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The Effects Evaluation of Various Dielectric Substrate of Square Patch Antenna on Sar Level for Human Head

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Abstract: A Square Patch Antennas (SPA) are first proposed and simulated. The antennas are designed to operate in L-band at 1.575 GHz for GPS applications. The antenna is the main source of EM radiation, so, the human body tissue can absorb it and cause a health effect. Specific Absorbing Rate (SAR) is the measure of the allowable scale of EM radiation to be produced by communication antenna in wireless device. In this study, SPAs are designed, simulated and then evaluated using CST Software 2014 for various dielectric substrate. Four different substrate materials with different dielectric constant are used in the design and simulation. The proposed antenna has been simulated with PCE material as square patch of length 43 mm and thickness of 0.6 mm. The dimensions of dielectric substrate material are varied. The thickness of dielectric substrate is 1.6 mm. The results show that, the increasing of the value of dielectric constant for the substrate materials will decrease values of the bandwidth, directivity and VSWR. In other side, the SAR levels for both IEEE and FCC standards are increased with increasing of the dielectric constant for substrate materials.

Key words: Square patch antenna, GPS, variable dielectric constant, Specific Absorption Rate (SAR), VSWR, bandwidth

INTRODUCTION

In the last 20 years, high demand to use patch antenna for wireless communication, especially, the GPS applications leads to large efforts to design and manufacture new structures of antenna. Generally, the square patch antenna has many features which made it has the priority in the portable wireless communication applications (Mane *et al*., 2014). Some of these features are light weight not expensive, easy to integration in many commercial transceiver systems and work in circular polarization. Its elements emit efficiently wave as devices on patch PCB. The square patch antenna has been wide used in civil and military applications as result for both their advantages and disadvantages. Sometimes, several of these disadvantages are counted as advantages. One of the disadvantages is the narrow band application which make the antenna operation is acting as filter. The function of the filter is to attenuate unwanted frequencies, so narrow band width is considered as benefit. Various methods have been suggested and implemented to investigate square patch antenna installation with single chip microcomputer (Rakesh *et al*., 2011; Kaur and Goyal, 2016).

The good characteristics of square patch antenna are supported from the combination of electrical and magnetic features for effective dielectric substrate material. Absolutely, the performance of the square patch antenna will be improved according to good selection in type of the dielectric substrate material and the thickness of substrate. In fact, the thickness of the substrate effect on the lower frequency range. The perfect design leads to good performance like wide band width, high efficiency and limited losses for radiation in space but in opposite side that will cause size enlargement (Elrashidi *et al*., 2011). Generally, low relative permittivity, high frequency operation and high substrate thin will produce high radiation.

In addition, cost and power loss play impact factor to choose the substrate material. The dielectric materials have different dielectric constant where the value is varied from 1 to higher than 10. The patch antenna volume is small when the relative permittivity is high. However, high relative permittivity will reduce each of band width and transmission efficiency. It is found that the correct selection of substrate material is a key factor for antenna design methodology (Mane *et al*., 2014; Choudhury, 2014).

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Every year, the World Health Organization (WHO) reports many reports about human health and pollution. These reports confirmed that the wireless devices such as mobile phone are main source of electromagnetic radiation. This device operates at high frequency which has high energy can penetrate the tissue of human body causing health hazard.

Brain tumor, cancer and sister chromatic exchange are diseases resulted from human exposure to high power electromagnetic waves for long time (Baligar *et al*., 2016). Biological organism will absorb the EM and convert it to heat inside the human body. The heat causes temperature rises and thermal effects.

Specific Absorbing Rate (SAR) is introduced by the interaction between the M field and tissue of human beings (Abdulrazzaq and Aziz, 2013). SAR is a term to express amount of power absorbed by human body tissue when the body is exposed to EM waves. Typically, the SAR is set to 1.6 W/kg in a 1gm averaging mass IEEE C95.1:1999 while it described in IEEE C95.1: 2005 to value of 2 W/kg in a 10 gm averaging mass. Indeed, SAR has been limited to 1.6 W/kg specified with respect to 1 g human tissue by (FCC) of USA (Hossain *et al*., 2015). SAR can have expressed mathematically as shown in Eq. 1 (Baligar *et al*., 2016; Abdulrazzaq and Aziz, 2013):

$$SAR = \frac{\sigma_i \ E_2}{\rho_i} \quad (1)$$

Where:

σ_i = Unit of (S/m) is the conductivity of the biological mat erial

ρ_i = Unit of (kg/m^3) is the material density

E = Unit of V/m is the electric field intensity

Literature review: The design of a simple microstrip patch antenna at operating at 60 b GHz for microwave applications was proposed. The design consists of conductive strips on the side of thin dielectric substrate. A patch is wider than strip. The dimension and the shape of the patch are limiting of the main characteristics of the antenna (Rakesh *et al*., 2011).

The discussion to use various dielectric substrate in design of patch antenna is presented improve efficiency of radiator. Theses substrates such as foam, duroid, benzocyclobutane, Roger 4350, epoxy, FR4, Duroid 6010 are used to obtain better gain and bandwidth. Dielectric substrate in origin is insulator which is a main part of the antenna structure. A thicker substrate is the better considered because it has direct proportionality with bandwidth while relative permittivity is inversely proportional to band width. It is necessary to mention the second factor that affect directly which is loss tangent that it shows inverse relation with efficiency. Pros and cons are listed in details of various substrates for perfect selection. A substrate supports mechanical strength to the radiator (Jain and Gupta, 2014). Choudhury (2014) study the variations with respect to change of each of resonant frequency, bandwidth, $|s_{11}|$ (dB) of a microstrip fed rectangular patch antenna by changing substrate thickness and its dielectric constant.

Comprehensive study of different dielectric substrates on characteristics parameters of patch antenna is presented at various frequencies. Antennas are simulated for various frequencies with two different dielectric substrates viz. FR4 and DURIOD. The final comparison is shown by Mane *et al*. (2014). The study by Paul *et al*. (2015) represents that antenna characteristics can be changed by varying each of substrate material and its height. The designed inset feed rectangular microstrip patch antenna works at 2.4 GHz (ISM band) was presented by Paul *et al*. (2015). It is proposed a rectangular patch antenna with parasitic stubs whose end have been removed. The antenna is designed using HFSS. Various substrates have been used to design the antenna like Epoxy-kevlar-xy and FR4-epoxy. The influence of change in dielectric substrate on the characteristics of antenna is discussed in terms of gain, return loss and radiation pattern. It is concluded that antenna characteristics varied when they change dielectric substrate (Kaur and Goyal, 2016; Khan and Nema, 2012).

From the previous studies, we noticed that the use of different substrate materials for design of square patch antenna will lead to obtain different bandwidth, gain and VSWR.

This study presents design of square patch antenna at 1.575 GHz for GPS applications. Four substrates materials are used to compare the characteristics of antenna (gain, BW, VSWR) and to compare the specific absorbing rate SAR for both IEEE and FCC standards.

MATERIALS AND METHODS

Antenna design: The demand for antenna with high performance for modern applications required to search for new method in design and simulation around the word of antenna. Indeed, many software programs are available in the market support us to develop our research. For the purposes above and the development in technology prepare good environment to produce many types of antenna shapes like dipole, square, triangular, rectangular, circular and elliptical. In other hand, the resonant frequency is determined from the resonant length of the antenna (Mane *et al*., 2014).

Basically, the construction of square patch antenna is simple. It contains two parallel conducting plate separated by a thin dielectric substrate material. The upper and lower layer's act as radiator and ground plane, respectively (Rakesh *et al*., 2011). When the ground plane is large, the antenna performance is better but the size will be large. The parameters of the proposed antenna design limit the radiator device operation performance (Kaur and Goyal, 2016).

In our research, the dimensions of the antenna are described in Cartesian coordinate (X-Y) axis. Each one of the four dielectric materials has different dielectric constant to make comparison about antenna's performance like good efficiency, wider bandwidth and higher radiation.

Let, the dimensions of the Patch antenna Width (Wp) and patch Length (L) are calculated from classical Eq. 2 and 4, the width W. is given as Mane *et al*. (2014):

$$w_p = \frac{\nu}{2f_r\sqrt{\frac{\varepsilon_{r+1}}{2}}} \quad (2)$$

Equation 3 is to calculate the thickness of the dielectric substrate (Rakesh *et al*., 2011):

$$hs = \frac{0.3\nu}{2\pi f_r\sqrt{\varepsilon_r}} hs \le 0.06\frac{\lambda d}{\sqrt{\varepsilon_r}} \quad (3)$$

The actual length is obtained using Eq. 4:

$$Lp = L_{eff} - 2\Delta L_p \quad (4)$$

According to Eq. 5 the length extension (Lp)can be determined by:

$$\Delta L_p = 0.412hs\frac{(\varepsilon_{reff}+0.3)\left[\frac{wp}{hs}+0.264\right]}{(\varepsilon_{reff}-0.258)\left[\frac{wp}{hs}+0.8\right]} \quad (5)$$

Effective dielectric constant () is calculated using Eq. 6 (Abd *et al*., 2015):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{hs}{wp}\right]^{-\frac{1}{2}} \quad (6)$$

$$L_{peff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (7)$$

where, L denotes the patch effective length.

Antenna modeling: In this study, square patch antenna has been designed using CST Software 2014. Four dielectric substrate materials are used. The substrate materials are Arlon AD 250, Rogers TMM4, Dupont 951 and Rogers RO 3010. Antennas are operated at resonance frequency of 1.575 GHZ for GPS applications. To calculate antenna dimensions by classical method, some parameters must be available such as: substrate thickness, dielectric constant and thickness of the patch. Table 1 shows modeling of antenna for operating frequency using four substrate materials. Arlon AD 250, Rogers TMM4, DuPont 951 and Rogers RO 3010 have dielectric constant of 2.5, 4.5, 7.8 and 10.2, respectively.

Table 1: Dimensions of the SP\A

Substrate materials/ Dimensions (mm)	Arlo n AD 250 $\varepsilon_r = 2.5$	Roge rs TMM 4 $\varepsilon_r = 4.5$	DuPo nt 951 $\varepsilon_r = 7.8$	Roger s RO 3010 $\varepsilon_r = 10.2$
hs	1.6	1.6	1.6	1.6
Ls, ws	115.0	86.0	65.8	57.5
t	0.6	0.6	0.6	0.6
x	11.5	8.6	6.6	5.2
y	0.0	0.0	0.0	0.0

RESULTS AND DISCUSSION

The square patch antenna is simulated using CST Software 2014 at a frequency 1.575 GHz for GPS applications. The results are divided four parts. Each part has return loss, gain, directivity, VSWR and SAR values for two standards IEEE, ICNIRP for different substrate materials.

The return loss values obtained for different substrate materials with different dielectric constants 2.5, 4.5, 7.8, 10.2 are -15.4, -17, -14.95 and -15 dB, respectively. All the values are having the return loss of <-10 dB as shown in Fig. 1.

In like manner, Fig. 2 shows the radiation pattern 2D gain for proposed antenna with different materials and different dielectric constant values. The maximum gain value obtained for dielectric constants 2.5 is 5.48 dB and the values of gain are decrease gradually with increase the values of dielectric constant. The values of VSWR and directivity for square patch antenna with different substrate materials (AD 250, Rogers TMM4, DuPont 951 and Rogers RO 3010) are in Table 2. All the values of VSWR are <2 at the resonant frequency 1.575 GHz. The maximum directivity values obtained for dielectric constants 2.5, 4.5, 7.8, 10.2 are 7.52, 6.51, 5.63 and 5.11 dBi at azimuth angle 90°.

The SAR value is calculated for head model. The head model consists of three layer (brain, skull and skin) and kept a distance with proposed antenna about 5 mm. Figure 3-6 show the head model with SAR value for different materials with different dielectric substrate. SAR values at 1 g are 0.0725, 0.4, 1.19 W/kg and 1.32

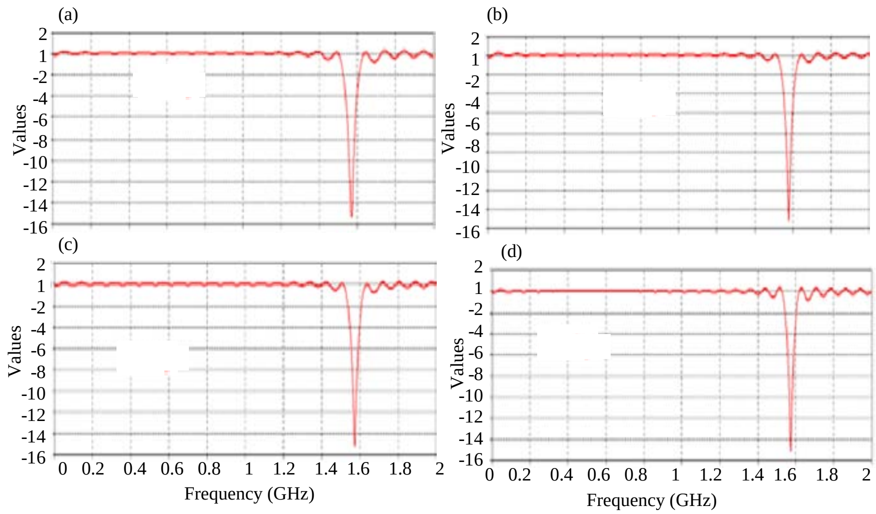

Fig. 1: Return Loss S11: a) Arlon AD250; b) Rogers TMM4; c) DuPont 951 and d) Rogers RO3010

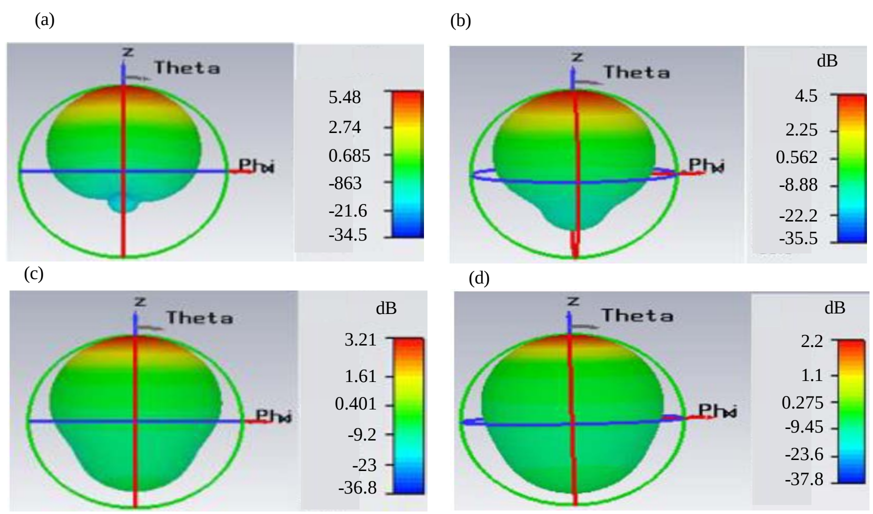

Fig. 2: 3D polar plot of gain: a) Arlon AD250; b) Rogers TMM4; c) DuPont 951 and d) Rogers RO3010

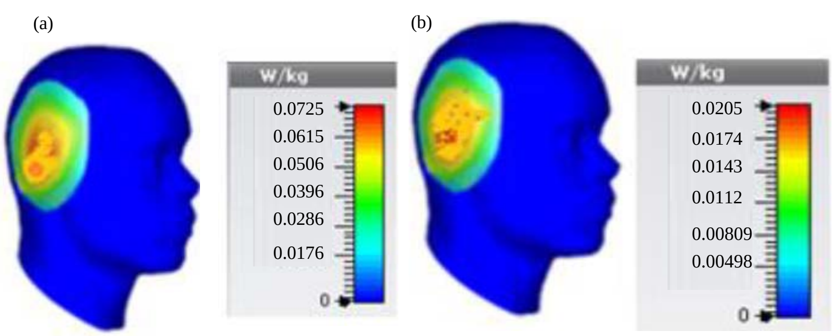

Fig. 3: Specific Absorbing Rate (SAR) for Arlon AD250: a) 1 g and b) 10 g

while SAR values at 10 g are 0.0205, 0.165, 0.485 and 0.521 W/kg for dielectric constant 2.5, 4.5, 7.8 and 10.2, respectively as shown in Table 2. The red color exhibits the area of brain tissue which absorbed EM radiations transmitted from antenna.

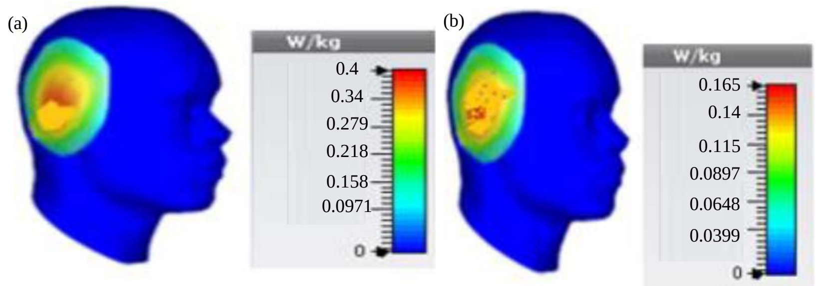

Fig. 4: Specific Absorbing Rate (SAR) for Rogers TMM4: a) 1 g and b) 10 g

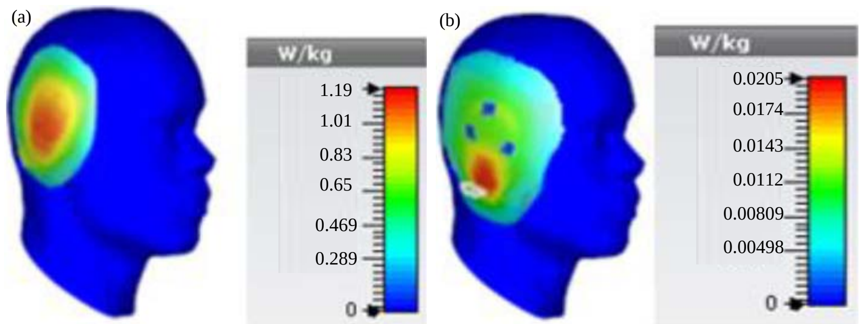

Fig. 5: Specific Absorbing Rate (SAR) for DuPont 951: a) 1 g and b) 10 g

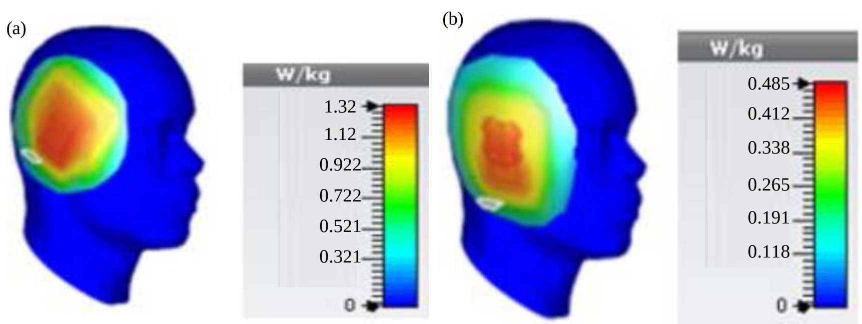

Fig. 6: Specific Absorbing Rate (SAR) for Rogers RO3010: a) 1 g and b) 10 g

Table 2: Characteristics of square patch antenna

Substrate Materials/ ch/cs of antenna	Arlan AD 250 $\varepsilon_r = 2.5$	Rogers TMM4 $\varepsilon_r = 4.5$	Dupont 951 $\varepsilon_r = 7.8$	Rogers RO 3010 $\varepsilon_r = 10.2$
Return loss (dB)	-15.4000	-17.000	-14.950	-15.000
Gain (dB)	5.4800	4.500	3.210	2.200
Directivity (dBi)	7.5200	6.510	5.630	5.110
VSWR	1.5500	1.500	1.480	1.420
SAR (1 g) (W/kg)	0.0725	0.400	1.190	1.320
SAR (10 g) (W/kg)	0.0205	0.165	0.485	0.521

CONCLUSION

In the research, we investigate new, compact, simple and low cost square patch antenna. It has been simulated as a candidate for use in 1.575 GHz for Global Positioning System applications. Square patch antennas are designed, SAR values are analyzed and simulated using CST Software 2014. The parameters of the Square Patch Antenna (SPA) such as (Gain, Directivity, Return Loss, VSWR and etc.,) depend on the structure, dimensions and substrate materials. The proposed antennas are designed at 1.575 GHz with four different substrate materials (AD 250, Rogers TMM4, DuPont 951 and Rogers RO 3010). The results show that by increasing the value of dielectric constant of the substrate material the bandwidth, directivity and VSWR are decreasing. While the SAR values for both IEEE and FCC standards are increased with increasing the dielectric constant of substrate materials.

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