Design of G-Shaped Defected Ground Structure for Bandwidth Enhancement

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ABSTRACT

This paper describes the effect of incorporation of G-shaped defected ground structure (DGS) on the performance of the simple microstrip patch antenna (MPA). The various antenna parameters such as Bandwidth (B.W.), Return loss (S_{11}) and Voltage Standing Wave Ratio (VSWR) get much improved in proposed antenna with Defected Ground Structure. Comparison of the performance characteristics of the proposed antenna with simple MPA without defect has been presented by simulating the antennas with Finite Element Machine (FEM) based software High Frequency Structure Simulator (HFSS) software Version-13.0 package. Simulated results reveal that the bandwidth of MPA is increased by 598.4 MHz with very good return loss of -49.43 dB with G-shaped DGS. Proposed antenna finds its application in C-band such as in satellite communications, Wi-Fi etc.

General Terms

Bandwidth (B.W.), return loss (S_{11}), Voltage Standing Wave Ratio (VSWR), gain and directivity.

Keywords

Defected Ground Structure (DGS), Microstrip Patch Antenna (MPA).

1. INTRODUCTION

Microstrip antenna is a topic of intensive research in recent years with the explosive growth of wireless system and booming demand for a variety of new wireless application. In recent years, as the demand of the small systems have increased, small size antennas have drawn much interest of researchers [1].

Microstrip antenna technology fulfill the requirements of modern communication system such as low profile, light weight, easy to fabrication, and conformability to mounting hosts in addition size reduction and bandwidth [1]. Therefore, the selection of microstrip antenna is suitable to apply at various fields such as telecommunication, medical application, satellite and military system [2]. However, microstrip antenna has its inherent shortcomings such as narrow bandwidth and low gain. The microstrip patch is inherently a narrow-band structure and a larger thickness of the grounded substrate helps in increasing its bandwidth [3]. But limited ground plane size is an essential requirement for its compactness as well as compatibility with the mobile wireless equipments. However, the bandwidth and the size of an antenna are generally conflicting properties i.e. improvement of one of the characteristics normally results in degradation of the other.

To overcome these drawbacks and to improve antenna characteristics, different techniques have been used by the researchers such as slotting, DGS, use of dielectric substrate of high permittivity [4] etc. The other method to miniaturize the microstrip antenna is to modify its geometry using irises [5] or folded structures [6-7] based on the perturbation effect [8]. Defected ground structure (DGS), where the ground plane metal of the microstrip antenna design is modified intentionally in order to enhance the performance [9-11]. The name for this technique simply means that a "Defect" has been etched off in the ground plane, which disturbs the shield current distribution in the ground plane and influences the input impedance as well as current flow of the antenna. A defect in the ground plane causes to increase in effective capacitance and inductance.

DGS may have various shaped slot like U-shaped slot, E-shaped slot, L-shaped slot, I-shaped slot etc. which helps to improve resonant bandwidth. Different types of antennas works in different frequency bands such as L-band ranges between 1-2GHz, S-band ranges between 2-4GHz, C-band ranges between 4-8 GHz and X-band ranges between 8-12 GHz etc. Each of these frequency bands has different working applications. Similarly proposed antenna finds its application in C-band such as in satellite communications, Wi-Fi etc. In this paper work, the design incorporates G-Shaped Defected Ground Structure in ground plane, which disturbs shielded current distribution in ground plane [12-13].

2. ANTENNA DESIGN

The equivalent circuit for a DGS is a parallel- tuned circuit in series with the transmission line to which it is coupled [14] as shown in Fig. 1. The input and output impedances are that of transmission line section, while the equivalent values of L, C and R are determined by the dimensions of the DGS structure and its position relative to the transmission line.

By specifying the following conditions, an antenna can be easily trimmed to the desired center frequency:

$$f_{10} = \frac{c}{\sqrt{\varepsilon_r}}\left(\frac{1}{2L}\right) \qquad (1)$$

where, f_{10} is resonant frequency in case of rectangular patch, “L” is length of patch, ε_r is substrate’s relative permittivity.

This is equivalent to say that the length "L" is one-half of a wavelength in the dielectric:

$$L = \frac{\lambda_d}{2} = \frac{\frac{\lambda_0}{2}}{\sqrt{\varepsilon_r}} \qquad (2)$$

where, λ_d is the wavelength in dielectric material.

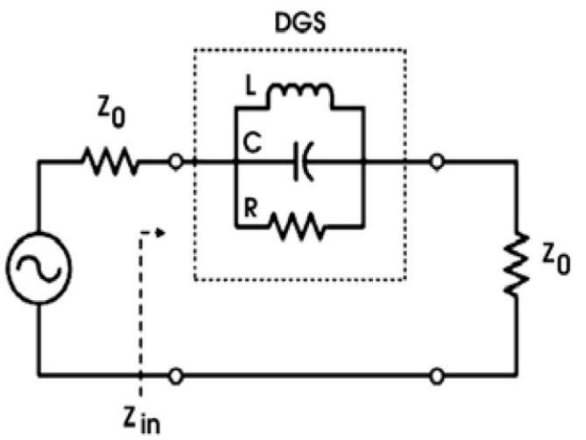

Fig 1: Equivalent circuit of a DGS element

Both MPA and proposed antennas are designed on Rogers RT/Duroid 5880 (tm) substrate with thickness (h_s) of 0.794 mm having relative permittivity (ε_r) of 2.2. The patch has the dimensions of 12.45mm × 16mm with height (h_p) of 0.05 mm. The ground has the dimensions of 28.1 mm × 32 mm with height (h_g) of 0.05 mm. Antenna is excited with microstrip feed having characteristics impedance of 50 Ω. The feed has dimension of 8 mm × 2.46 mm with height (h_f) of 0.05 mm. The complete geometry of simple MPA is shown in Fig. 2.

The proposed antenna design for C-band incorporates a G-Shaped slot in Ground. In G-shaped DGS antenna, the distance between inner turns is kept 9 mm and the width of turn is 2 mm. The complete geometry of proposed G-shaped DGS antenna is shown in Fig. 3.

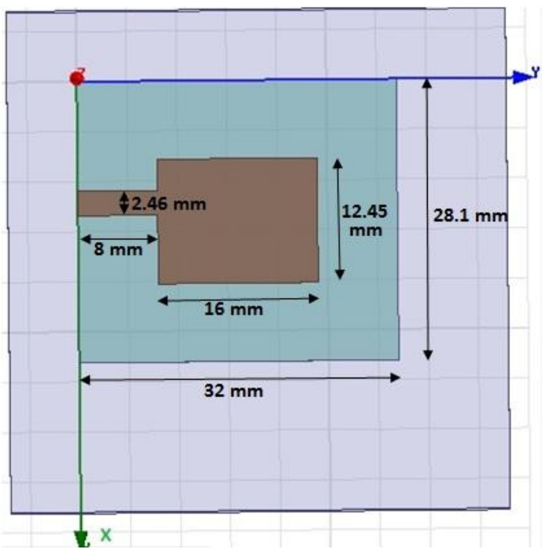

Fig 2: Geometry of simple MPA antenna

G-shaped DGS antenna also gives a large bandwidth as compared to simple MPA. To acquire large bandwidth, an antenna must satisfy the following relation:

$$W < 2L \quad (3)$$

$$W = 1.5\,L \text{ (Typical value)}$$

where, "L" represents the length of patch. The width "W" is usually chosen to be larger than L (to get higher bandwidth).

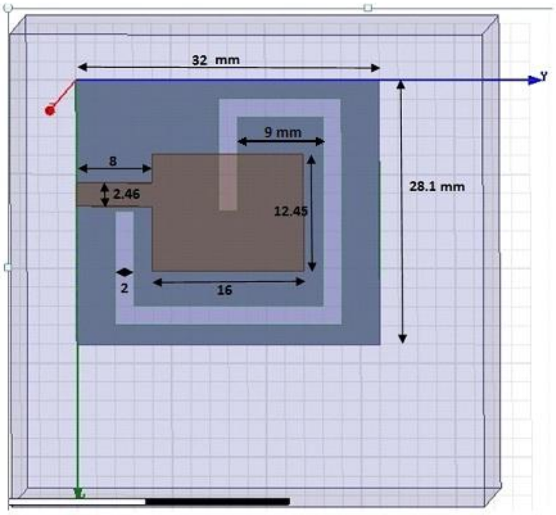

Fig 3: Geometry of G-shaped DGS antenna

Bandwidth is related to substrate thickness (h_s) and substrate permittivity(ε_r). If 'h_s' is greater than $0.05\lambda_0$, then probe inductance becomes too large to match the impedance. A higher substrate permittivity allows for a smaller antenna but lower bandwidth. Thus bandwidth and size of an antenna are generally conflicting properties i.e. improvement of one of the characteristics normally results in degradation of the other. In this paper, an appropriate dielectric material "Rogers RT/Duroid 5880 tm" is used for substrate with thickness (h_s) of 0.794 mm having relative permittivity (ε_r) of 2.2 and also satisfies all the above mentioned conditions.

In the design of patch, a few equations are used as reference before optimizing the dimension. With a specific resonant frequency f_r, the width and the length of patch are expressed as follows [15];

$$W_P = \frac{1}{2\, f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad (4)$$

$$L_P = L_e - \Delta L \quad (5)$$

$$L_e = \frac{c}{2 f_0 \sqrt{\varepsilon_e}} \quad (6)$$

$$\Delta L = 0.412\, h \, \frac{(\varepsilon_e + 0.3)(\frac{W}{h} + 0.2664)}{(\varepsilon_e - 0.258)(\frac{W}{h} + 0.8)} \quad (7)$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\,\frac{h}{W}\right]^{\frac{-1}{2}} \quad (8)$$

where , W_P = width of patch
L_P = length of patch
ΔL = extended length of patch
L_e = effective length of patch
ε_e = effective dielectric constant substrate
ε_r = relative dielectric constant of substrate

Table 1 shows some common design specifications for both antennas i.e. DGS and simple MPA.

Table 1. Common Design Specifications for simple MPA and DGS Antennas

Sr. No.	Specifications	Dimensions (mm) / Values
1.	Ground ($L_g \times W_g \times h_g$)	28.1×32×0.05
2.	Substrate ($L_s \times W_s \times h_s$)	28.1×32×0.79
3.	Patch ($L_P \times W_P \times h_p$)	12.45×16×0.05
4.	Feed ($L_f \times W_f \times h_f$)	2.46×8×0.05
5.	Permittivity of substrate material "Rogers RT/Duroid 5880 tm" (ε_r)	2.2

3. RESULTS AND DISCUSSIONS

The performance parameters of both antennas i.e. simple MPA and G-shaped DGS antenna are simulated with High Frequency Structure Simulator (HFSS) software Version-13.0.

3.1 Return loss (S_{11}) and bandwidth

S_{11} represents how much power is reflected from the antenna, and hence is known as the reflection coefficient. The bandwidth of the antenna can be calculated from return loss versus frequency plot at -10 dB.

Fig. 4 shows that when defect in ground plane is introduced, the proposed antenna resonate in C-band at resonant frequency (f_r) = 4.7154 GHz. A very good return loss of -49.43 dB at this resonating frequency (f_r) is obtained for this structure. At this resonant frequency, it gives a maximum impedance bandwidth of 687.5 MHz (i.e. m_1-m_2).

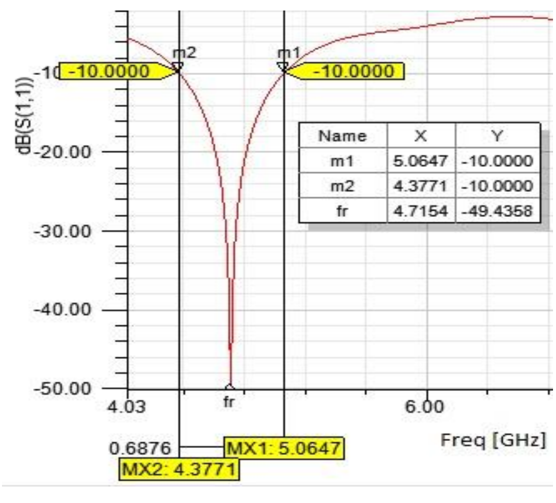

Fig 4: Return loss (S_{11}) of G-shaped DGS antenna

While from the Fig. 5, it is evident that in case of antenna structure without slotting in ground, the antenna also resonates in the C-band but at resonant frequency f_r = 7.53 GHz. The bandwidth of the microstrip patch antenna without slotting is 89.1 MHz at f_r 7.5351 GHz and also results in poor return losses (S_{11}) of -11.78dB.

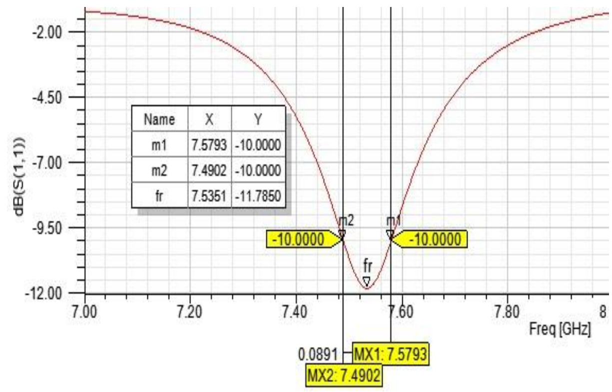

Fig 5: Return loss (S_{11}) of simple MPA without slotting

Thus it is concluded that with G-Shaped DGS, the bandwidth gets increased by 598.4 MHz than simple MPA (i.e. 687.5 MHz - 89.1 MHz = 598.4 MHz).

3.2 Voltage Standing Wave Ratio (VSWR)

VSWR is a measure of how well matched antenna is to the cable impedance. A perfectly matched antenna would have a VSWR of 1:1. This indicates how much power is reflected back or transferred into a cable. VSWR obtained from the simulation of G-type DGS antenna is 1.006 dB which is approximately equals to 1:1 as shown in Fig. 6. This shows the perfectly matching of an antenna with the port.

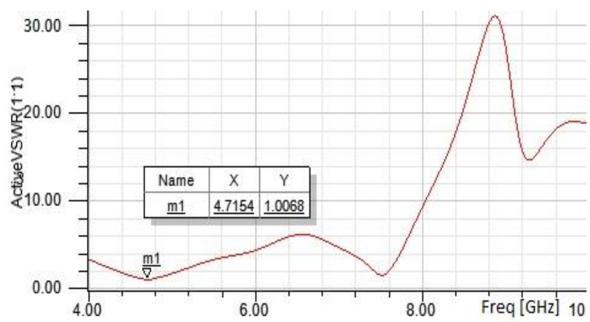

Fig 6: VSWR Plot of G-Shaped DGS Antenna

While the VSWR at resonating frequency f_r = 7.53 GHz, in case of simple MPA is 1.6935 as shown in Fig. 7. As the value of VSWR is more than 1.5, the port is poorly matched.

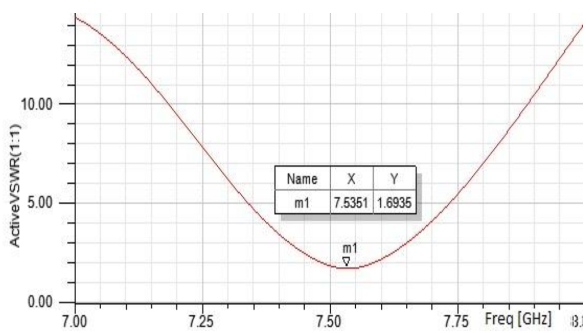

Fig 7: VSWR Plot of simple MPA without slotting

3.3 Input Impedance (Z_{in})

For an efficient transfer of energy, the impedance of the antenna and of feed line connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω impedance. Fig. 8 shows that the input impedance of G-shaped DGS antenna at the center frequency 4.71 GHz is 49.78 Ω; this is very close to the expected 50 Ω.

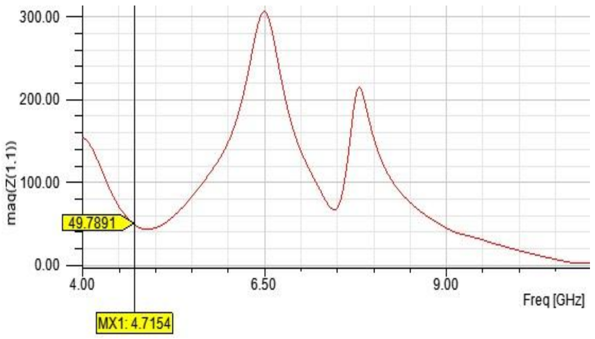

Fig 8: Input Impedance (Z_{in})

3.4 Total gain

Gain of an antenna is the ratio of the maximum radiation intensity in a particular direction from the test antenna to the maximum radiation intensity from reference antenna, when same input power is applied to both antennas.

Fig. 9 shows the simulated Polar plot for gain, obtained from G-shaped DGS Antenna. The Total Gain provided by proposed antenna is 7.12 dB.

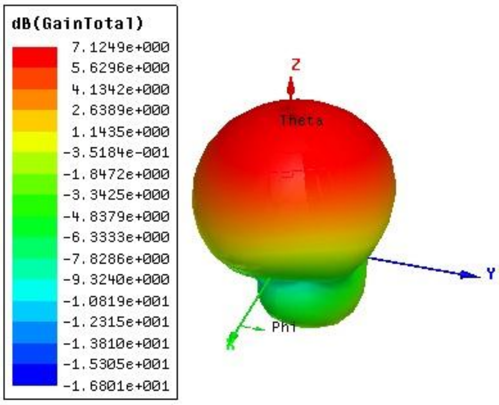

Fig 9: 3D Polar Plot of G-shaped DGS antenna for total gain

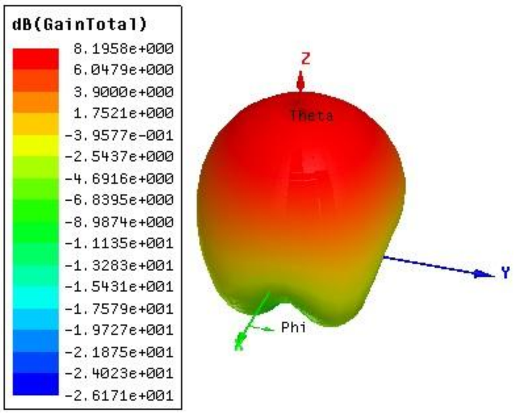

Fig 10: 3D polar plot of simple MPA antenna for total gain

While the simulated gain at resonant frequency f_r = 7.53 GHz, in case of simple MPA is 8.19 dB as shown in Fig. 10.

3.5 Directivity

Directivity of a non-isotropic antenna is equal to the ratio of its radiation intensity in a given direction over that of an isotropic antenna.

Fig. 11 shows the 3D Polar Plot of Total Directivity obtained from G-slot DGS Antenna. This figure shows that the Total Directivity of the proposed antenna is 7.14 dB.

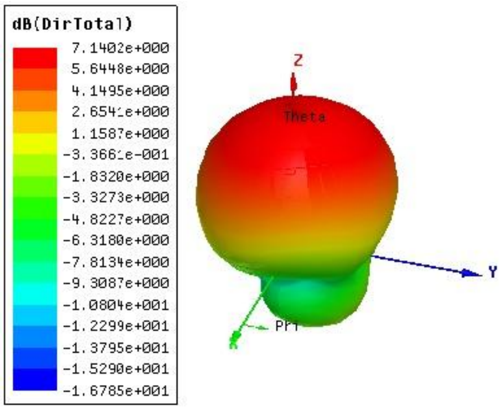

Fig 11: 3D Polar plot of G-shaped DGS antenna for total directivity

While the simulated directivity at resonant frequency f_r= 7.53 GHz, in case of simple MPA antenna is 8.20 dB as shown in Fig. 12.

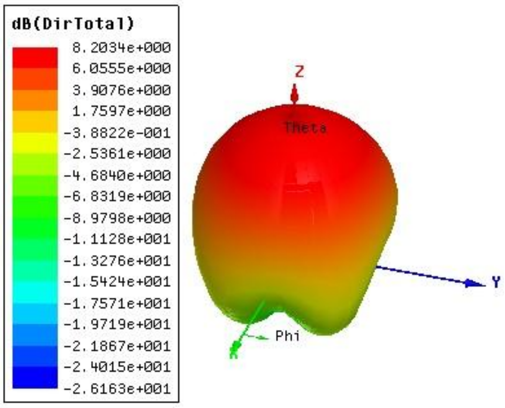

Fig 12: 3D polar plot of simple MPA for total directivity

Table 2 summarizes the obtained simulation features of the designed antennas.

Table 2. Comparison of simulated results of both antennas

Sr. No.	Parameters	MPA Antenna	G-Shaped DGS Antenna
1.	Resonating Frequency (GHz)	7.53	4.71
2.	Bandwidth (MHz)	89.1	687.5
3.	Return Loss (dB)	-11.78	-49.43
4.	VSWR	1.69	1.006 (≈ 1)

4. CONCLUSION

Simple MPA gives bandwidth of 89.1 MHz at resonant frequency of 7.53 GHz and also results in poor return loss of -11.78 dB as shown in Fig. 5. While G-Shaped DGS antenna provides bandwidth of 687.5 MHz and return loss reaches up to -49.43 dB at resonating frequency (f_r) of 4.71 GHz as shown in Fig. 4. It has been observed from the results that the impedance bandwidth of G-Shaped DGS antenna is very large as compared to the simple MPA. Bandwidth is increased by 598.4 MHz with G-shaped DGS antenna than simple MPA. The obtained value of VSWR is 1.006 dB in case of proposed G-shaped DGS antenna i.e. equal to unity. This G-Shaped DGS antenna design is useful for Wi-Fi and satellite communications.

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