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Performance Analysis of Patch Antenna Features Based on Different Substrate Material Properties

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Abstract—**This paper focuses on the performance analysis features of the patch antenna. This antenna is designed by using Flame Retardant 4 (FR4), and Roger 4350 substrate materials that will be operating in Wireless Local Area Network (WLAN). The frequency chosen for this paper is 2.4GHz and it has been chosen from IEEE 802.11 network uses for a Wireless Fidelity (WiFi) network. The proposed antenna was developed using Computer Simulation Technology (CST-MW) software. The proposed FR4 substrate shows a higher antenna bandwidth as compared to a Roger substrate, however the antenna gain and directivity was enhanced with Roger substrate. By using this substrate, the antenna gain was enhanced by 40%.**

Index Terms: **patch antenna, return loss, antenna gain, and antenna substrate.**

I. INTRODUCTION

In modern high-performance communication systems such as spacecraft, satellite, aircraft, and missile application, might need the features of a weight, size, cost, performance, ease of installation, and low-profile antenna properties. The patch antennas have been widely employed for the military and civilian applications such as, broadcast radio, television, mobile systems, radio-frequency identification (RFID), global positioning system (GPS), multiple- input multiple-output (MIMO) systems, vehicle collision avoidance system, direction founding, radar systems, remote sensing, biological imaging, satellite communications, surveillance systems, missile guidance, and so on [1]. They might be used based on these requirements. They are low profile, conformable to planar and non-planar surface, simple and low cost to manufacture by using a modern printed circuit technology. Patch antennas consist of a patch of metallisation on a grounded substrate. These are low-profile, lightweight antennas, most suitable for aerospace and mobile applications. Because of their low power handling capability, these antennas could be used in low-power transmitting and receiving applications [2]. The patch antennas were drawn high impact of the antenna community in recent year. A patch antenna is simple in structure using a microstrip fabrication technique. There are many features that are essential in designing the patch antenna. Dielectric substrate material is the main feature in antenna design purpose. The Wireless Fidelity (WiFi) communication network at 2.4GHz is considered in this paper. The performance analysis of the patch antenna using the Flame Retardant 4 (FR4) and Roger4350 as a dielectric substrate is considered in this paper to enhance overall efficiency of the antenna. Because these materials are most commonly used in fabrication of the antenna.

In the literature, the first concept of the patch antenna was proposed by Deschamps in 1953 [3], and its fabricated was developed in 1970s by Munson and Howell [4]. Up to now, many methods have been published based on dielectric substrate to improve the antenna performance. In recent research, different approaches are used to improve the antenna directivity, they include focusing lens such as capacitively loaded metallic rings (CLRs), that employed under the antenna, which have received a lot of attention because of its ability to create a higher gain compared with the conventional patch antenna[5]. Increasing requirements for personal and mobile communications has made the patch antennas very important [6]. In this paper the performance investigation is achieved by four features, which are directivity, return loss, gain and bandwidth. The purpose of this study was to investigate the potential benefits of the use of different dielectric substrate materials to design a patch antenna at 2.4 GHz. This paper demonstrates, through numerical simulations, (CST-MW- 2019). The patch antenna parameters can be controlled using a different dielectric substrate at 2.4GHz, which is the wireless local area networks operation frequency. Such a design may be advantageous for optimising the patch antenna performance as compared to different substrate materials. In section 2, a patch antenna design concept and its parameters are

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introduced and analysed for a different substrate materials. Section 3 shows the patch antenna design by using math equations and CST-MW simulator. Section 4 discusses the numerical simulation results for a different substrate material of the antenna, the impact of this is discussed.

II. PATCH ANTENNA CONCEPTS AND DESIGN

A. *The antenna concepts*

Figure. 1 illustrates the proposed patch antenna which consists of a radiating patch on one side of a dielectric substrate and has a ground plane on the other side. The patch conductors normally are made of copper or a gold. The radiating patch and feeding lines is usually photo printed at the dielectric substrate [7]. According to Fig.1, where P_L is the length of the patch, P_t is the thickness of the patch, P_W is the width of the patch and P_h is the height of the substrate. To achieve the high performance of the antenna, a thick dielectric substrate is required which has a low dielectric constant. This will provide higher efficiency, larger bandwidth and greater radiation. However, in order to achieve this, larger antenna size might be created. In order to reduce the size of the antenna which means to produce a compact design, a higher dielectric constant which is less efficient and could contribute a narrower bandwidth of the antenna.

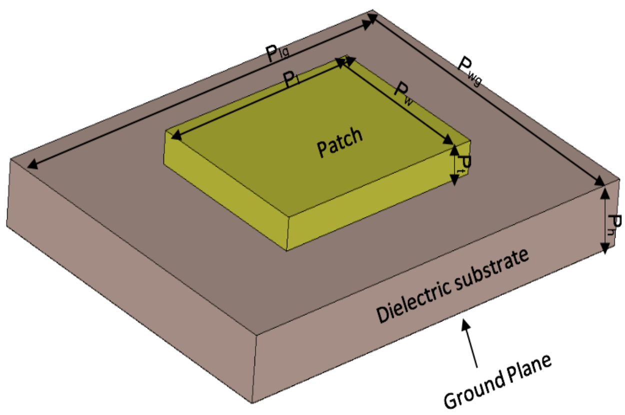

Figure1. The Proposed Patch Antenna

B. *The antenna properties*

The performance of the patch antenna can be characterised by these essential parameters which are: a directivity, gain, bandwidth, and return loss. Directivity can be outlined as the ratio of the power intensity in a given direction from the antenna to the power intensity averaged from all directions. The directivity can be expressed as (1) [8].

$$D = \frac{U_{max}}{U_0} \qquad (1)$$

where U_{max} is the maximum radiation intensity (W/unit solid angle) and U_0 is a radiation intensity of the or an isotropic source (W/unit solid angle). The antenna gain is similar to directivity however it measures considers the efficiency of the antenna and also the directional capabilities. The gain can be calculated by (2) [8].

$$Gain = \frac{power\ intensity}{total\ accepted\ power} \qquad (2)$$

The patch antenna bandwidth is the range of frequencies within the performance of the antenna, with respect to some characteristics. For the narrowband antenna, the bandwidth is expressed as a percentage of the frequency difference over the centre frequency for bandwidth. The bandwidth of the antenna can be determined by (3).

$$Bandwidth = \frac{HF_c - LF_c}{F_0} \qquad (3)$$

where HF_c, LF_c are the higher cut-off and lower cut-off frequencies respectively. F_0 is an operation frequency of the antenna and this frequency is considered to be 2.4GHz in this paper. The reflection coefficient or return loss can be defined by (4) [8].

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \qquad (4)$$

where Z_{in} and Z_o are the input antenna impedance and characteristic impedance, respectively.

III. THEORY AND CALCULATION OF PATCH ANTENNA

In order to design a rectangular patch antenna, there are essential features that are: the operating frequency of the antenna (F_0), dielectric constant of substrate material (ε_r), the height of the patch conductor (P_t), the height of the dielectric substrate (P_h), the patch width (P_W), patch length (P_L), the ground plane and substrate length (P_{Lg}) and width (P_{Wg}). These parameters can be calculated to (5), (10) [9].

$$P_W = \frac{c}{2F_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (5)$$

where the dimensions are in (meter), c is the wave propagation speed in free space equal $3 \times 10^8 m/s$.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{P_h}{P_W}\right)^{-0.5} \qquad (6)$$

$$P_{Leff} = \frac{c}{2F_0\sqrt{\varepsilon_{eff}}} \qquad (7)$$

$$P_L = P_{Leff} - 2dL. \qquad (8)$$

$$dL = 0.412P_h \frac{(\varepsilon_{eff} + 0.3)\left(\frac{P_h}{P_W} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{P_h}{P_W} - 0.8\right)} \qquad (9)$$

$$P_{Lg} = 2P_L, \quad P_{Wg} = 2P_W \qquad (10)$$

where ε_{eff} and P_{Leff} are the effective electrical permittivity and effective patch length respectively. The dL is a length due to fringing effects.

The designed antenna has dimensions, P_{Wg} and P_{Lg} printed on a (P_h) 1.6 mm thick FR4 substrate (εr = 4.3, loss tangent (tanδ) = 0.025) and Roger substrate (εr = 3.48, loss tangent (tanδ) = 0.004). The antenna material was assumed to be copper with no surface roughness and a conductivity of 5×10^7 S/m. The resulting patch width and length (PW = 39mm, PL=27mm), respectively as shown in Fig.2. In this paper, the RF antennas are used as a transmitter and the geometry was designed using computer simulation technology (CST- MW2019) and the antenna is animated by using waveguide port.

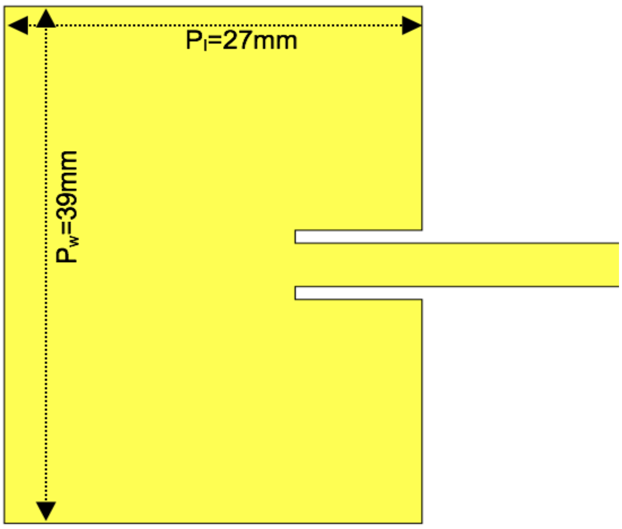

Figure 2. The Patch Conductor of the Antenna.

IV. FULL FIELD SIMULATION RESULTS

A. *Antenna Reflection Coefficient and Bandwidth*

Figure. 3 illustrates the simulated return losses S11 of the patch antenna for WiFi network a resonant frequency of 2.4GHz up to -20dB, and -15dB for FR4 and Roger substrate, respectively. It can be seen that, the S11 is better when the FR4 substrate is used compared to the Roger substrate. In terms of the bandwidth percentage (B_{Wp}), the B_{Wp} of the antenna is 1.89% and 1.67% of the FR4 and Roger substrates, respectively.

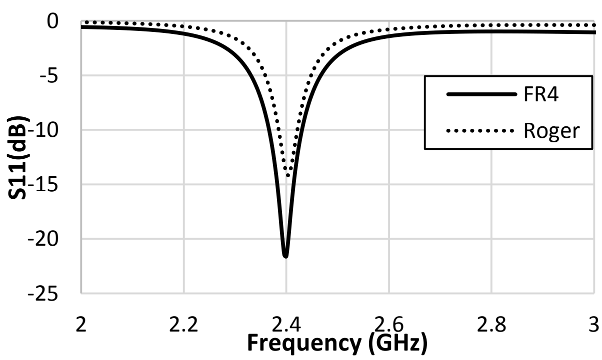

Figure 3. The Patch Antenna Input Matching

B. *Antenna Gain and Directivity*

Figure. 4(a) and (b) illustrates the directivity of the antennas when the FR4 and Roger substrate were employed, respectively. By using the Roger substrate the directivity was improved from 6.88 dBi to 7.41dBi .

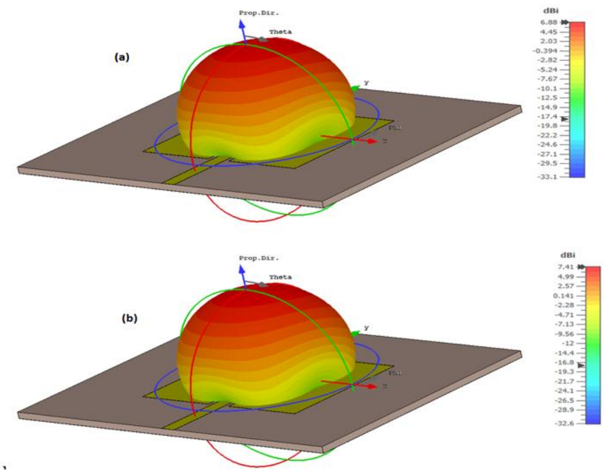

Figure 4. The Patch Antenna Directivity (a) within the FR4, (b) within the Roger.

Figure.5 shows the antennas gain distributing of using the FR4 and the Roger substrates, respectively. It is clear that the gain of the patch antenna with the Roger substrate is higher than the case when the FR4 used.

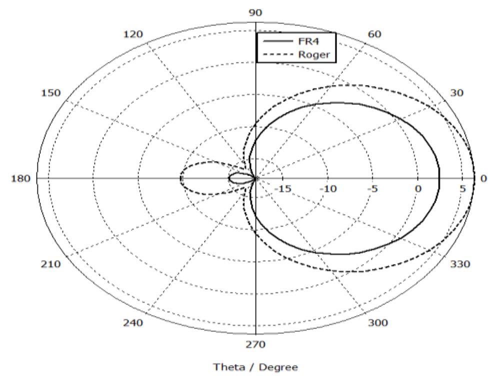

Figure 5.The Antennas Gain for FR4 and Roger Substrates

V. CONCLUSIONS

This paper shows the potential for designing and the simulation results of using two different substrate materials for the patch antenna operating at 2.4GHz. This paper has investigated the reflection coefficient, bandwidth, directivity and gain provided by the patch antenna the FR4 and Roger substrate and the results demonstrate that Roger substrate can improve the gain and directivity when compared to the FR4 case. However, the bandwidth and reflection coefficient for the FR4 case are better than the Roger case. The criterion for selection of right substrate is its price, efficiency and size. In future work we are investigating the passive design for improving the performance of the system for WiFi network at 2.4GHz.

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BIOGRAPHIES

Ismail Masoud Issa received the BSc. degree from University of Omer-Almukhtar, Libya in 2004, MSc degree from University of Technology Mara, Malaysia in 2011 and PhD degree from the University of Sheffield, UK in 2018, all in electrical and electronic engineering. His research interests include antenna design, metasurface and metamaterial structures and their applications in MRI systems. He works as a Lecturer in electrical and electronic engineering department, University of Misurata.