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A Simple Rectangular Microstrip Patch Antenna for K & Ku Band Applications

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Abstract: The microstrip patch antennas have become famous around the world due to their multifold advantages such as these antennas are easy to fabricate, they are less bulky, smaller in size and economical. Aside from this, patch antennas are being used in a variety of wireless communication systems for various applications which include aircrafts, space technology, cellular communication and satellite communication. One of the major drawbacks of using these antennas is that they usually have comparatively smaller or narrow bandwidth. In this paper, an attempt has been made to overcome the aforementioned issue by enhancing parameters of a patch antenna with a simple rectangular design. The simple design makes it easy to fabricate with minimal difference in simulated and actual parameters. The required results are obtained by simply etching two slits on the patch and changing the width of the feedline. The overall band thus acquired is about 11.4 GHz with directivity of 8.771dBi and Gain of 6.084 dB at 24 GHz. In order to get the desired results, the substrate material used is Rogers RO4350B with an epsilon value of 3.48. The overall size of the antenna is 14.31×9.2mm^2.

Keywords: Micro-strip patch antenna, Ku Band, K Band, CST Design, Bandwidth, Directivity, Gain

1. INTRODUCTION

The microtrip patch antenna is an interesting topic for the researchers who work in the field of wireless communications systems. This antenna has a variety of applications and is thus used in many systems. Due to their small size, economical cost and ease of fabrication, MSP antennas can be easily applied to different wireless communication systems as they meet the requirements of modern technology. MSP antennas were first proposed by Deschamps in 1952 (Deschamps 1953). However, the practical implementation of these antennas started in 1970s by Munson and Howell (Munson 1973) (Munson 1974) (Howell 1975). Aside from their multifold advantages, MSP antennas commonly face the issues of low gain, low bandwidth, low efficiency and low power handling capabilities (Balanis 2005) (Kumar and Ray 2003) (Garg, *et al.*, 2001) .

The antenna under discussion consists of three layers as shown in (**Fig.1)**. The material used in the top as well as in the bottom layer is conductor. The central layer is prepared from an insulating material (substrate), whose relative permittivity is usually small. The thickness of the metallic strip is not exactly the wavelength ($t \ll \lambda_0$) and for the height of dielectric substrate, the condition ($0.003\lambda_0 \leq h \leq 0.05\lambda_0$) where 'h' represents the height of the dielectric has been met. The Ku band is primarily used for satellite communication systems. As per the IEEE Standards, the Ku band starts from 12GHz and runs up to 18 GHz. The electromagnetic spectrum of the X band is between 8 and 12 GHz and is utilized for satellite communication as well, aside from that, the X band is suitable for the quick and secure communication of voice transmission, data transmission and distant video applications. The Ku band is highly appropriate for VSAT (Very Small Aperture Terminal) applications which are utilized for finding out the speed of an article. The conditions used to ascertain the width and length of the patch antenna are exhibited below:

The patch width is given by equation (1)

$$\boldsymbol{W = \frac{c}{2f_0}\left(\frac{2}{\varepsilon_0+1}\right)^{1/2}} \tag{1}$$

The effective dielectric constant is given by

$$\boldsymbol{\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2}} \tag{2}$$

Furthermore, the actual and the effective length of the top layer (patch) can be computed with the following two equations

$$\boldsymbol{\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}} \tag{3}$$

$$\boldsymbol{L_{reff} = \frac{c}{2f_0(\varepsilon_{reff})^{1/2}}} \tag{4}$$

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$$L = L_{reff} - 2\Delta L \tag{5}$$

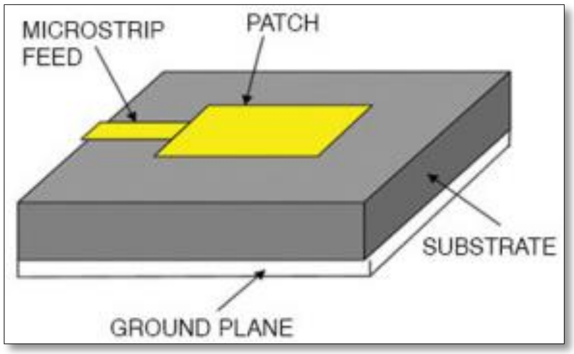

Fig. 1. Three Layers of the Antenna

There are two renowned methods used to feed MSP antennas namely contact method and non-contact method. Four most widely used feeding methodologies are mentioned as follows (Reddy, and Rana, 2009).

a. Microstrip line
b. Coaxial probe

The above mentioned feeding methodologies are contacting schemes. The two non-contacting feeding schemes are listed below.

c. Aperture coupling
d. Proximity coupling

The literature review of other such designs to enhance the overall performance of a MSP antenna is quoted here to build a concrete background of the work done in this paper. In (Kouhal, et *al.,* 2015), in order to overcome and address the weaknesses of a MSP antenna and enhance its bandwidth, three cuts were applied in the top layer (patch) and the author concluded enhancement in the Gain. Another circular polarized MSP antenna was discussed in (Yao, *et al*., 2017) for 5G applications and it was recommended for the bandwidth running from 81GHz to 95GHz. The results attained were declared very suitable for the future 5G wireless communication. Similarly, in (Rao, *et al.,* 2016), a gain of 17.22dB and 19.22 dB were demonstrated with a claim of 0.92 efficiency. The radar system is one of the areas where Ku band is utilized. In (Ram, and Kumar, 2015), a structure for ultra wideband radar applications was presented successfully. This antenna works satisfactorily in the measured bandwidth running from 3.0 GHz to 12.0 GHz. Another such MIMO antenna for ultra wide band applications is presented in (Jafri, *et al.,* 2016) and it was demonstrated that its achievements were better than the designs for the same areas in the past. Similarly, another proposal for MIMO applications in (Khan, *et al.,* 2017) was presented and it was argued that this design meets the requirements of WiMAX and WLAN (3.6 GHz and 5.2 GHz). Another yet important parameter for an antenna is the isolation. For this reason, (Iqbal, *et al.,* 2017) discussed high isolation between the radiating elements. In order to achieve a stable radiation pattern and to enhance the bandwidth a circularly polarized antenna is presented in (Liu, *et al.,* 2017). All the results were explained and the conclusion is that its bandwidth was enhanced. The substrate or the dielectric used in MSP antenna is also of vital importance. The most widely used substrate material is FR-4 and the same material was tested in (Bhadouria and Kumar., 2014), for Ku-band applications but the efficiency of this material for the mentioned band is very poor and this is why the researchers do not recommend it for this application.

The design proposed in (Misran, *et al.,* 2009) can work with two resonant conditions but its gain was not a very reasonable gain as it was 4dBi only.

A new shape is introduced in (Tumati, *et al.,* 2017). Instead of a typical and conventional circular, rectangular or square patch, the patch shape of the antenna resembles a bow-tie. It was claimed that this design can work in a wide band. A similar design to enhance the bandwidth is presented in (Ahmad *et al.,* 2018). The techniques used in this antenna focus on modifying and manipulating the ground of a MSP antenna and also etching parasitic patches on the main patch. Four different parasitic patches are etched on the top, bottom, left and right of the main patch whereas defected ground plane structure is adopted to modify the ground plane. The resultant gain of the antenna turned out to be 7.13 dB at 15.15GHz. The overall bandwidth of the antenna reached 5.51GHz. Another such design has been presented in (Ahmad., *et al*., 2017) which focuses on enhancing the bandwidth of a MSP antenna. The bandwidth of this antenna is better than the one described in the preceding manuscript and is given in Table 3. Similarly in (Ahmad., *et al*., 2018) a patch antenna for Ku band application demonstrated a bandwidth of 5.44GHz. This antenna attained a return loss of 62.38 at the resonant frequency of 16.93GHz.

In this paper, a Microstrip antenna with a rectangular patch has been presented that operates from 14GHz to 25GHz covering Ku and K band. The simple rectangular patch was modified in order to obtain the desired results. The antenna is simulated using CST programming. The essential parameter to be upgraded in this situation was the bandwidth. The parameters of the microstrip patch antennas can be optimized to produce better results. Researchers have proposed different methodologies to enhance the performance parameters of a MSP antenna and some of these are implemented here to improve the performance of the proposed antenna.

2. ANTENNA DESIGN

The design of the proposed microstrip patch antenna was made in CST studio is shown in **(Fig.2).** The substrate used in the design is Rogers RO4350B with the relative permittivity of 4.38.

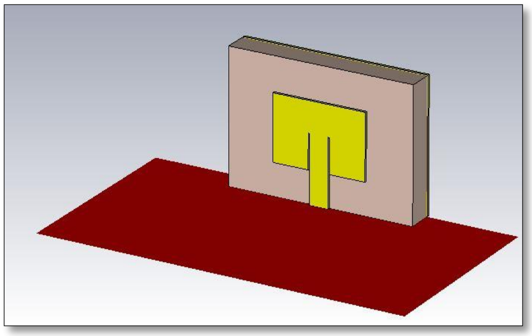

Fig 2. MSP Antenna for K and Ku Band in CST

The width, length and thickness parameters of the antenna were calculated using the formulas and equations shown previously. As seen in **(Fig. 2),** the structure of the antenna is rectangular with microstrip feed line. Aside from that, in order to enhance the performance and results, two slits have been engraved on the patch which enhanced the overall bandwidth and other constraints as well. The front view of the antenna with dimensions is displayed in **(Fig. 3).**

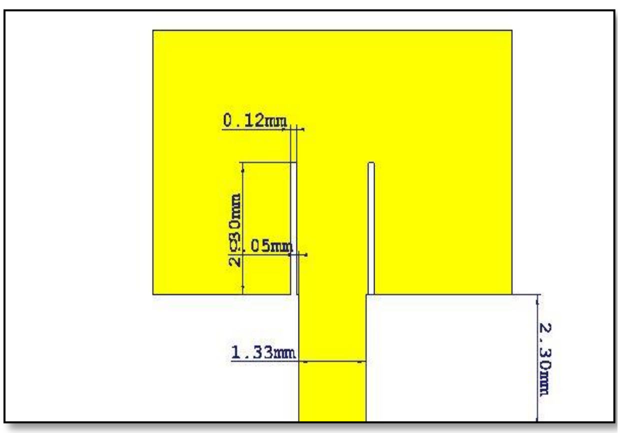

Fig 3. Front view with dimensions

Since the slits etched on the patch are very narrow, a closer view of the patch is shown in **(Fig. 4).** It is worth mentioning here that all the parameters are measured in millimeters and **Table 1** shows the final parameters of the designed antenna. The ground plane of the designed antenna is solid and defect has been created in it and this structure turns the design to be very simple and easy to fabricate.

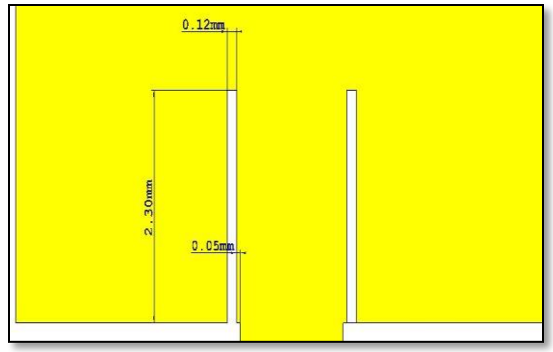

Fig 4. Closer Front View with Dimensions

Table 1: Summary of parameters of the final design

Dimension / Parameter	Value (mm)
Substrate /Ground width	14.31 mm
Substrate/Ground Length	9.20 mm
Substrate height	2 mm
Patch width	7.15 mm
Patch length	4.60 mm
Patch Thickness	0.20 mm
Feed line length	2.30 mm
Feed line width	1.33 mm
Slit width	0.12 mm
Slit length	2.30 mm

3. RESULT AND DISCUSSION

The proposed design after simulation shows considerably good results. The gain and directivity of the antenna at 24GHz is 6.09dBi and 8.78dBi respectively. The overall bandwidth is 11.4GHz. The overall spectrum covered by the antenna ranges between 14 and 25.4 GHz. **(Fig. 5)** shows the gain of the antenna whereas **(Fig. 6)** shows its directivity at 24GHz respectively.

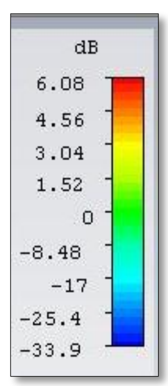

Fig.5.Gain at 24 GHz

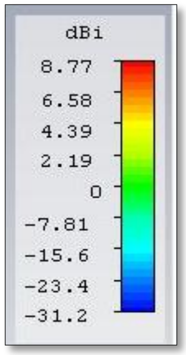

Fig.6.Directivity at 24 GHz

The 2D plot of gain is shown in **(Fig. 7)**. The parameters displayed in the figure depict that the main lobe direction is 54 degrees with side lobe level at -11.7dB. The directivity 2D plot likewise depicts the same in **(Fig. 8).**

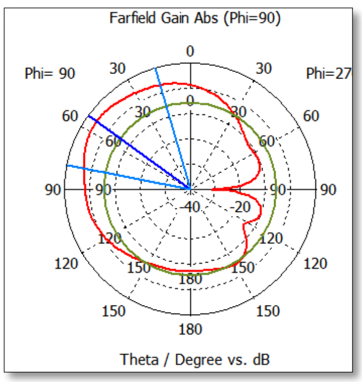

Fig.7.2D plot for Gain at 24 GHz

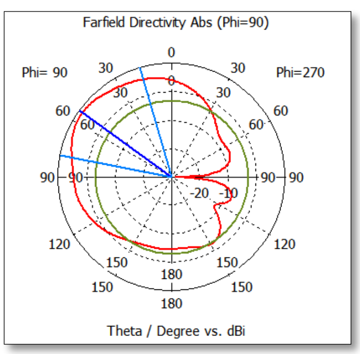

Fig. 8. 2D for Directivity at 24 GHz

Similarly, the same graphs were plotted at 20 GHz for a comparison. The plots in **(Fig. 9)** and **(Fig. 10)** show the gain and directivity of the proposed antenna at 20GHz respectively. It shows that the gain at 20GHz is comparatively lesser than that at 24GHz which is 3.49dBi whereas the directivity is 6.8dBi. The 2D graph shown in **(Fig. 11)** and **(Fig. 12)** show that the main lobe direction for both directivity and gain is 70 Degrees with a side lobe attenuation of -2.4 dB.

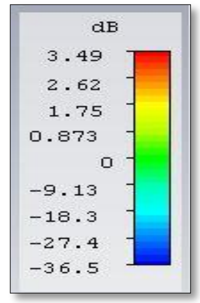

Fig. 9: Gain at 20 GHz Frequency

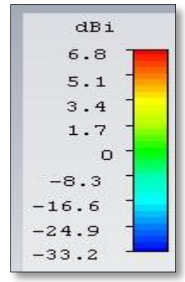

Fig. 10: Directivity at 20 GHz Frequency

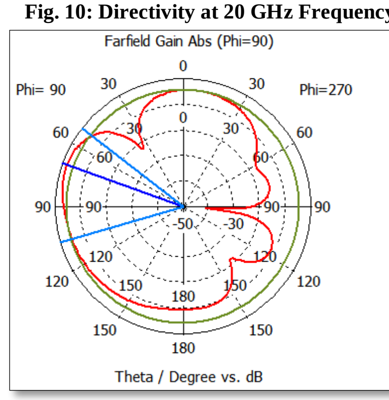

Fig. 11: 2D Gain plot at 20 GHz Frequency

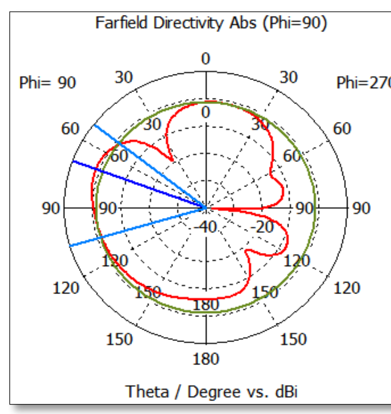

Fig 12: 2D Directivity plot at 20 GHz Frequency

The S-parameters of the antenna after simulation show the return loss and voltage standing wave ratio (VSWR). The return loss attains its maximum value around 24GHz. The VSWR remains close to 1.5 over the entire bandwidth which is why the overall performance of the antenna is enhanced. **(Fig. 13)** shows the return loss whereas **(Fig. 14)** shows the VSWR of the proposed antenna. A return loss of 28.1dB was recorded at the center resonant frequency of 23.86GHz and the voltage standing wave ratio at the mentioned frequency was 1.08.

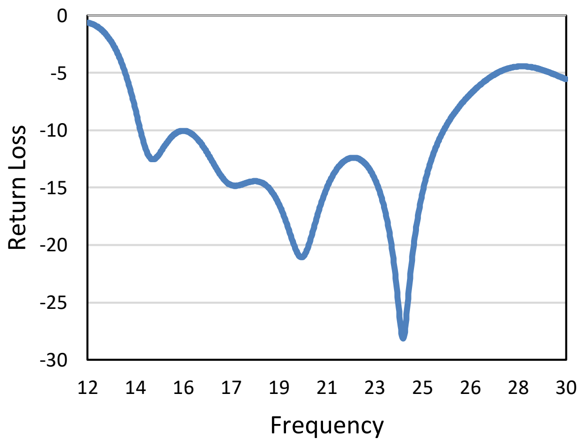

Fig.13. Return Loss

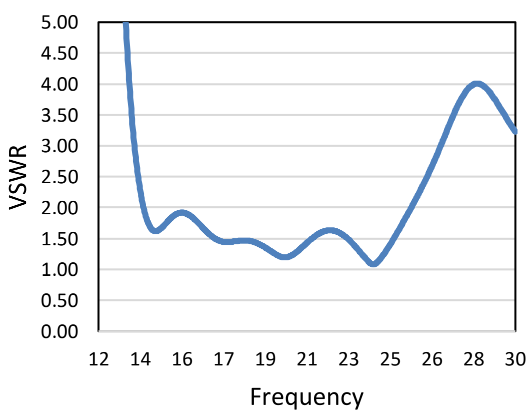

Fig. 14. VSWR

Another important parameter to measure the performance of the antenna in CST is the efficiency. **(Fig. 15)** shows the total and the radiating efficiency of the proposed antenna. The total efficiency varies from 28.5% to 51.4% in the mentioned bandwidth of the antenna. The total efficiency needs to be enhanced as it is a bit stumpy.

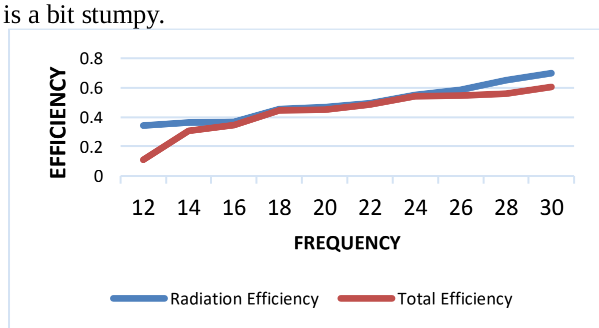

Fig. 15. Radiating and Overall Efficiency

Since the antenna covers a wide range of frequency spectrum, the directivity and gain of the antenna at different frequencies is displayed in **(Table 2).**

Table 2: Directivity and gain at different frequencies

Frequency(GHz)	Directivity (dBi)	Gain (dBi)
14	7.409	2.999
15	6.134	1.161
16	5.533	1.184
17	6.153	2.474
18	6.457	3.024
19	6.657	3.361
20	6.715	3.418
21	6.331	3.032
22	7.785	4.711
23	8.591	5.807
24	8.77	6.08
25	7.54	5.82

(Fig. 16) shows the graphical form of the tabulated data mentioned above.

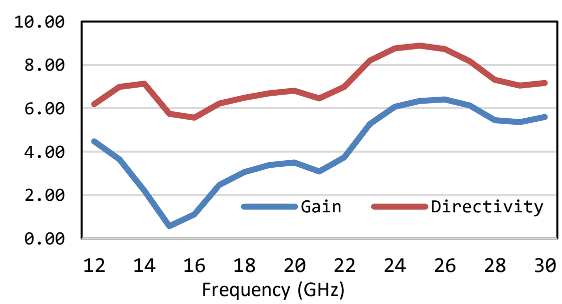

Fig. 16: Gain and Directivity VS Frequency

A comparison of the previous works with this proposed work is elaborated in **(Table 3)** which confirms that the bandwidth of the proposed design is better.

Table 3: Comparison with Previous Works

Manuscript	Bandwidth
(Ram, and Kumar, 2015)	9GHz
(Liu, *et al.*, 2017)	1.2GHz
(Ahmad *et al.*, 2018)	5.51GHz
(Ahmad *et al.*, 2017)	4.08GHz
(Ahmad *et al.*, 2018)	5.44GHz
This work	11GHz

3. CONCLUSION

The antenna design proposed in this paper uses Rogers RO4350 B substrate with the relative permittivity of 3.48. The simple design with a little bit of modification by etching two narrow slits in the patch near feed line and narrowing down the width of the feed line enables the antenna to achieve the bandwidth of about 11GHz which covers Ku and K band. The total efficiency of the antenna at 25.4GHz is about 51.4%. The gain and directivity of the antenna also show a considerable good value of 6.08 and 8.77dBi respectively. The substrate of this antenna is 9mm long, 14.31mm wide and 2mm thick. Such antennas have wide range of applications in satellite communication. Aside from that, the ease of fabrication due to its simple design, less weight and miniaturized size enables it to fit for every system.

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