Tri-Band Parallel Slots Loaded Circular Disk Patch Antenna for C and X-Band Applications

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Abstract

This paper presents the tri-band slot loaded patch antenna for mobile communication. The antenna consists of parallel slots loaded circular disk with defected ground structure antenna (DGS). The antenna without DGS, acts like wide band antenna and bandwidth is 34.45% (3.47 - 4.92 GHz) with maximum gain of 4.97 dBi, which can be used in WiMax application. This structure has the following advantages: 1) co-axial feeding technique, which is very simple as compared to other feeding technique, 2) simple and cost effective and 3) it is more efficient than the antenna without DGS. This antenna has been analyzed using IE3D simulation software.

Keywords

1. Introduction

Slot loaded circular disk antennas, with defected ground structure for WLAN, WiMax systems, mobile phone, radar, have been reported by several researchers [1]-[4]. Their work is confined to only single band, double band and wideband, which is not suitable for current market demands. Therefore, in order to overcome the market needs, a multi-band antenna with simple, low cost and solid structure is necessary [5]. Because, multiband antenna will have multi frequencies which can be used in different systems at the same time, the work related to tri-band antenna and multifunction applications have been published by several researchers. The advantage of

tri-band structure is that, when there is meddling in one band system, the other can still work usually. In 2011, Prasad *et al.* [6] have reported that circular disk antenna performs well superior than the rectangular microstrip patch antenna. A slot antenna and stacked antenna have many advantages, because of its simple structure, compact [7] such as wider bandwidth and less performer loss [8]-[10]. Recently, Anguera *et al.* [11] and Cao *et al.* report that the antenna will better perform when it is incorporated with different bands into stacked patches, cutting slots in the patches [11] [12]. Above presented papers have some drawbacks. Some have low return loss and low gain and some have large size. The large size of antennas is not more valuable in recent communication systems. In the present scenario of wireless communication, the compact and tiny antenna is required. Because it is more useful in different communication schemes at the same time, multiband antenna is mandatory. In this article, a probe-fed tri-band with three parallel slots loaded single layer circular patch antenna has been planned by using defected ground plane. Furthermore, the parallel slots on the circular patch and defected ground plane increase the current path on it and reduce the size of antenna.

Also the concert of the antenna was investigated by the performance of the surface currents on the patch. The sizes of three parallel-slots are selected in such a way so that planned antenna can display triple frequency activities with good matching condition. Without defected ground plane, antenna works like wideband antenna with good gain which is very useful in WiMax applications. The performance of our current design is better than the results published in [13] [14]. The bandwidth of the proposed design is better than [14]. Proposed design is very simple and uses the defected ground plane, which indicates that the proposed design is compact and that the size is reduced as compared to [13] [14]. The co-axial feed technique has been used for the study of the proposed antenna because it occupies less space and has low spurious radiation by using Teflon connector. Details of the antenna are given in next stage.

2. Antenna Design

2.1. Antenna Configuration

The geometry of a tri-band circular disk patch antenna with (DGS) is depicted in **Figure 1**. The triple band presentation is achieved by cutting three parallel slots on circular disk patch and rectangular slot on ground plane with a single layer patch. The coaxial probe is directly connected to the patch and FR4 dielectric is used as a substrate, which has dielectric constant of 4.4 and height of dielectric substrate is 1.6 mm. We have selected all the dimensions of proposed antenna, as desirable for triple-band antenna.

2.2. Design Equation

Due to the fringing effects, electrically the shining patch of the antenna looks bigger than its physical size; the increment on L is given by:

$$\Delta L = \frac{0.412h \left(\varepsilon_{reff} + 0.3 \right) \left(W\,h^{-1} + 0.264 \right)}{\left[\left(\varepsilon_{reff} - 0.258 \right) \left(W\,h^{-1} + 0.8 \right) \right]} \tag{1}$$

where the effective (relative) permittivity is,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\,h\,W^{-1}}} \tag{2}$$

This is associated to the ratio of h/W. The larger value of h/W is, then the smaller effective permittivity is [15] [16]. The effective length of the patch is given by:

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

The resonant frequency for the TM_{100} mode is:

$$f_r = \frac{1}{\left[2\,L_{eff}\,\sqrt{\varepsilon_{reff}\,\sqrt{\varepsilon_0 \mu_0}} \right]} \tag{4}$$

$$f_r = \frac{1}{\left[2\left(L + 2\Delta L \right)\sqrt{\varepsilon_{reff}\,\sqrt{\varepsilon_0 \mu_0}} \right]} \tag{5}$$
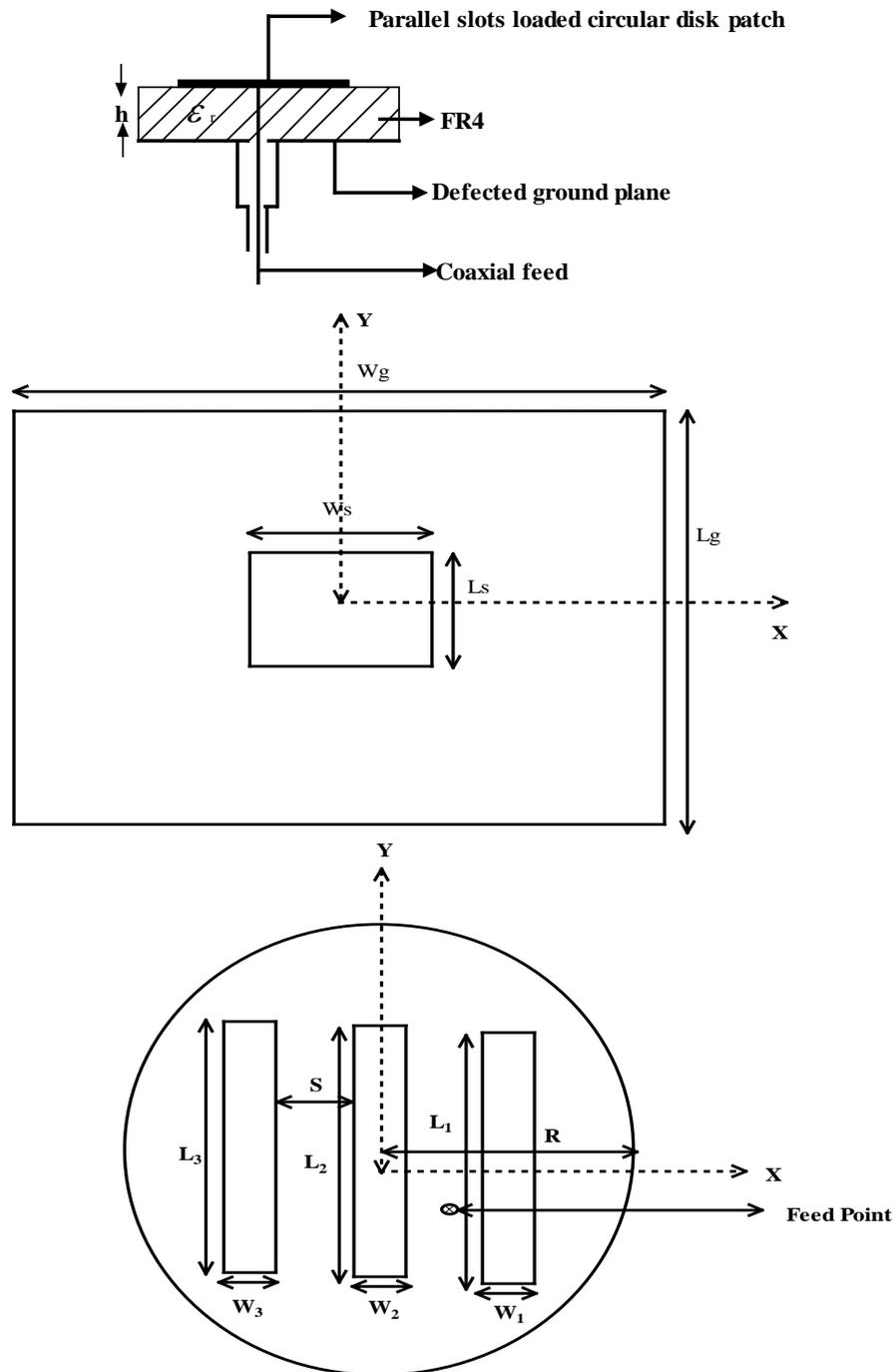
Figure 1. Top view and side view geometry of the proposed triple band antenna.

An optimized width for an efficient radiator is,

$$W = \frac{1}{\left(2 f_r \sqrt{\varepsilon \mu_0}\right) \times \sqrt{\dfrac{2}{\varepsilon_r + 1}}} \qquad (6)$$

Analysis of circular disk microstrip antenna is same as that of rectangular patch apart from the effective radius and its resonant frequency. Therefore, the analysis of a circular disk patch is carried out by assuming that it is

equivalent to a rectangular patch [17] in which length L is supposed to be equal to $2R$ and width W equal to $\frac{\pi R}{2}$ (**Figure 1**). The value of effective radius R_e is considered by equating the area of circular disk to the expanded rectangular patch of dimension L_e and W_e where L_e and W_e are calculated by [18]. The design method for original case is given in next step.

2.3. Design Method

If the substrate parameter (ε_r, h) and the operating frequency (f_r) are known then we can easily work out on the size of the patch antenna using above simplified equation following design method to design the antenna:

Step 1: Using Equation (6) to get out the patch width W.

Step 2: Calculate the effective permittivity using the Equation (2).

Step 3: Compute the expansion of the length using the Equation (1).

Step 4: Determine the length L by solving the equation for L giving the solution.

From Equation (6), (f_r) is the resonance frequency at which the rectangular/circular microstrip antenna is to be planned. The radiating edge W, patch width is typically kept such that it lies within the variety for efficient radiation. By using the above equations we can get the values of concrete length of the patch as:

$$L = \left[\frac{1}{\left(2f_r \sqrt{\varepsilon_{reff}} \sqrt{\varepsilon_0 \mu_0}\right)} \right] - 2\Delta L \tag{7}$$

The final optimized parameters of the antenna are given in **Table 1**.

2.4. Working Mechanism and Design Guideline

Our aim is to design the multiband antenna with the help of parallel slots loaded circular disk patch with (DGS). First, we have designed rectangular ground plane with rectangular slot cut on copper plate. We used the FR4 dielectric on copper plate with thickness of 1.6 mm. After that we stacked a parallel slots loaded circular disk patch with ground plane. With the above idea, the guideline of the design can be shown in four steps, which are given below.

First Step: In first step, by using above formulas, we have design three parallel slots loaded circular disk patch stacked with, without defected ground. We found that the results like broadband antenna with frequency range (3.47 - 4.92 GHz) and central frequency 4.20 GHz. The individual bandwidth of the broadband antenna is 34.45% with maximum gain is 4.97 dBi. All results of broadband antenna can be simply shown in **Figures 2-4**.

Table 1. Optimized dimensions of the antenna (unit: mm).

Parameter	Value
Lg	20.0
Wg	30.0
Ls	8.0
Ws	10.0
R	10.0
L_1, L_2, L_3	10.0
W_1, W_2, W_3	2.0
S	3.0
FR4	4.4
h	1.6
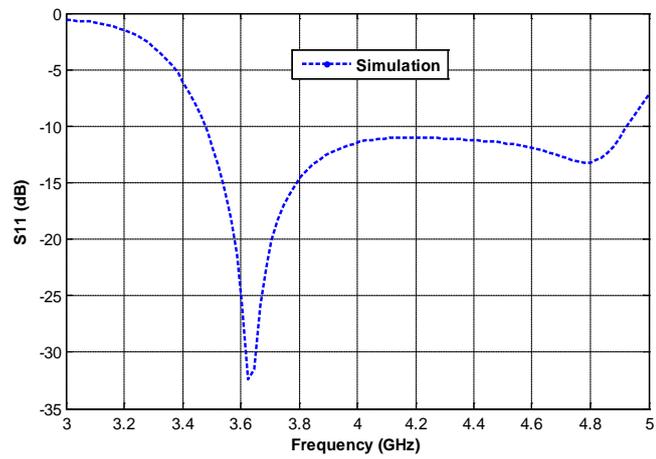
Figure 2. Variation of S11 parameter with frequency of the antenna without defected ground.
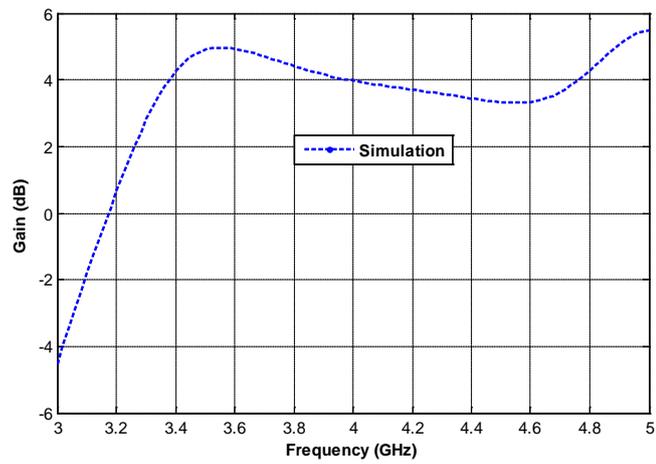
Figure 3. Variation of Gain with frequency of the antenna without defected ground.

Radiation pattern of without defected ground
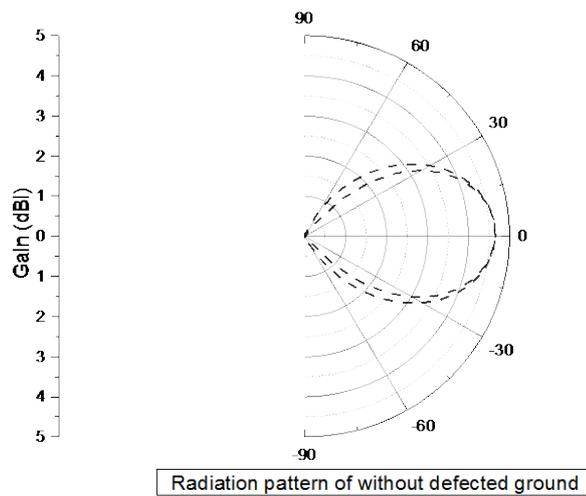
Figure 4. Radiation patterns of antenna without defected ground plane both E and H plane.

Through calculation and optimization, a broadband three parallel slots loaded disk antenna is achieved as shown in **Figures 2-4**. The radiation pattern of the broadband antenna is good in both E and H plane, which is shown in **Figure 4**. The dimensions of this broadband design are listed in **Table 1**.

We have already done more work on broadband antennas, so we are thinking about multiband antenna and then work on the next steps which are given below.

Second step: In second step, we think about the ground defected design, so we cut a rectangular slot on ground plane and stacked circular disk over a defected ground and got the multiband performance, which is my proposed antenna. The dimensions for this proposed design are listed in **Table 1** and performances are shown in **Figures 5-7**.

The **Figures 5-7**, indicate that the performance of the proposed antenna is tri-band antenna. The variation of S_{11} parameter with frequency is shown in **Figure 5**. The triple band antenna can be used in C and X band; first two bands in C-band and another last one is used in X-band performance. Similar performance of the gains of the proposed antenna is shown in **Figure 6**. The radiation pattern of the proposed antenna is shown in **Figure 7**, in all origin and polar form both the E and H-plane characteristics which is good as compared to published [14]. We have also checked the performance of the antenna with dual and single slot loaded in circular disk patch which is given in next coming steps.

Third step: In third step we used only two parallel slots on circular disk and ground defected is similar as earlier step. The dimensions for this design are listed in **Table 1** and performances are shown in **Figures 8-10**.
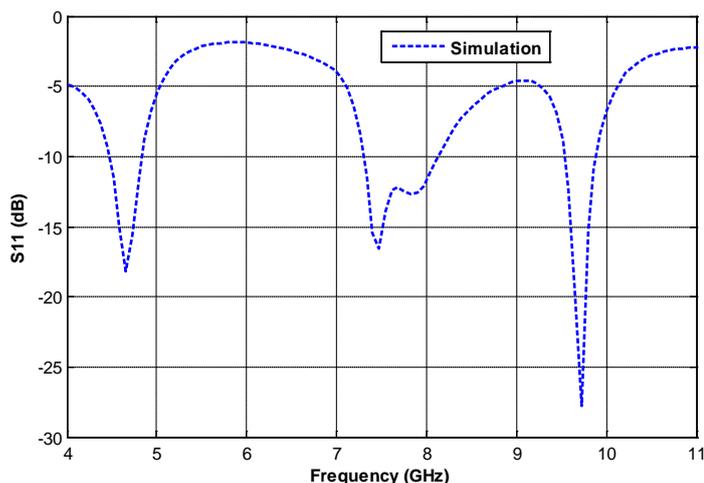
Figure 5. Variation of S_{11} parameter with frequency of the proposed antenna.
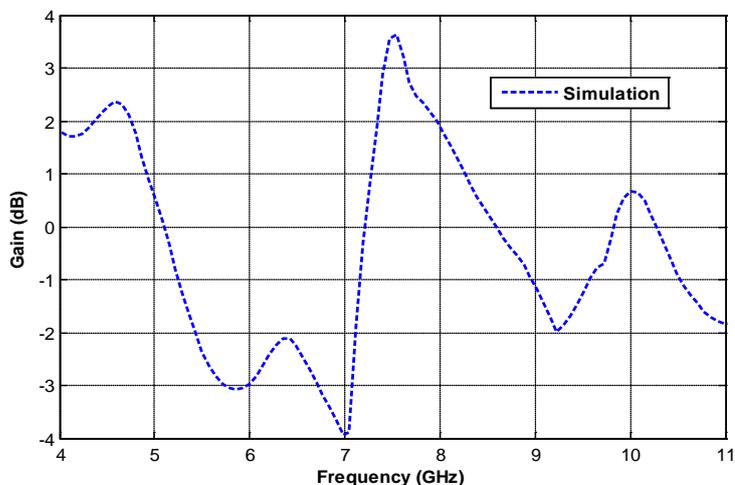
Figure 6. Variation of gain with frequency of the proposed antenna.

Gain (dBi)

Radiation pattern at frequency 4.64GHz

(a)

Gain (dBi)

Radiation pattern at 7.71 GHz

(b)

(180-φ)

Elevation Pattern Gain Display (dBi)

(c)

Elevation Pattern Gain Display (dBi)

(d)
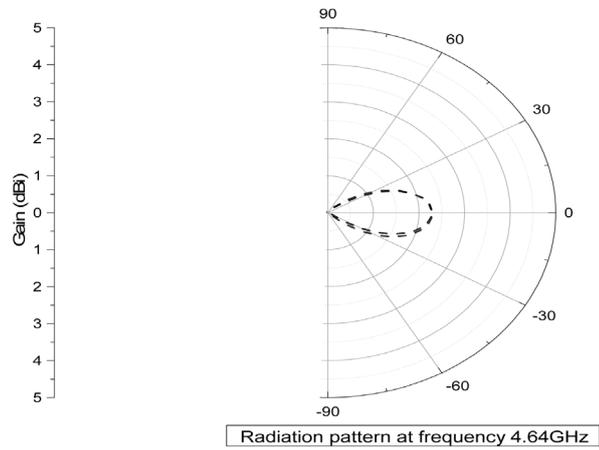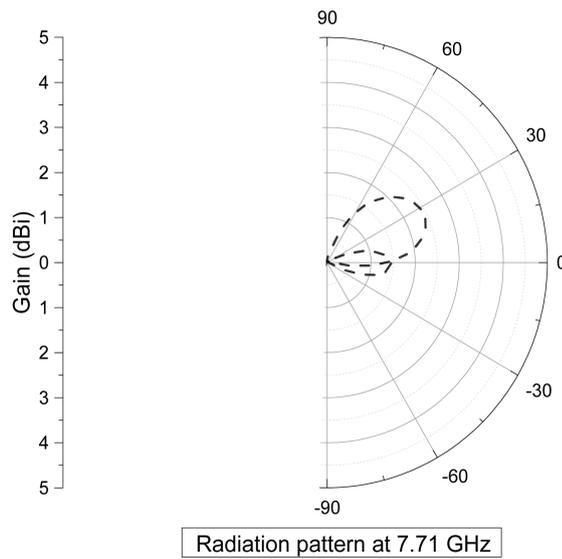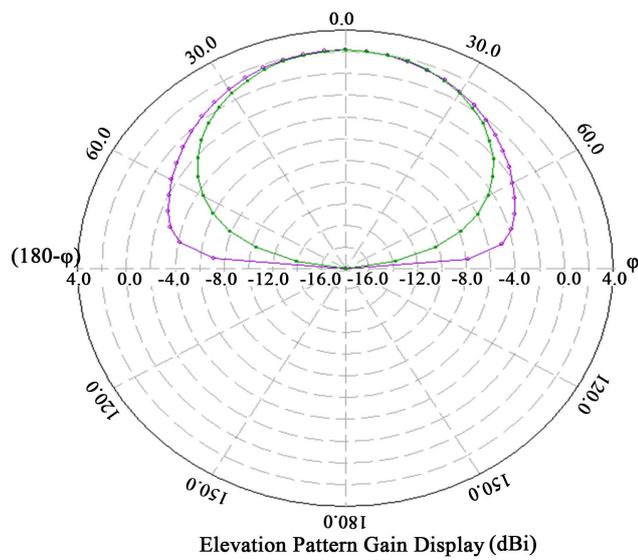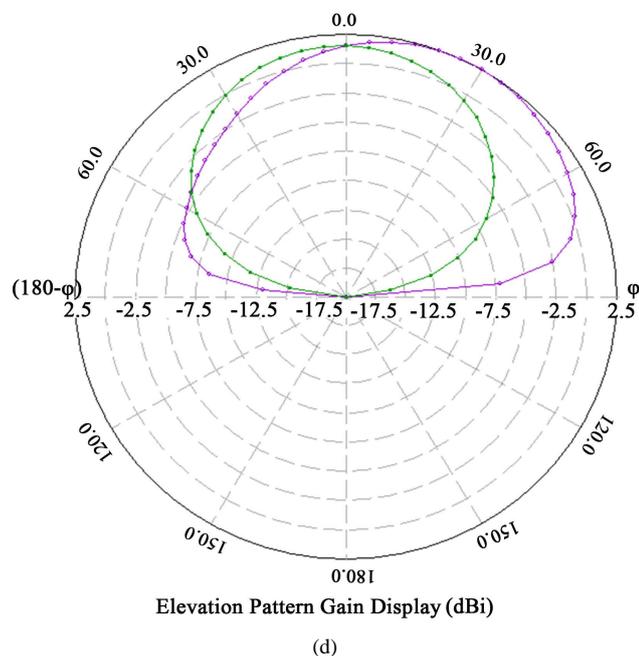
Figures 7. Radiation patterns of the proposed antenna. (a) Radiation pattern in origin polar plot form of first band; (b) Radiation pattern in origin polar plot form of second band; (c) Polar plot radiation pattern at 4.42 GHz; (d) Polar plot radiation pattern at 7.74 GHz.
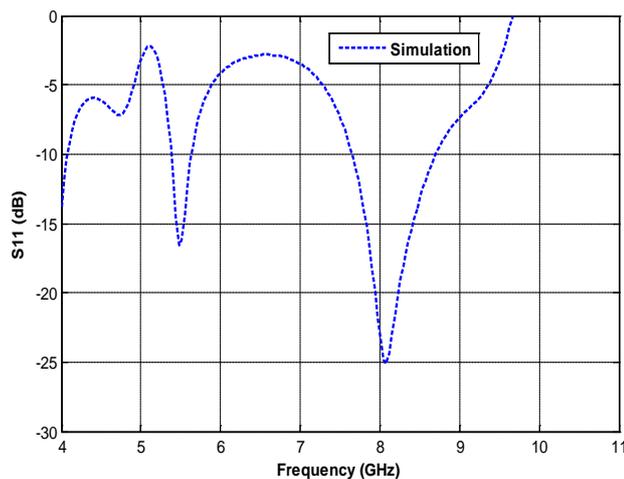
Figure 8. Variation of S_{11} parameter with frequency of the double parallel slots loaded circular disk.

If we used the double slots on circular disk patch the dual band antenna performance was found, which have already done in my previous work. The S_{11} and gain variation of the dual band antenna is shown in **Figure 8** and **Figure 9**. The radiation pattern of the dual band antenna is shown in **Figure 10**, which is not good as compared to other dual band antennas. And then think about single slot performance, which is shown in the next step.

Fourth step: In fourth step we used only single slot on circular disk and ground defected is same as earlier step. The dimensions for this design are listed in **Table 1** and presentation is shown in **Figure 11**. The performance of single slot is like a single band antenna, which is the basic of the antenna.

3. Simulated Results

Figure 12 shows that the variation of simulated S_{11} results between single, double and triple slots loaded on cir-
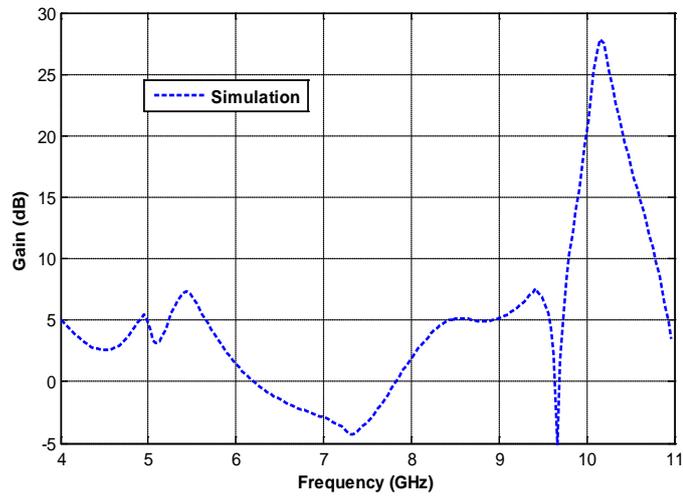
Figure 9. Variation of Gain with frequency of the double parallel slots loaded circular disk.

Radiation pattern at 5.48 GHz

Radiation pattern at 8.06 GHz
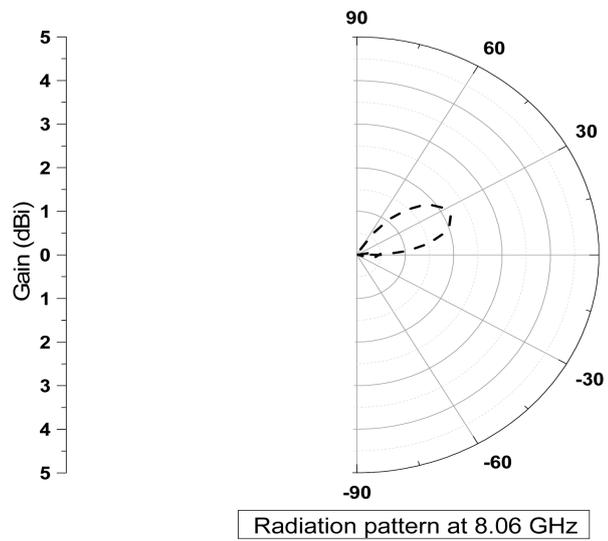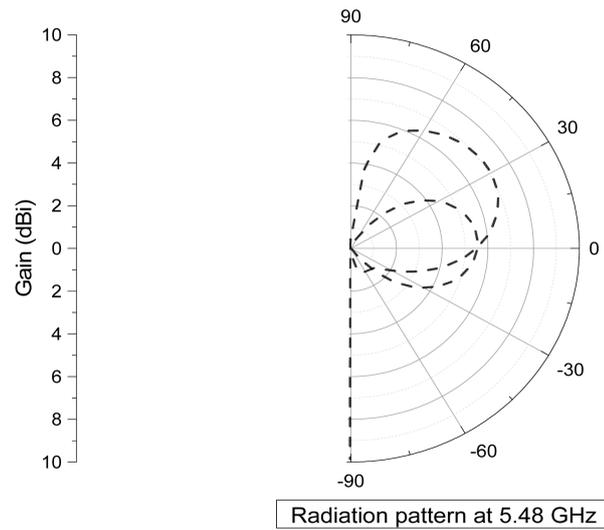
Figure 10. Radiation pattern both E and H plane of double slots loaded circular disk patch.
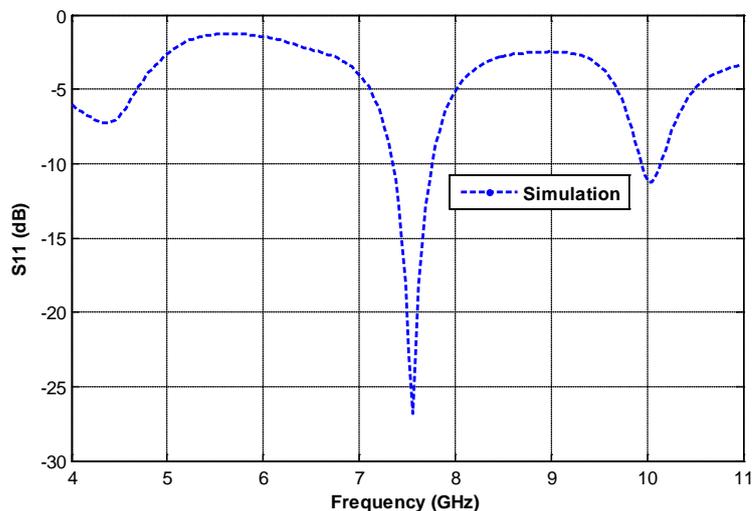
Figure 11. Variation of S11 parameter with frequency of the single slot loaded circular disk.
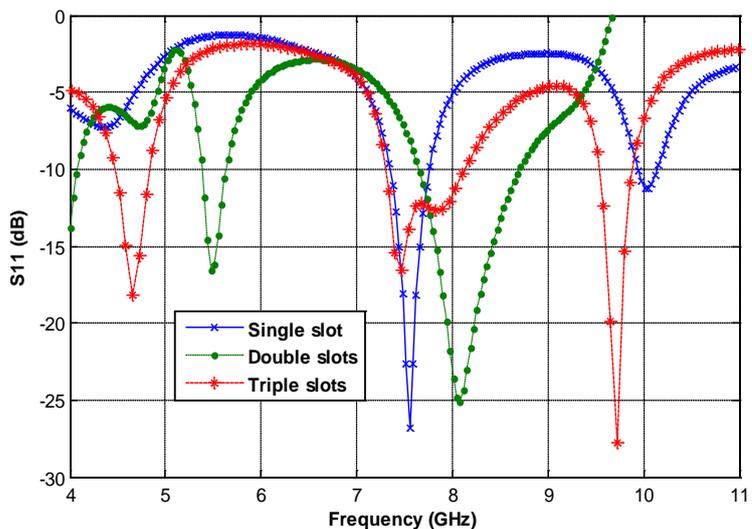
Figure 12. Variation of S11 parameter with frequency of the single, double and triple slot loaded antenna.

cular patch with defected ground plane. The simulated impedance bandwidths with 10 dB reflection coefficients of three different bands are 7.83%, 13.09% and 3.63% with gains, 2.30 dBi, 3.61 dBi and 0.67 dBi respectively. This is only for three parallel slots loaded on circular patch, which is shown in **Figure 12**. If there are only two parallel slots with defected ground then the simulated impedance bandwidths with 10 dB reflection coefficients of two bands are 4.56% and 12.9% with high gain 7.26 dBi at 4.45 GHz and 27.8 dBi at 10.16 GHz respectively. Further if there is only single slot on circular patch with defected ground then the simulated impedance bandwidth with 10 dB reflection coefficients is 5.39% but gain is very low. It is clear that when we used three parallel slots on circular disk with defected ground, receiving the results tri-band and for double and single slots, we obtained dual and single band antenna respectively, which is already shown in above steps of design guidelines. In triple band antenna, first band can be used in ISM band/mobile communication application and other two bands can be used in radar systems. The gain of single band antenna is very low but due to double and triple slots loaded, the variation of antenna gains between them is shown in **Figure 13**. The simulated radiation patterns both in E-plane and H-plane at all the resonance frequencies are shown in above every steps of design guidelines which are reasonably in good conditions.
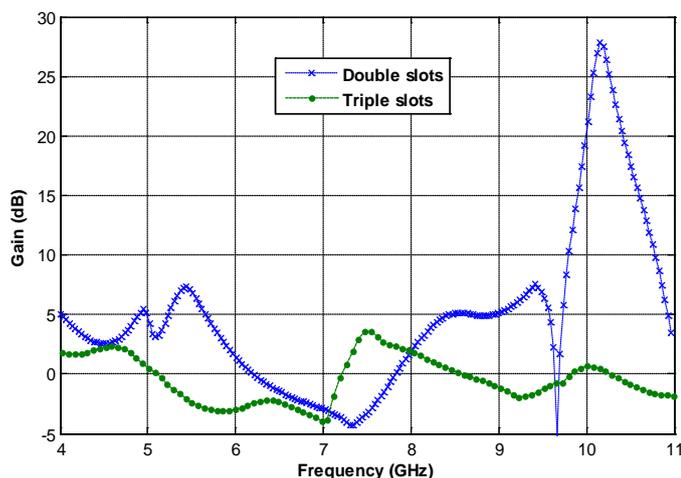
Figure 13. Variation of gain with frequency of the double and triple slot loaded antenna.

4. Conclusion

In this paper, a compact triple band circular disk antenna is realized by loading three parallel slots on circular disk and rectangular slot on the ground plane. The proposed antenna has impedance bandwidth covering the C-band (4.47 - 4.83 GHz, 7.30 - 8.13 GHz) and X-band (9.53 - 9.89 GHz) frequencies. The design guidelines and appropriate equations are described and validated via IE3D simulations. The proposed antenna can be used in mobile applications.

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