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A study of distilled water and zamzam water as dielecric dense patch antenna at 5 GHz

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ABSTRACT

This paper was performed in order to study about distilled water and zamzam water which act as dielectric dense (DD) patch antenna at 5 Ghz applications. This antenna is proposed and designed using FR-4 substrate that sandwiched together to perform DD structure. The proposed antennas employ simple rectangular structure that fed with inset feeder surround by electromagnetic bandgap (EBG) structure.In order too enhance the gain, superstrate is applied on top of the antenna. This antenna offers a wideband return loss of more than -10dB between 4.41-5.52Ghz (around 22.2%) which can be applied in 5 Ghz applications. Details of DD water antenna of center frequency for 5 Ghz is presented and discussed.

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1. INTRODUCTION

Microstrip antenna was focused because of several advantages compared to conventional antenna. The advantages includes low volume, light weight, low cost of fabrication, dual frequency and dual – polarization antenna can be easily made, simple feed for linear and circular polarizations, feed lines and matching networks can be fabricated with antenna structure [1-5]. However, microstrip antenna also facing some limitations compare to conventional antennas. The limitations include narrow bandwidth, lower gain, high metallic loss and lower power handling [1].

In 1980s, Stuart Long was developed a dielectric resonator antenna (DRA) in while microstrip antenna progressively explored [6]. There are many researchers interested in DRA because of its low loss, believed to be useful and good radiator and unique features differ from metallic patches [7-14]. Dielectric resonator antenna (DRA) is antenna which mounted directly above ground plane [6]. Referring to this DR structure will excited HEM_{11} mode [15]. Other than exciting at the high dielectric material in HEM_{11} DRmode, researched has been discovered that a TM_{11} cavity mode also can be excited in the region between circular dielectric resonator and metallic ground plane. This concept of antenna is designated as dense dielectric (DD) patch antenna. Dense dielectric (DD) patch antenna notion is considered as family of patch antenna rather than DRA. DD patch antenna is expected has higher efficiency compared to metallic conventional antenna, especially at higher frequencies where the radiation efficiency of microstrip antenna becomes low [16, 18-19].

Then, microstrip antenna also facing some limitations compare to conventional antennas. The limitation includes narrow bandwidth and high metallic loss [1]. Therefore, recently researcher widely proposed another material to replace metallic microstrip antenna in order to overcome the high metallic loss [17, 20-22]. Material that proposed must be easy to get, low cost, and can give good performance to the antenna design. Thus, water material is suitable to meet all the requirement to replace metallic antenna due to water has similar performance as well as the metallic microstrip antenna at the lower microwave frequencies [20].

Besides that, water is an alluring material to replace metallic due to it can give good performance and high permittivity as well as metallic microstrip patch antenna at lower microwave frequencies [20-21]. Most of the early studies of water antenna using fresh water had been recorded in [20, 22]. There are some advantages of using water such as easy available and green material. At lower frequency, pure water has high dielectric constant which can serve as a good choice for DDPA [20]. Figure 1 show the dielectric permittivity and loss tangent of pure water.

Other than that, zamzam water is holy water for Muslim which is very interesting material to discover.Surprisingly, zamzam water is very suit material material which can replaced metallic antenna. Researchers had investigated that zamzam water has higher electrical conductivity (1390µS/cm) compared to bottled water (740 µS/cm). Figure 2 show the comparison of water samples properties from Zamzam with two samples of bottled drinking and distilled waters analysed by [23].

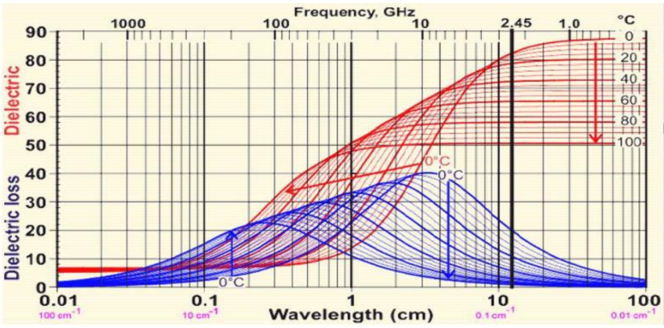


Figure 1. Dielectric permittivity and tangent loss of pure water

Parameter	Zamzam water	Bottled drinking water	Distilled water
Appearance	Clear	Clear	Clear
Odor	Acceptable	Acceptable	Acceptable
Turbidity	Nil	Nil	Nil
Suspended solids	Nil	Nil	Nil
Total dissolved solids	1000	452	—
pH	7.73	7.21	6.85
Conductivity (µS/cm)	1390	740	0.5
Residual chlorine	Nil	0.45	Nil
Total hardness	300	228	0.2
Calcium	220	136	0.1
Magnesium	80	92	0.1
Alkalinity $(CO_3)^{-2}$	Nil	Nil	Nil
Alkalinity $(HCO_3)^{-2}$	110	108	0.2
Chlorides	260	100	0.1
Floride	0.59	0.32	0.1
Sulfates	180	—	Nil
Nitrates	31.6	—	10
Phosphate	0.15	0.13	—
Ammonia	0.11	0.06	Nil
Iron	0.06	0.05	Nil
Copper	0.04	—	—
Silica	37.6	11.3	—

Results in mg/L, NTU (nephlometric turbidity units).

Figure 2. Comparison between Zamzam water bottled drinking water and distilled water parameters study

In this paper, a material of distilled water and zam zam water patch are study and compare when operate at 5 GHz communication applications. The calculated results show that proposed antenna can be achieved reflection coefficient S_{11} less than -10dB over the 4.41-5.52Ghz (around 22.2% bandwidth). Futhermore, in section 2, we describe about the structure of antenna design including of patch design and optimization by using EBG and superstrate. The proposed antenna results and analysis are presented and discussed in section 3. Lastly, the conclusion of this work is state in section 4.

2. PROPOSED DD PATCH ANTENNA ELEMENT

The proposed antenna employs simple rectangular structure that fed with inset feeder surround by electromagnetic bandgap (EBG) structure. EBG always be referred as high impedance surface that increase antenna efficiency by suppressing the unwanted surface wave current. By inserting EBG, helps to improve antenna performance such as backward radiation [24-25]. The antenna is printed on FR-4 dielectric substrate of thickness h = 1.6mm, tangent loss of 0.019 and relative permittivity of ε_r of 4.7. The dimensions of both substrate layers are 26 mm x 34 mm. The four patches of antenna are using the same size and can be calculated using formula below [6]:

Width of the patch, W:

$$W = \frac{c\,[(\varepsilon_r+1)/2)]^{-\frac{1}{2}}}{2fo} \tag{1}$$

The length of the patch:

$$L = \frac{c}{(2f_o\sqrt{\varepsilon_e})} - 2\Delta L \tag{2}$$

where ε and ΔL are ,

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{w}\right]^{-\frac{1}{2}} \tag{3}$$

and,

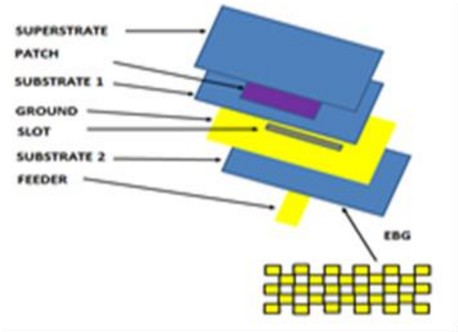
$$\Delta L = 0.412h\left[\frac{\varepsilon_r+0.300)}{\varepsilon_r-0.258}\right]\left[\frac{\frac{W}{h}+0.264)}{\frac{W}{h}+0.800}\right] \tag{4}$$

In this design, superstrate is place on top of the antenna. Patches are placed on top of first substrate, while the bottom of second substrate printed the feedline and Electromagnetic Bandgap (EBG). The ground is sandwiched between both substrates. Both substrates are use is FR-4 with the same relative permittivity tangent loss. The optimization of feedline width is done due to maintain the impedance characteristic of 50Ω.

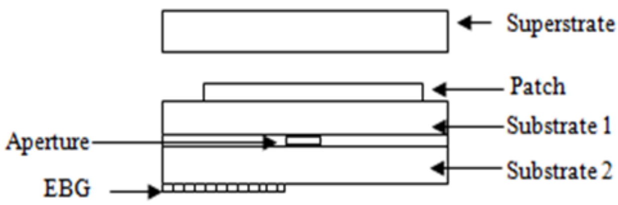
Table 1. Structure of Dielectric Dense (DD) Patch Antenna

Antenna Part	Characteristics
Shape	Rectangular antenna + monopole antenna for inset feed
Superstrate ,Substrate 1 & 2	Material = FR-4, Dielectric Constant, ε_r= 4.7 Tangent Loss, tan σ = 0.019 Thickness, h =1.6mm Size = W_s x L_s = 47.48 x 43 mm (calculated) = 40 mm x 26 mm (optimized)
Frequency of operation	5 GHz
Ground Plate Copper Plate	Material = Copper, Thickness, h = 0.035mm
Distilled water Dielectric Dense Patch	Material = acrylic + distilled water Thickness, h =1.3mm Size = W_s x L_s = 18.26 mm x 13.76 mm (calculated) = 36 mm x 13.7 mm (optimized)
Zamzam water Dielectric Dense Patch (optimize value)	Material = acrylic + zamzam water Thickness, h =1.3mm Size = W_s x L_s = 18.26 mm x 13.76 mm (calculated) = 26 mm x 13.7 mm (optimized)
Inset type	Inset feed
Electromagnetic Bandgap (EBG)	Size = W_{EBG} X L_{EBG} = 1mm x 1mm

The antennas first designed by using distilled water as a patch of antenna which acts as reference design. Then, the distilled water is switched by Zamzam water as patch of antenna. The size been optimize to get good performance of antenna. The antenna structure is as shown in Figure 3. For further gain improvement, a dielectric layer of superstate is applied above the antenna. Meanwhile, for return loss and bandwidth enhancement, EBG is designed at the bottom of antenna. The topology of EBG is as shown in Figure 4. The conductivity parameter of both water is experimentally test by using HI-991300 pH/EC/TDS/^{o}C handheld meter and the complex dielectric permittivity of water-based liquids for both is measured by using Keysight Dielectric Probe 85070E (performance probe). Result for both experimental parameters written in Table 2.



(a)



(b)

Figure 3. (a) General and (b) side view of microstrip distilled water antenna

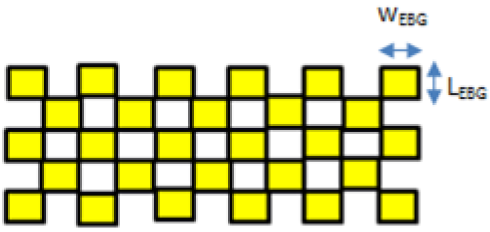


Figure 4. EBG topology

Table 2. Parameters of Distilled water and Zamzam Water

Types of water	Dielectric permittiviy , ε_r	Tangent loss,tan σ
Distilled water	75.81	0.24
Zamzam water	77.61	0.24

3. RESULTS AND ANALYSIS
3.1. Simulation

The antenna is designed by using distilled water patch as initial designed. This designed is simulated by using CST Design Environment and the result of return loss, S_{11} is as shown in Figure 5. The result of S_{11}=-17.18dB at resonance frequency of 5GHz. The patch distilled water antenna then is changed to Zamzam water and the value of return loss S_{11}=-45.6dB for frequency resonant of 5GHz. The operating frequency for Zamzam water patch antenna below -10dB is between 4.41-5.52 GHz (around 22.2%) as shown in Table 3. The proposed antenna is considered as good candicates for 5GHz communication applications.

Table 3. Result performance of distilled and Zamzam water dielectric dense patch antenna

Type of Water	5 GHz	Range Frequency Resonance	Bandwidth
Distilled water	-17.18 dB	a) 4.97 GHz - 5.04Ghz	a) 0.07GHz (1.4%)
		b) 5.83GHz to 5.89Ghz	b) 0.06GHz (1.2%)
Zamzam water	-45.6 dB	a) 4.4 - 5.51Ghz	a) 1.11 GHz (22.2%)
		b) 7.11 to 9.69 Ghz	b) 2.58 GHz (51.6%)

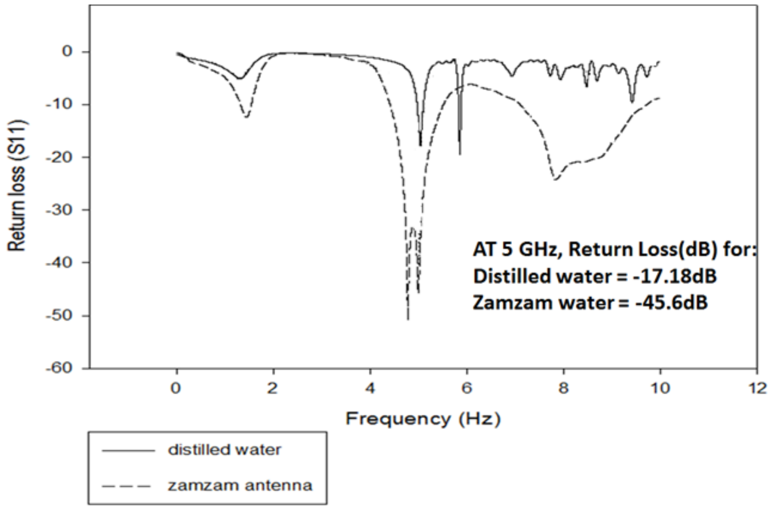


Figure 5. Simulation of Distilled water and Zamzam water patch antenna

Then, the structure is integrated with EBG and surprisingly, EBG can help in order to increase the return loss value. After using EBG the value of S_{11} become = -45.6GHz. Without EBG, the S_{11}= -20.169dB. From the result, it can be conclude by using EBG performance of antenna can be better than without using EBG. The simulation result is shown in Figure 6.

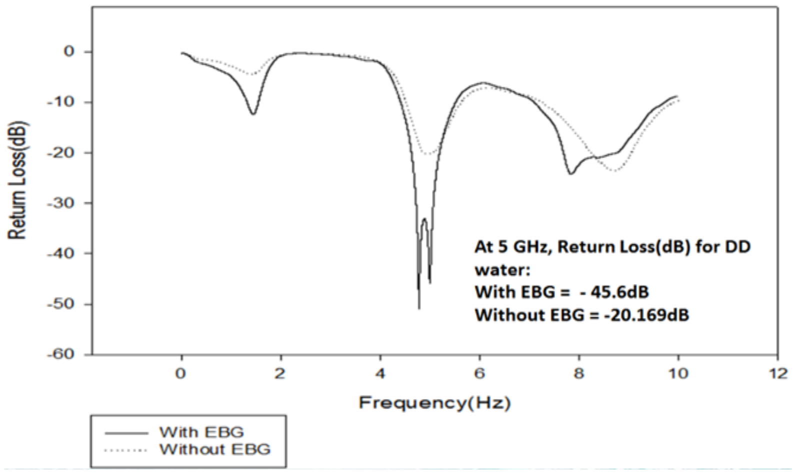


Figure 6. Simulation of with and without EBG for DD water antenna

The antenna then simulated by adding superstrate on the top layer of antenna by the distance of H_s. The Zamzam antenna is simulated in order to investigate the effect of superstrate to that antenna. The simulation with and without superstrate is as shown in Figure 7. Figure 8(a) and (b) show the gain after simulation of Zamzam water which is 1.397dB. Figure 8(c) show the gain in 3D without using superstrate that is -3.008. Therefore, that can be conclude that by applying superstrate the gain is improving. Figure 8(d) show the gain in phi=90^0 for Zamzam water patch antenna that is -5.9dB. By applying EBG can reduce the backlobe reduction by 0.3dBi.

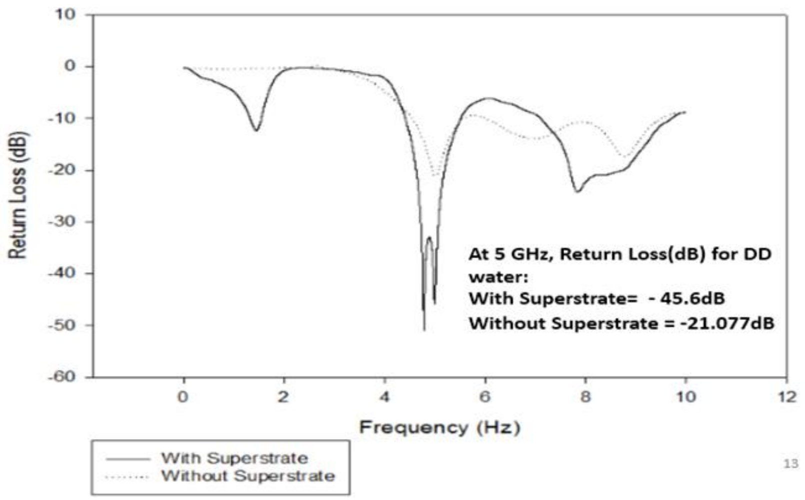
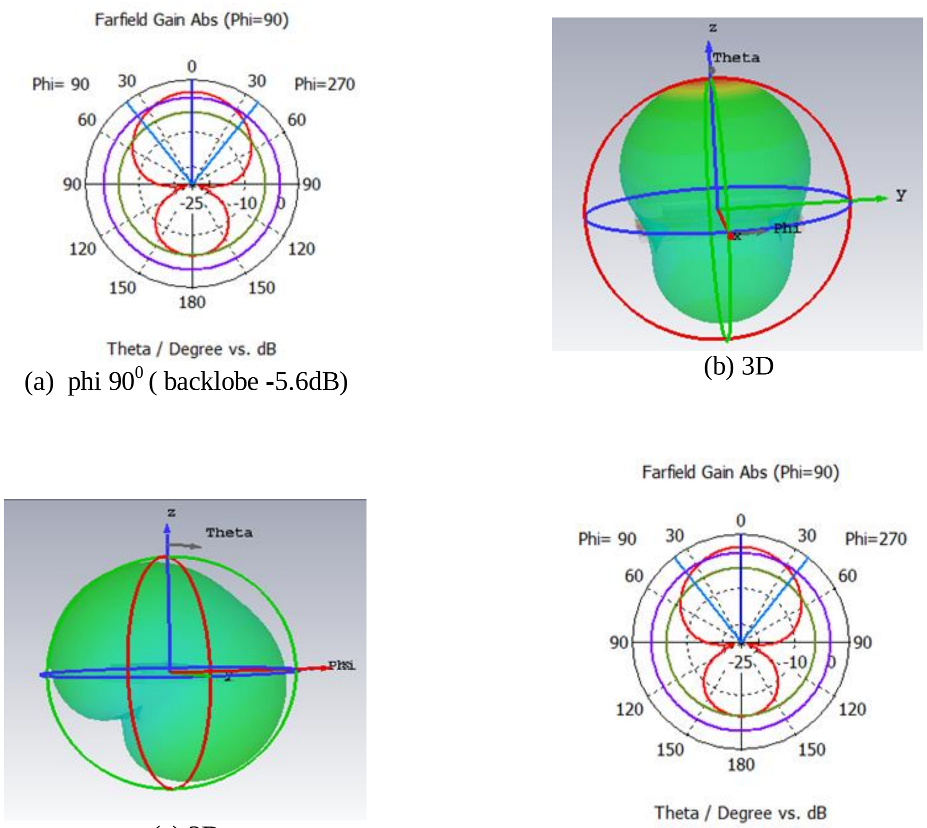


Figure 7. Simulation of with and without superstrate for DD water antenna



(a) phi 90^0 (backlobe -5.6dB)

(b) 3D

(c) 3D

(d) phi 90^0 (backlobe at -5.9dB)

Figure 8. (a) Gain for Zamzam water at phi 90^0, (b) Gain for Zamzam water in 3D, (c) Gain for Zamzam without superstrate in 3D, (d) Gain for Zamzam water without EBG at phi 90^0

3.2. Measurement

Both of structure distilled water and Zamzam water patch antenna are fabricated using FR-4 substrate and measurement process has been carried out. The distilled water patch antenna perform return loss, S_{11} =-16.96dB at 5.01GHz while Zamzam water patch antenna give return loss of -16.52dB at resonance frequency 5.03GHz as shown in Figure 9. This discrepancies is due to problem arises in fabrication process.

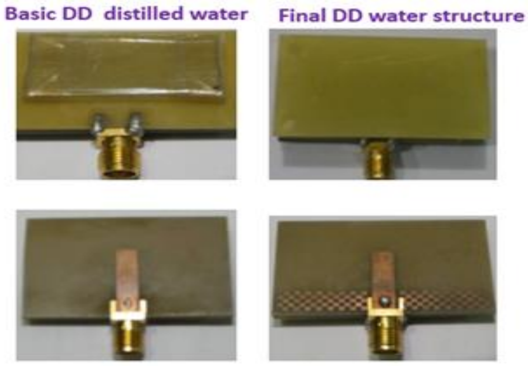


Figure 9. Antenna prototype

4. CONCLUSION

In this paper the DD antenna for wireless communication application was designed. With an overall adjustment, the antenna using zamzam water shows good agreement that can be operated between 4.41-5.52 GHz and 7.1153 to 9.7034 GHz frequency band. The final result shows good good radiation pattern and gain for the DD structure. Due to its light and small size, the antenna can be easily integrated in 5GHz communication applications.

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