A study of distilled water and zamzam water as dielectric 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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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 and high metallic loss [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 HEM₁₁ mode [15]. Other than exciting at the high dielectric material in HEM₁₁ DRmode, researched has been discovered that a TM₁₁ 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](image)

![Figure 2. Comparison between Zamzam water bottled drinking water and distilled water parameters study](image)

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). Furthermore, 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.

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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 εr = 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:

\[ W = \frac{c}{2\pi f_0 \sqrt{\epsilon_r}} \left( \frac{1}{2} \right) \]  

The length of the patch:

\[ L = \frac{c}{2f_0 \sqrt{\epsilon_r}} - 2\Delta L \]  

where \( \epsilon_r \) and \( \Delta L \) are ,

\[ \epsilon_r = \epsilon_{\text{air}} + \frac{1}{2} \left[ 1 + \frac{12h}{w} \right]^{-\frac{1}{2}} \]

and,

\[ \Delta L = 0.412b \left( \frac{w+0.300}{w} \right) \left( \frac{w+0.260}{w} \right) \left( \frac{w+0.800}{w} \right) \]

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, \( \epsilon_r = 4.7 \) |
|                                | Tangent Loss, tan \( \sigma = 0.019 \) |
|                                | Thickness, h = 1.6mm |
|                                | Size = \( W_s \times L_s \) |
|                                | = 47.48 mm 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 = \( W_s \times L_s \) |
|                                | = 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 = \( W_s \times L_s \) |
|                                | = 18.26 mm x 13.76 mm (calculated) |
|                                | = 26 mm x 13.7 mm (optimized) |
| Inset type                    | Inset feed |
| Electromagnetic Bandgap (EBG) | Size = \( W_{\text{EBG}} \times L_{\text{EBG}} \) = 1 mm x 1 mm |
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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 superstrate 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/°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.

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

![Figure 4. EBG topology](image)

| Parameters of Distilled water and Zamzam Water |
|-----------------------------------------------|
| Types of water | Dielectric permittivity , εr | 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 $S_{11}=-17.18$ dB at resonance frequency of 5 GHz. The patch distilled water antenna then is changed to Zamzam water and the value of return loss $S_{11}=-45.6$ dB for frequency resonant of 5 GHz. The operating frequency for Zamzam water patch antenna below -10 dB is between 4.41-5.52 GHz (around 22.2%) as shown in Table 3. The proposed antenna is considered as good candidates for 5 GHz communication applications.

![Table 3. Result performance of distilled and Zamzam water dielectric dense patch antenna](image)

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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 $-45.6\, \text{GHz}$. Without EBG, the $S_{11} = -20.169\, \text{dB}$. 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.

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 $1.397\, \text{dB}$. 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=$90^\circ$ for Zamzam water patch antenna that is $-5.9\, \text{dB}$. By applying EBG can reduce the backlobe reduction by 0.3dB.
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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, $S_{11} = -16.96$dB 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 7. Simulation of with and without superstrate for DD water antenna

Figure 8. (a) Gain for Zamzam water at phi 90°, (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°
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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REFERENCES

[1] R. Garg, et al., “Microstrip Antenna Design Handbook,” London, Artech House Boston, 2001.
[2] A. Kuruvilja, “The Design and Analysis of Microstrip Patch Antenna for Smart Connectors,” Utah State University, 2003.
[3] C. A. Balanis, “Antenna Theory-Analysis and Design,” 3rd ed., John Willey & Son, Inc, USA, 2005.
[4] K. L. Wong, “Compact and Broadband Microstrip Antennas,” Jon Wiley & Sons, Inc., 2002.
[5] J. R. James, et al., “Microstrip Antenna Theory and Design,” Peter Periginus, London, 1981.
[6] S. A. Long, et al., “The resonant cylindrical dielectric cavity antenna,” IEEE Transactions on Antennas and Propagation, vol. 31, pp. 406-412, May 1983.
[7] A. A. Kishk, et al., “Accurate prediction of radiation patterns of dielectric resonator antennas,” Electron. Lett. vol. 23, pp. 1374.
[8] A. A. Kishk, et al., “Broadband stacked dielectric resonator antennas,” Electron. Lett. vol. 25, pp. 1232-1233, 1989.
[9] K. W. Leung, et al., “Input impedance of aperture coupled hemispherical dielectric resonator antenna,” Electron. Lett., vol. 27, pp. 2259-2260, 1991.
[10] R. K. Mongia, et al., “Measurements of radiation efficiency of dielectric resonator antennas,” IEEE Microw. Guided Wave Lett, vol. 4, pp. 80-82, Mar 1994.
[11] A. Petosa, et al., “Magnetically tunable ferrite resonator antenna,” Electron. Lett., vol. 30, pp. 1021-1022, 1994.
[12] K. W. Leung, et al., “Characteristics of a low-profile circular disk DR antenna with very high permittivity,” Electron. Lett, vol. 31, pp. 417-418, 1995.
[13] K. W. Leung, et al., “Lowprofile circular disk DR antenna of very high permittivity excited by a microstrip line,” Electron. Lett., vol. 33, pp. 1004-1005, 1997.
[14] M. T. K. Tam and R. D. Murch, “Half volume dielectric resonator antenna designs,” IEEE Electron. Lett., vol. 33, pp. 1914-1916, 1997.
[15] A. A. Kishk, et al., “A numerical study of a dielectric disk antenna above grounded dielectric substrate,” IEEE Trans.Antennas Propag., vol. 41, pp. 813-821, Jun 1993.
[16] H. W. Lai, et al., “Dense Dielectric Patch Antenna – A new kind of Low Profile Antenna Element for Wireless Communications,” IEEE Trans. Antennas Propag., vol. AP-61, pp. 4239-4245, Aug 2013.
[17] S. G. o’Keefe and S. P. Kingsley, “Tunability of liquid dielectric resonator antennas,” IEEE Antennas Wireless Propag. Lett., vol. 6, pp. 533-536, 2007.
[18] O. M. Haraz, et al., “New dense dielectric patch array antenna for future 5G short-range communications,” Proceedings - ANTEM 2014: 2014 16th International Symposium on Antenna Technology and Applied Electromagnetics, 2014.
[19] Q. Lai, et al., “Comparison of the radiation efficiency for the dielectric resonator antenna and the microstrip antenna at Ka band,” IEEE Trans. Antenna Propag., vol. 56, pp. 3589-3592, Nov 2008.
[20] A. Technologies, et al., “Study and Design of a 2 × 2 Water Dielectric Patch Antenna Array for Wi - Fi Application,” vol. 62, pp. 5968-5973.
[21] Y. Li and K. M. Luk, “A transparent water dielectric patch antenna,” Proceedings of the 2015 IEEE 4th Asia-Pacific Conference on Antennas and Propagation, APCAP 2015, vol. 2, pp. 319-320, 2016.
[22] J. Sun and K. M. Luk, “Design of 4×4 aperture-coupled water patch antenna array,” TENCON 2015 - 2015 IEEE Region 10 Conference, pp. 1-3, 2015.
[23] S. H. Fatani and A. T. Babakr, “Effect Of Water Intake Pattern on Serum Mineral and Electrolyte Levels in Makkah People,” vol. 1, pp. 442-456, 2014.
[24] A. K. Gupta and P. K. Singhal, “Microstrip antenna Parameters Improvement Using EBG Structure,” in International Journal of research in engineering & Technology (IJERT), vol. 11, pp. 35-40, Aug 2013.
[25] P. Vats and D. Dabas, “Design analysis of Patch antenna without EBG and with cross-shape EBG and Analyse the Effect of Different Feed Position,” in International Journal of Engineering Trends and Technology (IJETT), vol. 7, pp. 3086-3089, 2013.

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