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An Investigative Study of Ground Plane Size on the Performance of a Compact Co-Axial-Fed Microstrip Patch Antenna

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Abstract

The distribution of current in a patch antenna changes with the variation in the ground dimensions. This changes the radiation properties, impedance and performance parameters of antenna under study. In this paper, a parametric analysis of size of ground in a small rectangular microstrip antenna at frequencies 2.4 GHz, 5 GHz and 10 GHz is performed and its influence on antenna performance is investigated. Also, the equivalent circuit analysis is done to show the effect of inductance, capacitance and resistance values of coaxial probe and patch on the resonant frequency and performance of the antenna. CST Microwave Studio simulator has been used for the design and simulation of the patch antenna. The influence of ground dimensions on different performance parameters of antenna like gain, return loss, frequency shift, radiation pattern, total efficiency and directivity were studied and are presented in the paper.

Keywords: Microstrip antennas, Ground plane, Coaxial probe, Efficiency, Directivity.

1. Introduction

The demand for high speed wireless communication systems is growing nowadays. The antenna designers are constantly trying to design efficient, compact, wideband and multiband antennas that can provide higher data rates, more reliability while maintaining optimal antenna performance [1]. To improve antenna performance parameters like gain, directivity, return loss, bandwidth and efficiency, various techniques like defected ground surface (DGS), multilayered structures, substrate integrated waveguide antennas etc. are used which increase the cost and complexity of microstrip antenna [2–8]. Planar microstrip antennas are most commonly used in majority of the wireless platforms because they are simple to design and fabricate and can be easily integrated with other circuits. The antennas which offer low gain, less bandwidth, and large size are not suitable for latest wireless applications like IoT, RFID and cognitive radio [9–12]. Even though the antenna designers are able to achieve high gain and broad bandwidth, they do not focus much on other important antenna parameters like efficiency, return loss, frequency shift and directivity etc. which change considerably due to change in size of ground. For microstrip patch antenna (MPA) analysis, the size of ground is assumed to be infinite by the analytical studies [13, 14]. However, practical MPA systems have a finite ground surface. Ground is an essential part of the antenna systems, hence its size is crucial in determining the net electrical size and performance of the patch antenna [15]. Size of ground also affects the miniaturization of patch antennas [15,16]. In practical antenna design, the ground size is a little more than the patch size [16,17]. The patch antenna performance parameters like bandwidth, impedance, radiation patterns and operating frequency etc. are affected by changing the ground size [17–29] which also changes the front-to-back ratio of a patch antenna because of the change in the edge diffraction [30, 31]. This makes dimensions of ground very significant in determining the performance of microstrip antenna. Optimization of patch size helps in fabricating large antenna array topologies for latest compact device applications.

The existing literature reports a very few investigations about microstrip antennas having small ground planes. In [15] different miniaturization techniques like optimization of geometry and antenna loading using lumped elements, high-dielectric materials, short circuits etc were investigated. It was found that one of the efficient ways to minimize size of antennas is to either change their geometry or to make use of modified ground planes. This changes the current distribution and makes the antennas look electrically large. The ground size effect on efficiency of a patch antenna and its input impedance was examined in [18] and [19]. The studies showed that any discontinuity in the ground causes diffraction of surface waves, which changes the efficiency and input impedance of a microstrip antenna. The authors discussed the effect of side current radiation and also calculated the equivalent radiation conductance and diffraction susceptance due to diffraction. In [20–23], antenna radiation pattern with finite ground was investigated by presenting various theories and numerical techniques like slot theory, modal expansion theory, Geometrical Theory of Diffraction and moment method. Current distribution on patch surface and field distributions on dielectric substrate were calculated to determine the effect of edge diffraction on the patch antenna. Authors in [24] and [25] investigated radiation efficiency in a circular microstrip antenna with finite ground. Based on current distribution on antenna structure, they showed that size of ground is useful in improving the patch antenna radiation pattern. In [32] the effect of defected ground structure (DGS) on a meandered monopole antenna for RFID applications was examined which showed a change in the cross polar levels of patch antenna. The effect of change in shape and size of patch

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ground in a graphene-coated rectangular microstrip antenna and a circular ring microstrip antenna was studied in [33] and [34] respectively. The results showed that modifying the ground shape and size alters the ground edge diffractions which in turn cause variations in radiation pattern, resonant frequency and impedance bandwidth. In [35] and [36] the patch antenna designs having a partial ground instead of a full ground were presented for 5G and UWB applications respectively. The authors concluded that truncating the ground changes the return loss, directivity and gain of a patch antenna. In [37] and [38] slots were incorporated in ground of a microstrip antenna and which showed that the introduction of slots improved its bandwidth and impedance matching. The effect of slotted ground on gain and bandwidth of a patch antenna was investigated in [39] and [40] respectively. The results showed that embedding the slots in ground improves the gain and bandwidth of a microstrip antenna. In [41] and [42] miniaturized patch antennas were designed by incorporating Modified Koch Fractal and square fractal slots respectively to the ground surface. The experimental results showed that the fractal structures reduce the resonant frequency with a slight improvement in the antenna bandwidth.

However, very small ground sizes have not been taken into consideration in these studies and secondly, only a few antenna parameters have been examined. In this study, the effects of the small sized ground on antenna parameters like return loss, frequency shift, directivity, gain, radiation pattern and total efficiency of a patch antenna have been studied and reported here. Equivalent circuit analysis is performed to include the effect of feed reactance for better optimization of ground size and more efficient antenna performance. The analysis shows how the antenna performance can be optimized by changing ground size without adding fractals, slots, DGS etc. which increase cost and complexity of patch antenna. The rest of the paper is organized into following sections. In Section 2 the designed antenna used for the parametric analysis is shown along with the design equations for frequencies 2.4 GHz, 5 GHz and 10 GHz. Section 3 shows the simulated results. Section 4 gives the detailed equivalent circuit analysis of the probe fed antenna. Section 5 compares some recent existing works with the proposed work and section 6 concludes the paper.

2. Antenna Design for Parametric Analysis

A coaxial fed patch antenna is designed to investigate the effect of ground size on performance of antenna. The study was conducted at frequencies 2.4 GHz, 5 GHz and 10 GHz. CST Microwave studio simulator has been used to design patch antennas at these frequencies using the design equations [43] given below.

$$W_p = \frac{c}{2\sqrt{\frac{\varepsilon_r + 1}{2}} f_r} \tag{1}$$

$$L_{eff} = \frac{c}{2\sqrt{\varepsilon_{eff}} f_r} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W_p}\right)}}\right] \tag{3}$$

$$L_{eff} = L_p + 2\Delta L \tag{4}$$

$$L_p = L_{eff} - 2\Delta L \tag{5}$$

$$\Delta L = 0.412h\left[\frac{\left(\left(\frac{W_p}{h} + 0.264\right)\left(\varepsilon_{eff} + 0.3\right)\right)}{\left(\left(\frac{W_p}{h} + 0.8\right)\left(\varepsilon_{eff} - 0.258\right)\right)}\right] \tag{6}$$

$$L_p = \frac{c}{2\sqrt{\varepsilon_{eff}} f_r} - 0.824h\left[\frac{\left(\left(\frac{W_p}{h} + 0.264\right)\left(\varepsilon_{eff} + 0.3\right)\right)}{\left(\left(\frac{W_p}{h} + 0.8\right)\left(\varepsilon_{eff} - 0.258\right)\right)}\right] \tag{7}$$

where W_p, L_p, h, c, ε_r, f_r , L_{eff}, ε_{eff} , ΔL are the patch width, patch length, substrate thickness, free space velocity of light, dielectric constant of substrate, resonant frequency, effective length due to fringing, effective substrate dielectric constant including fringing and increase in length due to fringing respectively.

As shown in Fig.1, the patch antennas are designed using an FR-4 substrate (tan δ= 0.02 and ε_r= 4.4) having size 114 mm x 114mm x 1.6 mm with a rectangular ground on the back side. Design parameters of antenna are shown in Table. 1.

Table 1. Design Parameters of Patch Antennas.

Parameter (mm)	Operating Frequency (GHz)		
	2.4	5	10
Length of patch (Lp)	29	13.76	6.43
Width of patch (Wp)	38	18.25	9.12
Width of substrate (Ws)	114	114	114
Length of substrate (Ls)	114	114	114
Substrate thickness (h)	1.6	1.6	1.6
Width of ground (Wg)	Variable	Variable	Variable
Length of ground (Lg)	Variable	Variable	Variable

To study the effects of the ground size on performance of the selected microstrip antenna, a normalization factor γ has been defined.

$$\gamma = \frac{Size\ \ of\ \ ground}{Size\ \ of\ \ patch} \tag{8}$$

In the study the γ has been varied in steps of 0.1 over a range of 1 to 3.

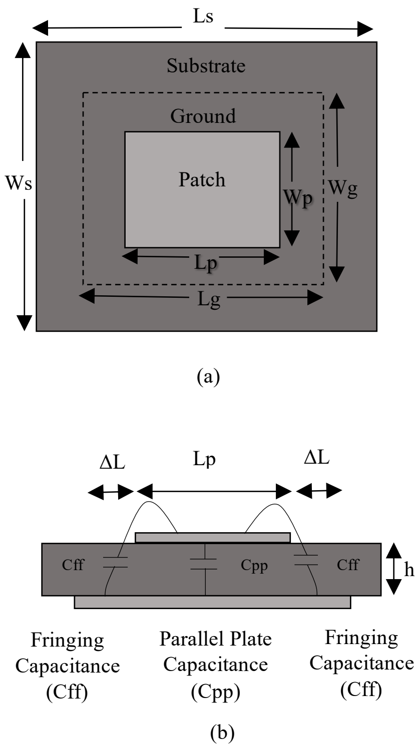


Fig. 1. Geometry of rectangular patch antenna (a) Top view (b) Side view showing the parallel plate and the fringing capacitances.

3. Simulation Results and Discussions

The effect of size of ground on return loss, gain, directivity, radiation pattern and total efficiency was investigated and the simulated results are presented in the following sections.

3.1. Frequency Shift and Return Loss

In Fig. 2, the shift in nominal frequencies of 2.4 GHz, 5 GHz and 10 GHz by varying γ is shown. The plot shows that the frequency shift is more in case of 5 GHz and 10 GHz as compared to 2.4 GHz for the same values of γ. This is because the amount of shift increases due to the change in antenna reactance as frequency increases. The plot also shows that the shift remains almost constant for γ ≥ 1.5.

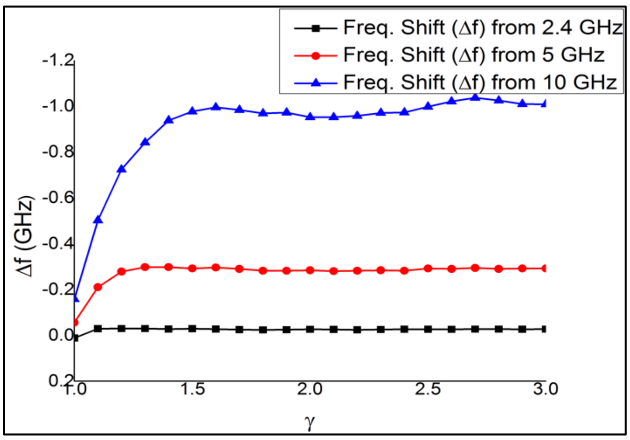


Fig. 2. Frequency shift (Δf) in microstrip antenna with γ.

The normalized frequency shift with respect to the desired resonant frequency ($\Delta f / f_r$) by varying γ is plotted in Fig. 3 which shows that the normalized frequency shift also increases by increasing the frequency.

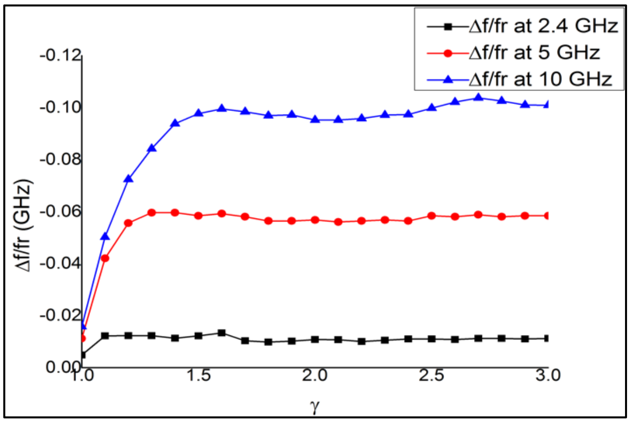


Fig. 3. Normalized Frequency shift ($\Delta f / f_r$) by varying γ.

Return loss plot with varying γ is shown in Fig. 4. It is observed that decreasing the ground size increases the return loss because there is an increase in substrate edge diffractions due to smaller ground. Therefore, for efficient design, the patch as well as the ground size need to be optimized for less return loss and better impedance matching.

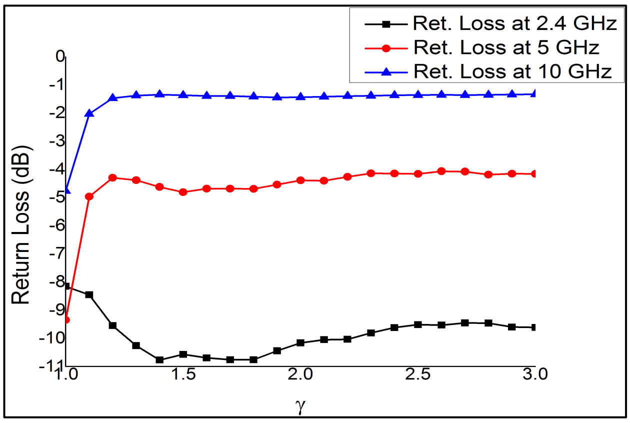


Fig. 4. Return loss of patch antenna for different values of γ.

3.2. Gain

A plot of gain of the antenna with varying ground size has been given in Fig. 5. It shows that the gain increases by increasing the size of the ground and stabilizes for γ ≥ 1.5. Also, the gain is more at high frequency as compared to that at low frequency for the same value of γ.

The gain of an antenna is given by [43].

$$G(\phi,\theta) = 4\pi \frac{U(\phi,\theta)}{P_{in}} \tag{9}$$

where ($U(\Phi,\theta)$ denotes the intensity of radiation in a particular direction and P_{in} is the accepted input power.

Larger ground planes reduce the scattering of waves along the undesired directions and concentrate the radiation energy more along the desired direction. Hence there is an increase in gain with when γ increases. Gain also depends on frequency as [44]:

$$G = \frac{4\pi A_e f^2}{c^2} \tag{10}$$

where A_e is the effective aperture of microstrip antenna and f is the patch antenna frequency which validates the simulation results.

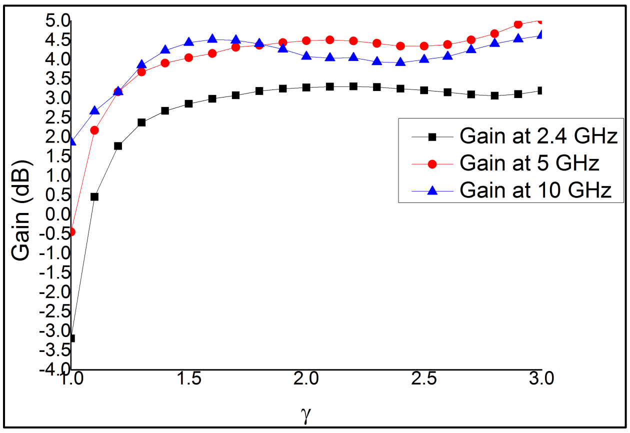


Fig. 5. Variation of patch antenna gain with γ.

3.3. Directivity

Patch antenna directivity is shown in Fig.6. Simulation results show that the directivity increases when the value of γ increases.

Antenna directivity is given by [43]:

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_{rad}} \tag{11}$$

where U denotes the intensity of radiation in a given direction, U_o is the intensity of radiation averaged over all directions and P_{rad} is the total power radiated from an antenna.

When ground size is reduced, directivity decreases because the reflected wave is scattered in different undesired directions. So, the ground size has to be increased for improving the directivity.

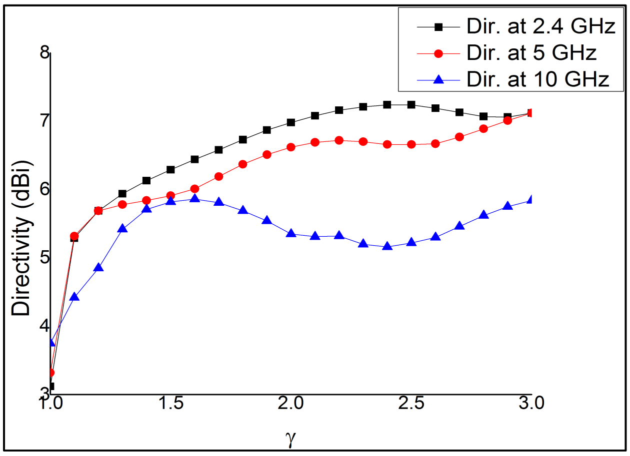


Fig. 6. Variation of directivity in a patch antenna with γ.

3.4. Total Efficiency

The efficiency of an antenna η is given by [44]:

$$\eta = \frac{P_r}{P_r + P_d + P_c} \tag{12}$$

where P_r is the radiated power, P_d is the power loss in dielectric substrate and P_c is the power loss in conductor (patch and ground). Fig. 7 shows the plot of the simulated results of the total efficiency with varying value of γ. At 2.4 GHz, there is an increase in total efficiency when the size of ground increases due to an an increase in the radiated power as evident from equation (12). Finally, the efficiency stabilizes at approximately γ = 1.5. Similar is the case for 5 GHz and 10 GHz except when γ changes from 1 to 1.1 which shows a dip in efficiency. This is because the return loss at γ = 1 is much lesser compared to the return loss at γ = 1.1 as shown in Fig. 4, which makes the efficiency at γ = 1 more than what we get at γ = 1.1 and hence the dip. Also, when frequency increases it increases the dip in total efficiency because the probe impedance and hence the impedance mismatch is more at higher frequencies which reduces the efficiency. The plot also shows that the variation of γ has less effect on total efficiency at higher frequencies than at lower frequencies.

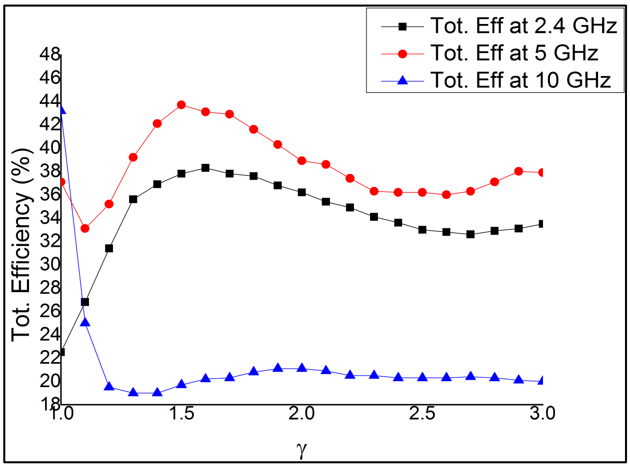
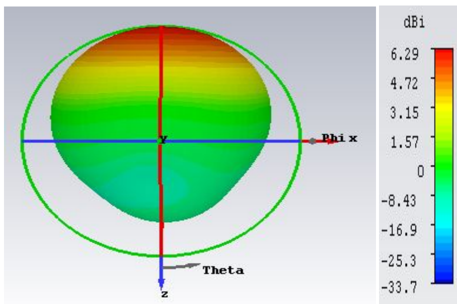


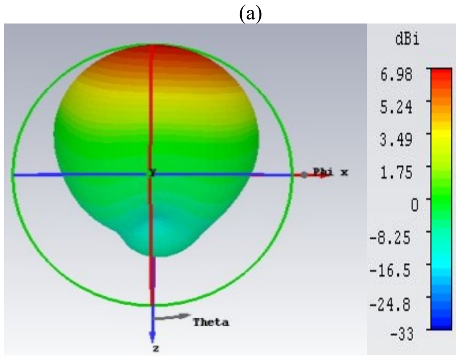
Fig. 7. Percentage total efficiency for different values of γ.

3.5. Radiation Pattern

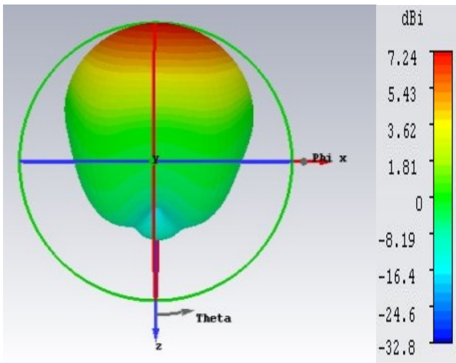
Change in ground size affects the antenna's radiation pattern because it changes the distribution of current on the patch as well as the ground. The back lobe radiation increases due to minimization in the size of ground. This reduces the front-to-back ratio which increases the level of cross polarization. The radiation patterns at frequencies 2.4 GHz, 5 GHz and 10 GHz for different values of γ are plotted in Fig. 8, Fig 9 and Fig. 10 respectively.



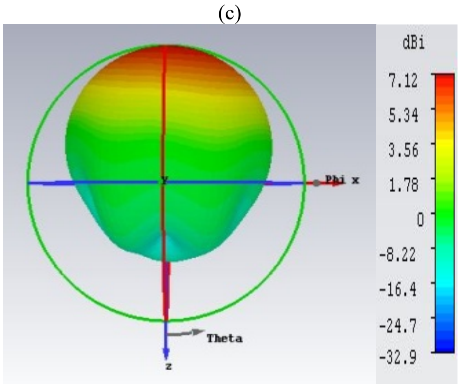
(a)



(b)

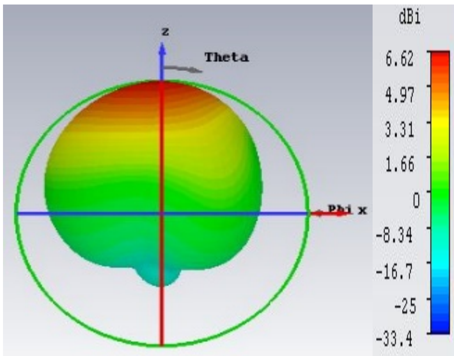


(c)

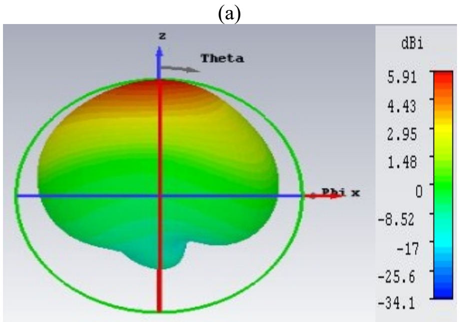


(d)

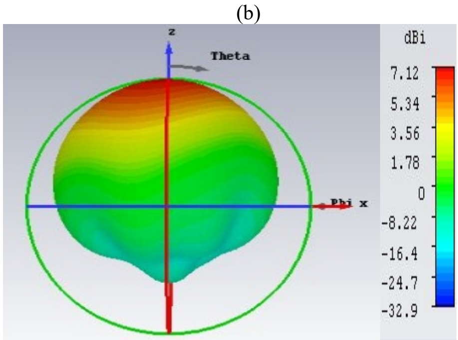
Fig. 8. Radiation pattern of patch antenna at 2.4 GHz for values (a) γ =1.5, (b) γ =2, (c) γ =2.5 and (d) γ =3.0.



(a)



(b)



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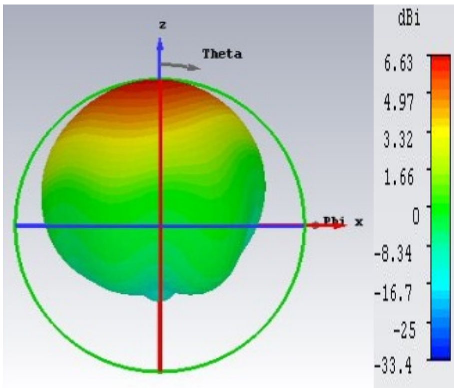
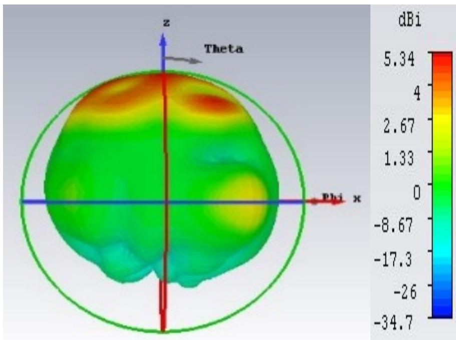
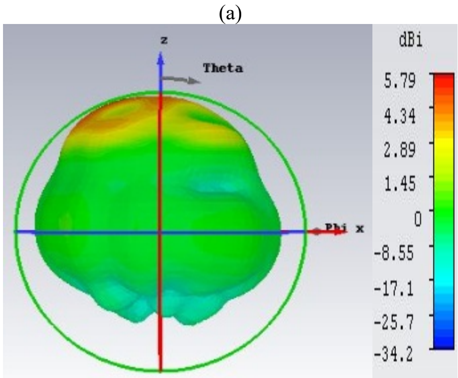


(d)

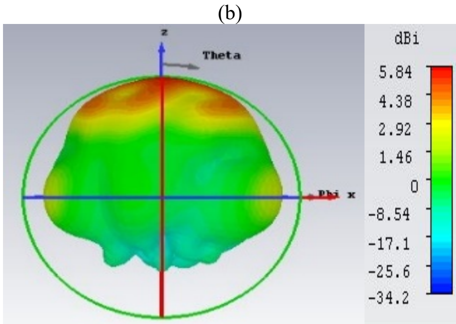
Fig. 9. Radiation pattern of patch antenna at 5 GHz for values (a) γ =1.5, (b) γ =2, (c) γ =2.5 and (d) γ =3.0.



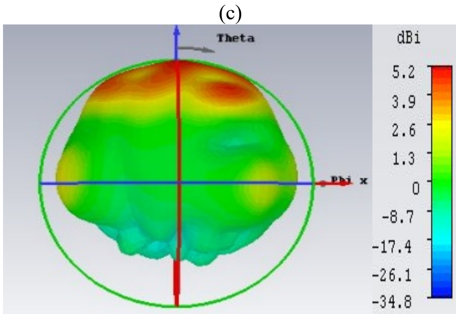
(a)



(b)



(c)



(d)

Fig. 10. Radiation pattern of patch antenna at 10 GHz for values (a) γ =1.5, (b) γ =2, (c) γ =2.5 and (d) γ =3.0.

4. Equivalent Circuit Analysis

The patch antenna is modelled by a resonant parallel RLC circuit. But in order to take into account the coax feed probe, a reactance is connected in series to it as shown in Fig. 11.

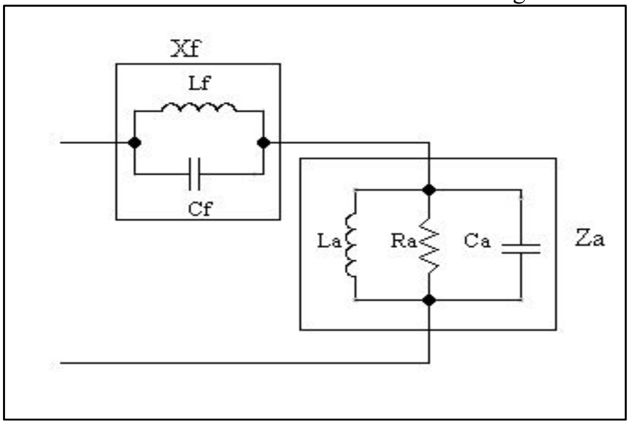


Fig. 11. Equivalent circuit of a probe-fed rectangular microstrip antenna.

The equivalent circuit in Fig. 11 is used to derive an approximate value of resonant frequency in terms of inductance, capacitance and resistance values of both the coaxial probe and the patch antenna by the following mathematical analysis.

Feed Reactance:

The net feed reactance (X_f) comprises of two parts i.e. the inductive reactance of probe (X_L) and the capacitive reactance (X_C) of probe.

$$X_f = X_L + X_C \tag{13}$$

So, the admittance (Y_f) of the feeding section is given as:

$$Y_f = \frac{1}{jwL_f} + jwC_f = \frac{w^2 L_f C_f - 1}{-jwL_f} \tag{14}$$

Therefore, impedance (Z_f) of the feeding section is given as:

$$Z_f = \frac{1}{Y_f} = \frac{-jwL_f}{w^2 L_f C_f - 1} \tag{15}$$

Where w, L_f and C_f represent the angular frequency, probe inductance and probe capacitance respectively.

Antenna Impedance:

Due to the presence of fringing fields as shown in Figure 1(b), total capacitance of the patch (C_a) will be the sum of parallel plate capacitance (C_{pp}) between the the ground and the patch and the fringing field capacitance (C_{ff}) given as[45]:

$$C_a = C_{pp} + 2C_{ff} \tag{16}$$

where

$$C_{pp} = \frac{\varepsilon_o \varepsilon_r W_p L_{eff}}{h}$$
(17)

$$2C_{ff} = \frac{\sqrt{\varepsilon_{reff}}}{cZ_o} L_{eff} - \frac{\varepsilon_o \varepsilon_r L_{eff} W_p}{h} \tag{18}$$

So, patch antenna capacitance (C_a) is given by

$$C_a = \frac{\sqrt{\varepsilon_{reff}}}{cZ_o} L_{eff} \tag{19}$$

where c denotes the velocity of light and Z_o is the characteristic impedance of patch antenna.

Now, admittance (Y_a) of the patch antenna section is given as:

$$Y_a = \frac{1}{R_a} + \frac{1}{jwL_a} + jwC_a = \frac{1}{R_a} + j\left(wC_a - \frac{1}{wL_a}\right) \tag{20}$$

Therefore, impedance (Z_a) of the patch antenna section is given as:

$$Z_a = \frac{1}{Y_a} = \frac{1}{\frac{1}{R_a} + j\left(wC_a - \frac{1}{wL_a}\right)} \tag{21}$$

where w, L_a, C_a and R_a represent the angular frequency, patch antenna inductance, patch antenna capacitance and patch antenna resistance respectively.

So, the total input impedance of a probe fed antenna includes both the probe reactance and the patch impedance given as:

$$Z_{in}(total) = Z_f + Z_a$$
(22)

$$Z_{in}(total) = \frac{-jwL_f}{w^2 L_f C_f} + \frac{1}{\frac{1}{R_a} + j\left(wC_a - \frac{1}{wL_a}\right)} \tag{23}$$

$$Z_{in}(total) = \frac{R_a}{1 + \left(wR_aC_a - \frac{R_a}{wL_a}\right)^2} + j\left\{\left(\frac{-wL_f}{w^2 L_f C_f - 1}\right) - \frac{\left(wR_a^2 C_a - \frac{R_a^2}{wL_a}\right)}{1 + \left(wR_aC_a - \frac{R_a}{wL_a}\right)^2}\right\} \tag{24}$$

At resonance, imaginary part of impedance is zero. So,

$$\left\{\left(\frac{-wL_f}{w^2L_fC_f-1}\right)-\frac{\left(wR_a{}^2C_a-\frac{R_a{}^2}{wL_a}\right)}{1+\left(wR_aC_a-\frac{R_a}{wL_a}\right)^2}\right\}=0$$

(25)

$$f_r=\frac{1}{2\pi}\sqrt{\left[\frac{\left\{\left(\frac{2R_a{}^2C_aL_f}{L_a}-L_f+C_aR_a{}^2+\frac{R_a{}^2C_fL_f}{L_a}\right)+\sqrt{\left(\frac{R_a{}^2L_f}{L_a{}^2}+\frac{R_a{}^2}{L_a}\right)\left(4R_a{}^2C_a{}^2L_f+4L_fC_fC_aR_a{}^2\right)}\right\}}{2\left(R_a{}^2C_a{}^2L_f+L_fC_fC_aR_a{}^2\right)}\right]} \tag{26}$$

Also, fringing capacitance depends on the change in length by the following equation [45].

$$\frac{C_{ff}}{W_p}=\frac{\Delta L}{h}\frac{\sqrt{\varepsilon_{reff}}}{cZ_o\frac{W_p}{h}} \tag{27}$$

The probe inductance leads to impedance mismatch in the designed antenna due to which the resonant frequency shifts. Also, from equation (26) it is clear that the capacitive reactance between the ground and the patch changes the antenna frequency. Since, the change in ground size changes the effective length of patch, this in turn changes the capacitive reactance as shown in equation (27). Thus, the change in capacitive reactance introduces a shift in the frequency as γ changes. This shift (Δf) is given as:

$$\Delta f=f_o-f_r \tag{28}$$

where f_o and f_r represent the frequency observed at a given value of γ and the frequency for which the antenna is designed respectively.

Resonant frequency of patch (f_r) is given by [43]:

$$f_r=\frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{eff}}} \tag{29}$$

The above equation shows that f_r is a function of L_{eff} and ε_{eff}, so, the partial derivatives of f_r for L_{eff} and ε_{eff} [45] can be calculated to derive the shift in frequency as:

$$\begin{cases}\frac{\partial f_r}{\partial L_{eff}}=\frac{c}{2\sqrt{\varepsilon_{eff}}}\left(-L_{eff}{}^{-2}\right),\\ \frac{\partial f_r}{\partial \varepsilon_{eff}}=\frac{c}{2L_{eff}}\left(-\frac{1}{2}\varepsilon_{eff}{}^{-\frac{3}{2}}\right)\end{cases} \tag{30}$$

From equations (29) and (30), the relationship between shift in frequency and change of physical parameters is given by:

$$\begin{cases}\frac{\partial f_r}{f_r}=-\frac{\partial L_{eff}}{L_{eff}},\\ \frac{\partial f_r}{f_r}=-\frac{1}{2}\frac{\partial \varepsilon_{eff}}{\varepsilon_{eff}}\end{cases} \tag{31}$$

$$\frac{|\Delta f|}{f_r}=\left[\left(\frac{1}{2}\frac{\Delta\varepsilon_{eff}}{\varepsilon_{eff}}\right)^2+\left(\frac{\Delta L_{eff}}{L_{eff}}\right)^2\right]^{\frac{1}{2}} \tag{32}$$

From equation (26) and (32) we conclude that the change in ground dimensions changes the capacitive reactance between the ground and the patch which in turn changes the effective length of the antenna. This change in effective length introduces a shift in antenna frequency and also affects the return loss, gain, directivity and total efficiency of the co-axial fed patch antenna.

5. Comparison with some of the existing works

The comparison of some of the related research works with the proposed work shows that most of the research works investigated only a few antenna parameters by making different modifications in the ground surface. In [32], effect of defected ground surface on radiation pattern is studied which shows a changes in the antenna's cross polar levels. In [33], the shape of ground is changed which alters the ground edge diffractions and causes variations in radiation pattern and bandwidth of a patch antenna. A partial ground is used in [36] which shows that truncating the ground changes the return loss, directivity and gain of the patch antenna. Slots are incorporated in [38–40] which change the current distribution of antenna structure and thus affects the gain, impedance matching and bandwidth of a microstrip antenna. Fractal techniques are used in [41,42] and their effect on resonant frequency is studied. The study shows that fractal structures reduce the resonant frequency with a slight improvement in the antenna bandwidth. The drawbacks of these modifications and techniques is the increase in cost, complexity and size of the antenna systems which are the most important design constraints in latest wireless applications. Also, only a few antenna parameters are studied and the effect of ground dimensions and feed reactance is not taken into consideration which significantly affects the antenna performance. In the proposed work, almost all the parameters of interest like return loss, directivity, frequency shift, gain, radiation pattern and total efficiency are investigated. In addition to the study of effect of ground dimensions on antenna performance, the equivalent circuit analysis of probe-fed antenna is performed to include the effect of feed reactance for calculating the overall change in antenna performance parameters. The proposed study shows that the antenna performance can be optimized by changing ground size without incorporating fractals, slots, DGS etc. which increase cost and complexity. Ground size effect on shift in frequency will help in the efficient design of frequency agile reconfigurable microstrip antennas. Also, optimization of ground dimensions will save space which will help antenna design engineers in effective MIMO implementation on the same substrate for 5G, LTE, IoT and UWB applications.

6. Conclusion

The gain, efficiency, radiation pattern and other performance parameters of a patch antenna are functions of the current distribution on both ground and patch. So, the choice of suitable dimensions of ground is extremely important for optimization of physical size of an antenna without compromising the overall performance. The optimal antenna design makes best use of the allotted space, minimizes losses and provides a nearly constant antenna gain. In this paper, a probe-fed patch antenna for 2.4 GHz, 5GHz and 10 GHz has been designed, and investigated through simulation using CST Microwave Studio simulator. To study the effect of size ground on the performance of the patch antenna, a new normalization factor γ is introduced. The simulation results show that the optimum ground plane size at which the gain attains highest value is around $\gamma = 1.5$ after which the gain almost stabilizes. The study also shows that the radiation pattern exhibited omnidirectional features for smaller sized ground-plane which reduces as the size of ground increases. It has also been observed that the antenna's directivity increases when the size of ground increases and the same stabilizes at around $\gamma = 1.5$. Similarly, it was observed that there is an increase in total efficiency when the size of ground increases. This also stabilizes at around $\gamma = 1.5$. The simulation study shows a frequency shift in the antenna from its nominal designed value, which increases with the size of ground. The observed frequency shift is more at higher values of nominal frequency. The observed frequency shift remains almost constant when $\gamma \geq 1.1$, $\gamma \geq 1.3$ and $\gamma \geq 1.5$ for 2.4 GHz, 5 GHz and 10 GHz respectively. The knowledge of shift in nominal resonant frequency by varying size of ground will help the antenna design engineers in efficient design of frequency agile antennas. The study shows that the antenna performance can be optimized by changing ground size without incorporating additional circuitry which not only adds complexity but also increases the cost and size of the antenna system. The optimization of ground size is important for the implementation of efficient miniaturized MIMO systems in compact hand held devices for latest wireless applications.

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