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The Effect of Magneto Dielectric Material to the Performance of Rectangular Microstrip Patch Antenna

Jude Blaise Ramek[1], See Khee Yee[1]*

[1] Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA.

*Corresponding Author Designation

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Abstract: In moving toward to fifth generation (5G) network, many antennas are using magneto dielectric material as their substrate to fulfilled a demand of small, high performance and wideband antennas. However, the effect of the magneto dielectric material properties to the performance of the antenna are unknown. Therefore, in this research intends to investigate the effect of dielectric constant, electric loss tangent, relative permeability and magnetic loss tangent to the performance of rectangular microstrip patch antenna. The value of each property is varied so that the performance of the antenna such as return loss, gain, directivity, radiation pattern and bandwidth at 3.5 GHz can be analyzed. The simulated result is analyzed by using CST Microwave Studio software. Based on the simulation results, it is found that the antenna with higher dielectric constant value substrate is good for antenna miniaturization but it lowers down the gain, bandwidth and directivity of the antenna. While, as the relative permeability of the substrate is getting higher, it is difficult to optimize the dimension of the antenna in order to achieve resonance at 3.5 GHz. The size of the antenna also getting bigger. Besides that, it is also observed that electric and magnetic loss tangent of the substrate is proportional to the directivity of the antenna, however, it narrows the bandwidth and gain of the antenna. The outcome from the analysis has provided a guideline for antenna design using magneto dielectric material. The desired performance can be achieved by choosing suitable substrate material. For future work, the simulations should be carried out at smaller step size and wider range. Besides that, the thickness of the substrate can be varied and the performance can be analyzed.

Keywords: 5G Network, Magneto Dielectric, Microstrip Patch Antenna

1. Introduction

One of the challenging issues in microwave engineering is to design compact, high performance and wideband antennas. Among the techniques which are applied for antenna compactness, it is found

**Corresponding author: skyee@uthm.edu.my*

that magneto dielectric material is adequate for antenna miniaturization and bandwidth enhancement [1]-[2].

In moving toward to fifth generation (5G) network, many studies have been conducted on microstrip patch antennas that are using magneto dielectric substrate because of their compactness, cheap and fast manufacturing [3]-[5]. Magneto dielectric material is commonly used for antenna miniaturization because it has higher permeability than the conventional dielectric substrate (FR-4, Rogers, Duroid, Taconic board, and others) [6]. It is also used for bandwidth enhancement and efficiency [7]. According to Reza Karimian et. al, they had achieved a 75 % reduction in the term of size in their design of a low Specific Absorption Rate (SAR) coplanar waveguide (CPW) antenna using magneto dielectric artificial magnetic conductor (MDAMC) [8]. In [9], antenna with magneto dielectric substrate has the radiation efficiency of 89 % and the gain of 6.9 dBi. Meanwhile, the antenna with conventional substrate has the radiation efficiency of 83.27 % and the gain of 5.23 dBi. Although magneto dielectric being promising in antenna miniaturization, bandwidth enhancement, and improved efficiency, further research and development in the material must be conducted to make it practically applicable in modern day electronics.

Therefore, in this paper, a rectangular microstrip patch antenna operating at 3.5GHz will be designed using CST Microwave Studio. This frequency is selected as it is the 5G operating frequency in Malaysia. Next, the substrate dielectric properties will be changed, and their performance will be analyzed.

2. Materials and Methods

2.1 Antenna Design Based on Equation

In the first stage of simulation, a conventional dielectric material, FR-4 is used as antenna substrate. The dimension and properties of FR-4 is tabulated in Table 1. A rectangular patch of copper is pasted at top of the FR-4 substrate layer. The ground plane of the antenna is fully covered by copper. The patch is fed by a 50 Ω microstrip line as shown in Figure 1.

The resonant frequency (f_r) for the rectangular patch is fixed at 3.5 GHz to comply with Malaysian 5G operating frequency. The geometry of the antenna is shown in Figure 1.

Table 1: FR-4 Dimension and Dielectric Properties

FR-4 Parameters	Values
Dielectric constant (ε_r)	4.3
Substrate height (mm)	1.6
Relative permeability (μ)	1
Dimension (mm)	36 x 30

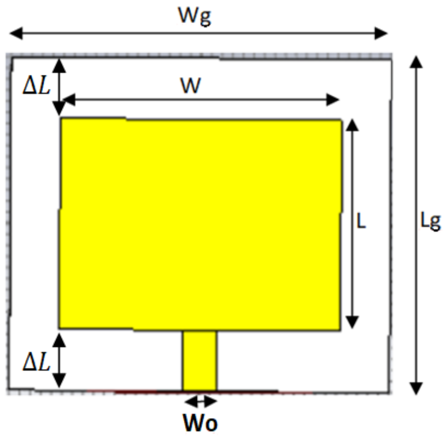

Figure 1: Antenna geometry

After choosing the substrate material and resonance frequency, the dimensions of the patch were designed using the approximation Eq. 1 to Eq.5 [10].

Length, L

$$L = L_{eff} - 2\Delta L \qquad \text{Eq.1}$$

where:

ΔL the length of the extension.

L is length of the patch.

The effective length, L_{eff}

$$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{reff}}} \qquad \text{Eq.2}$$

where:

C is the speed of light in free space.

f is resonance frequency.

ε_{reff} is the effective dielectric constant.

The effective dielectric constant, ε_{reff}

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^2 \qquad \text{Eq.3}$$

where:

h is height of substrate in mm.

W is width of the antenna patch in mm.

ε_r is dielectric constant.

Effective length will be subtracted with the length of the extension to get the actual length of the patch. The length of the extension equation is shown in Eq.4 and Eq.5 below.

$$\frac{\Delta L}{h} = 0.412\,\frac{[\varepsilon_{reff}+0.3][\frac{W}{h}+0.264]}{[\varepsilon_{reff}-0.258][\frac{W}{h}+0.8]} \qquad \text{Eq.4}$$

Antenna patch width ,W

$$W = \frac{c\sqrt{2}}{2f\sqrt{\varepsilon_r+1}} \qquad \text{Eq.5}$$

To ensure the impedance of the antenna is matching (50 Ω), the width of the antenna microstrip line is determined using Eq.6.

$$Zo = \frac{120\pi}{\sqrt{\varepsilon_{reff}}}\left[\frac{W_o}{h} + 1.393 + 0.667\ln(\frac{W_0}{h} + 1.444)\right] \qquad \text{Eq.6}$$

where:

-W_o is the width of microstrip line

Table 2 shows the parameter of the rectangular microstrip patch antenna to achieve its resonance frequency of 3.5 GHz. The substrate size is 36 x 30 mm², and the distance from the patch to the substrate edge is three times substrate thickness. The patch parameters and microstrip line width, Wo are calculated using the equation

Table 2: The parameters of the rectangular microstrip patch antenna

Parameters	Values (mm)
Ground plane width, Wg	36
Ground plane length, Lg	30
Patch width, W	26.31
Patch length, L	19.48
Microstrip line width, Wo	3.14
Trace thickness	0.035

2.2 Parametric Study of the Substrate Dielectric Properties

Table 3 shows the parameters of the simulation to study the effect of each dielectric property to the performance of the antenna. The return loss, gain, radiation pattern, and directivity of rectangular patch antenna with different substrate properties are observed

Table 3: The Parameters of Simulation

Simulation	Dielectric constant, ε_r	Relative permeability, μ_r	Electric loss tangent, tan δ_e	Magnetic loss tangent, tan δ_m
1	1-10(step size 1)	1	0	0
2	1	1-10(step size 1)	0	0
3	1	1	0-0.1	0
4	1	1	(step size 0.02)	0-0.1
			0	(step size 0.02)

3. Results and Discussion

The entire antenna in this simulation resonates at the same frequency which is at 3.504 GHz

3.1 Performance of the Antenna When Using FR-4 Substrate

Table 4 shows the return loss, bandwidth, gain, and directivity of the antenna that using FR-4 as a substrate. The antenna with FR-4 substrate resulted in low gain and low bandwidth antenna.

Table 4: Summary of the return loss, bandwidth, gain, and directivity result for antenna using FR-4 substrate

ε_r	μ_r	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)	Area of patch (mm^2)
4.3	1	-11.586	222.87	3.372	5.510	512.52

3.2 Effect of Dielectric Constant to the Performance of the Antenna

The effects of the bandwidth, gain, directivity, and area of antenna due to the varying of dielectric constant are summarized in Table 5. Increasing the relative permittivity value does help on antenna miniaturization but it also decreases the gain and bandwidth of the antenna. The antenna gain dropped down from 7.006 dBi to 3.950 dBi with average decrement of 0.187 dBi. While, The graph shows a constant decrease of directivity from 7.156 dBi to 4.434 dBi when ε_r = 1 until ε_r = 10 with average decrement of 0.302 dBi. The return loss of the antenna also higher and this will cause reflection in the signal.

Table 5: Summary of the return loss, bandwidth, gain, and directivity result for the changes of dielectric constant value at antenna substrate

ε_r	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)	Area of patch (mm²)
1	-5.779	495.3	7.006	7.156	1713.54
2	-5.771	444.9	5.444	6.534	1010.63
3	-7.059	347.9	5.056	5.956	715.82
4	-7.974	301.3	4.740	5.573	553.72
5	-8.618	278.1	4.531	5.280	450.09
6	-8.784	274.2	4.373	5.039	378.37
7	-8.123	305.2	4.254	4.878	326.50
8	-7.751	313.0	4.136	4.709	286.70
9	-7.189	332.3	4.036	4.562	255.27
10	-6.645	355.6	3.950	4.434	230.08

3.3 Effect of Relative Permeability to the Performance of the Antenna

Refer from Table 6, improving the relative permeability value does not help much in the antenna performance because the result shows an inconsistent changed at return loss, gain, directivity and radiation pattern. As the value of relative permeability is higher, it isn't easy to find a perfect patch dimension to make the antenna resonate at the desired frequency. When the value of relative permeability is higher than relative permittivity, it does not have specific formula to calculate the patch dimension. When the relative permeability value is higher than 3, it start to narrow the bandwidth of the antenna.

Table 6: Summary of the return loss, bandwidth, gain and directivity result for the changes of relative permeability value at antenna substrate

μ_r	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)	Area of patch (mm²)
1	-5.779	495.3	7.006	7.156	1713.54
2	-4.220	1491	5.377	6.856	1087.06
3	-25.431	39.101	4.472	5.727	1150
4	-14.615	133	5.506	6.268	1012.5
5	-12.384	89.932	3.871	4.611	1690
6	-9.801	208.21	4.452	5.214	1374.3
7	-12.573	132.94	3.664	4.696	1131.9
8	-35.149	15.64	3.559	4.982	950.4
9	-30.025	31.281	5.696	7.885	1875.2
10	-24.185	39.1	2.668	5.782	3010.5

Figure 2 and Figure 3 show the result of simulated gain radiation pattern when μ_r value is 1 to 10. The gain radiation pattern of the antenna keep changing as the value of relative permeability is higher. Only when μ_r = 6 and μ_r = 7 have the same radiation pattern with not much different between main lobe magnitude. When μ_r = 6, the main lobe magnitude of the antenna is 3.629 dBi. While when μ_r = 7, the main lobe magnitude of the antenna is 2.867 dBi. The lowest main lobe magnitude in this simulation is when μ_r = 5 with 0.103 dBi and the highest value of main lobe magnitude is when μ_r = 6.

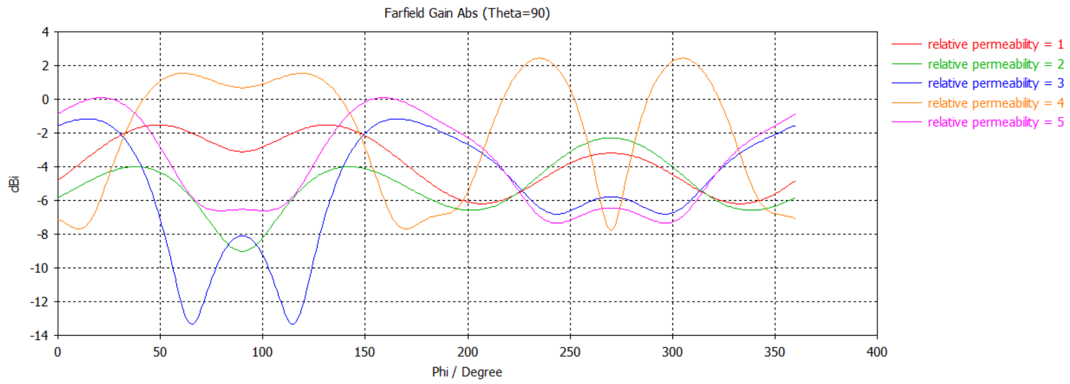

Figure 2: Simulated gain radiation pattern when μ_r value is 1 to 5

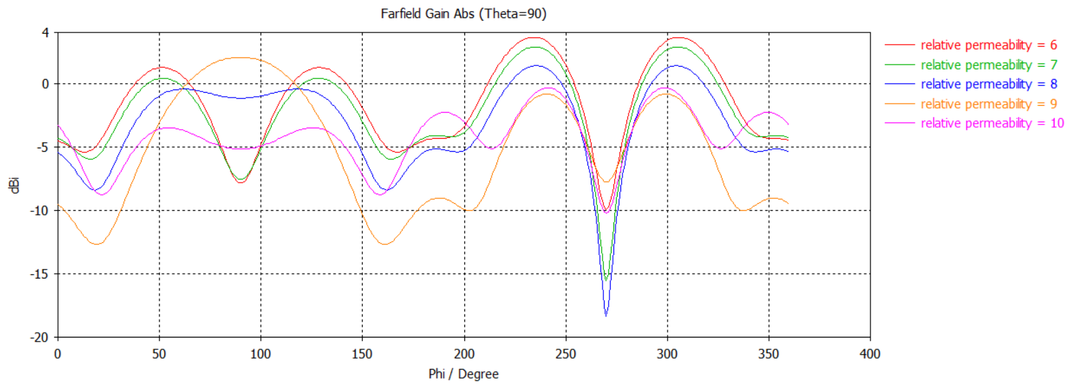

Figure 3: Simulated gain radiation pattern when μ_r value is 6 to 10

3.4 Effect of Electric Loss Tangent to the Performance of the Antenna

As shown in Table 7, increasing the electric loss tangent value makes the antenna bandwidth narrower. There are not many changes in the area of the patch of the antenna. It does improve the directivity and return loss of the antenna. Lower return loss means more power into the antenna and less reflection. Increasing the value of the electric loss tangent also reduces the percentage of radiation efficiency of the antenna.

Table 7: Summary of the return loss, bandwidth, gain and directivity result for the changes of electric loss tangent value at antenna substrate

tan δ_e	Return loss (dB)	Bandwidth (MHz)	Gain (dB)	Directivity (dB)	Area of patch (mm²)
0	-5.779	495.3	7.006	7.156	1713.5
0.02	-6.023	495.3	7.069	9.723	1713.5
0.04	-8.644	351.8	5.627	9.724	1712.7
0.06	-11.614	254.2	4.503	9.715	1711.8
0.08	-15.223	187.7	3.588	9.699	1708
0.1	-19.758	125.1	2.818	9.675	1705.8

3.5 Effect of Magnetic Loss Tangent to the Performance of the Antenna

As shown in Table 8, the change of magnetic loss tangent value at antenna substrate has affected the gain and bandwidth of the antenna. As the value of magnetic loss tangent is higher, the result of bandwidth and gain of the antenna is dropped. The return loss of the antenna decreases as the value of magnetic loss tangent is higher. It's also effect the radiation efficiency of the antenna from 97 % when tan δ_m = 0 to 20 % when tan δ_m = 0.1. However, it does improve the directivity and return loss of the antenna.

Table 8: Summary of the return loss, bandwidth, gain and directivity result for the changes of magnetic loss tangent value at antenna substrate

tan δ_m	Return loss (dB)	Bandwidth (MHz)	Gain (dB)	Directivity (dB)	Area of patch (mm²)
0	-5.779	495.3	7.006	7.156	1713.5
0.02	-6.203	472	6.943	9.723	1713.5
0.04	-9.146	332.4	5.406	9.722	1713.5
0.06	-12.389	230.7	4.295	9.712	1711.8
0.08	-16.659	160.3	3.343	9.694	1709.3
0.1	-22.209	93.84	2.571	9.664	1706.7

4. Conclusion

In this research, the effect material properties to the performance of the antenna has been presented successfully. A rectangular microstrip patch antenna is used in this research because it is a basic antenna and easy to design. The different properties range of the magneto dielectric substrate has been designed and simulated where the substrate thickness is fixed at 1.6 mm and the resonant frequency is 3.504 GHz.

The antenna with higher dielectric constant value is good for antenna miniaturization but it also lowers the gain, bandwidth and directivity of the antenna. The relationship between the relative permeability and the antenna performance is not consistence and it not easy to find a perfect patch dimension to make the antenna resonate at the desired frequency. Apart from that, the radiation pattern of the antenna is completely changed when the relative permeability is higher than 2. On the other hand, by increasing the electric loss tangent and magnetic loss tangent of substrate has reduced the bandwidth and gain of the antenna. Besides that, the radiation efficiency of the antenna decreases as low as 20 % when electric and magnetic loss tangent is 0.1. The return loss amplitude also decreases as the electric and magnetic loss tangent increase. However, increase the value of electric and magnetic loss tangent does help to increase the directivity of the antenna.

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References

[1] K. Min and T. V. Hong, "Miniaturization of Antenna Using Magneto-Dielectric Materials," 2006 Asia-Pacific Conference on Communications, 2006, pp. 1-5, doi: 10.1109/APCC.2006.255884.

[2] E. Andreou, T. Zervos, A. A. Alexandridis and G. Fikioris, "Magnetodielectric Materials in Antenna Design: Exploring the Potentials for Reconfigurability," in IEEE Antennas and Propagation Magazine, vol. 61, no. 1, pp. 29-40, Feb. 2019, doi: 10.1109/MAP.2018.2883029.

[3] R. K. Goyal and U. Shankar Modani, "A Compact Microstrip Patch Antenna at 28 GHz for 5G wireless Applications," 2018 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, India, 2018, pp. 1-2, doi: 10.1109/ICRAIE.2018.8710417.

[4] Sa'don, Siti & Jamaluddin, Mohd haizal & Kamarudin, M.R. & Ahmad, Fauzan. (2019). "A 5G graphene antenna produced by screen printing method". Indonesian Journal of Electrical Engineering and Computer Science. 15. 950-955. 10.11591/ijeecs.v15.i2.pp950-955.

[5] M. A. Summakieh and M. Mokayef, "Single Wideband Microstrip Patch Antenna for 5G Wireless Communication Application", eee, vol. 2, no. 6, pp. 07-08, Jun. 2016.

[6] F. Farzami, K. Forooraghi and M. Norooziarab, "Miniaturization of a Microstrip Antenna Using a Compact and Thin Magneto-Dielectric Substrate," in IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 1540-1542, 2011, doi: 10.1109/LAWP.2011.2181968.

[7] C. Niamien, S. Collardey, A. Sharaiha and K. Mahdjoubi, "Compact Expressions for Efficiency and Bandwidth of Patch Antennas Over Lossy Magneto-Dielectric Materials," in IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 63-66, 2011, doi: 10.1109/LAWP.2011.2107493.

[8] R. Karimian, J. Pourahmadazar, M. Nedil and T. A. Denidni, "On the design of low SAR CPW antenna with magneto dielectric AMC based ground plane," 2016 10th European Conference on Antennas and Propagation (EuCAP), Davos, 2016, pp. 1-5, doi: 10.1109/EuCAP.2016.7481411.

[9] A. Pinsakul and S. Promwong, "Artificial Magneto-Dielectric Metamaterial with Microstrip Antenna for Wireless Applications," 2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2019, pp. 1-4, doi: 10.1109/ICEAST.2019.8802536.

[10] C.A. Balanis, Antenna Theory: Analysis and Design, 3rd ed., John Wiley & Sons, 2005, pp. 816-819.