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MULTIPLE BAND MICROSTRIP PATCH ANTENNA WITH DGS FOR X BAND, KU BAND AND K BAND APPLICATIONS

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Abstract -*A multiple band antenna in X band, Ku band and K band frequencies for radar and satellite application is presented .The X band ranges from 8 to 12 GHz and Ku band range falls between 12 to 18 GHz and K band range falls between 18 to 26.5 GHz. The proposed antenna is performed with low cost FR4 epoxy dielectric substrate material with thickness of 1.6mm and designed different rectangular slots. The antenna design is included with Defected Ground Structure (DGS) which improves the antenna performance. High frequency structural simulator (HFSS) based on Finite element method (FEM) is used to analyze the result. This antenna has been composed of rectangular slots to generate multiple resonances. With 9.1 GHz and 10.1 GHz and 11GHz, 16.7 GHz, 19.1 GHz as the resonance frequencies, return loss of -24.32 dB, -22.59 dB,-24.46 dB, -16.3 dB, -23.423 dB are obtained. Therefore, this antenna can be applicable for X-band, Ku-band and K band applications respectively*

Key Words: Microstrip patch antenna; radar; FR4 Epoxy, Satellite, Ku band, K band …

1. INTRODUCTION

Microstrip antennas have a lot of advantages over conventional microwave antenna. Microstrip patch antenna is a milestone in wireless communication system. Microstrip patch antennas are mostly used at microwave frequencies. In Modern wireless communication systems, requires low profile, light weight, high gain, ease of installation, high efficiency, simple in structure to assure reliability and mobility characteristics. Microstrip antennas are well suited for such requirements. Key features of a microstrip antenna are, low profile, low weight, comfortable to place on planar and non-planar surfaces, simple and inexpensive to manufacture by using printed circuit board. These advantages of microstrip antennas [1] make them popular in many wireless communication applications such as communication Satellites, Vehicle speed detection, Missile applications and High-resolution and close range targeting radars aboard military airplanes, medical applications and missile applications [2].

1.1 X band, Ku band and K band

The frequency range for radar application as defined by IEEE Standard 521 in 2002 is the X band frequency ranges that vary from 8 to 12 GHz [3] Primarily used in radar applications such as continuous-wave, pulsed and dual-polarization, synthetic aperture radar. X band is used for air traffic control, military for weather monitoring, satellite communication and deep space telecommunication. The Ku band ranges from 12 to 18 GHz used for satellite communications. The K band ranges from 18 to 26.5 GHz. This frequency used for police radars for vehicle speed detection, satellite communication etc. So, this antenna is useful to meet the demands of X-band, Ku-band and K band applications. This operating frequency can be varied by changing the dimensions of rectangular strip and patch. Simulation software HFSS (version 12.0) which is based on Finite Element Method has been used for the analysis of design.

1.2 Defected Ground Structure

The concept of Defected Ground Structures (DGS) has been developed to improve the characteristics of many microwave devices. DGS [4] adds an extra degree of freedom in microwave circuit design and opens the door to a wide range of application. For this purpose the DGS is also used in the microstrip antenna for some advantages such as antenna size reduction, mutual coupling reduction in antenna arrays etc. Ground Structure provided with slots and defects helps in achieving better radiation characteristics, which patterns the effective inductance and capacitance of the microstrip patch antenna. Defected Ground Structure (DGS) is one of the methods, which are used to miniaturize the size of microstrip antennas DGS consist etching of a simple shape in the ground plane. This defected structure can be of any fractal model [4].

In proposed model, the line feed is used for excitation. The microstrip line is used for feeding because of its ease in fabrication and simple to match by controlling inset positions [5]. To achieve multiple band operation, the patch used can be provided with slots [6] and with the defected ground structure [7].Defected Ground Structure (DGS) is one of the methods, which are used to miniaturize the size of microstrip antennas, DGS consist etching of a simple shape in the ground plane, or sometimes by a complicated shape for the better performance.

2. DESIGN MODEL.

The proposed antenna design model encompasses the low cost FR4 epoxy dielectric substrate material with thickness of 1.6mm and of relative permittivity 4.4, dielectric loss tangent of 0.02 and placed in between the ground plane and the radiating patch [3]. The proposed design model consists of slotted circular patch placed on the top of substrate, with three rectangular strips attached to the edge of the slotted circular patch. Separation of each rectangular strip from each other, by an angle of 120°[3].The overall size of the antenna is of 31.34 × 28.33 × 1.6 mm3.The direct contact method given for excitation; mainly line feeding technique is used. Microstrip line feeding is a technique in which a conducting strip is connected directly to the edge of the microstrip patch. The width of conducting strip is smaller as compared to the patch. The direct line of feeding method has advantages that it's easy in fabrication and simple to match by controlling inset positions. One of the rectangular strip acts as a feed line for excitation. The slot provided on the circular patch extended to the feeding strip. The other two strips are provided with rectangular slots hence the antenna resonates at multiple frequency bands.

In order to resonate at multiple band and progress the performance of the depicted antenna model, the ground plane is provided defected ground structure. For this purpose the DGS is also used in the microstrip antenna [8] for some advantages such as antenna size reduction, mutual coupling reduction in antenna arrays etc. The defected ground structure is a periodic or no periodic cascaded configuration of defect provided in the ground plane [3]. The provided DGS in this antenna is circular ring slot. This defect provided disturbs the currentdistribution of the patch antenna. In this antenna, the line feed is used for excitation. The microstrip line is used for feeding because of its ease in fabrication and simple to match by controlling inset positions. The geometry of the proposed model is designed and evaluated using the An soft HFSS (High Frequency Structural Simulator) Version 12. The design model of the proposed novel shaped antenna is shown below.

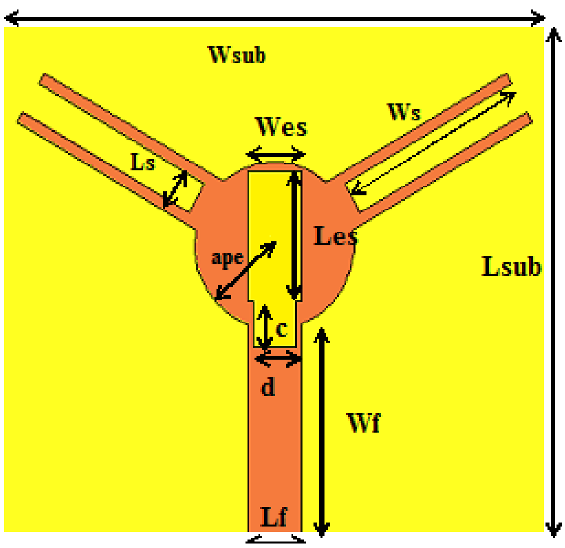


Fig -1 proposed design model – view at front

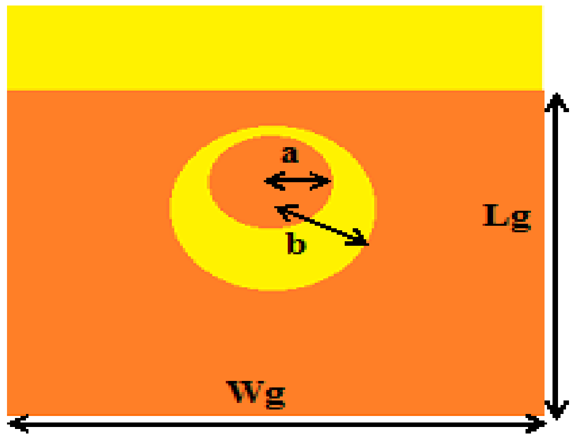


Fig -2 proposed design model view from bottom

3. MATHEMATICAL OUTLINE OF THE PROPOSED MODEL

The design formula and constraints of the circular microstrip patch antenna and rectangular microstrip patch antenna given as follows.

3.1Effective radius of circular microstrip patch antenna

The circular shapes used in the design are of at the middle section of the radiating patch and for the slots in the ground plane. CMPA have a radius formulated using the design formula given in (1) – (2). A good radiation characteristic in terms of radiation pattern, return loss, gain, bandwidth, etc. can be achieved by the consideration of the effective radius in the design [9].

$$a = \frac{F}{\{1+\frac{2h}{\Pi\varepsilon F}[\ln[\frac{\Pi F}{2h}]+1.7726]\}^{\frac{1}{2}}} \qquad \text{............. (1)}$$

$$F = \frac{8.791 \text{ x } 10^9}{f_r\sqrt{\varepsilon_r}} \qquad \text{..............(2)}$$

Equation (1) does not take into consideration the fringing effect. Since effective radius of patch $'a_e'$ is used and is given by

$$a_e = \frac{1.8412\, c}{2\Pi f_{r\sqrt{\varepsilon_r}}} \qquad \text{......... (3)}$$

3.2 Width and length of Rectangular Microstrip Patch Antenna

The conducting strips and slot provided on the patch are of rectangular shape. The width W and length L of the rectangular strip are based on the equations given below. The thickness of the dielectric substrate is represented by h [10] which is 1.6 mm. The design formula for the rectangular microstrip patch antenna is presented as follows [9].

$$W = \frac{c_0}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \quad \text{............ (4)}$$

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left(1+\frac{12h}{W}\right)^{\frac{-1}{2}} \quad \text{.......... (5)}$$

Where c_0 the speed of light in free space ($3\times 10^8 m/s$), ε_{reff} is the effective dielectric constant of the material and f_r is the Center or Resonant frequency in GHz.

$$\frac{\Delta L}{h} = .412\frac{(\varepsilon_{reff}+.3)(W/h+.264)}{(\varepsilon_{reff}-.258)(W/h+.8)} \quad \text{......... (6)}$$

$$L = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad \text{......... (7)}$$

Here, ΔL represents the effectual length of the patch to be deliberated for overall dimension of the rectangular patch.

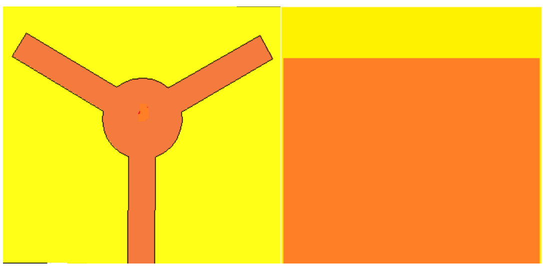
$$L_g = 6h + L \quad \text{.......... (8)}$$

$$W_g = 6h + W \quad \text{......... (9)}$$

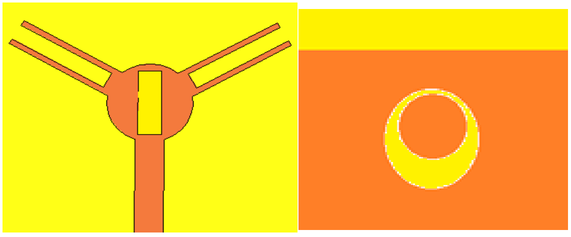
The parameters of the ground plane is considered from width *W* and length *L* of the patch calculated above and is to be added with almost six times the height of the dielectric substrate *h* for delivering effective radiation [11].

4. CONFIGURATION AND DESIGN APPROACH

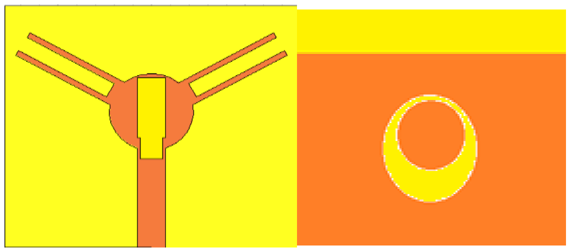
The various iterations of the proposed design model is given below. The simple microstrip patch antenna is shown in Antenna 1 in Fig 3. In this antenna structure the ground plane is not provided with defected ground structure. This antenna will resonate single frequency in X band. In second iteration the ground structure is modified with DGS and rectangular slot are provided in the middle and two strip of the antenna. The DGS are of circular ring slot. This antenna will resonate at triple frequency in X band. Finally slight modifications are done in the antenna structure. In third iteration extending the length of the rectangular slot in the middle towards the strip which acts as feed line to provide better performance in multiple band frequency of operation.



Antenna 1



Antenna 2



Antenna 3

Fig 3: Front view and back view of various iterations

After the first iteration the antenna 1 without slot and DGS resonates at single frequency of 10.7GHz with a return loss of -40dB.To have an additional resonance, the above said antenna is modified with DGS and is included with additional slots on the patch across the center circle, and in the rectangular blades which are not used as the feed line. This is shown in Antenna 2 in Fig 3. Due to this, the antenna resonates in triple frequency bands 9.2GHz, 10.1GHz, 10.9GHz with a return loss of -27.2dB, -32.4dB, -24.5dB respectively. By adjusting the DGS and extending the slot in middle of circle, the antenna resonate multiple frequency in X band and Ku band and K band. The X band widely used for air traffic control, military for weather monitoring, satellite communication and deep space telecommunication. The Ku band used for satellite communications. Police radar. The K band used for police radars, vehicle speed detection, satellite communication.

The following Fig. 4, 5, 6 represents the return loss plot (reflection coefficient (dB) vs. frequency (GHz)) comparison for the iterated models.

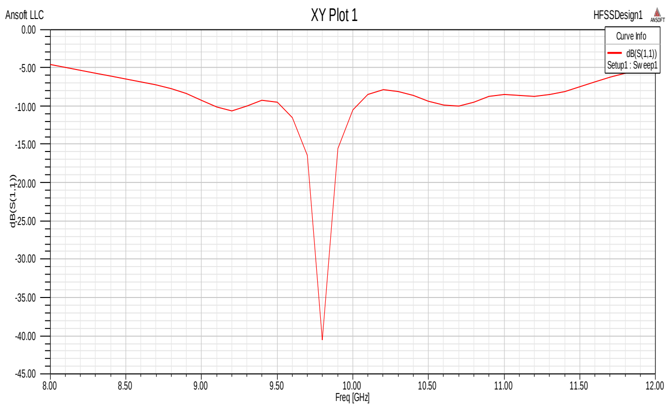


Fig 4: Return loss after first iteration

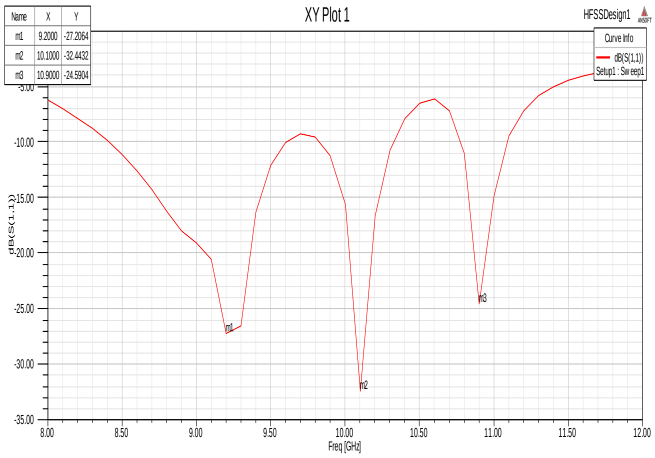


Fig 5: Return loss after second iteration

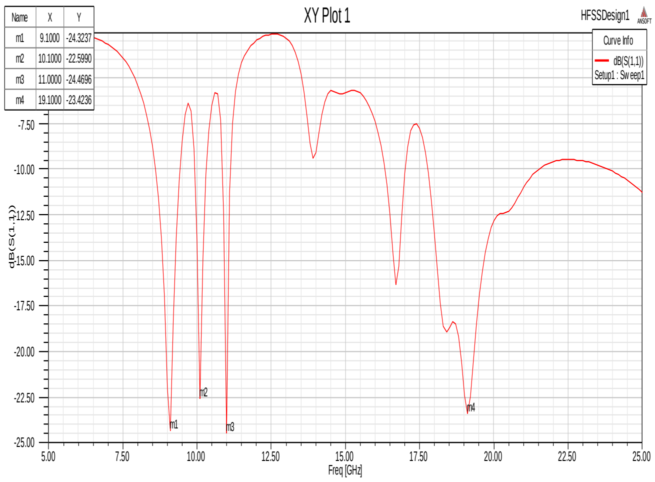


Fig 6: Return loss after last iteration

The Fig 7 shows the VSWR plot after the final iteration of the antenna.

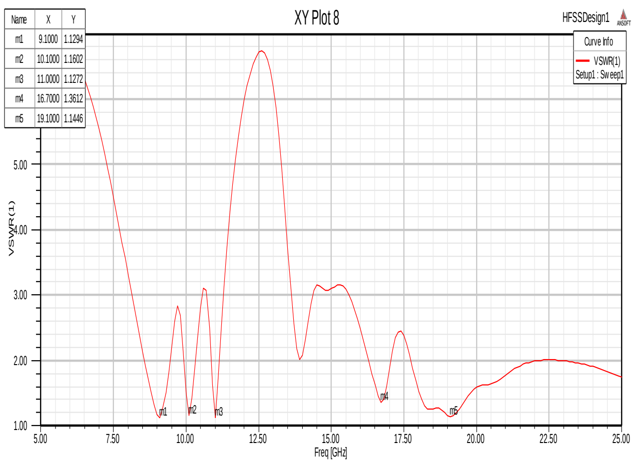


Fig 7: VSWR plot after last iteration

The values of the variables used in the design model shown in Fig 1 and Fig 2 are given in the table 1.

Table -1: Dimensions of proposed microstrip patch antenna

S. No.	Parameter name	Designed Values
1	Dielectric Substrate Length, L_{sub}	28.33 mm
2	Dielectric Substrate Width, W_{sub}	31.34mm
3	Rectangular Patch and Feed length, L &L_g	3.01mm
4	Rectangular Patch and Feed length, W & W_f	11.45mm
5	Relative permittivity of the dielectric substrate, ε_r	4.4mm
6	Dielectric Substrate thickness, h 1.6 mm	1.6mm
7	Slot length at the blades, W_s	1.8mm
8	Slot width at the blades,L_s	10.85mm
9	Effective radius of the circular patch, ape	4.46mm
10	Circular patch Slot length, L_{es}	7.23mm
11	Circular patch Slot width, W_{es}	2.41mm
12	Ground Length, L_g	25.31mm
13	Ground Width, W_g	31.34mm
14	Resonant frequency, f_r	9GHz
15	Resonant frequency for slotted surface on patch,f_s	10GHz
16	Resonant frequency for DGS calculation, f_{dgs}	11GHz
17	Circular ring slot – inner radius, a	4mm
18	Circular ring slot – outer radius, b	6.5 mm
19	Extended slot length, c	4.2 mm
20	Extended slot width, d	2.4 mm

The circular and rectangular shapes in Antenna 1 are designed for a resonant frequency of 9 GHz. The radius of the circle is optimized from 4.65 mm in the formula to 4.5 mm. Similarly, the width and length is assumed to be from 10.14 mm and 7.24 mm to 11.45 mm and 3.01 mm respectively. The length is assumed to be approximately half of the dimension calculated from the formula. Since, the dimensions are slightly modified the antenna 1 resonates at 10.7 GHz. For better results, the width and length of the ground plane is considered to approximately 13 times of the dielectric thickness h [3] added to the width and length of rectangular patch. Similarly, the dimension of the DGS included in the ground plane for antenna 2 is calculated using the resonant frequency of 10 GHz using (4). The length and width of the slots provided on the patch is dimensioned with a resonant frequency of 10 GHz. In antenna 3 extending the slot in the middle of circle by adding a small slot. As a result of this, the antenna resonates in Ku band and K band. The length and width of the extra slot provided on the patch in antenna 3 dimensioned with a resonant frequency of 19 GHz.

5. RESULTS AND DISCUSSION

The proposed antenna shape given above is designed and simulated using the An soft High Frequency Structural Simulator (HFSS) version 12. The result parameters obtained for the depicted model is discussed below.

5.1 Return loss

Return loss gives us amount of power being reflected by the input port. For antenna, return loss below -10 dB is considered to be quite efficientFig. 8 represents the return loss plot for the proposed model (Antenna 3). It resonates at multiple frequency bands with a return loss of -24.32dB, -22.59 dB and -24.46 dB, - 16.3 dB and -23.42 dB for 9.1 GHz, 10.1 GHz and 11 GHz, 16.7 GHz, 19.1 GHz respectively. This result shows that the antenna is suitable for X band, Ku band, K band applications.

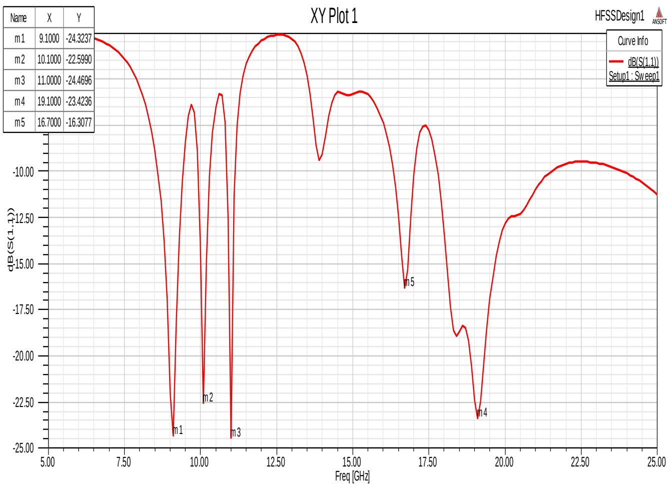


Fig 8.S – Parameters for the proposed model

5.2 VSWR

VSWR is simply the ratio of peak amplitude of Standing wave to the minimum amplitude of standing wave VSWR below 2 is considered well for an antenna. . Fig. 9 represents the VSWR plot for the depicted model with a VSWR value of 1.12, 1.16 and 1.27, 1.36, 1.14for the corresponding resonant frequencies of 9.1 GHz, 10.1 GHz and 11 GHz, 16.7 GHz, 19.1 GHz. The obtained VSWR characteristics exhibit good impedance matching over the wide operational frequency bands which were analyzed from the return loss vs. frequency plot.

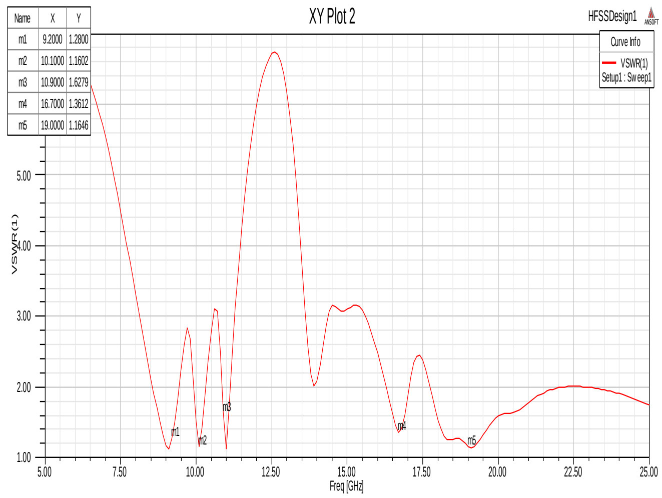


Fig9.VSWR plot for depicted antenna

6. CONCLUSION

Hence the microstrip patch antenna with DGS (defected ground structure) is designed to resonate at multiple bands with optimal result obtained in each of the antenna parameters. The proposed model is well efficient for triple band in X band and single bands in Ku band K band. The X band particularly for radar. The Ku band for satellite communication and K band for mobile allocation, satellite communication respectively. The DGS and rectangular slot helps to achieve multiple band and good radiation characteristics. Thus, the novel design provided with the rectangular slots on patch gives good radiation characteristics in terms of bandwidth, gain, directivity, return loss and VSWR.

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