Development of Micro Strip Patch Antenna and its Performance Evaluation using CST Tool for Wireless Application

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Abstract: the design and development of microstrip patch antenna is the potential study in the wireless communication systems. The microstrip patch antenna has been designed and developed using FR4 substrate with epoxy as one of the base materials for the plate. The analysis of the antenna was made using ground plane with defected ground structure (DGS) by applying E and inverted T shapes. The results were analyzed and simulated using CST suit studio software. It was observed that the maximum directivity obtained from the simulation of the antenna was 7.224 dBi. The antenna results in high return loss for desired frequencies with the enhancement gain. The simulated results with and without DGS has been recorded for the geometrical constraints of the microstrip patch antenna. The obtained results are in acceptable limits of the applications.
Keywords: microstrip; CST software; defective ground; wireless applications; rectangular

1. Introduction

Optimization of the performance of antennas to meet the specific requirements and to explore their usage for different applications is one of the creative concepts in the field of wireless communication. The broad band operation is the major problem connected with these antennas where it is not possible to operate effectively over a wide frequency range [1]. The resonance nature will limit the application of these antennas because of bandwidth. In order to enhance the usage of these antennas in the field of wireless communications, microstrip patch antennas serve as a solutions and the effective tool for the modern wireless communication system. These antenna systems are preferred because of compactness, lightweight, ease of integration, low cost, ease of fabrication and compatibility with planar circuitry [2]. The find their wide applications in mobile devices, satellite communications, radar systems and wireless networks. The planar structures of microstrip patch antenna provide flexibility in conformal and multiband designs conveying their adoptability to diverse environments and frequency requirements. Further, these antennas can be modified easily and optimized to meet the specific design requirements which can meet various communication needs. The low profile nature of microstrip patch antennas suits for the integration in to portable devices [3]. Limited band width, low radiation frequency and sensitivity to the surrounding are some of the disadvantage which limits the application of microstrip patch antennas. The narrow band width is one of the limitation of the microstrip patch antenna.

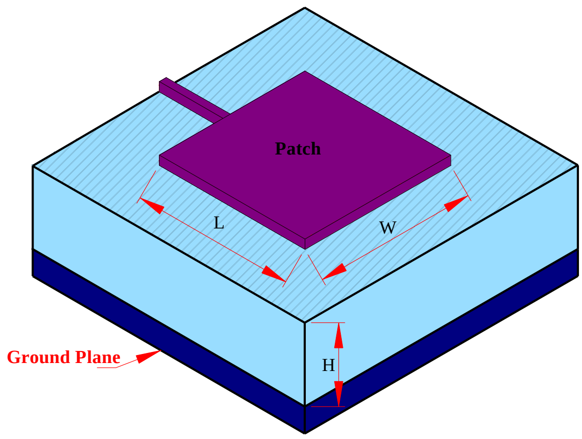
This limitation can be overcome using several techniques. One common solution is the use of parasitic elements, such as additional patches or slots which modify the electromagnetic field distribution and introduce additional resonances, thereby broadening the bandwidth. Careful design optimization and iterative adjustments of the antenna's physical dimensions and substrate properties can also contribute to broadening the bandwidth. Many researchers have contributed to the field of wireless communication through wireless patch antennas. Design and development of tri -band microstrip patch antenna for wireless applications has been studied and reported by Jabire et al [4]. They designed the micropstrip patch antenna for wireless communication using high frequency simulator software. It was observed from their work that the antenna works with triple band ranging from 1.5 to 4 GHz. It was noticed from their work that the performance of antenna depends on relative permittivity of the dielectric under the patch, feed location, the position of the parasitic patch, geometry of the substrate. Kaur et al [5] design and implemented the rectangular Zig- Zag microstrip patch antenna with swastik shape DGS for WLAN, C and Ku- Band application. The antenna has been designed using FR4 Substrate of epoxy material with thickness 1.6 mm. The findings of implementation showed that simulated bandwidths are operating at three specific resonating frequencies 64 MHz (11.9 - 13.6 GHz) (for Ku - band), 110 MHz (5.71 - 5.82 GHz) 100 MHz (4.5 - 4.6 GHz) (for C - band) with return loss below -10dB. Hussain et al [6] design and developed the multiheaded star fish multiband microstrip patch antenna for satellite communication. The antenna has been designed to resonate at frequency bands of 3.057, 7.88, 9.225, 10.27 GHz and band widths 32,108.4, 220,210 MHz. The implementation of these antennas has designed many communication systems. Abdullah-Al-Mamun et al [7] showed the antenna system using Inset Fed PBG Substrate with DGS Slotted Rectangular Microstrip Patch Antenna for C-Band Satellite Applications. It was observed from the test that antenna's return loss, bandwidth, gain and directivity are -28.7 dB, 241.7MHz, 5.0828 dBi and 5.2161 dBi respectively. The inset fed PBG with DGS slotted rectangular microstrip antenna was analyzed effectively and found that the proposed antennas proficiency is 98.5%. Further, they also recommended the proposed antenna for C- band satellite application. Banupraksh et al [8] designed the antenna system using microstrip for Bluetooth, WLAN and X band communication applications using Defective Ground Structure. They used FR4 multiband substrate of 1.6 mm thickness for the design. L and I shaped slot were etched on the metal portion of the ground structure. The designed antenna reflects with the resonation at 2.6, 5.2, 7.3 and 9.4 GHz frequencies with a return loss of -14.49, -18.95, -17.63 and -17.37 dB respectively. The findings of the antenna system confirm that the designed antenna works with a gain of 3.57 to 5.52 dB through a bandwidth for VSWR less than 2. The design, development and analysis of microstrip patch antenna using Tortoise shaped Quad B, C and Ku – Band application has been carried out by Krishna et al [9]. This antenna system has been proposed to increase the band width using square Koch fractal (SKF). The model is prepared suing FR4 substrate with thickness 1.6 mm. A quad band transmission line feed tortoise shaped microstrip patch antenna with optimized self – similar slotted ground structure is proposed for C–band (4 – 8 GHz) and Ku –band (12–18 GHz). It was found that the Koch fractal (SKF) improves the impedance bandwidth and number of resonances. Further, it was concluded that the slotted patch with DGS increases number of resonances. This antenna operates at frequencies 4.12 GHz 5.92 GHz, 7.72 GHz and 12.40 GHz.

Mishra et al [10] proposed the designed antenna model for sensitivity analysis of fractal DGS integrated microstrip patch antenna for X-Band RADAR Applications. They described the effect of Defected Ground Structure (DGS) on the radiation characteristics of aperture feed patch antenna operating at 10 GHz. It was revealed from the result that the performance achieved by this antenna structure is size reduction with good gain. Further, they suggested this antenna for RADAR applications. Guatham et al [11] designed and fabricated a DGS microstrip patch antenna for S, C & X Band Applications. The proposed antenna is a combination of circular-rectangular patch antenna incurring 50Ω microstrip feed and semi ground plane is designed. The simulation is performed by means of the software program HFSS V.15.0. The antenna is fabricated on FR-4 epoxy substrate with copper patch, ranges from 3.34 -8.72 GHz (impedance BW is 89.22%) and the second band ranging from 9.22-13.06 GHz (impedance BW is 34.47%). It was noticed that for the first band the resonating frequencies are 3.92 GHz and 7.88 GHz with return loss -35.59 dB and -31.99 dB. For the second, it resonates at 10.58 GHz with return loss -55.52 dB and gain is 7.09 dB. The project on high gain microstrip patch antenna with slotted ground plane for Sub-6 GHz 5G Communications has been proposed by Olawoye and Kumar [12]. The designed antenna was simulated and optimized using CST software. It consists of T – slots on the rectangular patch strip antenna with defective ground structure. The tested results showed that antenna experienced a maximum gain of 5.49 dB with a maximum directivity of 7.12 dB. The proposed antenna resonates with 4.96 GHz through a bandwidth from 4.775 GHz to 5.049 GHz. Nguyen et al [13] designed the micro strip patch antenna with wide band compact triangular slot . They used the compact triangular slot antenna with microstrip feed line technique to achieve a smaller slot size and wider bandwidth. The antenna includes the whole C-band (4–8 GHz) including 5.8 GHz ISM and sub-6 GHz band of 5G. The fabricated prototype shows a high potential for suppressing interferences in wireless communication systems. The best feeding point location using microstrip patch antenna has been design and developed by Jusoh et al [14]. They used HFSS tool for the identification of the best feeding location. They designed the patch antenna for the operating frequency of 2.4 GHz. The patch antenna designed for operating frequency at 2.4GHz. The LaAlO-3 is used as a substrate material for the designed patch antenna with a dielectric constant of 23.5, and a height of 1.5 mm. The findings of the project showed that the impedance of feeding point for microstrip patch antenna can be controlled by changing the location of feed point. Raj and Dwivedi [15] proposed the model of microstrip patch antenna for large gain with DGS suitable for the wireless applications. The proposed antenna is designed with defected ground structure and an air layer along with PTFE substrate in hexagonal pattern. The proposed antenna resonates at 2.4 GHz, 4.2 GHz and 5.8 GHz which covers two ISM band frequencies with a gain of 5.6 dB and 6.22 dB. The reduction of surface waves by the triangular slots on ground plane showed improvement in gain. Further, they suggested that improvement in gain can be obtained by adding an air layer with glass - PTFE substrate. Reddy and Muthusamy [16] proposed the antenna model for the wireless communication through Gain Enhancement of dual layer truncated corner triangular slot with DGS patch antenna for 5G/WLAN applications. They used FR-4 dielectric material with dielectric constant of 4.3 for both the layer with thickness of 0.8mm each. For better impedance matching, they used quarter wave length feeding techniques. The designed antenna resonates at 3.58 GHz and 5.3 GHz. They proved that the triangular cut and quarter wave feed structure improves return loss, gain, radiation pattern and VSWR. The antenna proposed here is suitable for WLAN and 5G wireless applications. Gopal et al [17] designed the inset feed Tri-band Microstrip patch antenna for GPS and IRNSS Application. The project design involves the inset feeding technique and FR-4 substrate. Findings showed that the inverted F and T shaped slot in ground plane results in multiband. Simulated results showed that patch resonates in L1 Band (1.575 GHz), L5 Band (1.176 GHz) and S-Band (2.49 GHz) with antenna parameter values. The gain and directivities were fall in the limits of 0.6 -1 dB and 6 - 7.1 dB making it eligible to work for GPS and IRNSS application. Patidar and chouhan [18] proposed the multiband microstrip patch antenna with DGS for different wireless applications. Thy described the rectangular multi–band frequency patch antenna with a seven-band operation. The antenna has been designed and simulated in CST microwave studio. In this proposed antenna, FR-4 material was used for substrate with a 4.3 dielectric constant and 1.6 mm thickness. The designed antenna can resonate at eight frequencies ranging from 1 GHz to 12 GHz. The resulting bandwidth is 3.716 GHz with a return loss of -40.463dB. Akash Modi et al [19] planned and implemented the **c**ompact design of multiband antenna for IRNSS, satellite, 4G and 5G applications. They designed the microstrip patch and simulated using a high-frequency structure simulator (HFSS). They showed that antenna resonates at 2.4 GHz frequency with a return loss of -20.1390 dB.

From the above literature survey, it is clear that the different microstrip patch antennas have been proposed for different wireless applications. But the design and analysis of the rectangular patch antenna with DGS is very limited in supply. Further, optimization of antenna parameters for the effective communication using CST suit software is not reported. Therefore, an attempt has been made to design and develop the rectangular microstrip patch antenna for the wireless communication bench. Further, the simulation of these antenna communications with the surroundings is studied and reported.

2. Materials and Design Considerations, Software Requirements and Implementation

2.1 Materials and Design Considerations



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The material used for the substrate is FR-4 glass – epoxy composite with a thickness of 1.6 mm and having dielectric constant in the range of 4.2 to 4.7. FR-4 glass epoxy is a flexible high-pressure thermoset plastic laminate material with high strength to weight ratio. They have a relatively low dielectric constant which allows for compact antenna designs. The low loss tangent of FR-4 substrates contributes to low dielectric losses in the antenna structure, enabling improved radiation efficiency. FR-4 substrates also have good electrical insulation properties and can withstand high temperatures, making them suitable for various operating conditions. The compact geometrical slots embedded on the ground plane of microwave circuits are referred to as Defected Ground Structure (DGS). DGS has been integrated on the ground plane with planar transmission line, that is, micro-strip line, coplanar waveguide, and conductor backed coplanar wave guide. The defects on the ground plane disturb the current distribution of the ground plane. The design consideration for the microstrip patch antenna is as follows:

If W= Width of the patch antenna, L= Length of the patch antenna, F_0 = Resonant frequency, C = Speed of light ($3x10^8$ m/s), ε_r = Dielectric constant of the substrate, L_{eff} = Effective length, ΔL = Length of extension, H = Substrate thickness, ε_{eff} = Effective dielectric constant, then for the effective functioning of the antenna, the following empherical relations have been used for the analysis.

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \qquad \Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

$$L = L_{eff} - 2\Delta L \qquad \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

The first step is to define the material and dimensions of the substrate that will be used for the patch antenna. This includes the dielectric constant, substrate thickness, and substrate size. The antenna was designed by using FR-4 dielectric substrate material with dielectric constant 4.3 and having the thickness 1.6mm. The dimensions for the antenna design are calculated using the above equations. The patch antenna geometry includes the patch shape, size, and feed point location. Here we considered the rectangular shape patch and inset feeding. We have setup the simulation environment in CST Studio Suite. This includes defining the simulation frequency range, the type of solver, and the simulation settings. Assign material properties to the substrate and other components in the simulation, such as the ground plane and the feed line. Design and create the feed line that will be used to excite the patch antenna. After this, apply the feeding technique and Defected Ground Structure (DGS). Run the simulation in CST Studio Suite to analyze the performance of the microstrip patch antenna. The simulation results can be used to optimize the antenna design and adjust the parameters for desired performance. Finalize the design by optimizing the geometry, feed line, and other parameters to achieve the desired performance, such as gain, bandwidth, and radiation pattern (Flow chart 1).

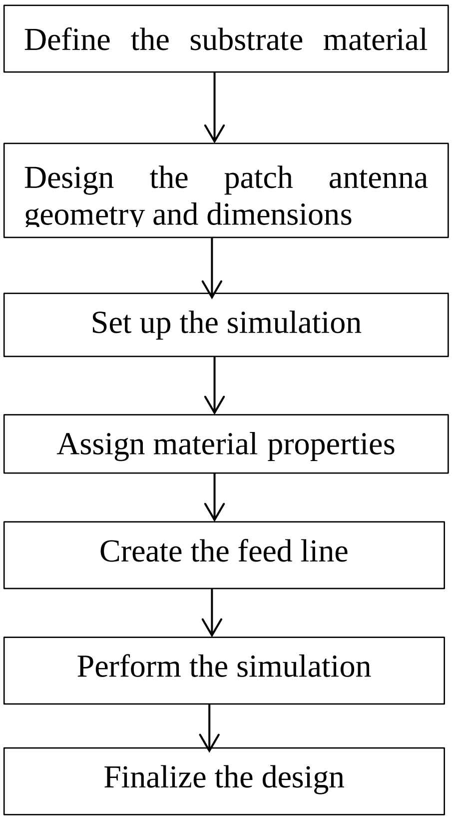


Figure 2: Design Procedure of Microstrip patch antenna

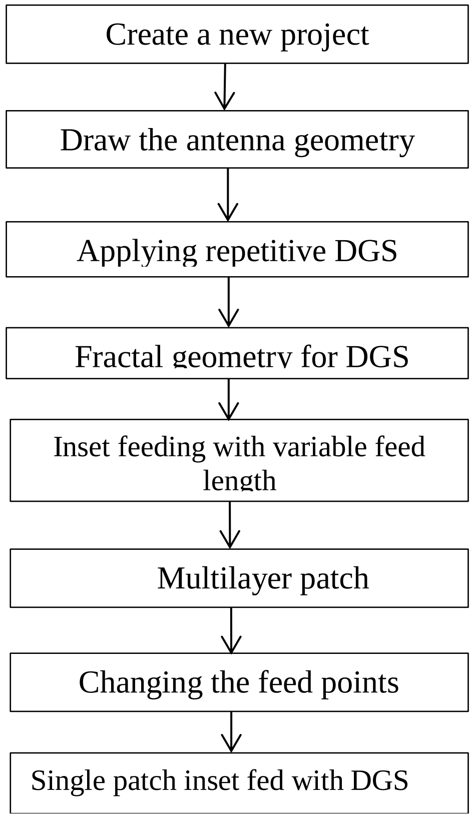


Figure 3: Implementation using CST Suit studio software

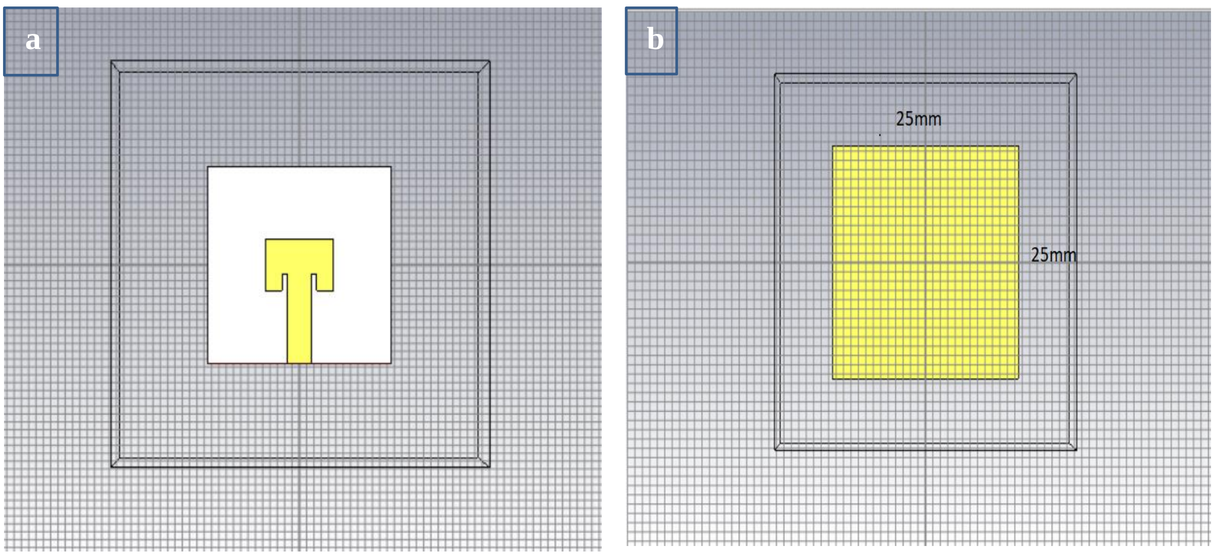


Figure 3: a) An antenna from the CST studio suit and b) Ground plane of the microstrip patch antenna

The design of microstrip patch antenna has been simulated using CST studio suite software for the desired frequency using the step shown in the flow chart 2. The inset feeding technique was used to get the high return loss. Defecting the ground plane of microstrip patch antenna enhances the gain of the antenna.

Table 1: Dimensions of the designed microstrip patch antenna

Particulars	Parameters	Designed dimensions (mm)
Patch	W_P	9.393
	L_P	6.666 25
Ground Plane	W	25
	L	25

System requirements for the implementation

The implementation of the software is very important for the analysis of the microstrip patch antenna using CST studio suite software. The following hardware and software specifications are required for the analysis. Operating System: Windows 7, 8, 8.1, or 10 (64-bit versions only), Red Hat Enterprise Linux 6 or 7 (64-bit versions only), Processor: Intel or AMD processors with SSE2 support dual-core processor (quad-core recommended) with at least 2 GHz clock speed, Memory (RAM): Minimum: 4 GB (8 GB recommended), large models may require more RAM and Hard Disk Space: Minimum 20 GB of free disk space.

3. Results and Discussion

The design and analysis of the excited microstrip patch antenna for the wireless application has been presented in the figure 4 without the DGS. The system has been excited by using the range of frequencies from 9.7 to 10.8 GHz. The obtained parametric results are tabulated in the table 2.

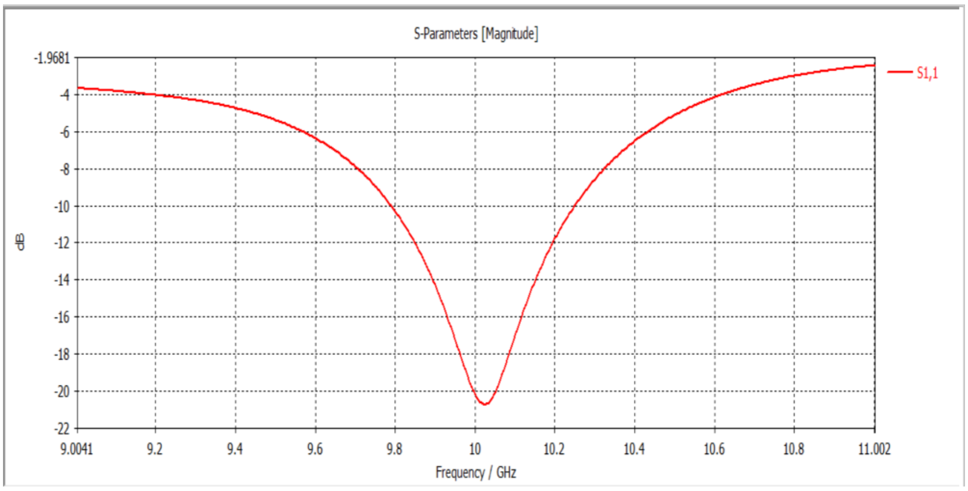


Figure 4: Effect of frequency on the return loss of microstrip patch antenna without DGS

When the antenna was excited using different frequency range from 9.7 to 10.8 GHz without DGS, the directivity of the system increases from 6.679 to 6.677 (dBi) followed by decrease in Gain from 6.106 to 5.824 dBi.

Table 2: The parametric results of microstrip patch antenna with out DGS

Frequency (GHz)	Directivity (dBi)	Gain (dBi)	Return loss (dB)	VSWR
9.7	6.679	6.106	-6.6	2.25
10	6.846	6.185	-12.5	1.6
10.8	6.677	5.824	-3	5

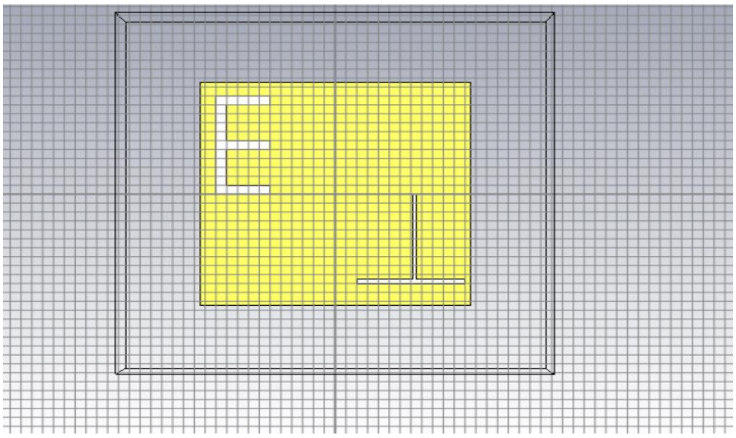
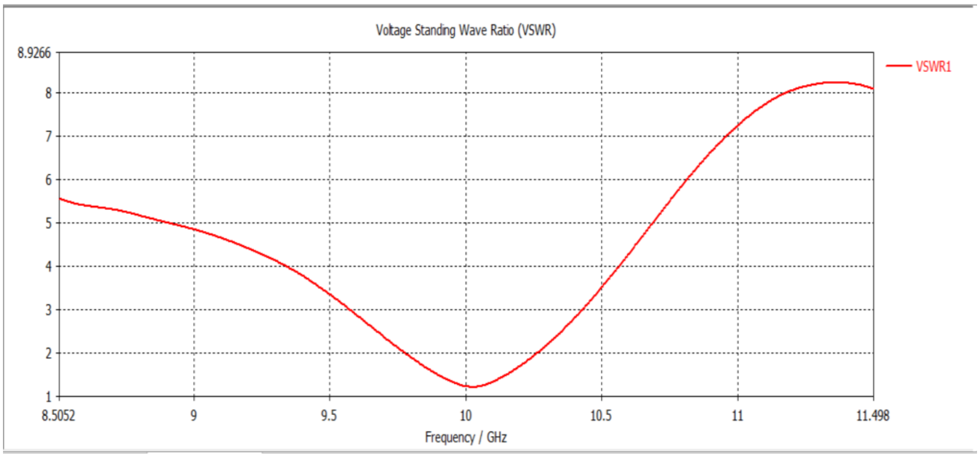


Figure 5: Ground plane with DGS by applying E and inverted T shapes

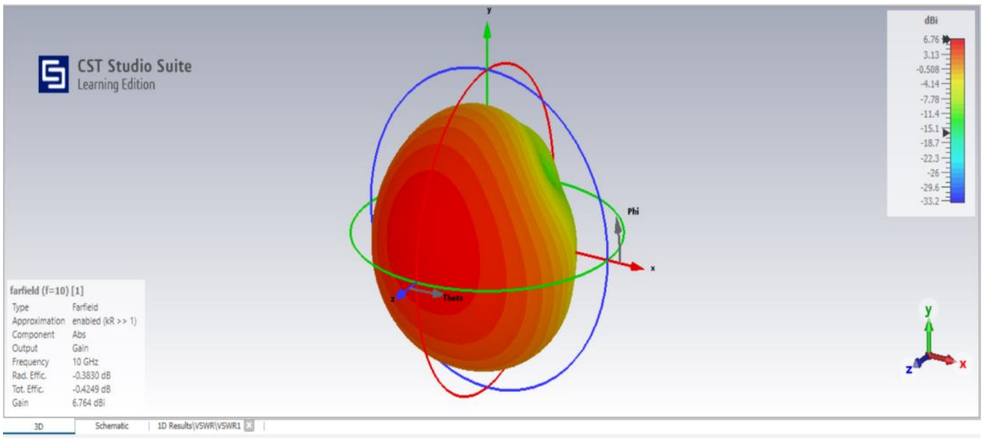
Table 3: The parametric results of microstrip patch antenna with DGS

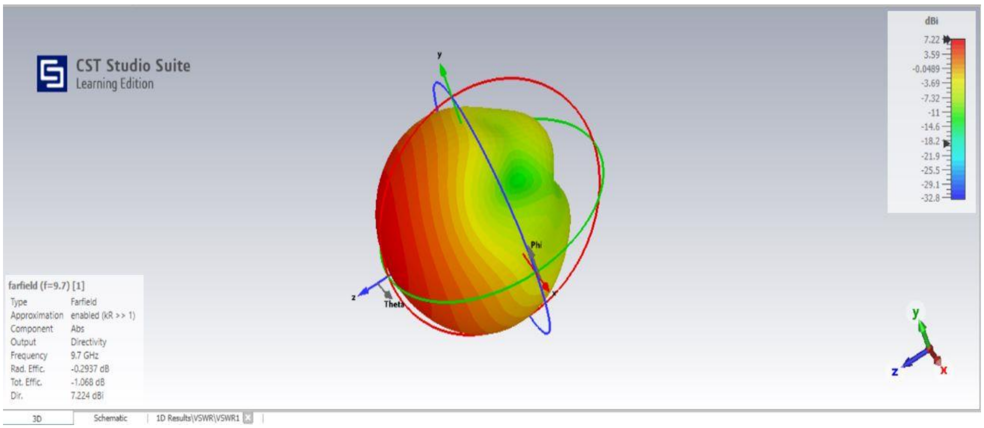
Frequency (GHz)	Directivity (dBi)	Gain (dBi)	Return loss (dB)	VSWR
9.7	7.224	6.93	-8.1	2.25
10	7.147	6.8	-20.2	1.22
10.8	6.567	5.850	-13.3	5

When the antenna was excited using different frequency range from 9.7 to 10.8 GHz with DGS, the directivity of the system decreases from 7.224 to 6.567 (dBi) followed by decrease in Gain from 6.93 to 5.850 dBi. The maximum directivity obtained from the simulation of the antenna is 7.224 dBi. The antenna results in high return loss for desired frequencies with the enhancement gain. The effect of DGS is most significant in the design and analysis of the microstrip patch antenna.



It is observed from the table and figure 6 that the VSWR value will be minimum for 10 GHz and was maximum for 10.8 GHz. This showed that the effect of DGS is most appreciable in this analysis.





4. Conclusion

The following conclusion is drawn from the design and development of microstrip patch antenna:

- The rectangular microstrip patch antenna is designed and simulated using the CST studio suite software
- The proposed antenna works at the frequency ranges from 8 GHz – 12GHz
- The defected ground structure not only helps in achieving the multiband operation but it also helps to improve the performance of an antenna with respect to its gain and bandwidth
- The maximum directivity and gain obtained from the simulation of the antenna is 7.224 dBi and 9.93dBi respectively
- The antenna results in high return loss for desired frequencies with the enhancement gain and other parameters
- The designed antenna can be used for X–band applications such as space communication, defense tracking and air traffic control

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