

Multi-Band Rectangular Patch antenna with F-Type Defected Metal Structure

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Abstract-In this work, a novel multi-band microstrip patch antenna having two “F” shape slits and 1 circular slot as defected metal structures is proposed. This antenna works on Four bands i.e. 2.38 GHz, 2.54 GHz, 4.98 GHz, and 5.56 GHz with sufficiently large bandwidth. This antenna provides return loss as high as 48 dB at one of the bands and more than 30 dB at other two bands and 18 dB at the remaining band. The antenna is designed on FR4 substrate with an area of 45*60 mm² and yields bandwidth from 60 MHz to 210 MHz at different bands.

Index Terms-Microstrip Antenna, Return Loss, Impedance Bandwidth, Defected Metal Structures (DMS).

1. INTRODUCTION

A microstrip antenna is generally a three-layered structure. It consists of a dielectric substrate having ground on side while patch is present on the other side of the substrate. Ground and patch are made up of conducting materials for e.g. copper. The main advantages of microstrip antennas over conventional antennas are compact size, moderately high gain and lower cross polarization. In the today's world, people are interested in miniaturization of the devices and microstrip antennas come handy in that sense. A general microstrip antenna structure is shown in figure 1.

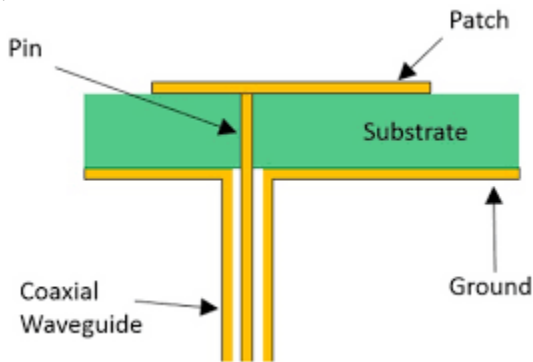


Figure 1: Microstrip Antenna with coaxial feed

It is evident from figure 1, outer conductor of the coaxial feed is connected at the ground and inner conductor is connected to the patch via hole in substrate. The feed is connected at a location where the impedance matching occurs to transfer the maximum power.

Microstrip antenna is also known as patch antenna. Shape of the patch can be rectangular, circular, square or any arbitrary shape. Patch antenna is a three layered structure consists of patch and ground plane separated by substrate with feeding (coaxial, microstrip line,

aperture coupled or proximity feed). The first step in designing of a patch antenna is to choose an appropriate substrate which affects the electrical performance of the antenna. There is no ideal substrate but the choice of the substrate depends on the application. Available substrates are PTFE (Polytetrafluoroethylene), Polystyrene, Polyolefin, Alumina, Sapphire, Quartz, Rutile and Semiconductor Substrate etc. Dielectric constant range of the substrate for efficient operation of a patch antenna is (2.2 to 12).

Thick substrate with low dielectric permittivity provides a good bandwidth. The physical size of the patch is small but the fringing effect makes it electrically large. As the thickness of the substrate increases, difficulties in antenna integration and surface wave problem increases which makes resonance unfeasible. To overcome these problem, slit and slot loading in the patches are introduces to ensure the small size and low profile of the antenna.

Slits are the arbitrary cutting in the boundaries of the patch while slot is the arbitrary cut within the patch. The position and dimensions of slit and slot are properly selected in order to maintain the broadside operation. Shape, size and the position of the slit and slot ensures the multiband and wideband operation of the patch antenna.

Slit and slot divides the patch in number of parts and each part represents an equivalent resonant circuit and resonant at different frequencies. This also provides an additional size reduction. Proper feeding and position of feed is used to match the impedance for excitation of the radiator which results in low return loss, high gain, bandwidth and directivity.

So, the position and width of the slit controls the frequency band of the antenna. This technique provides an additional advantage of size reduction. By cutting a slot in the patch, the antenna is considered

as two different resonators of different shape and size and makes an antenna dual or multiple bands operated for different mobile and wireless applications.

The equivalent circuit of the slit loaded patch is shown following

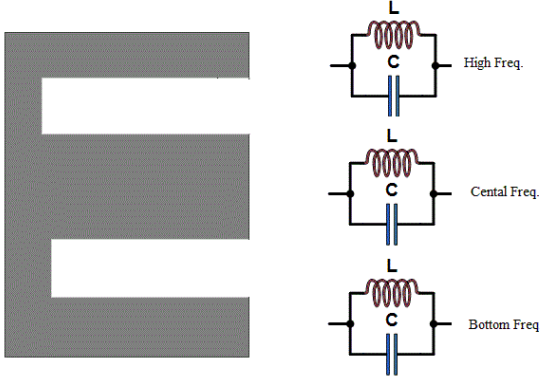


Figure 2: Equivalent circuit of the slit loaded patch

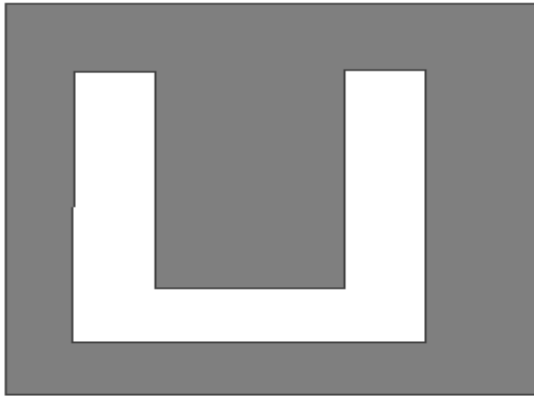


Figure3: Slot loaded patch

Fundamental bandwidth is defined as

$$B.W. = f_H - f_L$$

And Fraction Bandwidth

$$B.W. (Fractional) = B.W. / f_c$$

Where f_c = Center Frequency

The patch antenna behaves like a resonant cavity when it is excited using the coaxial feeding which generates strong field inside the cavity and a strong current flow on the surface of patch and significant radiation starts using the fringing field effect.

In the presented work, two F-type slits and one circular defected metal structures are introduced in the patch. Defected metal structures allow us to reduce the size by increasing the effective length of the antenna and

thus compact size antennas can be designed at lower frequencies. Defected Metal Structures (DMS) can be of any shape and size. Besides effective length, they also enhance bandwidth, gain and reduces cross polarization. These factors depend on size, shape, and location of the DMS.

2. CONVENTIONAL RECTANGULAR PATCH ANTENNA:

To design a rectangular patch antenna, after selecting the substrate material, we have few design equations which provides the effective length, effective width, effective dielectric constant for the microstrip patch antenna.

A conventional rectangular patch antenna with patch dimensions 30mm X 40mm is designed over a 3.2 mm thick FR-4 dielectric substrate having 4.4 relative dielectric constant and loss tangent of 0.025. Substrate has an infinite ground plane and the overall size of the antenna is 50mm X 60mm. This antenna is fed through the 50 Ohm SMA connector.

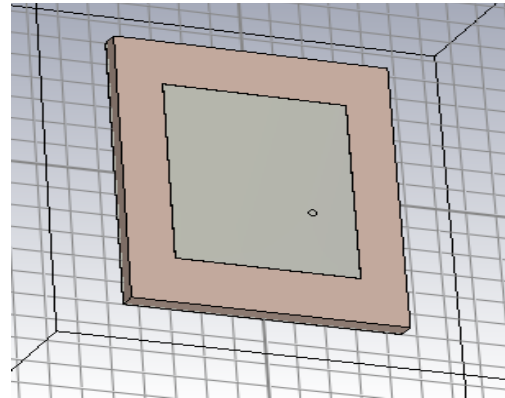


Figure 4: Conventional Rectangular patch antenna

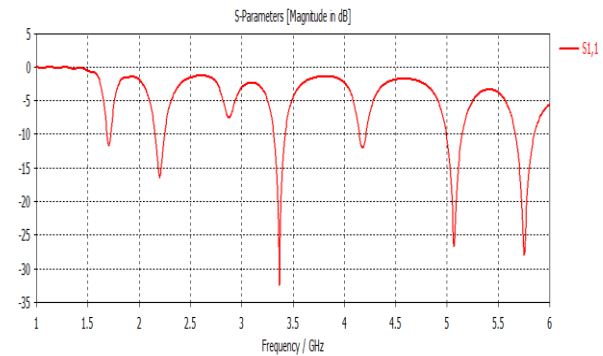


Figure 5: S_{11} Plot for the Rectangular Patch Antenna.

Figure 4 represents the top view of the geometry of the proposed antenna in CST- Microwave studio

software. Figure 5 shows S11 vs Frequency graph for the antenna.

The result obtained shows that the antenna is multi band antenna have a return loss of 32.45 dB at 3.36 GHz and corresponding bandwidth is 110MHz which is very low. Improvement in the performance of the rectangular patch antenna is further improved with the insertion of the some defected structure in the patch shape. Here F-shape structure is used. Results obtained with the introduction of the F-Shape slits are presented in the next section.

3. PROPOSED RECTANGULAR PATCH ANTENNA WITH F-TYPE SLITS:

The geometry of the conventional rectangular patch antenna is modified to improve the performance. As shown in the following figure that the two F-Type slits are introduced in the geometry of the patch. The geometry of the inserted slits are same, only difference is the orientation of the insertion.

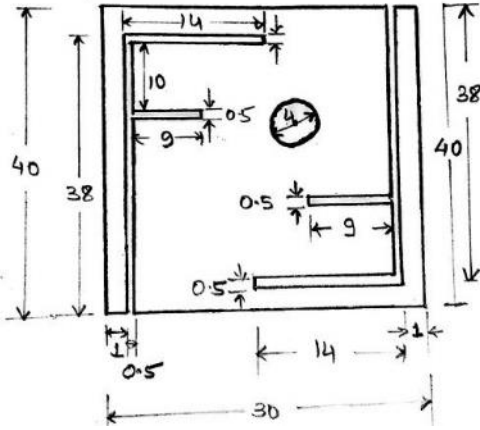


Figure 6: Design dimensions of the proposed antenna.

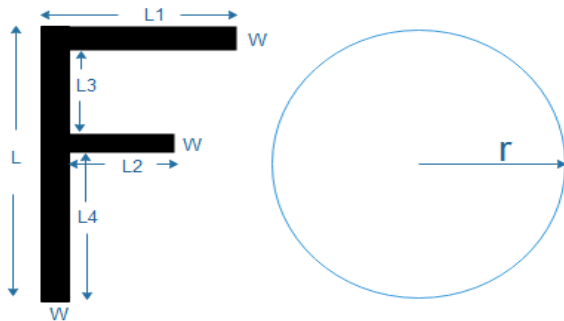


Figure 7: Prototypes of the Defected Metal Structure

As shown in figure 8, a rectangular patch is designed with two F-type slits and one circular slot in the patch.

A prototype of the F-type slits is shown in figure 3 where $L = 38$ mm, $L1 = 14$ mm, $L2 = 9$ mm, $L3 = 10$ mm, $L4 = 27$ mm and $w = 0.5$ mm. whereas the radius for the circular slot is $r = 2$ mm.

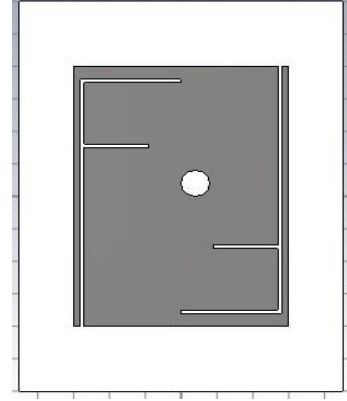


Figure 8: Top view of the proposed antenna

This proposed antenna is again designed on the same FR-4 dielectric substrate with same design parameters and simulate on the commercially available software CST- Microwave studio.

The design parameters for the proposed antenna are summarized in table 1.

Table 1: Parameters of the proposed antenna

Parameter	Value
Substrate	FR4
Relative Dielectric Constant	4.4
Substrate Thickness	3.2 mm
Patch Length	30 mm
Patch Width	40 mm
Feed Point Location (x, y)	(8 mm, -6 mm)
Ground Plane	50x60 mm ²

The design equations used for the calculations are as follows:

Width of the patch

$$W = \frac{c}{2f_r \sqrt{\frac{\epsilon_r + 1}{2}}}$$

Where the notations are in SI units and f_r is the desired resonant frequency where $c = 3 \times 10^8$ m/Sec, the speed of light in vacuum.

Now, considering fringing field effects, the effective dielectric constant can be given by

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + \frac{12h}{W} \right]^{-\frac{1}{2}}$$

Where h is the height of the substrate and W is the width of the patch calculated using Equation 1.

The increment in the length due to fringing field can be calculated by following equation

$$\Delta L = \frac{h}{\sqrt{\epsilon_{eff}}}$$

And Length of the patch can be calculated by

$$W = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} - (2\Delta L)$$

The proposed antenna is having four bands working in the range of 2.38 GHz – 5.56 GHz with reasonably good bandwidth and moderately high gain.

4. RESULTS AND DISCUSSION

All the simulations and designing of the proposed antenna is carried out on CST Microwave Studio software. Figure 4 shows the return loss S_{11} response of the design. For impedance bandwidth, return loss higher than 10 dB is considered and with this definition, this antenna is resonating on four bands given by 2.38 GHz, 2.545 GHz, 4.98 GHz, and 5.56 GHz with bandwidth of 3-5%.

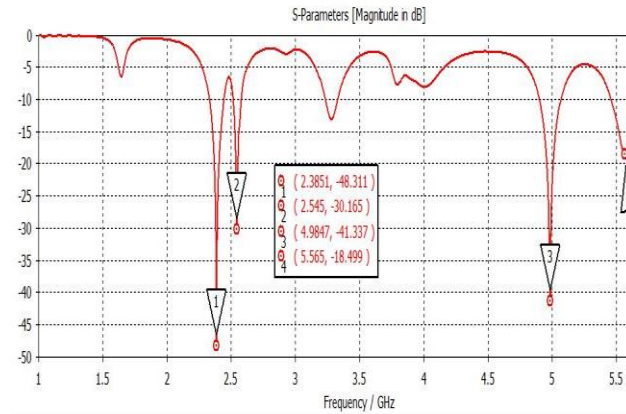


Figure 9: S_{11} response of the antenna

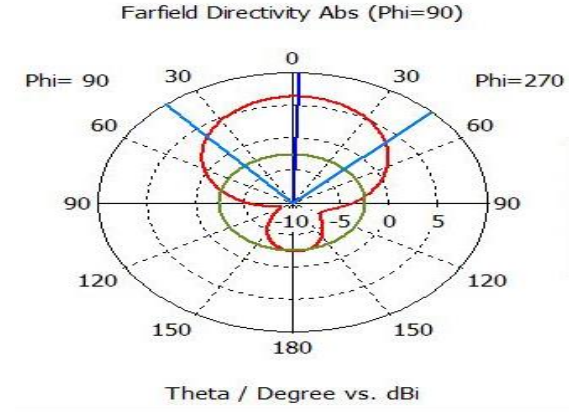


Figure 10: Far-field radiation pattern at 2.38 GHz

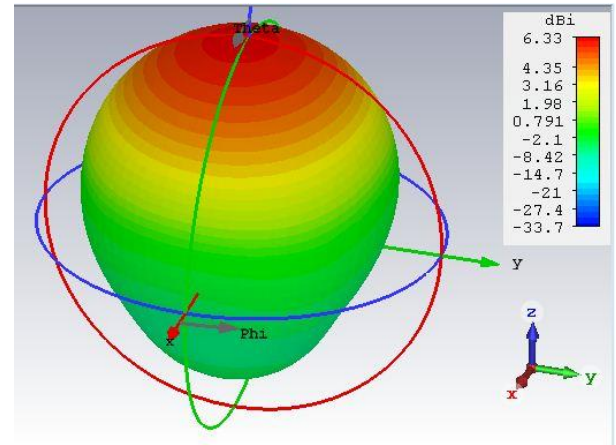


Figure 11: Far-field radiation pattern at 2.38 GHz

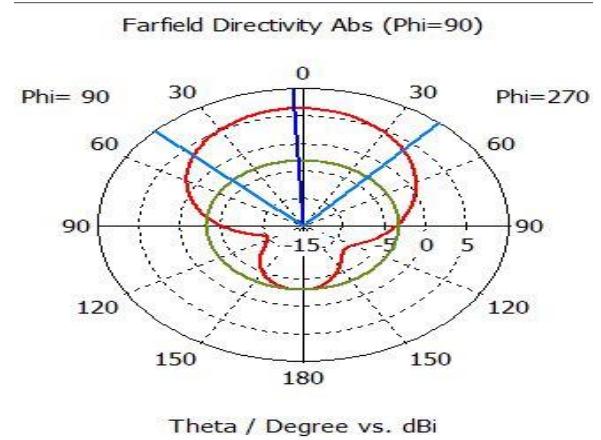


Figure 12: Far-field radiation pattern at 2.54 GHz

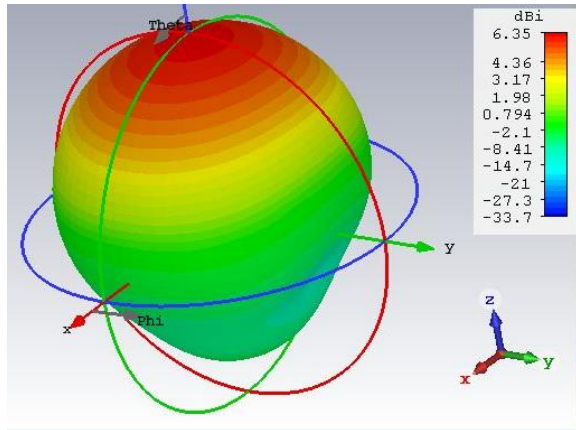


Figure 13: Far-field radiation pattern at 2.54 GHz

Figure 5-8 show the far-field radiation pattern at 2.38 GHz and 2.54 GHz respectively. Polar representation of these graphs clearly indicates high directivity and gain as well. At 2.38 GHz, the half power beam width (HPBW) is 86.3 deg which results in directivity of 6.33 dBi and at 2.54 GHz, HPBW = 88 deg which gives the directivity of 6.35 dBi.

5. CONCLUSION

A novel multi-band rectangular patch antenna with defected metal structure is reported. The proposed antenna is working on four band with sufficiently high bandwidth and providing good return loss. The directivity achieved is more than 6 dBi and gain is also more than 5 dBi.

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