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PERFORMANCE ANALYSIS OF A RECTANGULAR MICROSTRIP PATCH ANTENNA ON DIFFERENT DIELECTRIC SUBSTRATES

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Abstract

The sizes and weights of various wireless electronic systems (e.g. mobile handsets) have rapidly reduced due to the development of modern integrated circuit technology. A Microstrip antenna (MSA) is well suited for wireless communication due to its light weight, low volume and low profile planar configuration which can be easily conformed to the host surface. However, MSAs suffers from low bandwidth. MSA bandwidth is greatly affected by the dielectric substrate material used in its design. Larger bandwidth can be achieved by using a thicker substrate with a lower dielectric constant value. In this paper, the effect of various dielectric constants on rectangular microstrip patch antenna performance is investigated. By keeping the substrate thickness constant over various dielectric constants, simulations were carried out using MATLAB® and Antenna Magus software. The results show that the dielectric constant effectively determines the performance of MSAs.

Keywords: Microstrip Antennas (MSAs), Dielectric Constant

1.0. INTRODUCTION

With the wide spread proliferation of wireless communication technology in recent years, the demand for compact, low profile and broadband antennas has increased significantly. To meet the requirement, microstrip patch antennas (MPAs) have been proposed. MPAs are widely used in wireless communication applications because of their low profile, lightweight, low cost and compatibility with integrated circuits (Guney and Sirikaya, 2004). However, the conventional MPA has a disadvantage of a narrow bandwidth. There are numerous and well-known methods of increasing bandwidth of this type of antennas, and amongst the most common ways are increasing the thickness of the substrates and using a low dielectric constant substrate material (Dheyab and Hamad, 2011). However, the bandwidth and the size of an antenna are generally mutually conflicting properties, that is, improvement of one of the characteristics normally results in degradation of the other. A thick dielectric substrate having a low dielectric constant is more desirable as it provides better efficiency, larger bandwidth, and better radiation (Indrasen Singh *et al*, 2011).

There are numerous substrates that can be used for the design of MPAs and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$ (Guney and Sirikaya, 2004; Indrasen Singh *et al*, 2011). MPAs radiate primarily because of the fringing fields between the patch edge and the ground plane. The radiation increases with frequency increase and using thicker substrates with lower permittivity, and originates mostly at discontinuities. The dielectric constant is the ratio between the stored amount of electrical energy in a material and to that stored by a vacuum. It is also a measure of the degree to which an electromagnetic wave is slowed down as it travels through the insulating material (Mutiara *et al*, 2011). Dielectrics are used in capacitors to store more electrical charge than vacuum. The lower the dielectric constant is, the better the material works as an insulator, and the better an insulator, the better it resists electrons from being absorbed in the dielectric material, creating less loss (Mutiara *et al*, 2011; Balanis, 1997). Radio frequency (RF) applications are characterized by the need for low dielectric losses, low leakage, and low and uniform dielectric constant accompanied by a low layer count. Choosing a material based on its dielectric constant characteristics and losses usually dominates over other considerations (Dheyab and Hamad, 2011; Mutiara *et al*, 2011). This paper analyses the effect of various dielectric constants in the design of rectangular MPA. A coaxial fed rectangular MPA was designed to operate at a resonant frequency of 2GHz. Simulations were carried out using MATLAB® and Antenna Magus softwares and various antenna characteristics analyzed.

2.0. RECTANGULAR MICROSTRIP PATCH ANTENNA DESIGN

In its most basic form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in Figure 1. The bottom surface of a thin dielectric substrate is completely covered with metallization that serves as a ground plane.

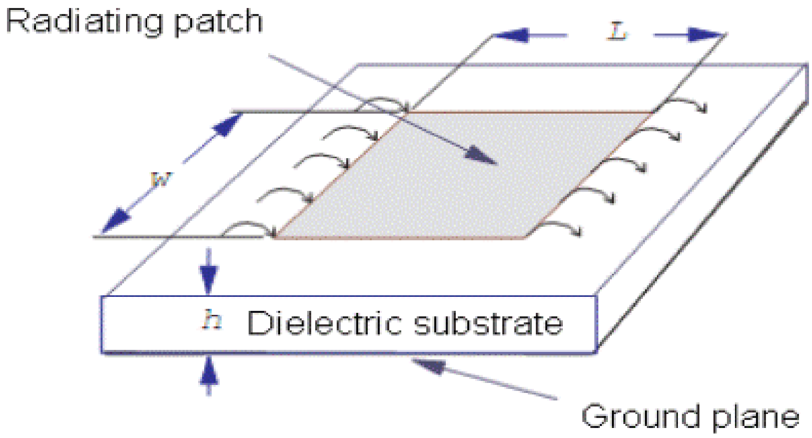

Figure 1: Structure of a Rectangular Microstrip Patch Antenna

The rectangular MSA is made of a rectangular patch with dimensions width (*W*) and length (*L*) over a ground plane with a substrate thickness (*h*) and dielectric constant (ε_r) as shown in Figure 1. There are numerous substrates that can be used for the design of MSAs, and their dielectric constants are usually in the range of $2.2 < \varepsilon r < 12$.
The steps followed in the design of rectangular MSAs as discussed in (K. Guney and N. Sirikaya, 2004; Balanis, 1997; Saeed and Sabira, 2005; Dafalla, 2004) are as follows;

***The Patch Width* (*W*)** for efficient radiation is given as;

$$W = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where, W is the patch width, v_o is the speed of light, f_r is the resonant frequency, and ε_r is the dielectric constant of the substrate

***The Effective Dielectric Constant* (ε_{reff}) -** Due to the fringing and the wave propagation in the field line, an effective dielectric constant (ε_{reff}) must be obtained.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

where, ε_{reff} is the effective dielectric constant, h is the height of the dielectric substrate

***The Effective Length* (L_{eff})** for a given resonance frequency f_r is given as;

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \qquad (3)$$

***The Length Extension* (ΔL)** is given as;

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (4)$$

***The Patch Length* (*L*).** The actual patch length now becomes;

$$L = L_{eff} - 2\Delta L \qquad (5)$$

***The Bandwidth* (*BW*)**

$$BW\% = 3.77\left(\frac{(\varepsilon_r - 1)}{\varepsilon_r^{\,2}}\right)\left(\frac{W}{L}\right)\left(\frac{h}{\lambda_o}\right) * 100\% \qquad (6)$$

where, λ_o is the wavelength in free space.

The Feed Co-ordinates. Using coaxial probe-fed technique, the feed points are calculated as;

$$Y_f = W/2 \qquad (7)$$

$$x_f = \frac{L}{2\sqrt{\varepsilon_{reff}}} \qquad (8)$$

where, y_f and x_f are the feed co-ordinates along the patch width and length respectively

The Plane Ground Dimensions:- It has been shown that MSAs produces good results if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery (Balanis, 1997; Dafalla, 2004).

$$L_g = 6h + L \qquad (9)$$

$$W_g = 6h + W \qquad (10)$$

where, L_g and W_g are the plane ground dimensions along the patch length and width respectively.

3.0. SIMULATION RESULTS AND DISCUSSION

By using MATLAB®, simulation was carried out to generate the values of various rectangular MSA parameters namely patch width, patch length, and feed points. Also, simulation was carried out using Antenna Magus software and the results tabulated and plotted.

As illustrated in (Ahamed Maruf *et.al.*, 2012; Sandu *et.al.,* 2003) the substrate thickness is inversely proportional to dielectric constant with reference to bandwidth. Figure 2 to 5 plots various MPA parameters (Patch Width, Patch Length, and Feed Point) with relation to resonant frequency.

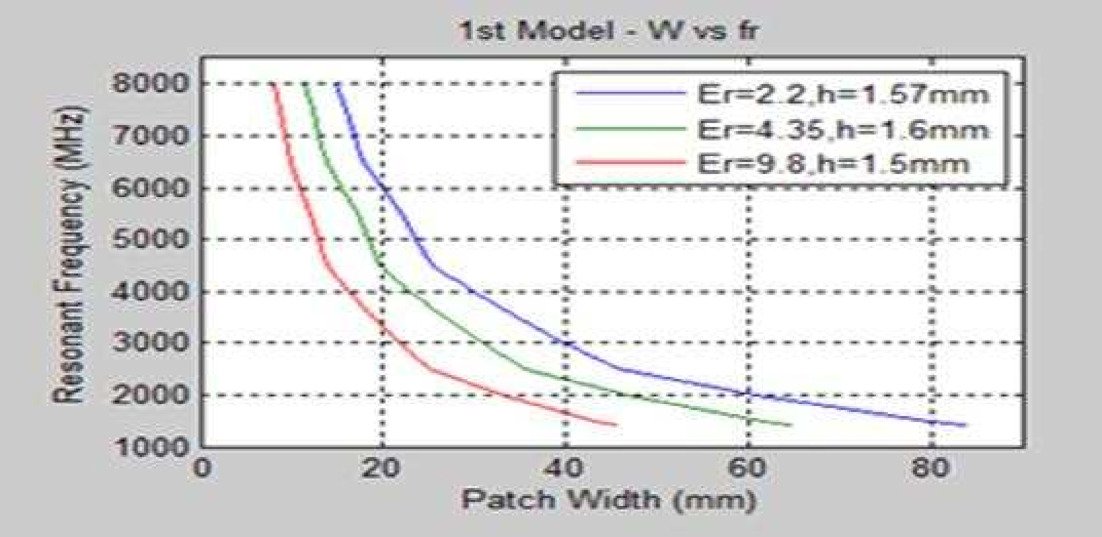

Figure 2: Patch Width vs Resonant Frequency

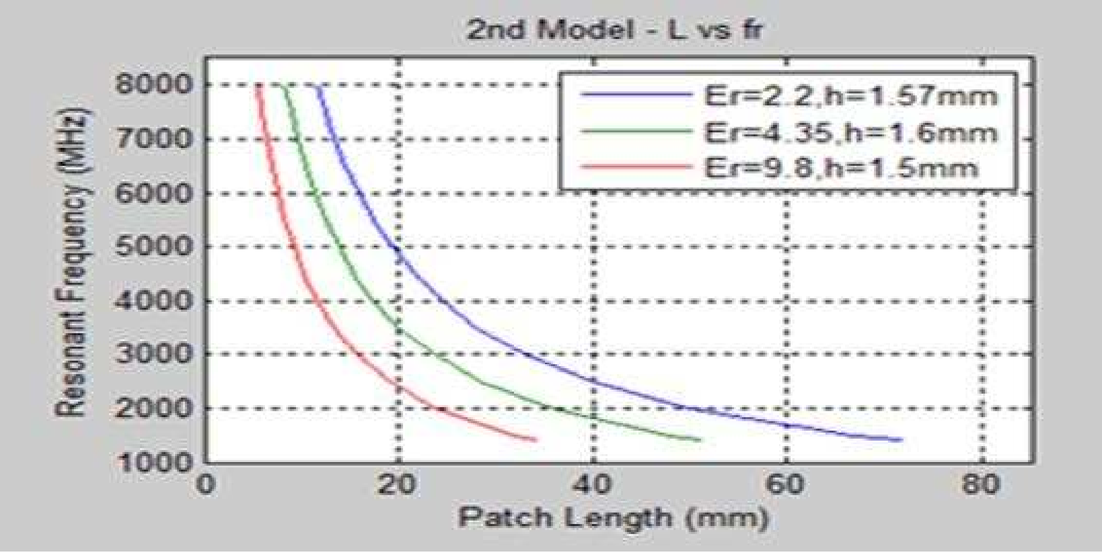

Figure 3: Patch Length vs Resonant Frequency

Figure 4: Feed Point along Patch Width vs Resonant Frequency

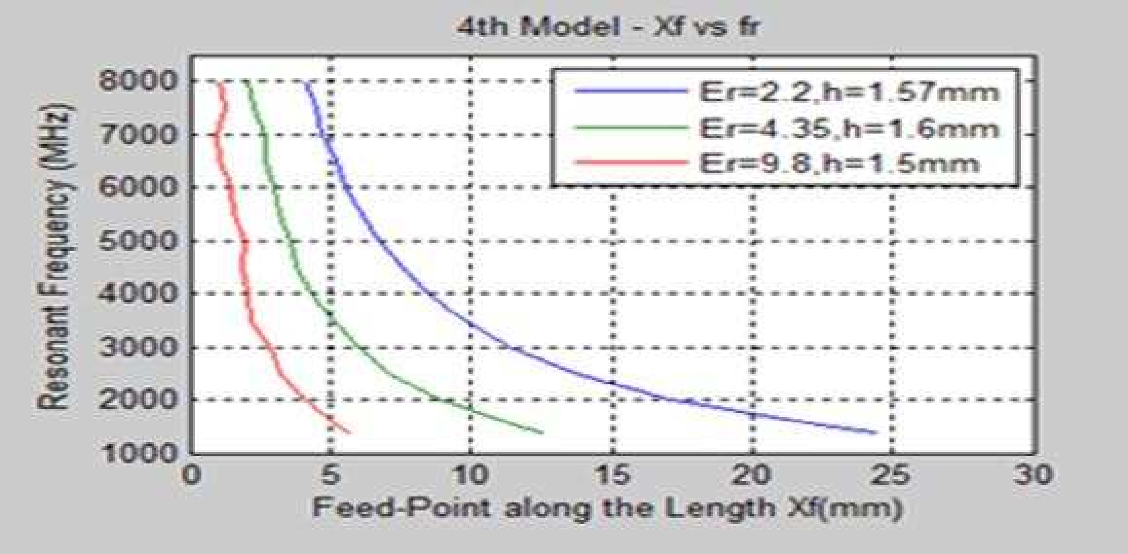

Figure 4: Feed Point along Patch Length vs Resonant Frequency

From Figure 2, it can be clearly seen that the various dielectric substrates produces different parametric values of a patch antenna resulting in varying antenna performance.

Maintain a constant resonant frequency of 2 GHz, simulation was carried out using Antenna Magus software. Table 1 shows the simulated antenna parameters for the three substrate materials namely; Duroid 5880, FR4, and Alumina.

Table 1: Rectangular MPA Design Parameters

Antenna Parameters	**Dielectric Substrates**		
	Duroid 5880	**FR4**	**Alumina**
Resonant Frequency (GHz)	2	2	2
Height (h) (mm)	1.57	1.6	1.5
Dielectric Constant (ε_r)	2.2	4.0	9.8
Patch Width (W) (mm)	59.25	47.40	32.25
Patch Length (L) (mm)	49.27	36.73	23.55
Feed Point along Width (Yf) (mm)	29.63	23.7	16.13
Feed Point along Length (Xf) (mm)	17.03	13.18	9.31
Ground Plane along Width (mm)	118.50	94.81	64.51
Ground Plane along Length (mm)	98.53	73.47	47.10

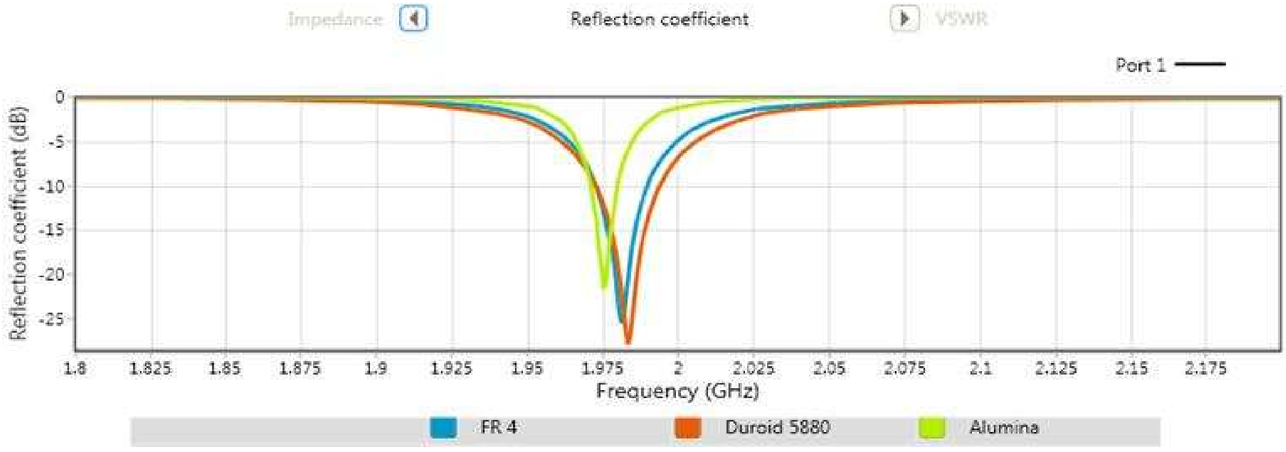

Figure 6: Reflection Coefficient S_{11} for Various Dielectric Substrates

In the process of designing an MPA to perform efficiently there is always a reflection of the power which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio (*VSWR*). As the reflection coefficient ranges from -∞ to 1, the *VSWR* ranges from 1 to ∞. For the practical applications *VSWR* = 2 is acceptable as the return loss would be -9.54dB [10].

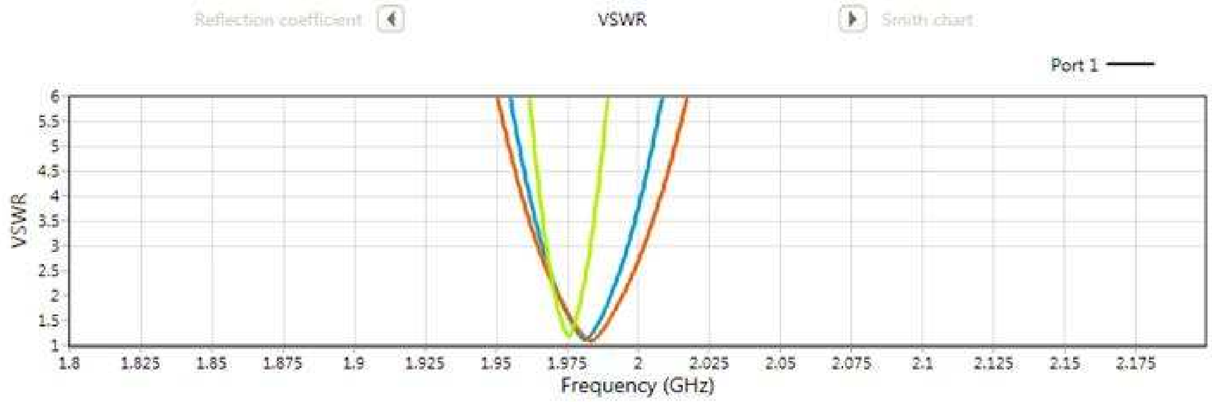

Figure 7: VSWR for Various Dielectric Substrates

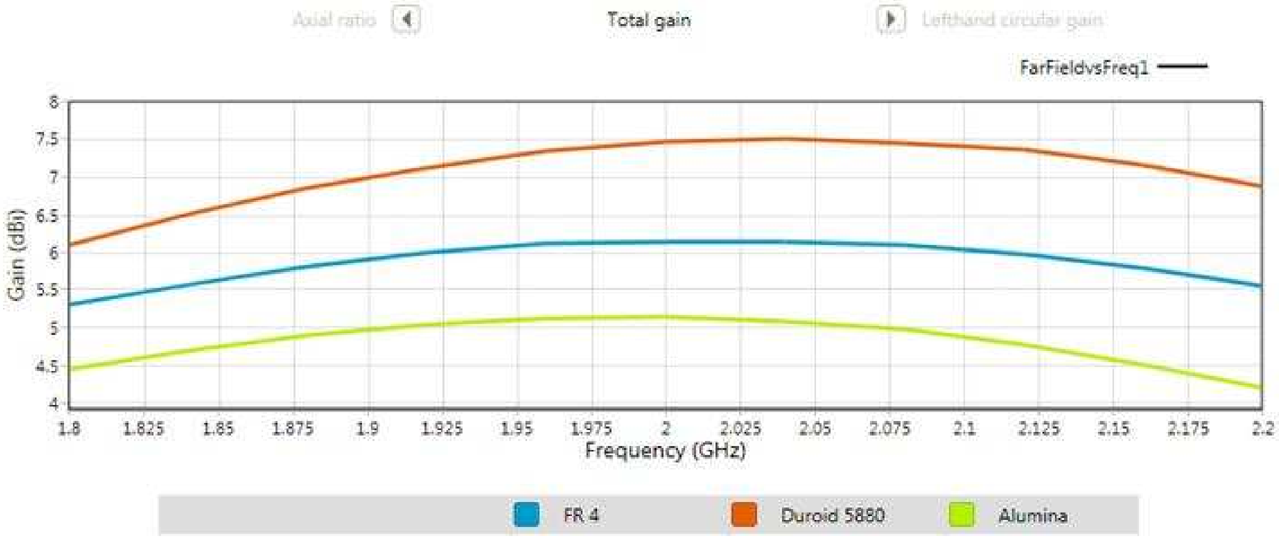

Figure 8: MPA Gain for Various Dielectric Substrates

Figure 8 shows the relationship between the antenna gain and the resonant frequency on three dielectric substrate materials with different dielectric constants and substrate heights. From Figure 8 and Table 2, it can be seen that rectangular MPA designed using Duroid 5880 substrate material produces the highest gain and bandwidth of all the three substrates.

Table 2: Comparison of Rectangular MPA Simulated
Results on different Dielectric Constants

Dielectric Substrates	**Dielectric Constants**	**Gain (dBi)**	**Peak Impedance (Ω)**	**Minimum VSWR Value**	**Reflection Coefficient (dB)**	**Bandwidth where S_{11} = -10dB**
Duroid 5880	2.2	7.50661	49.9053	1.08447	-27.8457	21.52 MHz
FR4	4.0	6.15198	48.7713	1.11310	-25.4292	17.33 MHz
Alumina	9.8	5.14271	45.1252	1.18228	-21.5635	8.73 MHz

4.0. CONCLUSION

From the simulations, it was clearly shown in Table 2 that the higher the value of the dielectric constant, the lower the gain and bandwith. A Maximum of 7.5 dB gain was obtained using Duroid 5880 substrate material which a dielectric constant of 2.2, while a gain of 5.1 dB gain was obtained using Alumina substrate material. The results prove that using a substrate material with a lower dielectric constant in design of MPA leads to better antenna performance. From this paper, it can be clearly seen that substrate material and specifically the dielectric constant effectively determines the performance of a rectangular microstrip patch antenna.

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