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Bandwidth Enhancement of Rectangular Microstrip Patch Antenna using Defected Ground Structure

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Abstract

This paper presents the bandwidth enhancement of a Proximity Coupled Feed Rectangular Microstrip Patch Antenna using a new Defected Ground Structure - an 'inverted SHA' shaped slot on the ground plane of the proximity coupled feed rectangular Microstrip patch antenna. The parameters such as Bandwidth, Return loss, VSWR and Radiation efficiency are improved in the proposed antenna than simple proximity coupled feed rectangular Microstrip patch antenna without Defected Ground Structure. A comparison is also shown for the proposed Microstrip patch antenna with the antenna structure without Defected Ground Structure. The proposed antenna resonates in S-band at frequency of 2.4 GHz with bandwidth of 180 MHz. A very good return loss of -47.9223 dB is obtained for the Microstrip patch antenna with an 'inverted SHA' shaped Defected Ground Structure. Implementing an 'inverted SHA' shaped defect in the ground plane of the proximity coupled feed rectangular Microstrip patch antenna results in 5.3% improvement in bandwidth with 16.01% reduction in the overall area of the ground plane as compared to the Microstrip patch antenna without Defected Ground Structure.

Keywords: *An 'inverted SHA' defected ground structure, proximity coupling, 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 and miniaturization of Microstrip patch antennas is usually demanded for practical applications.

The most straightforward way to improve the Microstrip patch antenna 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, Defected Ground Structure (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].

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Defected Ground Structure (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 [7].

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., [7].

DGS 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].

In this paper an antenna with enhanced bandwidth dedicated to different wireless applications in the S-band, like IMT, WLAN, ISM, RFID and Bluetooth applications is presented. Bandwidth enhancement is studied by using an 'inverted SHA' shaped Defected Ground Structure in the ground plane, and it is found to be a simple and effective method to enhance the performance of the antenna. Etching this DGS in the ground plane of the proximity coupled feed rectangular Microstrip patch antenna (PRMPA), bandwidth broadening is achieved.

2. Antenna Design

The Microstrip patch antenna is made up of rectangular radiating patch printed on the first substrate. The microstrip feed line is placed on the upper side of the second substrate. The ground plane and the 'inverted SHA' shaped slot are on lower side of the second substrate. The geometry of a Proximity Coupled Feed Rectangular Microstrip Patch Antenna (PRMPA) is shown in Figure 1.

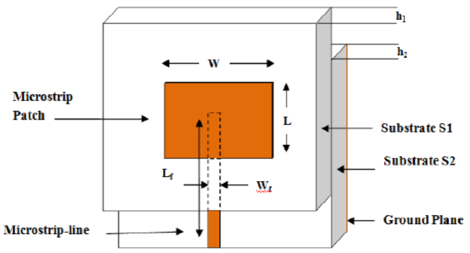

Figure 1. Geometry of a Proximity Coupled Feed RMPA

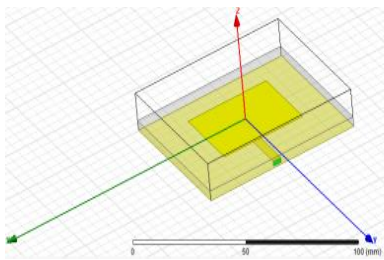

Figure 2. Deigned Structure of the PRMPA

The antennas are 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 31.4mm and 41.8mm, which are dimensioned to resonate at 2.4GHz. 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 used in the RMPA without DGS is 31.25mm, and the location of the feed line is (-2,-2.25,-1.905) for best impedance matching. The designed geometry of the proximity coupled feed RMPA without DGS is shown in Figure 2.

In order to improve the bandwidth and performance of the antenna, the ground plane is defected with an 'inverted SHA' shaped slot. The slot 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. The designed geometry of the microstrip patch antenna with the DGS is shown in Figure 4. An enhanced performance is obtained by reducing the length of the feed line from 31.25mm to 28mm and varying the location of the feed line for best impedance matching, the location of the feed line for this case is (0, 0, -1.905). By changing the feed point where matching is perfect, high return loss can be achieved at the resonant frequency.

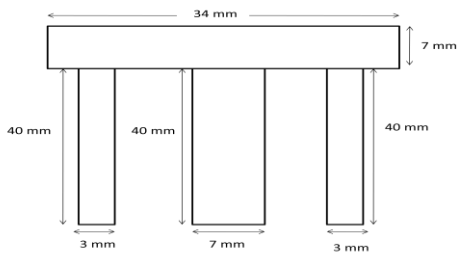

Figure 3. The 'inverted SHA' shaped DGS with its Dimensions

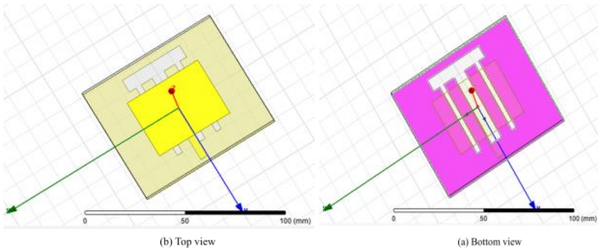

Figure 4. The Designed PRMPA with an 'inverted SHA' shaped DGS

The proposed antenna resonates at frequency (f_r) of 2.4 GHz. The resonant frequency, also called the center frequency, is the one at which the return loss is minimum. 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:

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

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 ($\boldsymbol{\varepsilon_{reff}}$) - Due to the fringing and the wave propagation in the field line, an effective dielectric constant (ε_{reff}) must be obtained.

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

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;

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

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

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

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

$$L = L_{eff} - 2\Delta L \quad (5)$$

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]:

$$L_g = 6h + L \quad (6)$$

$$W_g = 6h + W \quad (7)$$

3. Results and Discussions

The proposed PRMPA with an 'inverted SHA' shaped DGS is evaluated against different parameters to study its performance. A comparison is also done with simple proximity coupled feed RMPA without DGS.

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 PRMPA with an 'inverted SHA' shaped DGS shows good return loss of -47.9223 dB at the resonant frequency of 2.4 GHz as shown in Figure 5. At this resonant frequency, it gives a bandwidth of 180 MHz.

While the PRMPA without DGS gives a bandwidth of 171 MHz at the resonant frequency of 2.4 GHz. The return loss of the antenna without DGS at this resonant frequency is found to be -45.9128 dB as shown in Figure 6.

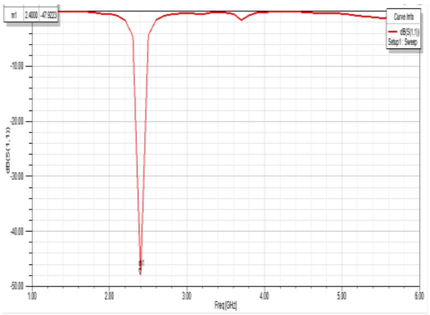

Figure 5. Return Loss of PRMPA with an 'inverted SHA' shaped DGS

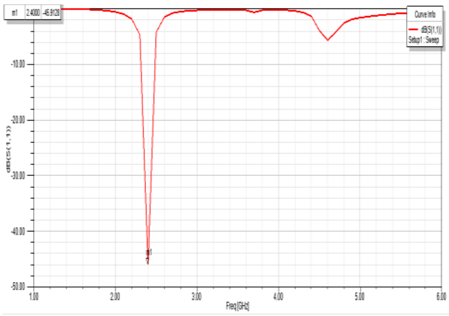

Figure 6. Return Loss of PRMPA without DGS

Thus it can be concluded that with an 'inverted SHA' shaped DGS, the bandwidth of the proximity coupled feed rectangular Microstrip patch antenna can be increased by 9 MHz (i.e. 180 MHz – 171 MHz = 9 MHz).

3.2. VSWR

Figure 7 shows VSWR plot of the proposed PRMPA with an ‘inverted SHA’ shaped DGS. At the resonant frequency of 2.4 GHz, the VSWR is found to be 1.0081. As the value of VSWR is approximately equal to 1 at the resonant frequency, the proposed antenna results in perfect impedance matching.

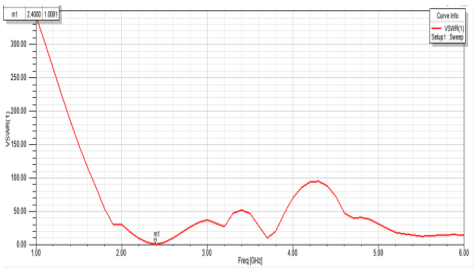

Figure 7. VSWR of PRMPA with an ‘inverted SHA’ shaped DGS

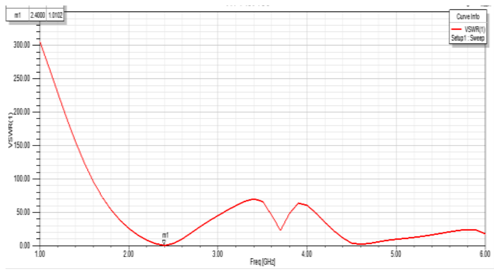

Figure 8. VSWR of PRMPA without DGS

While the VSWR in case of PRMPA without DGS, is 1.0102 at resonant frequency of 2.4 GHz as shown in Figure 8. Thus PRMPA with DGS exhibits better VSWR.

3.3. Directivity

Figure 9 shows the 3D polar plot of total directivity obtained for PRMPA with an ‘inverted SHA’ shaped DGS. As shown in this figure, the Total Directivity of the proposed antenna at resonant frequency of 2.4 GHz is 4.9412 dB.

Figure 9. 3D Polar Plot of Total Directivity of PRMPA with an ‘inverted SHA’ Shaped DGS

While the Total Directivity in case of PRMPA without DGS at resonant frequency of 2.4 GHz, is found to be 4.9277 dB as shown in Figure 10. Thus PRMPA with DGS exhibits better Directivity.

Figure 10. 3D Polar Plot of Total Directivity of PRMPA without DGS

3.4. Total Gain

Figure 11 shows the polar plot of total gain obtained for PRMPA with an 'inverted SHA' shaped DGS. As shown in this figure, the Total Gain of the proposed antenna at resonant frequency of 2.4 GHz is 4.7761 dB.

Figure 11. 3D polar plot of total Gain of PRMPA with an 'inverted SHA' shaped DGS

Figure 12. 3D polar plot of total Gain of PRMPA without DGS

While the total gain in case of PRMPA without DGS at resonant frequency of 2.4 GHz, is found to be 4.7190 dB as shown in Figure 12. Thus PRMPA with DGS exhibits better gain.

Table 1 summarizes the performance comparison of the designed antennas.

Table 1. Performance comparison of the 'PRMPA without DGS' and 'PRMPA with an inverted SHA shaped DGS' resonating at 2.4 GHz

Antenna parameter	Value PRMPA without DGS	PRMPA with an 'inverted SHA' shaped DGS
Return loss	-45.9128 dB	-47.9223 dB
Bandwidth	171 MHz	180 MHz
VSWR	1.0102	1.0081
Impedance	49.4966 ohms	49.6041 ohms
Directivity	4.9277 dB	4.9412 dB
Gain	4.7190 dB	4.7761 dB
Radiation efficiency	95.309%	96.269%

From Table 1, we can conclude that the PRMPA with an 'inverted SHA' shaped DGS exhibits improved radiation characteristics compared to PRMPA without DGS.

4. Conclusion

Microstrip patch antenna design with a new Defected Ground Structure working in S-band has been successfully accomplished in this paper. The bandwidth of the Microstrip patch antenna without DGS is 171 MHz at resonant frequency of 2.4 GHz with return loss of -45.9128 dB. While Microstrip patch antenna with an ‘inverted SHA’ shaped DGS provides bandwidth of 180 MHz and the return loss reaches up to -47.9223 dB. Thus it has been concluded that with an ‘inverted SHA’ shaped DGS, the bandwidth of the Microstrip patch antenna is increased by 9 MHz, i.e., which accounts for 5.3% improvement in bandwidth. And the other antenna parameters are also found be to improved with 16.01% reduction in the overall area of the ground plane. The proposed antenna is useful for different wireless applications in the S-band, like IMT, WLAN, ISM, RFID and Bluetooth applications.

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