Design and Optimization of a 2×2 Directional Microstrip Patch Antenna

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Abstract. In this paper, a 2x2 inset-fed directional microstrip patch antenna is proposed for the industrial, scientific and medical (ISM) frequency band. The proposed antenna is designed at 2.45 GHz for commercially available substrate RT/Duroid 4350 having thickness 0.762 mm and relative dielectric constant 3.48. The EM simulation has been carried out to study the radiation pattern of the proposed antenna using IE3D Software. The simulation results show a gain of 7.3 dBi with a directivity of 9.6 dBi and a 3 dB beam width of 59.8^o. Further the proposed antenna design is compared with other antenna designs.

Keywords: Microstrip patch antenna, Microstrip patch array antenna, Inset-fed

1 Introduction

An antenna is an electric transducer used to convert electrical power to radio waves or vice-versa. It has its application in wide areas such as radio broadcasting, communication receivers, cell phones and so on [1]. A microstrip patch antenna is used quite often because of its low cost, simplicity of fabrication, light weight etc.

A microstrip antenna consists of a dielectric substrate placed in between radiating patch and a ground plane [2] as shown in Fig. 1. The radiating patch is made of a conducting material like copper or gold which can be of any shape [3]. The dielectric constant normally lies in the range of $2 \leq \epsilon_r \leq 12$ [1]. The radiation from the microstrip antenna is mainly due to fringing field between the patch and the ground plane as shown in Fig.2. A microstrip patch antenna also has some disadvantages such as low gain and bandwidth.The bandwidth, gain and radiation pattern of patch antenna can be improved by using a thick dielectric substrate of low dielectric constant [4, 5]. But this type of substrate increases the size of the patch antenna.

In order to compensate these disadvantages, an array of patch antennas is used. This array improves the gain, bandwidth and radiation pattern of the patch antenna [3]. In this paper a 2x2 inset-fed microstrip patch antenna is designed for commercially available substrate RT/Duroid 4350 having relative dielectric constant of ϵ_r= 3.48 and thickness of h= 0.762 mm.

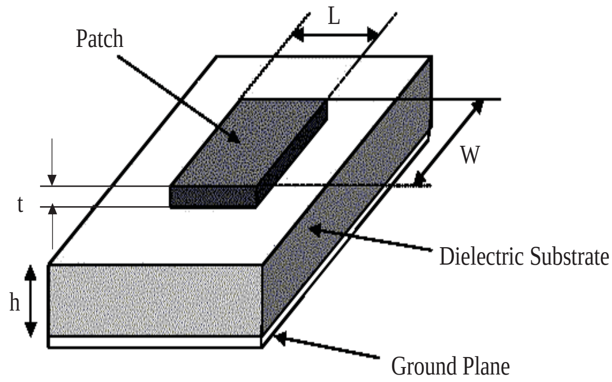

Fig. 1. A microstrip patch antenna [2]

This paper is organized as follows. Section 2 describes the transmission line model in order to analyze the microstrip patch antenna. Section 3 describes the design procedure of a microstrip patch antenna. Simulation results of a 2x2 microstrip patch antenna are given in Section 4. Finally, the paper is concluded in Section 5.

2 Method of Analysis

One of the simplest methods to analyze the microstrip patch antenna is illustrated by transmission line model. In a transmission line model the microstrip patch antenna consists of a transmission line of length L that separates two slots of height h and width W as shown in Fig. 3. Here the microstrip antenna consist of a non-homogeneous line of two dielectrics (substrate and air)

A part of the electric field resides in the air and a major portion lies in the substrate as shown in Fig.2. Due to this the pure transverse-electric-magnetic (TEM) mode of transmission cannot be sustained in the transmission line as the phase velocity of the wave is not the same in the air and in the substrate (dielectric). As a result the dominant mode of propagation in the transmission line is quasi TEM mode. Due to this an effective dielectric constant is attained according to Balanis and given [6] by

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

where ϵ_{reff} is the effective dielectric constant, ϵ_r is the relative dielectric constant of substrate, h is the height of dielectric substrate and W is the width of the patch.

For the antenna to work in the TM_{10} mode, the length of the patch antenna must be less than $\lambda/2$ (where λ is the wavelength in dielectric medium) [7, 8]. But $\lambda = \lambda_0/\sqrt{\epsilon_{reff}}$ (where λ_0 is the wavelength in free space).

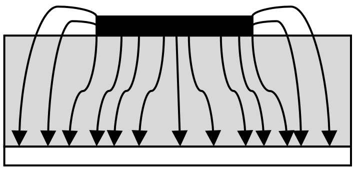

Fig. 2. Electric field distribution in microstrip patch antenna

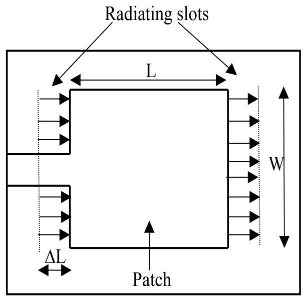

Fig. 3. Top view of patch antenna

As shown in Fig. 4, the normal and tangential components of the electric field at the edge can be resolved with respect to ground plane. As the length of the patch antenna is $\lambda/2$, the normal components of the electric field will cancel out and the tangential component will add up to give maximum radiation pattern perpendicular to the surface [1] as shown in Fig. 4. Thus the electrical patch will increase and is greater than the physical length. The increase in length is given by Hammerstad [2] as

$$\Delta L = 0.412h \left[\frac{\epsilon_{reff} + 0.3}{\epsilon_{reff} - 0.258}\right] \left[\frac{W/h + 0.264}{W/h + 0.813}\right] \tag{2}$$

Hence the effective length is given by

$$L_{eff} = L + 2\Delta L \tag{3}$$

At given resonant frequency f_0, the effective length is given [9] as

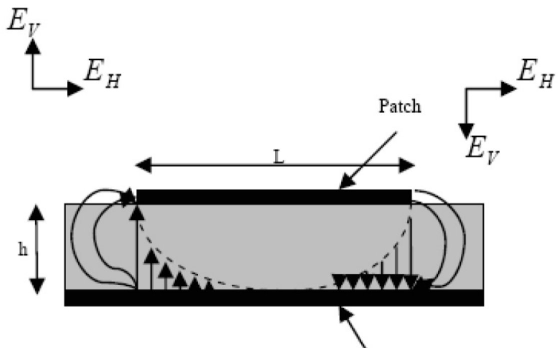

Fig. 4. Side view of patch antenna [1]

$$L_{eff} = \frac{c}{2 f_o \sqrt{\epsilon_{reff}}} \tag{4}$$

James and Hall modeled the resonant frequency of the rectangular microstrip patch antenna for TM_{MN} mode [2] as

$$f_o = \frac{c}{2\sqrt{\epsilon_{reff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right]^2 \tag{5}$$

where m and n are modes along the length and width of the patch antenna respectively.

The width of the patch antenna is given by Bahl and Bhartia for effective radiation [10] as

$$W = \frac{c}{2 f_o \sqrt{\frac{\epsilon_r + 1}{2}}} \tag{6}$$

3 Design Procedure

In this section, the design of a microstrip patch antenna is discussed. The objective is to design an antenna for ISM frequency band (2.45 GHz). The Rogers RT/ Duroid substrate 4350 (Dielectric constant=3.48 and substrate height =0.762 mm) is chosen because of its availability, low cost and low loss. A transmission line model as discussed in previous section is used to calculate the physical dimensions/parameters of microstrip patch antenna. These physical parameters are:

- Calculation of width (W): *The width of the antenna is obtained from (6) by setting* $c = 3 * 10^8$ *m/s and* f_0*=2.45 GHz. Hence* W *= 27.3 mm*

- Calculation of effective dielectric constant (ϵ_{reff}): *The effective dielectric constant is obtained from (1) by setting* ϵ_r *=3.48 , h=0.762 mm and W=27.3 mm. Hence* ϵ_{reff} *= 3.3*

- Calculation of effective length (L_{eff}): *The effective length of the antenna is obtained from (4). Hence* L_{eff} *=33.6 mm*

- Calculation of length extension (ΔL): *The length extension is obtained from (2). Hence* ΔL *=0.35 mm*

- Calculation of actual length of patch (L): *The actual length of patch is obtained from (3). Hence L =32.9 mm*

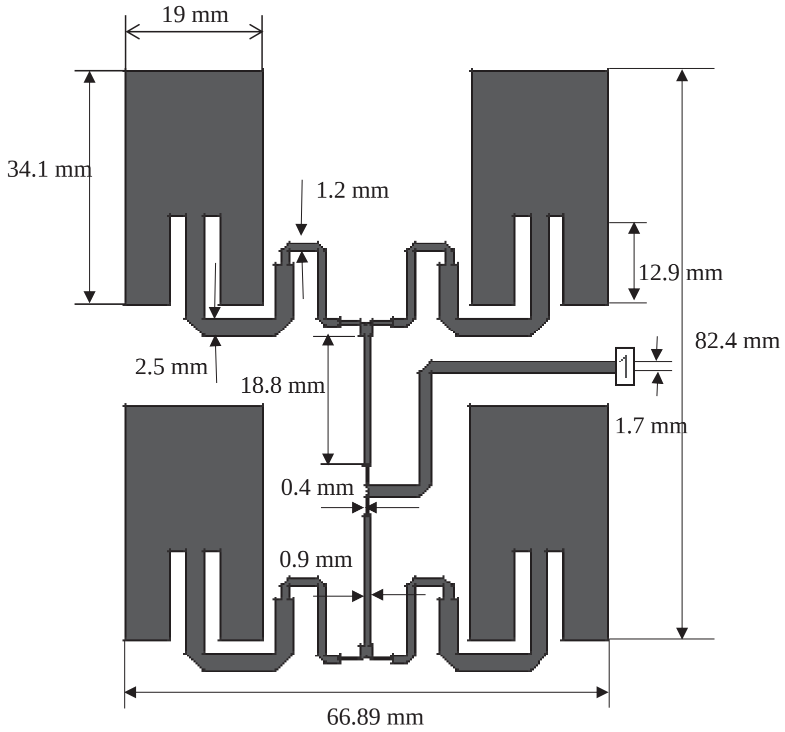

Fig. 5. Proposed 2x2 inset-fed microstrip patch antenna

4 EM Simulation

The proposed 2x2 inset-fed microstrip patch antenna is shown in Fig. 5. The proposed antenna consists of 4 patches and impedance matched feed lines. The EM

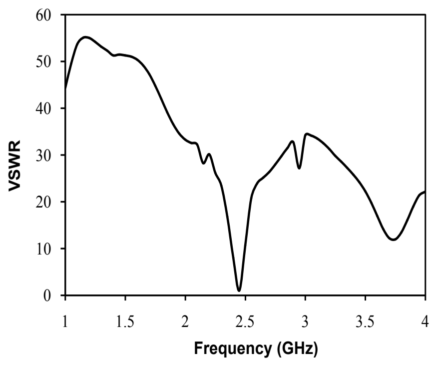

Fig. 6. VSWR of the 2x2 microstrip patch antenna

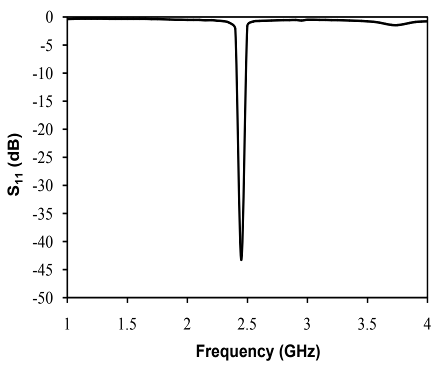

Fig. 7. S_{11} of the 2x2 microstrip patch antenna

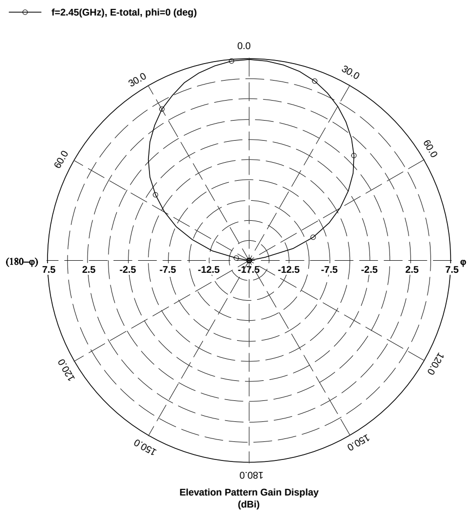

Fig. 8. 2-D elevation pattern of E-Total's at phi=0^o

simulation has been carried out using IE3D software [11]. The dimensions of the single patch antenna are calculated using transmission line model as discussed in previous section. Then, these single patches are connected using quarter wavelength impedance transformers as shown in Fig. 5. The optimized length and width of a single patch are 34 mm and 19 mm, respectively. The total size of the microstrip patch array comes out to be 66.89 mm x 87.5 mm.

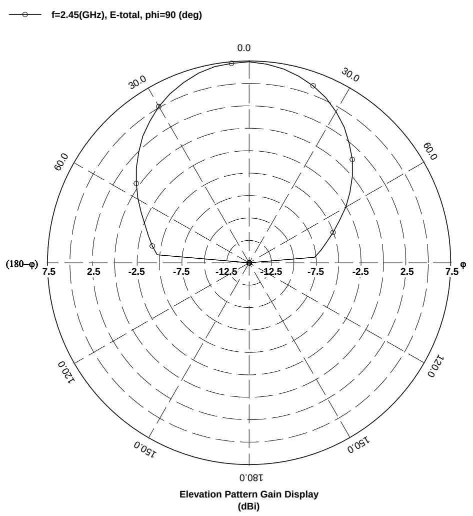

Fig. 9. 2-D elevation pattern of E-Total's directivity at phi=90^o

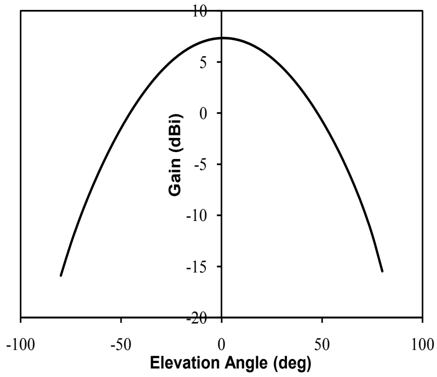

Fig. 10. 2-D elevation pattern of E-Total's gain at phi=0^o

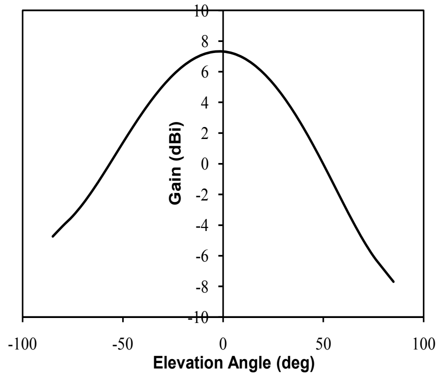

Fig. 11. 2-D elevation pattern of E-Total's gain at phi=90^o

The microstrip line length and width of 50 Ω, 100 Ω are calculated using lincalc [6]. The microstrip line with a width of 0.4 mm has a length of 2.78 mm and is of 100 Ω whose values were calculated from lincalc. The microstrip line with a width of 2.5 mm has a length of 33 mm. The microstrip line with a width of 1.2 mm has a length of 17.7 mm as shown in Fig. 5. The simulation results provide VSWR = 1.014 and S_{11} = -43.28 dB as shown in Fig. 6 and Fig. 7, respectively. The value of S_{11} is less than -15 dBm and the value of VSWR is less than 2. Hence the attained result will provide a good impedance matching to the 50 Ω load. The 2-D radiation pattern of the antenna is normal to the surface as shown in Fig. 8. The gain attained is 7.3 dBi with a directivity of 9.6 dBi and a 3 dB Beam Width of 59.8^o in E-plane. Based on the gain, directivity, and 3 dB beam width attained, it provides a narrow beam with a high gain. Fig. 8 and Fig. 9 show that the 2-D elevation pattern of directivity of total electric field in $phi = 0^o$ and 90^o, respectively.

Based on Fig. 8 and Fig. 9, the radiation pattern for directivity is normal to the surface with a gain of 9.6 dBi. Fig. 10 and Fig. 11 show that the 2-D elevation pattern of gain of total electric field in $phi = 0^o$ and 90^0, respectively. Based on the Fig. 10 and Fig. 11, the radiation pattern for the gain is normal to the surface with a gain of 7.3 dBi.

5 Conclusion

In this paper, a 2x2 directional microstrip patch antenna has been proposed. This antenna is based on a single microstrip patch antenna which is arranged in a 2x2 matrix fashion to facilitate directive radiation pattern. The proposed antenna exhibits the gain of 7.3 dBi and directivity of 9.6 dBi. To provide better insight, the attained simulation results are compared with similar antennas made on RT/Duroid 4003C [12] and on RT/Duroid 5880 [1]. The comparison is tabulated in Table 1. It is clear from Table 1 that a thick substrate with a

Table 1. Comparison of different series of rogers substrates

Substrate	Length of patch (mm)	Width of patch (mm)	Gain (dBi)	S_{11} (dB)
4350	34	19	7.32	-43.2
4003C [12]	34	30	11.5	-16.4
5880 [1]	49.4	41.3	12	-12.2

low dielectric constant exhibits better gain but at the cost of bigger patch area. Therefore, if application needs better gain, efficiency, bandwidth etc then a thick dielectric substrate with a low dielectric constant is chosen. If application needs small antenna size then a thin dielectric constant with high dielectric constant is chosen.

Future works include the fabrication of the designed patch array antenna followed by measurements. We choose RT/Duroid 4350 substrate because of its availability, low loss and low cost. Other substrates will also be evaluated.

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