Dumbbell Shaped Defected Ground Structure High Gain Antenna for Dual Band Application

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Abstract. Based on the traditional antennas with DGS, we have compared three similar circular DGS designs to find a better one in this paper. Meanwhile, four T-shaped slots impedance transformer is used on the patch as a dual-band recouple to achieve dual-band technology. With the simulation, it is found that the antenna with three circular defects on the ground plane has better performances than the other two antennas. It has two resonant frequencies at 7.5GHz and 8.9GHz. The relative bandwidth is 3.33% and 3.94%, and the corresponding gain value is 9.45 dBi and 13.37dBi at two different resonance frequencies. Further, we obtained a higher gain, lower return loss and dual-band characteristics which can be used in the satellite communications.

Keywords: High gain, dumbbell shape defected ground, dual-band, bandwidth, return loss, compact antenna

1. Introduction

Modern wireless communication systems typically require an antenna that meets the low cost, high performance, compact size, broadband, and small size. Due to its simple structural design, microwave components with a defective structure (DGS) are gaining popularity among all the reported technologies for enhancing the parameters. Kim and Park [1,2] first proposed the structure and used the term 'DGS' to describe a single unit of the dumbbell-shaped defect. DGS can be considered as a simplified form of EBG structure [3], which also has a band-stop characteristic [4]. Due to its simplicity and low cost, it has become an EBG substitute for modern applications.

A variety of novel DGSs have been proposed and this structure has also played a significant role in the exploration of microwave circuits. Since then, the development process of different DGS designs and properties have been explored and reported [4-11]. Dumbbell-shaped DGS was originally used to implement filters [12-20], and other shapes were subsequently reported for use in various microwave circuit areas such as amplifiers [21], mouse competing couplers [22], branch line couplers and Wilkinson power distribution [23,24]. Some researchers have integrated DGS with MPA [25]. Different DGS printed antennas are under study [11].

The DGS unit has inherently resonant characteristics and the equivalent circuit of unit DGS was represented by the parallel combination of L (inductance) and C (capacitance). This property of DGS is mostly used to develop the filter circuits. Besides, many studies have shown that the DGS structure can reduce the mutual coupling between the antenna elements, so the structure can improve the gain of the antenna. The defect implanted in the ground plane disturbs the current distribution in the ground plane. The resonator can be developed by implanting DGS in the ground plane. Various shapes could be etched on the microstrip to form a unit DGS. Therefore, the DGS plays a very important part in designing of microstrip patch antenna.

Many approaches were taken to achieve dual band characteristics. Printed dipoles [26], printed monopole [27], planar, and slot [28] antennas are widely used to realize dual-band operation. However, the slots make the patch structures of these antennas relatively complicated. Dielectric resonators [29, 30] and Chip antennas [35,36] also provide dual-band coverage, but the fabrication process is complex and difficult to produce. Although providing these two bands, rectenna [31,32], stacked patch [33,34] and aperture-coupled antennas [37,38] take up a lot of space and are difficult to integrate with handheld devices. Meanwhile, the gain of these reporting antennas is usually low, relatively less than 7 dB; however, for long-range detection of RFID transponders, a reader antenna of high gain is indispensable.

In this paper, a high-gain dual-band antenna with defected ground structure covering frequency bands of 7 and 10 GHz is introduced. Four T-shaped slots impedance transformer are used on the patch as a dual-band recouple [39, 40] to reduce the mutual coupling of two very closely positioned dual-band PIFAs. Through the simulation results presented in Figures. (2-7) and Table 2 below, we can find that the proposed antenna has the advantages of simpler and smaller structure as well as a higher gain than the previously developed dual-band antennas.

2. Design structure

There are many techniques to enhance the performance of conventional microstrip antennas, such as using stacking, different feeding techniques, frequency selective surfaces (FSS), photonic band gap (PBG), electromagnetic band gap (EBG), metamaterial, and so on. Microwave component with defected ground structure (DGS) has been gained popularity among all of them due to its simple structural design. A compact geometry slot embedded in the ground plane of a microwave circuit is called a defective ground structure (DGS). DGS may contain a single defect (cell) or multiple periodic and periodic defect configurations.

Therefore, DGSs are referred to as the periodic and/or periodic defects etched on the ground plane of the planar microwave circuit.

The proposed antenna is shown in Figure 1. The proposed antenna (size 35×30×1.6mm^3) is designed on the substrate with relative permittivity(ε_r) of 2.2, loss tangent of 0.0009 and 1.6 mm thickness. Four T-shaped slots are cut on the four sides of the radiating patch to achieve dual-frequency operation. The length of each slot is 6mm and width 1mm with a spacing of 2mm from the edge respectively. The defected ground structure is used in the proposed antenna which has already shown in Figure 1. The radius of each circle on the ground is 3mm. Specific parameters are given in Table 1. The theory and discussion part described in the following sections.

3. Theory

Because of the fringing effects, electrically the patch of the antenna looks larger than its physical dimensions the enlargement on L is given by:

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

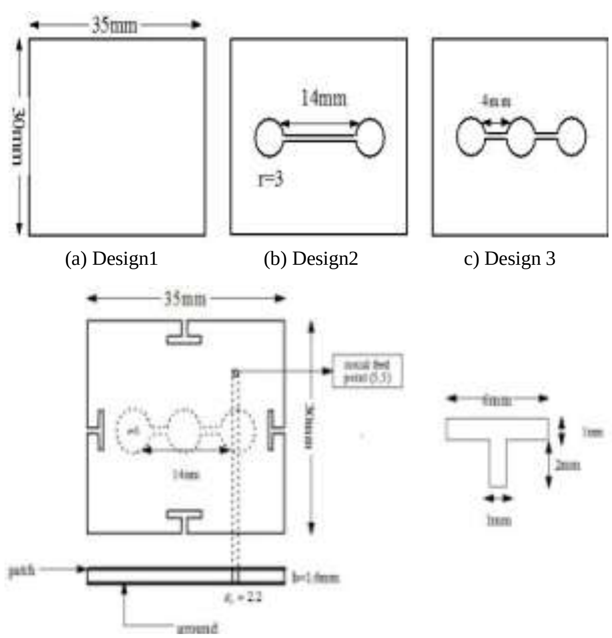
Where the effective (relative) permittivity is,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2\sqrt{1+12\,hW^{-1}}} \quad (2)$$

This is related to the ratio of *h/W*. The larger the *h/W*, the smaller the effective permittivity. The effective length of the patch is given by:

$$L_{eff} = L + 2\Delta l \quad (3)$$

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



(a) Design1 (b) Design2 c) Design 3

(d) (e)

Fig.1: (a) Without defected ground plane (b) with defected 2 circle (c) with defected 3 circle (d) proposed antenna (e) T-shape slot geometry.

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

An optimized width for an efficient radiator is,

$$W = \frac{1}{\left(2\,f_r\sqrt{\varepsilon\;\mu_0}\right)\times\sqrt{\frac{2}{\varepsilon_r+1}}} \quad (5)$$

3.1. Design procedure

If the substrate parameter (ε_r and h) and the operating frequency (f_r) are known then the dimensions of the patch antenna are calculated using above simplified equations. Following design procedure is used to design the antenna:

Step1: Using Eq. (5), find out the patch width *W*.

Step2: Calculate the effective permittivity using the Eq. (2).

Step3: Compute the extension of the length using the Eq. (1)

Step4: Determine the length *L* by solving the equation for *L* giving the solution.

Eq. (4) gives the resonance frequency at which the rectangular microstrip antenna is to be designed. The radiating edge *W*, patch width is usually kept such that it lies within the range for efficient radiation. The ratio gives good performance according to the side lobe appearances. The actual value of resonance frequency is slightly less than because fringing effect causes the effective distance between the radiating edges of the patch to be slightly greater than *L*. By using the above equations we can find the values of actual length of the patch as:

$$L = \left[\frac{1}{\left(2\,f_r\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_0\mu_0}\right)}\right] - 2\Delta L \quad (6)$$

The most sensitive parameters are found to be the thickness of substrate, shape, and size of slots; notches are selected for the parametric study. To accurately understand the influence of these parameters on its impedance bandwidth, only one parameter at a time was varied, while others were kept constant. The dimensions of the proposed antenna design are given in Table 1.

4. Results and discussion

The proposed antenna is simulated using ANSYS HFSS 15.0. The size of the antenna is about a quarter of the working wavelength. In this section, simulation results of the reflection coefficient, gain, radiation patterns about antennas with different defected ground structures are compared.

Figure 2, shows the S_{11} characteristics of three antennas design. It is observed that the resonance of antenna1 occurred at 8.0 GHz with a return loss value 15.02dB. The resonances of antenna 2 occurred at 7.9GHz, 9.0GHz with the corresponding return loss values of 13.19dB and 10.82dB, respectively. The resonances of antenna 3 occurred at 7.5GHz, 8.9GHz with the corresponding return loss values 23.79dB and 16.11dB, respectively. The details of which are given in Table 2.

Table: 1: Design Parameters

Parameters	**Value (mm)**
Patch Length (*L*)	35
Patch Width (*W*)	30
Defected patch Length (*Lg)*	35
Defected Patch Width (Wg)	30
Substrate (Rogers 2.2) Thickness (*h*)	1.6
First Defected sphere radius (r_1)	3
Second Defected sphere radius (r_2)	3
Third Defected sphere radius (r_3)	3
Notch Length (Ln_1 Ln_2 $Ln_3,$ Ln_4)	2
Notch Width (Wn_1 Wn_2 $Wn_3,$ Wn_4)	1
Slot Length (Ls_1 Ls_2 $Ls_3,$ Ls_4)	6
Slot Width (Ws_1 Ws_2 $Ws_3,$ Ws_4)	1
Ground Slots length (LGs_1LGs_2)	4
Ground Slots Width (WGs_1WGs_2)	1
Feed Location (X_0,Y_o)	(5,5)

Table 2: Variation of resonance frequency and gain of three different antennas

Antenna Type	Resonance Freq (GHz)	BW%	Gain(dB)
Antenna1	8.0 GHz (7.85-8.06)	2.60	16.74
Antenna2	7.9 GHz (7.85-7.97)	1.50	13.51
	9.0 GHz (8.9-9.2)	3.33	12.47
Antenna3	7.5 GHz (7.4-7.65)	3.33	9.45
	8.9 GHz (8.75-9.10)	3.93	13.37

Figure 3 shows the simulated gain versus operating frequency plot of the proposed antenna, the difference in the simulated gain increases more or less above 5.0 GHz in the specified region. The gain value of three antennas at the entire frequency band is reported in Figure 3 which confirms that gain is well positive at all the resonating frequencies. The gain value of the first antenna design at the resonating frequency 8.0 GHz is 16.74 dB, the gain value of the second antenna design at the resonating frequencies 7.9 GHz, 9.0 GHz is 13.5 dB and 12.47 dB, the gain value of the third antenna design at the resonating frequencies 7.5 GHz, 8.9 GHz is 9.45 dB and 13.37 dB, which represents that proposed antenna is a good radiator. Furthermore, we have described the radiation pattern of the proposed antenna, which can see in next section.

Radiation characteristics of the proposed antenna are analyzed through Figures.(4-7).The radiation characteristics in the E-plane(Y-Z plane) and H-plane (X-Y plane) are presented at various resonating frequencies according to the practical applicability of the proposed antenna design. It is obvious from Figures.4-5 that the three antennas are radiating well at an angle of φ =0at E-plane and φ =90 at H-plane and at their first resonating frequencies. From Figures 6-7, one can see that the three antennas are radiating well at an angle of φ =0 at E-plane and φ =90at H-plane and at their second resonating frequencies. Radiation characteristics of the proposed antenna are analyzed through Figures (4-7).

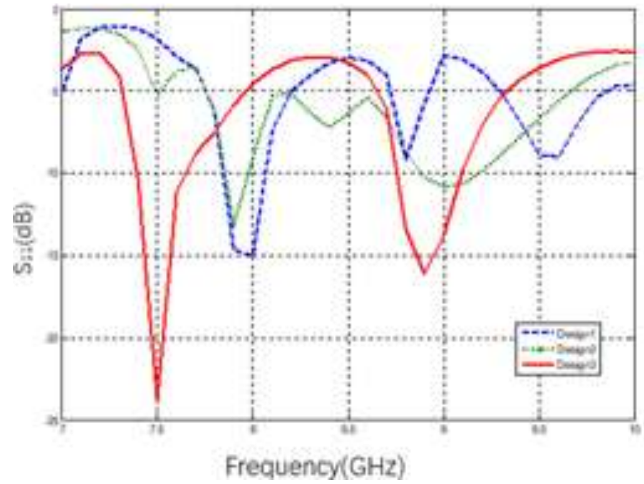


Fig.2 Variation of reflection coefficient *vs* frequency of antenna design 1-2-3.

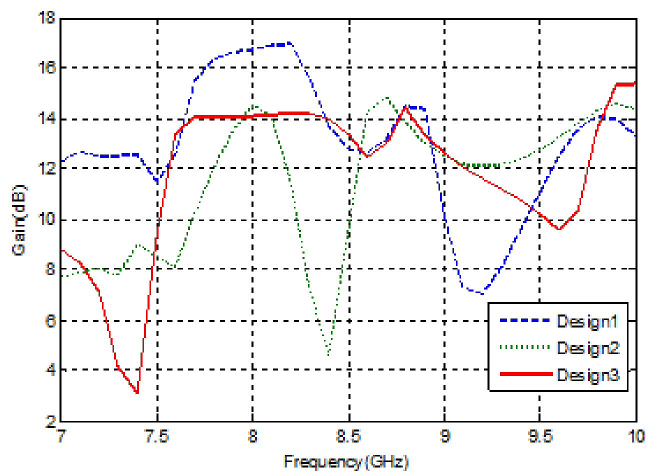


Fig.3: Variation of gain vs. frequency of antenna design 1-2-3.

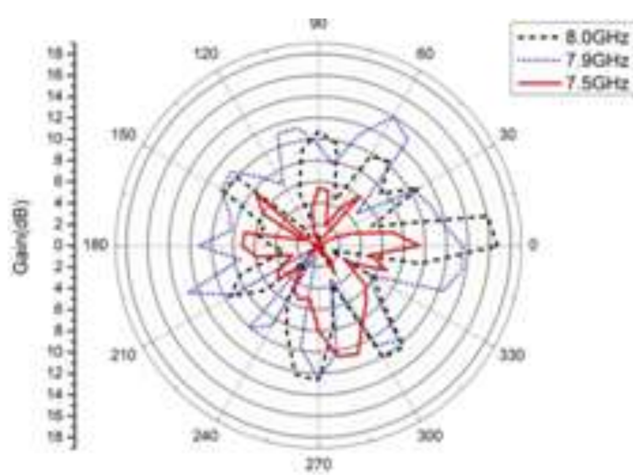


Fig.4: Radiation pattern of antenna (F_1=8.0GHz, Antenna-1) (F2=7.9 GHz, Antenna-2) (F_3=7.5 GHz, Antenna-3) (Cross -Co Polarization).

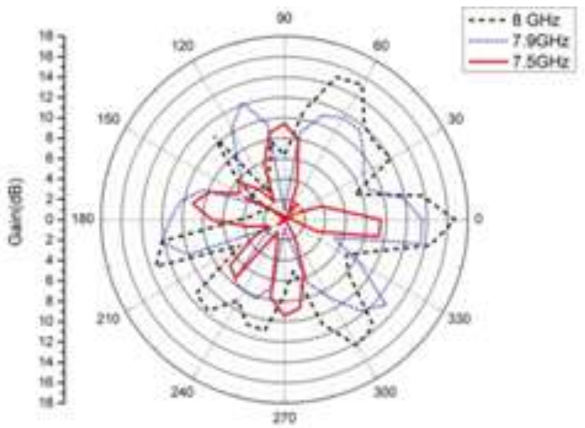


Fig.5: Radiation pattern of antenna H-plane (F_1=8.0GHz, Antenna-1) (F2=7.9 GHz, Antenna-2) (F_3=7.5 GHz, Antenna-3).

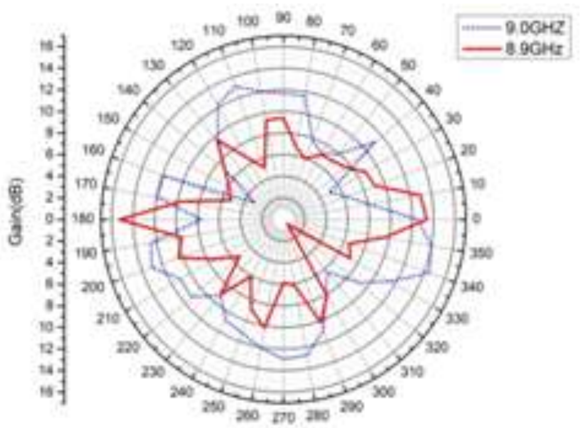


Fig.6: Radiation pattern of antenna E-plane (F2=9.0 GHz, Antenna-2) (F_3=8.9 GHz, Antenna-3).

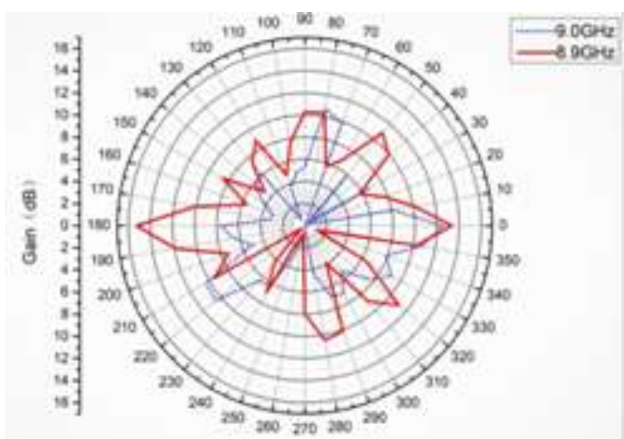


Fig.7: Radiation pattern of antenna H-plane (F2=9.0 GHz, Antenna-2) (F_3=8.9 GHz, Antenna-3).

The radiation characteristics in the E-plane(Y-Z plane) and H-plane (X-Y plane) are presented at various resonating frequencies according to the practical applicability of the proposed antenna design.

It is obvious from Figures 4-5 that the three antennas are radiating well at an angle of φ=0at E-plane and φ=90 at H-plane and at their first resonating frequencies From Figures 6-7, one can see that the three antennas are radiating well at an angle of φ=0 at E-plane and φ=90at H-plane and at their second resonating frequencies. Two different angles of 'φ' have been decided just to provide the broader view of the Performance of antenna otherwise it is sufficient to plot the radiation patterns at a single angle of 'φ'.

5. Conclusion

In this paper, high gain dual-band antenna with DGS has been proposed. The proposed antenna is small in size, light weight, low cost, and can reach a maximum gain value of 13dBi in a limited volume. Its operating frequencies are at 7.5GHz and 8.9GHz and the relative bandwidth are 3.33% and 3.94%. It can be used for short-range communication and measurement antenna like Radar. It can also be used as a reference for the next step on a larger scale, higher gain rectangular microstrip antenna design.

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