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Dual-Band Proximity Coupled Feed Microstrip Patch Antenna with 'T' Slot on the Radiating Patch and 'Dumbbell' Shaped Defected Ground Structure

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Abstract

This paper presents Dual-Band proximity coupled feed rectangular Microstrip patch antenna with slots on the radiating patch and Defected Ground Structure. Initially a simple proximity coupled feed rectangular Microstrip patch antenna resonating at 2.4 GHz is designed. Etching out a 'Dumbbell' shaped defect from the ground plane and 'T' shaped slot from the radiating patch of the proximity coupled feed rectangular Microstrip patch antenna, results in a Dual-Band operation, i.e., resonating at 2.4 GHz and 4.5 GHz; with 30.3 % and 18.8% reduction in the overall area of the patch and the ground plane of the reference antenna respectively. The proposed antenna resonates in S-band at frequency of 2.4 GHz with bandwidth of 123.6 MHz and C-band at frequency of 4.5 GHz with bandwidth of 200 MHz, and a very good return loss of -22.1818 dB and -19.0839 dB at resonant frequency of 2.4 GHz and 4.5 GHz respectively is obtained. The proposed antenna is useful for different wireless applications in the S-band and C-band.

keywords: dumbbell shaped defected ground structure, t-shaped slot, proximity coupling, dual- band, bandwidth

1. Introduction

The development in communication systems requires the development of low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a wide spectrum of frequency. The Microstrip antenna is very good for wireless communication due to their planar structure, light weight, low volume, low profile planer configuration which can be easily made conformal to host surface, and ease of integration with active devices. Additionally, some of its characteristics like low fabrication cost, supportive nature for both linear and circular polarization, and low sensitivity to manufacturing tolerance make this antenna very important for next generation [1]. However, conventional Microstrip Patch Antennas (MPA) have some drawbacks of low efficiency, narrow bandwidth (3-6%) of the central frequency; its bandwidth is limited to a few percentage which is not enough for most of the wireless communication systems nowadays [2]. Bandwidth enhancement, miniaturization and multi-band operation of Microstrip patch antennas is usually demanded for practical applications.

The most straightforward way to improve the MPA bandwidth is to increase the patch-ground plane separation by using a thicker substrate [3]. Many kind of miniaturization techniques, such as using of dielectric substrate of high permittivity [4], slot on the patch, DGS at the ground plane or a combination of them have been proposed and applied to Microstrip patch antennas.

The proposed antenna uses proximity coupled feeding because of its advantages, such as high bandwidth, less spurious radiations, good suppression of higher order modes and ease of impedance matching. In this technique, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The power from the feed network is coupled to the patch electromagnetically [5]. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), compared to other feeding mechanisms, due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices

between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances [6].

DGS is realized by etching off a simple shape in the ground plane, depending on the shape and dimensions of the defect, the shielded current distribution in the ground plane is disturbed, resulting a controlled excitation and propagation of the electromagnetic waves through the substrate layer. The impedance and surface current of the antenna is affected by DGS. The shape of the defect may be changed from the simple shape to the complicated shape for the better performance. Different shapes of DGS structures, such as rectangular, square, circular, dumbbell, spiral, L-shaped, concentric ring, U-shaped and V-shaped, hairpin DGS, hexagonal DGS, cross shaped DGS and combined structures have appeared in literatures. DGS is used in the Microstrip antenna design for different applications such as radiation properties enhancement, antenna size reduction, harmonic suppression, cross polarization reduction, mutual coupling reduction in antenna arrays, design approach for circular polarization, etc. Defected Ground Structure was initially invented by Park et al. in the year 1999 retaining the notion of Photonic Band-Gap Structure (PBG). Defected Ground structures (DGS) have two main characteristics- Slow Wave propagation in Pass band & Band Stop characteristics in microwave circuits. The DGS is considered as an equivalent circuit consisting of capacitance and inductance. The equivalent inductive part increases due to the defect and produces equivalently the high effective dielectric constant, that is slow wave property- due to this fact the DGS line has the longer electrical length than the standard Microstrip line- for the same physical length. By varying the various dimensions of the defect the desired resonance frequency can be achieved [7].

The purpose of this paper work is to present a compact Dual-Band MPA resonating at 2.4 GHz and 4.5 GHz dedicated to different wireless applications in the S-band and C-band. In this work, the Dual-Band operation and miniaturization of the antenna is studied by using a 'Dumbbell' shaped Defected Ground Structure in the ground plane and 'T' shaped slot on the radiating patch. It is found to be a simple and effective method to achieve a compact Dual- Band Microstrip patch antenna. Combining a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch a Dual-Band operation with reduced antenna size can be obtained.

2. Antenna Design

The MPA is made up of rectangular radiating patch printed on the first substrate, and a 'T' shaped slot is etched out form the center of this rectangular radiating patch. The microstrip feed line is placed on the upper side of the second substrate. The ground plane and the 'Dumbbell' shaped slot are on lower side of the second substrate. The geometry of a proximity coupled feed rectangular Microstrip patch antenna (RMPA) is shown in Figure 1.
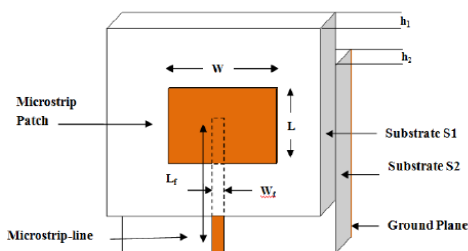

Figure 1. Geometry of a Proximity Coupled Feed RMPA

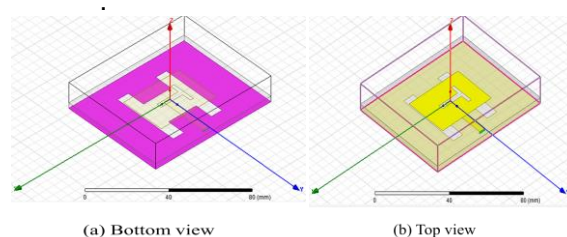(a) Bottom view   (b) Top view

Figure 2. The Proposed Proximity Coupled Feed MPA with a 'Dumbbell' shaped DGS and 'T' Shaped Slot on the Radiating Patch

The antenna is designed using TMM-3 substrate material with dielectric constant, $\varepsilon_r = 3.27$ and dissipation factor, $\tan \delta = 0.0020$. The two substrates used for this design are of different thickness, $h_1 = 1.905\ mm$ and $h_2 = 1.270\ mm$. When using proximity coupled feed method, the substrate parameters of the two layers can be selected to increase the bandwidth of the patch and to reduce spurious radiation from the microstrip feed line, for this the lower

layer should be thin. The radiating patch being placed on the double layer gives a larger bandwidth [8]. The length and width of the patch are 27mm and 35.943mm, which are dimensioned to resonate at 2.4 GHz and 4.5 GHz. The length and width of the ground plane are 62.3mm and 75.6mm. The microstrip feed line is dimensioned for 50Ω characteristic impedance, the width of the feed line is 4mm and the length is 31.23mm, and the location of the feed line is (-2,-2.23,-1.905) for best impedance matching. The designed structure of the proximity coupled feed MPA with 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch is shown in Figure 2

Initially a simple proximity coupled feed RMPA is designed to resonate at 2.4 GHz. Next, a 'Dumbbell' shaped defect (i.e., shown in Figure 3 with its dimensions) is etched out from the ground plane of the proximity coupled RMPA, which results in an enhanced antenna performance. Etching out a 'T' shaped slot (i.e., shown in Figure 4 with its dimensions) from the radiating patch surface of the proximity coupled RMPA with 'Dumbbell' shaped DGS, results in a shift in resonant frequency down from 2.4 GHz to 2.2 GHz. This is mainly attributed to the inserted defect which lengthens the current path making the patch radiator to appear larger, hence radiating at a lower frequency than before. To make the proximity coupled MPA with 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch radiate at the original frequency of 2.4 GHz, the dimensions of the patch must be reduced. This means compensating for the current path already lengthened, which results in size reduction of the reference antenna, i.e., the simple proximity coupled RMPA without DGS and slots on the radiating patch. Reducing the patch dimensions of the reference antenna, i.e., the simple proximity coupled RMPA without DGS and slots on the radiating patch, to the values given earlier 27mm * 35.943mm which accounts to 30.3 % reduction in the overall area of the patch, and varying the length and location of the feed line for best impedance matching, a compact Dual-Band MPA resonating at 2.4 GHz and 4.5 GHz is achieved.

The 'Dumbbell' shaped defect in the ground plane, which is shown with its dimensions in Figure 3, is centered below the microstrip feed line with respect to x-axis.
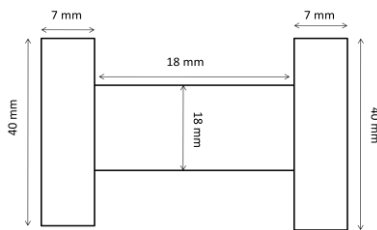

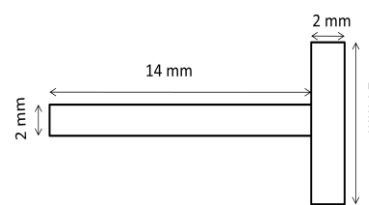Figure 3. 'Dumbbell' shaped DGS with its dimensions

Figure 4. 'T' shaped slot on the radiating patch with its dimensions

The implemented 'T' shaped slot on the radiating patch with its dimensions is shown in Figure 4.

For a specific resonant frequency (f_r), dielectric constant of the substrate (ε_r) and height of the substrate (h); the design procedure of a rectangular MPAs using transmission-line model is as follows:

1. The Patch Width (W): for efficient radiation is given as;

$$W = \frac{c}{2f_r} \sqrt{\frac{\varepsilon_r + 1}{2}}$$ (1)

Where,
W, is the patch width.
c, is the free space velocity of light,
f_r, is the resonant frequency, and
ε_r, is the dielectric constant of the substrate

2.   The Effective Dielectric Constant (ε_{reff}) **-** Due to the fringing and the wave propagation in the field line, an effective dielectric constant (ε_{reff}) must be obtained.

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

Where,
ε_{reff} , is the effective dielectric constant
h, is the height of the dielectric substrate
3.   The Effective Length (L_{eff}): for a given resonance frequency (f_r) is given as:

$$L_{eff} = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} \tag{3}$$

4.   The Length Extension (ΔL): is given as:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

5.   The Patch Length (L): The actual patch length now becomes:

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

6.   Calculation of Ground Dimensions (L_g and W_g)
    The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, the ground plane dimensions would be given as [9]:
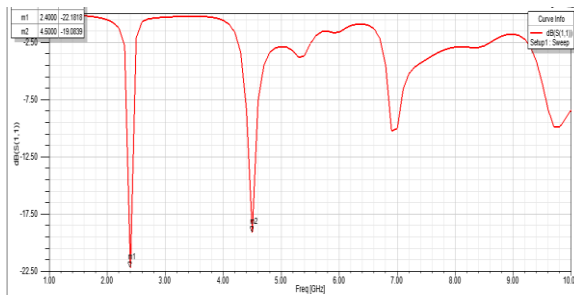
$$L_g = 6h + L \tag{6}$$

$$W_g = 6h + W \tag{7}$$

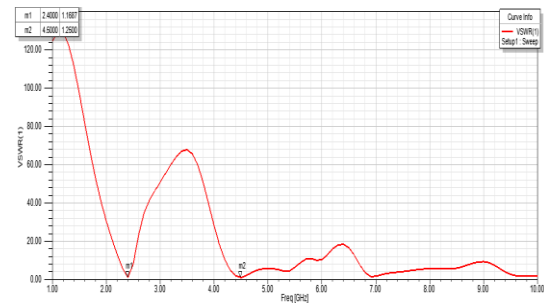Figure 5. Return Loss of the Dual-Band proximity coupled MPA SHA' shaped DGS

Figure 6. VSWR of the Dual-Band proximity coupled MPA DGS

3. Results and Discussions
    Full-wave Electromagnetic (EM) Field Simulator, High Frequency Structure Simulator (HFSS) software package Version 13.0 (HFSS V.13.0) is used to obtain the performance parameters of the proposed antenna.

3.1. Return loss and Bandwidth
    The proximity coupled MPA with a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch shows good return loss of -22.1818 dB at 2.4 GHz and -19.0839 dB at 4.5 GHz

as shown in Figure 5. The bandwidth of the designed antenna is found to be 123.6 MHz at 2.4 GHz and 200 MHz at 4.5 GHz.

3.2. VSWR

Figure 6 shows VSWR plot of the proposed proximity coupled MPA with a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch. The designed antenna shows the VSWR of 1.1687 at 2.4 GHz and 1.2500 at 4.5 GHz, which shows that the proposed antenna results in acceptable impedance matching.

3.3. Directivity

Figure 7 shows the 3D Polar Plot of Total Directivity obtained for the proposed proximity coupled MPA with a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch. The Total Directivity of the proposed antenna is found to be 4.8440 dB at 2.4 GHz, and 7.1733 dB at 4.5 GHz as shown in Figure 7(a) and 7(b).
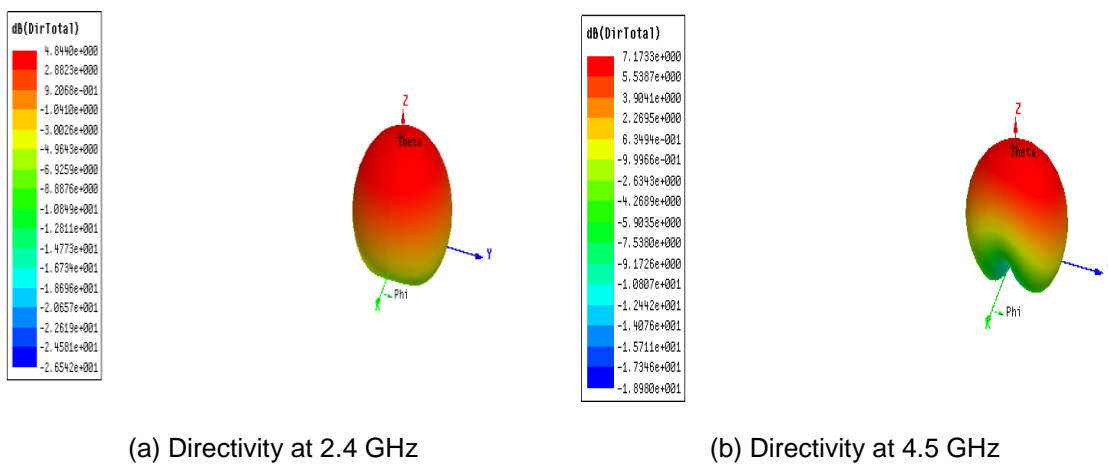

(a) Directivity at 2.4 GHz   (b) Directivity at 4.5 GHz

Figure 7. 3D polar plot of Total Directivity of the Dual-Band proximity coupled MPA

3.4 Total Gain

Figure 8 shows the Polar Plot of Total Gain obtained for the proposed proximity coupled MPA with a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch. The Total Gain obtained is 4.5568 dB at 2.4 GHz, and 6.9770 dB at 4.5 GHz as shown in Figure 8(a) and 8(b).
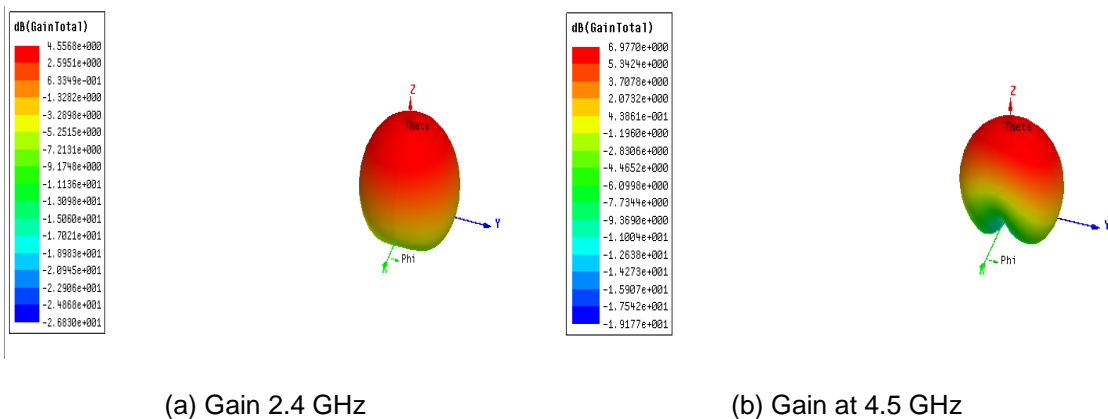

(a) Gain 2.4 GHz   (b) Gain at 4.5 GHz

Figure 8. 3D Polar Plot of Total Gain of the Dual-Band proximity coupled MPA

4. Conclusion

A compact Dual- Band proximity coupled Microstrip patch antenna design with a 'Dumbbell' shaped DGS and 'T' shaped slot on the radiating patch working in S-band and C-band has been successfully accomplished in this paper. Etching out a 'Dumbbell' shaped defect from the ground plane and 'T' shaped slot from the radiating patch of a simple proximity coupled feed rectangular Microstrip patch antenna resonating at 2.4 GHz, a compact Dual-Band MPA resonating at 2.4 GHz and 4.5 GHz, with 30.3 % and 18.8% reduction in the overall area of the patch and the ground plane of the reference antenna respectively is achieved. The proposed antenna is useful for different wireless applications in the S-band and C-band.

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