Defected Ground Structure Multiband Microstrip Patch Antenna using Complementary Split Ring Resonator

Jigar M. Patel, Shobhit K. Patel and Falgun N. Thakkar

Abstract: **In this paper, Defected Ground Structure (DGS) microstrip patch antenna using Complementary Split Ring Resonator (CSRR) is designed and analysed. The aim to design such type antenna is to achieve multiband application which is the demand of current technology. Here Microstrip patch antenna with rectangle shape of patch with patch dimension 50×50 mm^2 is analysed. The proposed design is tuned with seven bands in the frequency range of 1–5 GHz depending on the geometric specification of antenna and the location of feed which can be used for multiband applications. Design results of VSWR, Return loss (S_{11}), Radiation Pattern are shown in this paper which is obtained by High Frequency Structure Simulator (HFSS).**

Keywords- **Microstrip, Multiband, DGS, CSRR.**

I. Introduction

It is necessary to design multiband antennas to cover wide range frequency as per the requirement of mobile communication in current scenario. The design of such antenna has several advantages like light weight, small size, low cost fabrication and easy to integration with feed networks [1-10]. Microstrip patch antennas are mostly used in wireless device and other compact sizes with multiband applications.

Microstrip patch antennas have narrow bandwidth and bandwidth enhancement is the practically application demand of today. In addition some applications of MPA required small size to meet the miniaturization in communication systems.

Jigar M. Patel, and Shobhit K. Patel are with G. H. Patel College of Engineering and Technology, V.V.Nagar, Gujarat, India Shobhit K. Patel and Falgun N. Thakkar is with Charotar University of Science and Technology, Changa, Gujarat, India, Email: jmp_ec@yahoo.com, shobhit_65@yahoo.com, falgungcet@gmail.com

Defected Ground Structure is the one of the methods to use for this purpose. In this method the size of the antenna is reduced. DGS is realized by introducing a shape defected on a ground plane thus will disturb the shielded current distribution depending on the shape and dimension of the defect .The disturbance at the shielded current distribution will influence the input impedance and the current flow of the antenna. It can also control the excitation and electromagnetic waves propagating through the substrate layer. DGS is any defect etched in the ground plane of the microstrip can give rise to increasing the effective capacitance and inductance. DGS have the characteristics of stop band slow wave effect and high impedance.

DGS are basically used in microstrip antenna design for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc. DGS is widely used in microwave devices to make the system compact and effective. Therefore, in this paper we design a microstrip patch antenna with Defected Ground Structure for bluetooth to determine the effect of using DGS. Complementary Split Ring Resonator (CSRR) is used as DGS.

Complementary Split Ring Resonator is the dual of Spilt Ring Resonator (SRR), has been very popuplar resonator and widely used to synthesize metamaterial. Metamaterial exhibit qualitatively new electromagnetic response functions that cannot be found in the nature [11-37]. In 2004, Falcone et al introduced CSRR originally. The structure and its equivalent circuit model are shown in figure 1.

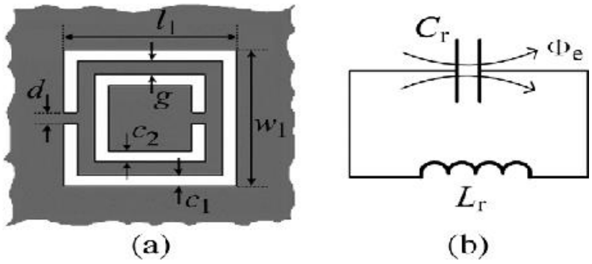

Fig. 1. (a) Topology and (b) its equivalent circuit model of the CSRR [14]. Gray zone represents the metallization.

The CSRR is modeled as a shunt LC resonator tank [14] which can be excited by the orthogonal electric field. It can be equivalent to an electric dipole placed along the ring axis [14]. As a dipole it essentially generates wave propagating along the plane of ring surface and relies on the edges of the patch for radiation. The coupling between the CSRR and patch mainly comes from the capacitive coupling through the ring slot and the magnetic coupling through the split of the outer ring. By properly feeding the antenna, the inherent half-wavelength patch resonant mode can still be well excited. It is interesting to note that the interaction between the CSRR-inspired resonance and the patch resonance is very weak when they are orthogonally polarized. Under this condition circular polarization (CP) is attainable when they share the same operating frequency with a 90 phase delay in excitation. In addition, the interaction is strong when they are polarized in the same plane, which gives rise to two mixed modes.

It would be helpful to know the characters and design methodology for the CSRRs while designing the proposed CSRR-loaded patch antennas. The CSRR can be represented by an LC resonator tank as shown in Figure 1 when the loss is neglected. Its inherent resonance frequency is determined by

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{1}$$

where the capacitance C_r of the CSRR is approximately equal to that corresponding to a metallic disk surrounded and backed by the ground plane [14]. Here the inductance can be calculated based on a CPW structure with an equivalent perimeter of the CSRR, strip width , and slot width . The detailed properties for the CSRR is presented in [14], including the analytical calculation of the resonance frequency. However those equations are lengthy and calculation would become extremely difficult for irregular CSRR structures.

Recently a defected ground structure (DGS) has been introduced, DGS is realized by etching of 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 shape of the defect may be changed from the simple shape to the complicated shape for the better performance. Defected Ground structures (DGS) have two main characteristics slow wave propagation in Pass band & Band Stop Characteristics in microwave circuits [17].

In order to explain the cutoff and the attenuation pole characteristic of the proposed DGS section simultaneously, the equivalent circuit should exhibit performances of low-pass and bandstop filter at the same time [18]. Generally it is accepted that the microstrip line should have the impedance around 100– 130 ohms. By using the defected ground structure in the ground plane the effective inductance will increase and at the same time the capacitance will be decreased and finally the impedance of the transmission line increases and becomes more than 200 ohms. This high impedance of the DGS is used in the interconnects used in the digital systems [18].

Based on the idea of photonic band-gap (PBG) structure, defected ground structure (DGS) was firstly proposed by Park et al. in 1999, and has found its application in the design of planar circuits and low pass filters [19]. DGS is realized by etching a defective pattern in the ground plane [20], which disturbs the shield current distribution in the ground plane. This disturbance can change the characteristics of a transmission line such as equivalent capacitance and inductance to obtain the slow-wave effect and band-stop property.

II. Design and Modelling

This section, we will introduce the design of our antenna. First the conventional patch length and width is designed. After designing the patch, we have taken CSRR as DGS in the ground. Basic length and width is designed with the use of following equations.

$$w = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{2}$$

The width of the patch can be designed using the equation (2), here f_0 is the center frequency, ε_r is relative permittivity and c is speed of light.

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

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\frac{\sqrt{1 + 12t}}{w}} \right) \tag{4}$$

$$\Delta L = 0.412t \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{t} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{t} + 0.8\right)} \tag{5}$$

$$L = L_{eff} - 2\Delta L \tag{6}$$

Length of the patch can be designed by using the equations (2-6). Here t is the thickness of substrate. Using these equations we have designed length and width of conventional patch here.

Here we designed square patch so length and width are same and it is 50 mm, so a square patch is 50×50 mm^2 over here which is shown in Figure 1. We have taken out CSRR as DGN in the ground and to improve the results as shown in figure. The CSRR taken out have dimension as shown in figure 4(a). The top view and side view of the design is shown in Figure 4(a) and 4(b) respectively.

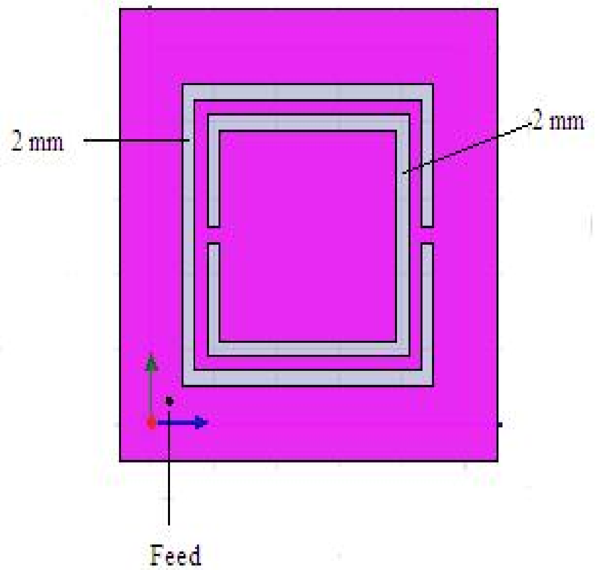

Fig.4 (a) Top View of Proposed Antenna

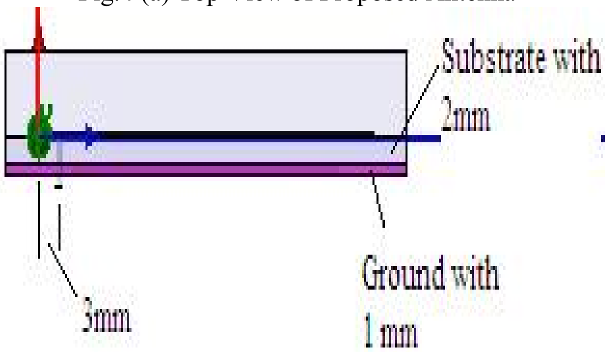

Fig.4 (b) Side View of Proposed Antenna

Table: 1 Material used for patch antenna

	Material
Patch	Copper
Substrate	FR4 epoxy with ε=4.4

Table 1 shows details about the material. Patch is of copper material. Substrate is of FR4 epoxy material with ε=4.4. The base material is also of copper.

III. Simulation results and discussions

For simulation we used HFSS 11 of Ansoft, which is very good simulator for RF antennas. After simulating the design the result we got is as follows. Figure 5 shows the Return Loss (S_{11}) plot of the design and Table 2 shows values of Return Loss (S_{11}) in dB for different bands with their frequency. The minimum return loss which we are getting for this design is -31.25 dB for the second band centred around 1.9423 GHz.

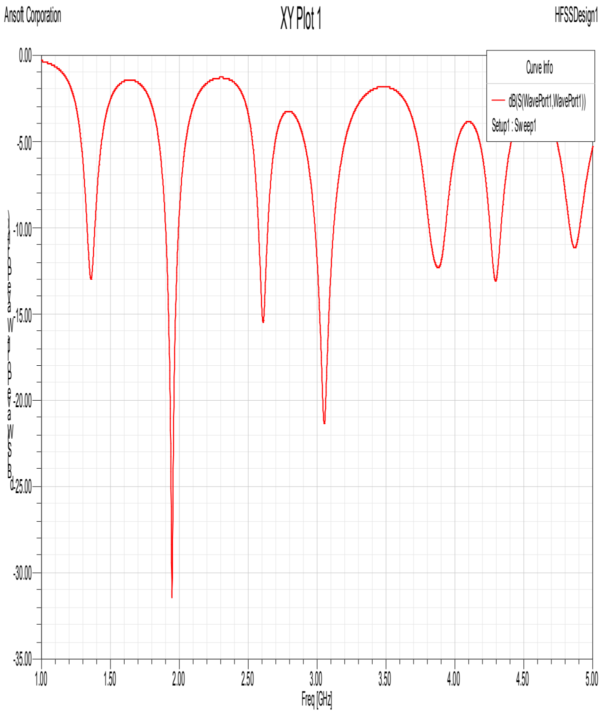

Fig.5 Return Loss (S_{11}) parameter of the antenna

Table: 2 Return Loss (S_{11}) values

Band	**Frequency in GHz**	**Minimum Return Loss (S_{11}) in dB (Negative Values)**
1st	1.3538	12.8846
2nd	1.9423	31.25
3rd	2.6038	15.3846
4th	3.0538	21.25
5th	3.8769	12.2115
6th	4.2962	12.9808
7th	4.8654	11.1538

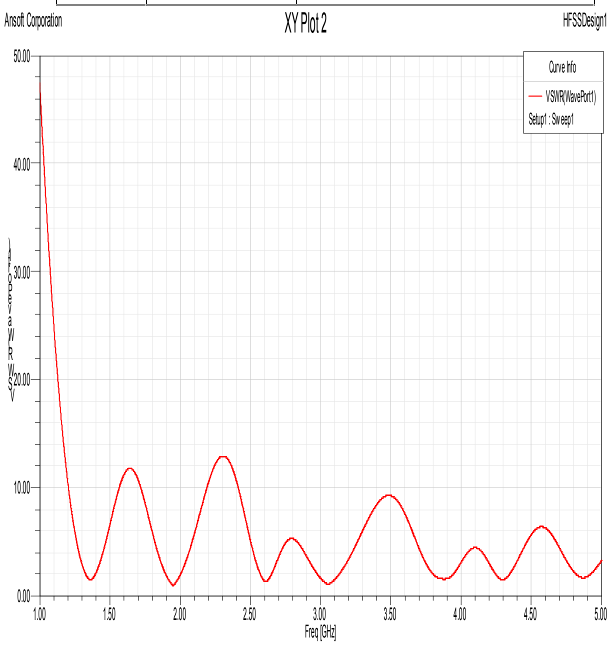

Fig. 6 VSWR of Antenna

Figure 6 shows the voltage standing wave ratio (VSWR) plot of the design and Table 3 shows values of

VSWR for different band with frequencies. For the entire band VSWR is less than 2 and lowest VSWR for the design is 1.2363 for the second band centered around 1.9423 GHz.

Table: 3 VSWR Values

Band	Frequency In GHz	VSWR
1st	1.3538	1.6484
2nd	1.9423	1.2363
3rd	2.6038	1.5110
4th	3.0538	1.3736
5th	3.8769	1.6484
6th	4.2962	1.5110
7th	4.8654	1.7857

Figure 7 shows thr radiation pattern of thr design which shows the total gain of freruency range 1 - 5 GHz.

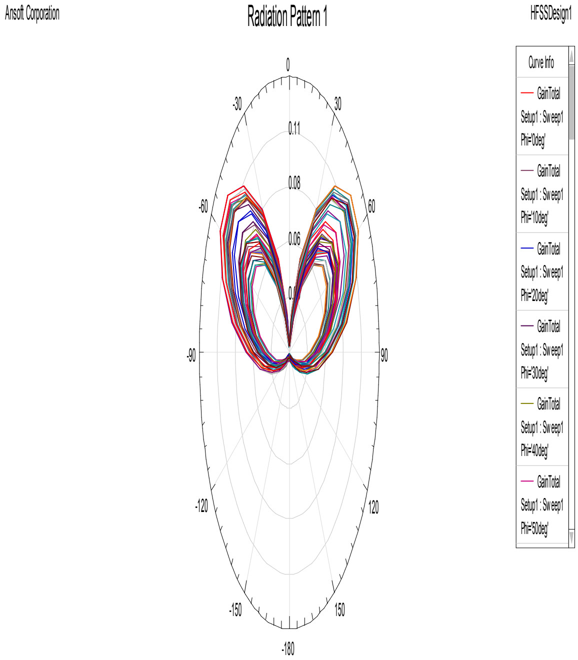

Fig.7 Radiation Pattern of Antenna

The Total gain of antenna in dB is shown in figure 8 which is in 3D View. The Total gain of antenna is -5.8802 dB as shown in 3D Polar Plot. Figure 9 shows the total directivity of the antenna which is -3.2921 dB as shown in 3D Polar Plot.

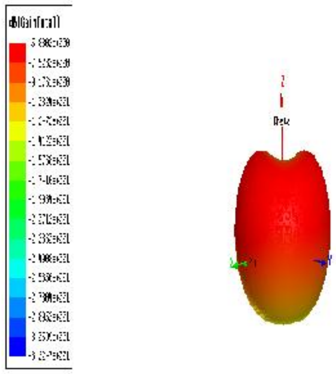

Fig.8 3D Polar Plot (Total Gain) of Antenna

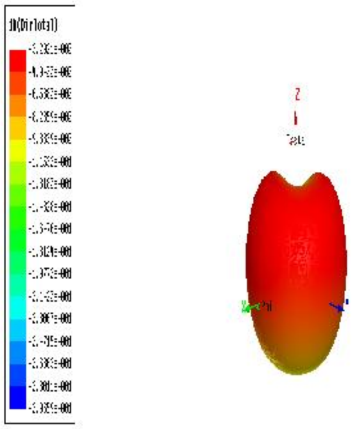

Fig.9 3D Polar Plot (Total Directivity) of Antenna

Figure 10 and 11 shows the magnirude plut of E - Field and H – Field respectively of the Antenna. As shown in figure the magnitude value of E – Field is 2.2318e+004 and the magnitude value of H – Field is 7.0881e+001.

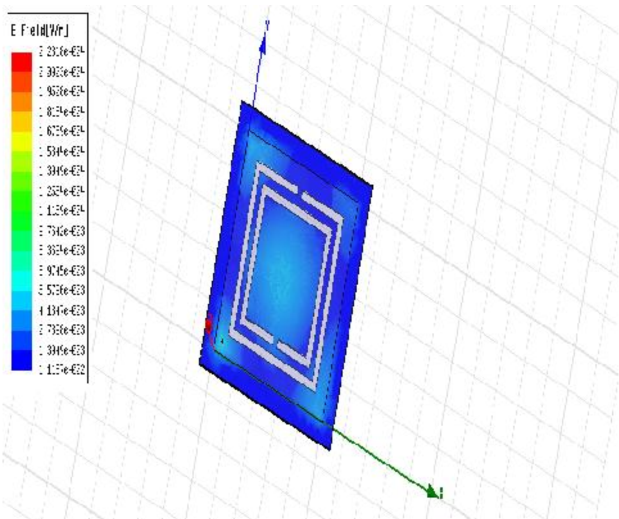

Fig.10 E Field Plot (Total Directivity) of Antenna

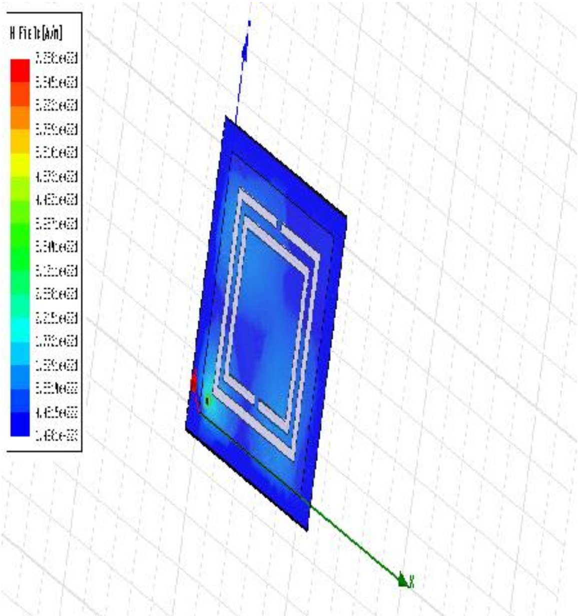

Fig.11 H Field Plot of Antenna

IV. Conclusion

Microstrip antennas have become a rapidly growing area of research. Their potential applications are limitless, because of their light weight, compact size, and ease of manufacturing. Here DGS microstrip patch is designed for multiband applications. The modelling and iterative simulations are carried out at centred frequency of 2.5 GHz. The result indicates the three bands so the antenna can used for L Band and S Band Applications. Further design can be modified to have a multiband for other applications in C Band, X Band and other bands. The results are in very good agreement with the industry and standard published antenna-requirements with respect to ease of fabrication, compactness and volume miniaturization compared to other antennas so far designed for similar applications. Instead of natural material, the artificial material, meta material can be used to improve the result and also using multilayer substrate can be used to improve the result.

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