behavior due to high temperatures in electronic devices hence dielectric behavior may also change. The use of different water compositions in terms of saline level may serve as a remedy for such changes.

Considering the advantages of water-based liquid antennas, we have worked to design an antenna for microwave communication within frequencies where water has an acceptable signal absorption profile. The design is performed on numerical modeling and analytical tools of ANSYS and HFSS.

The remaining of this paper has been structured in different sections. Section II consists of a summary of relevant reports and articles in the field of liquid antennas. We present the design method and approach of water-based DDPA in Section III followed by simulation results in Section IV. A concluding statement is presented in Section V.

II. STATE OF THE ARTWORK

We found some early scholarly articles that discussed the concept of liquid antennas in the early 1990s [10]. Since then a significant number of researchers turned their focus to exploring the possibilities and variations of liquid antennas from metallic and non-metallic categories. A sizeable literature has been available in the last 20 years which emphasizes the significance of this relatively new category of antennas [11].

The water-based antenna reported in [12] realizes the advantages of using water as a Dielectric Resonant Antenna (DRA). Water as dielectric was found as a cost-effective solution for low microwave frequencies with the additional advantages of flexibility and convenient electrical contacts.

Liquid materials are primary components of liquid antennas which have different characteristics in terms of electrical properties. Therefore, Antennas based on these materials exhibit different features. Mercury is a well-known material found in liquid form. Its toxic and explosive features prevented further use of mercury as an antenna.

Other materials were explored which are mostly composite and hybrid materials. Features of different metallic liquid materials are presented in table I whereas critical

properties of water-based materials are presented in table II [13].

Table I: Features of Potential Liquid Metallic Materials

Material	Melting Point (C°)	Conductivity (S/m)	Composition
Mercury	-39	1×10^6	Pure Hg
EGaIn	16	3.4×10^6	75% Ga, 25% In
GaIn ₁₀ Ink	16	3.0×10^6	~90% Ga, 10% In, 0.026% O
Galinstan	-19	3.3×10^6	68.5% Ga, 21.5% In, 10% Sn
EGaIn Nano Particles	~16	0.092×10^6	EGaIn Nano Particles

Table II: Properties of Water-Based Liquid Materials

Material	Freezing Point (C°)	ϵ_r	Loss Tangent
Pure Water	0	78	0.05
Sea Water	~-2..6	74	0.85
Saline Water (Salinity 5%)	-2.5 to -3	65	2.2
Water (5% PG)	-2 to -4	77.5	0.06
Water (30%PG)	-11 to -12	67.8	0.14
Water (5% Ethanol)	-2 to -4	77	0.05
Water (30% Ethanol)	-15	63.6	0.11

As evident from table II, water-based antennas are prospective candidate due to their high electric permittivity. In [14], researchers demonstrated the experiment using a seawater-based antenna to make a successful communication in the 400MHz range. In [15], the water-based antennas have been explored in terms of their reconfiguration features. The radiation pattern of the antenna was successfully reconfigured along with the frequency range of the antenna was altered by changing the physical shape of the antenna. In [16], saline water-based antennas have been experimented with for particular radio frequencies for maritime applications. Besides reconfiguration using water-based antennas, the polarization of these antennas has also been reconfigured in a reported research article [17]. The formation of antennas using optically transparent pure water has been reported in [18]. Water-based antennas are dependent on the dielectric properties of liquid. Liquid antennas may vary their chemical behavior due to high temperatures in electronic devices hence dielectric behavior may also change.

Reconfigurable antennas are capable of changing their radiation pattern, resonance frequency, and bandwidth to meet dynamic conditions. Conventional reconfigurable antennas achieve this robustness by use of electronic arrangements which include RF switches, varactors, and tunable materials. These electronic components connect or disconnect to influence the final radiation of the antenna structure. Due to the electronic components in the reconfiguration mechanism, there are challenges of relatively more power consumption in the antenna structure itself [20].

There are issues of isolation control in parts of patches of antenna along with matching issues. Liquid antennas, on the other hand, demonstrate greater ability as far as reconfiguration is concerned. Liquid is naturally convenient to reshape by just reshaping the container.

There is neither a need for multiple patches nor the impact of isolation issues. Therefore, liquid antennas are considered low-cost, low-profile, and flexible alternatives to electronic-based reconfigurable antennas [13].

III. PROBLEM STATEMENT AND PROPOSED SOLUTION

Keeping in view the reports and articles about liquid antennas, we witnessed application-specific antenna designs using a variety of material types. Water-based antenna is useful for many applications, especially in dynamic RF environments. We have mainly focused on cellular applications for the proposed antenna. Moreover, applications in the UHF range of radio frequencies such as radar systems, and satellite communication are one of the potential deployment scenarios for such designs. The innovations in the field of communication require components of wireless communication systems to be more robust and adaptable. Being an integral part of any communication system, antennas are viewed to be robust, reconfigurable, and efficient for different modes of communication. In this work, we are exploring reconfigurable water-based patch antenna specifically for frequencies near 1GHz to make it compliant for many personal communication devices.

In this article, we present the design of a reconfigurable water-based DDPA. There is a range of radio frequencies where water exhibits high relative permittivity ($\epsilon_r \sim 80$) with a lower value of loss tangent. Therefore, one can tune the thickness of water to control the resonance frequency. Due to its liquid nature, the signal feed is also flexible and can be attained without air gaps. Therefore, the proposed reconfigurable water DDPA can be a good option for low radio frequency applications. Famous numerical simulation tools of CST microwave studio and ANSYS HFSS have been used for validating the design and finding results in this work.

The electrical properties of pure water are a function of frequency and temperature. At higher frequencies, the loss of signal increases linearly with frequency hence water is not a good dielectric for the upper band of microwave frequencies [19]. Figure I demonstrates the geometry of our proposed antenna. It has a plexiglass formation with dimensions of $388 \times 194 \times 19 \text{ mm}^3$.

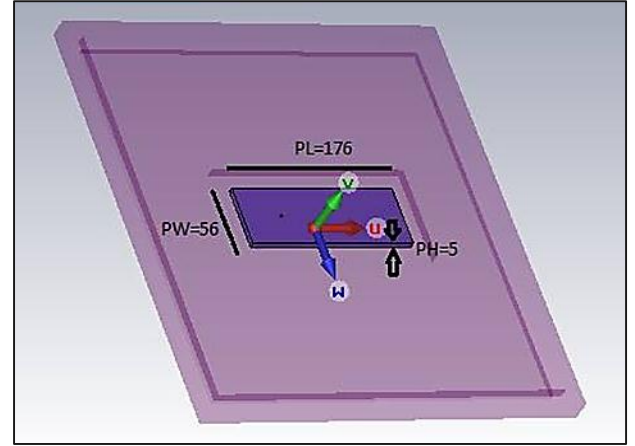
The large plexiglass object serves as a substrate whereas the smaller plexiglass on the top serves as supporting water patch material. This patch is filled with water. The dimensions of the water patch are denoted by PH (Patch Height), PL (Patch Length) and PW (Patch Width). The dimension of the substrate and patch has been optimized to achieve better impedance matching. The optimized dimensions of the patch and substrate are presented in table III.

Table III: Optimized Dimensions for Water-Based DDPA

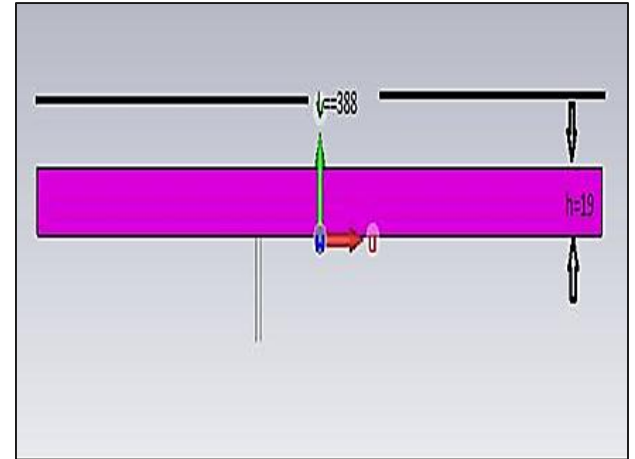
Design Parameters	Units (mm)
Substrate Length: L	388
Substrate Height: H	19
Spacing S	30
Patch Height: PH	5
Patch Length: PL	176
Patch Width: PW	56

The designed formation has been developed in HFSS as well. Its front, back, and side views in HFSS are shown in figure II.

In this article, we concentrated on the effects of water type and dimensions of water formation in liquid antenna. The impact of allied assembly in the form of the substrate and its dimensions are included in the responses of the whole antenna.



(a)



(b)

Figure I: Dimensions of the Reconfigurable Water-Based DDPA with Co-Axial Probe Feed: (a) Front View; and (b) Side View

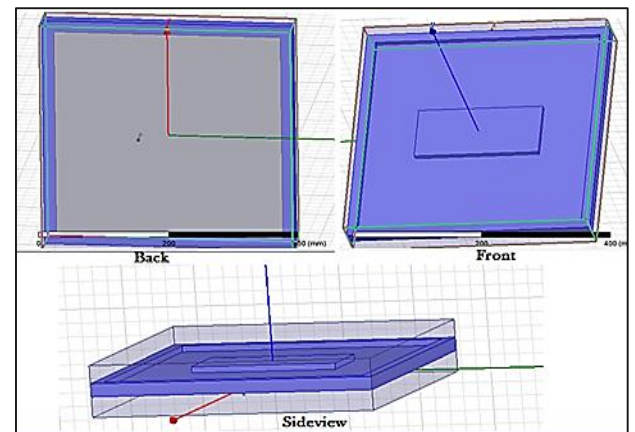


Figure II: Views in HFSS: (a) Rear View; (b) Front View; and (c) Side View

IV. RESULTS AND DISCUSSIONS

In this section, we present the outcomes of numerical simulation performed on CST microwave studio and HFSS.

The computed reflection coefficient curve S_{22} is present in figure III at our desired frequency of 1.001 GHz. Here the return loss is -49 dB for bandwidth of 70 MHz and the bandwidth of the antenna has been indicated with marker 1 and marker 2. Both markers indicate the range of frequencies for which the reflection coefficients are less than -10 dBm.

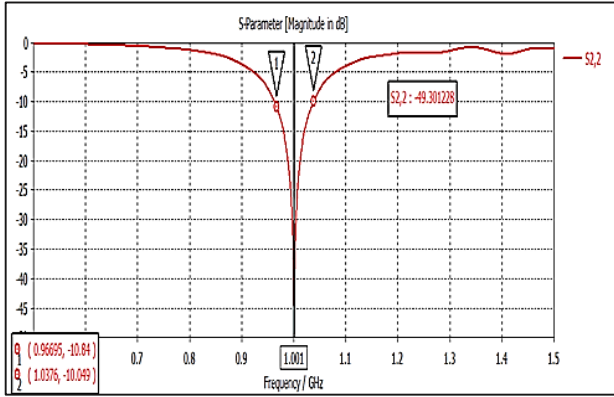


Figure III: S Parameters for the Proposed Design of Water-Based Antenna at 1 GHz

To confirm the design of the antenna in different numerical simulation environments, we tested the same design in HFSS as well. The proposed design has been validated in HFSS for its reflection coefficient S_{11} with a resonating frequency of 1.001 GHz. Figure IV represents the simulation results for a proposed design.

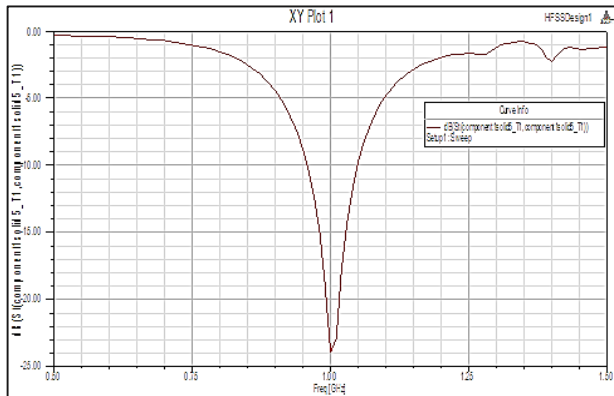


Figure IV: S_{11} Simulated in HFSS at 1 GHz

Directivity for the desired antenna is considered an isotropic point source. Color-coded diagrams indicate the intensity of radiation on the three-dimensional periphery of the point source. The radiation intensity of the designed antenna with reference to the point source has been presented in figure V.

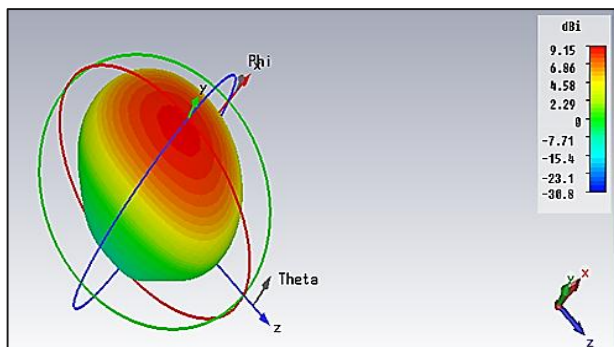


Figure V: Directivity of Newly Designed Water-Based DDPA

The Gain of an antenna is a significant design parameter. Gain is expressed in dBs and measured in the direction of maximum radiation. In this case, the far-field gain for the main lobe is 7.78 dB at 1.001 GHz frequency. This value has been achieved at 90° of the main lobe direction along with the angular width of the main lobe is 81.90. This gain performance is better as compared to other patch antennas [17]. The gain profile of our designed DDPA is shown in figure VI.

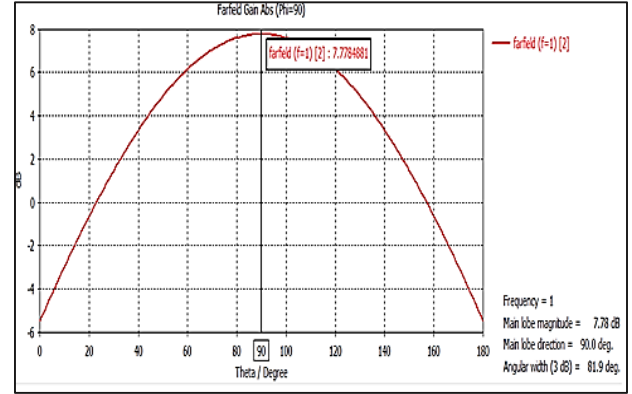
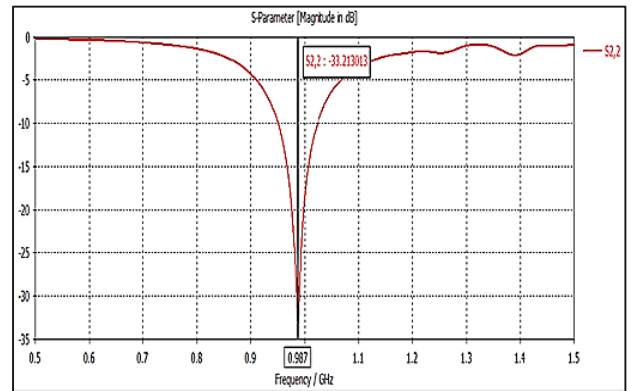


Figure VI: The Gain Curve for Water-Based DDPA (at 1GHz)

To observe the impact of the thickness of the structure, we have repeated the numerical simulation for patch height starting from 5 mm to 7 mm. These iterations are considered necessary to ensure the sustainability of the desired performance of the proposed DDPA for any possible changes in the dimensions of the reconfigurable antenna due to operational conditions. The results are presented in figure VII.

Moving forward in our experiment, the patch height was set to 5.2 mm and the simulation was repeated. Figure 7(b) indicates the S_{22} parameter at -38 dBm for an operating frequency of 994 MHz. Patch height is directly influenced by the density and viscosity of the contained liquid in the patch. Therefore, we tried this setup at a patch height of 6mm to confirm the results. At a frequency of 938 MHz, the antenna exhibited a reflection of -22 dBm at the receiving end.

Finally, the trial with a patch height of 7 mm was executed. The results of S_{22} are less than -17 dBm at 888 MHz. The variations of patch height in the simulation satisfactorily exhibit the acceptable reflection coefficients for the proposed design. However, the resonating frequency shifts from 1.001 GHz to 0.888 GHz.



(a)

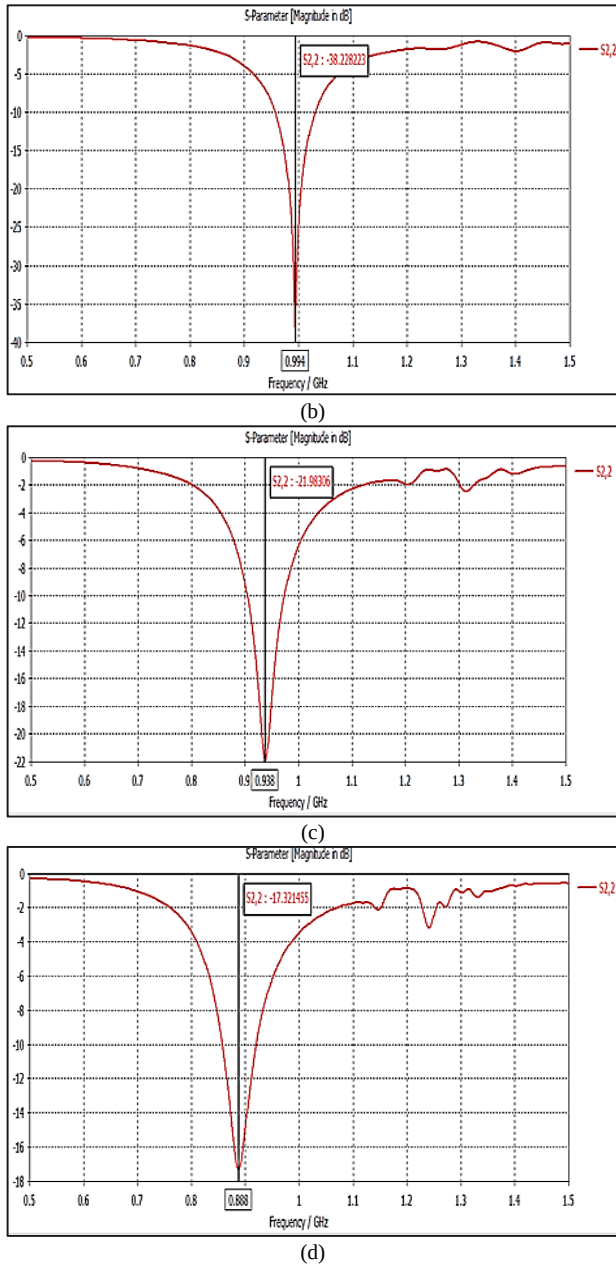


Figure VII: Effect of Patch Height: (a) Height is 5.1 mm; (b) Height is 5.2 mm; (c) Height is 6 mm; and (d) Height is 7 mm

V. CONCLUSION

We have presented a design of a reconfigurable water-based dense dielectric patch antenna which is fed by a coaxial probe. It is proposed to meet the communication requirements for microwave applications in the range of 1 GHz. The radiation theory of this antenna resembles other patch antennas. The high relative permittivity of water has been used to reduce the dimension of the antenna. With 7% impedance bandwidth, an isotropic gain of 7.78dBi, and 71% radiation efficiency, this antenna can be used for microwave communication including cellular applications. The antenna can be tuned by varying the height of the water-based patch to shift the resonance frequency for a suitable application.

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Authors Contributions

The contribution of the authors was as follows: Abid Munir's contribution to this study was the concept, technical implementation, project administration, and correspondence. The methodology to conduct this research work was proposed by Shahab Ahmad Niazi. The rest of the authors namely Dileep Kumar, Umar Fayyaz and, Madiha Mukhtar jointly perform, supervision, data collection, data compilation/validation, and paper writing.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source, i.e., electronic or print media. The information obtained from all of the sources is properly recognized and cited below.

Data Availability Statement

The testing data is available in this paper.

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