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A Novel Patch Antenna Design with Slotted Ground Plane for Satellite Communications

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Abstract: In this paper a microstrip patch antennais proposed for Ku-band satellite applications on the basis of its performance. The bandwidth of 6.12GHzhas been achieved with the help of parasitic patches, defected radiating patch and defected ground structure. The overall size proposed antenna is 16x8mm^2.Four parasitic patches have been introduced and the antenna has obtained a return loss of 48.84dB at the center frequency of 16.77GHz. This antenna has been simulated using FR-4 substrate with dielectric constant of 4.3.Thisantenna can be used for satellite communications in Ku- Band.

Keywords: Return Loss, Bandwidth, Gain, VSWR and Ku-Band

I. INTRODUCTION

Microstrip patch antenna can be manufactured easily and it has the merits of below profile, light weight and small compact planner size. The microstrip patch antenna in its simplest form consists of three layers as shown in Fig.1.The bottom layer is made of conductor and is known as the ground plane. The central layer is made of a dielectric material and is called the substrate. The height and the dielectric constant of the substrate play an important role in the design of the antenna. The top layer is made of copper and it is known as the patch of the antenna. The length as well as the width of the patch determines the resonant frequency of the antenna. Different feeding techniques like coaxial feed line and Microstrip transmission line are used to excite the patch antenna. The feed line is connected to the patch and the ground plane.

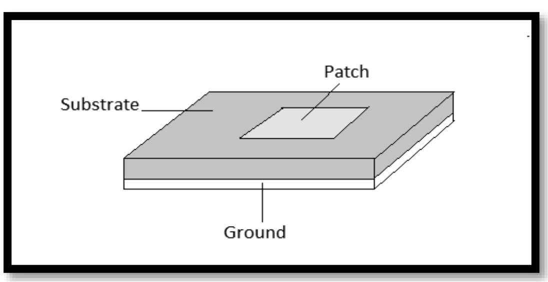

Fig.1. Patch Antenna

In (Nor, *et al.,* 2016) a patch antenna has been designed and it has achieved an impedance bandwidth of 2.1GHz. The Gain of the antenna in this research is reported to be 12.1 dBi. The fractional bandwidth of the patch antenna in (Bashar and Elias, 2013) is 13.3% at the center frequency of 12.57 GHz. Howell, in 1975, of fered an antenna of circular and rectangular shapes (Howell, 1975). The author has reported that the antenna bandwidth depends on the thickness and relative permittivity of substrate. Several geometries of microstrip patch antennas have been achieved so for. Rectangular, circular, square, triangular and elliptical shaped antennas have been discussed in (Balanis. 2005) but the combination of these shapes can also be used for the design of microstrip patch antennas.

Ku band (12-18GHz) is widely used band in satellite wireless communication system (Jana, *et al.*, 2013) (Sinhamahapatra, *et al.,* 2013) (Saluja, *et al.*, 2008) Various microsrip patch antennas for Ku band application have been reported in the literature. In (Azim, *et al.*, 2011). the patch antenna has been presented for Ku band application. This antenna has got an impedance bandwidth of 0.95 GHz and peak gain of 7.6dBi. The size of the antenna is 15 x 15 mm^2.

A rectangular shape, patch antenna has been suggested in (Dubey, *et al.,* 2011), The proposed antenna in this literature has obtained bandwidth of 0.6 GHz, 0.52GHz and 0.382 GHz for various bands. It has been reported that the antenna size is 7.6 x 10 mm^2 and it has been printed on Teflon dielectric material with thickness of 0.8.Ku band micro strip patch antenna has been designed on Teflon substrate with thickness of 0.8 mm. It has been concluded that the bandwidth of the antenna was 4.1553 GHz. The overall size of the antenna was 4.5 x 23.2mm^2. The gain was 6.906dBi, and the antenna has demonstrated a Return loss of 26.5578dB (Chodavadiya, and Aggarwal, 2014).

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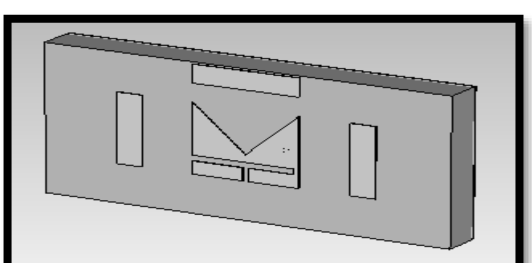
Another rmicrostrip antenna has been developed for Ku-band applications that has a size of 9.5×10 mm^2 and it has been printed on Rogers RT/Duroid 5880. The height of the substrate is 0.254 mm and the antenna has a maximum bandwidth of 0.90 GHz (Misran, *et al.*, 2009) In order to enhance the bandwidth of the patch antenna the researchers have presented patches of different shapes. The patches of A, E, M, U, hexagonal and defected shape have been presented in (Sanjeev *et al.*, 2013). (Fan *et al.*, 2001). (Tapan and Das, 2016). (Manoj *et al.*, 2015).

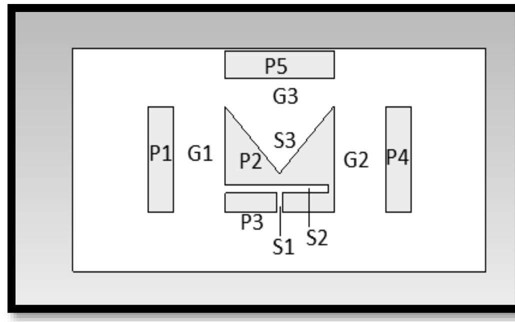
The antenna for Ku- band satellite communication has been printed on Rogers RT/Duroid 6010. The height of the material used as substrate of the antenna is 1.905 mm. The size of the antenna has been reported to be 8.5 × 7.96 mm^2.The antenna works in the bandwidth of 0.576 GHz (Samsuzzaman, *et al.*, 2013). An antenna with size of 9.50 × 10 mm^2has been reported for Ku-band communication. The height of substrate has been adjusted to 0.254 mm. The return loss of 23.83dB and 14.04 have been obtained at various bands (Islam, *et al.*, 2010)

2. DESIGN METHODOLOGY OF THE ANTENNA

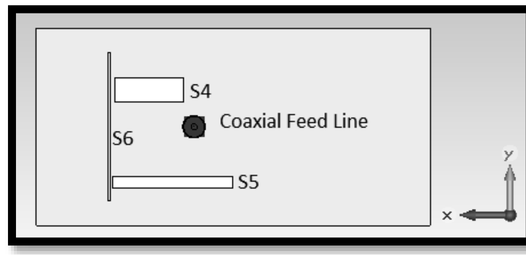
A rectangular antenna with four parasitic patches have been designed and simulated as shown in **(Fig. 2a).** The material of the substrate of the antenna is low cost FR-4 with a dielectric constant of 4.3. The height of the substrate has been adjusted to 1.64 mm. The overall size of this rectangular patch antenna is16x8 mm^2.Two rectangular slots S_1 and S_2 while one triangular slot S_3 have been produced on the radiating patch P_2as shown in **(Fig.2b).** The technique of defected ground structure (DGS) has been implemented for the enhancement of the impedance bandwidth of the antenna. Three rectangular slots S_4, $S_5$and S_6have been etched on the ground plane as shown in **(Fig.2c).** The antenna has been energized using coaxial feed line. The dielectric material of the coaxial feed line is Teflon with dielectric constant of 2.2. The resistance of the feed line has been adjusted to 50Ohms. The coaxial feed line has been adjusted at 1.6mm on the x-axis. The dimensions of all the parameters of this proposed antenna are given in **(Table 1a and Table 1b)**. The perspective, front and back view of the antenna are shown in **(Fig. 2a, 2b and 2c)** respectively.



(a)



(b)



(c)

Fig.2. The antenna (a) Front View (b) Back View

Table.1a. Parameters of the antenna

Name	Description	Value (mm)
A1	Overall size of the rectangular antenna	16x8
A2	Size of the rectangular driven patch P2 before the elimination of the slots	3.8x4.2
A3	Size of the Parasitic patches P1 & P4	1x3.8
A4	Size of the Parasitic patch P5	4.2x1
T	Thickness of the copper material	0.035
h	Height of the substrate	1.64
G1	The air gap between P1 and P2	2
G2	The air gap between P2 and P4	2
G3	The air gap between P2 and P5	1
X1	The X coordinates of the vertical slot S1 on the patch P2	(-0.1,0.1)
Y1	The y coordinates of the vertical slot S1 on the patch P2	(-1.2,-1.9)
X2	The X coordinates of the vertical slot S2 on the patch P2	(-2.1,-1.9)
Y2	The y coordinates of the vertical slot S2 on the patch P2	(-0.9,-1.2)
X3	The X coordinates of the vertical slot S4 on the ground plane	(2,4.8)
Y3	The y coordinates of the vertical slot S4 on the ground plane	(1,2)
X4	The X coordinates of the vertical slot S5 on the ground plane	(0,4.9)
Y4	The y coordinates of the vertical slot S5 on the ground plane	(-2,-2.5)
X5	The X coordinates of the vertical slot S6 on the ground plane	(5,5.1)
Y5	The y coordinates of the vertical slot S6 on the ground plane	(-3,3)

The vertices of the triangular slot S_3 on the driven patch P_2 are given in **(Table 1b).**

Table.1b. Vertices of the triangular slot S_3

X (mm)	Y(mm)
2.1	1.9
-2.1	1.9
0	0

3. RESULTS AND DISCUSSION

A. Reflection coefficient

Reflection Coefficient is the amplitude of the electric field intensity of the reflected wave to the amplitude of the electric field intensity of incident wave. The reflection of the signal takes place if the antenna is not matched properly. It can be reduced by improving the impedance matching.

The return loss of the proposed antenna is shown in **(Fig. 3).** The impedance bandwidth of this antenna is 6.12GHz. The Return loss of48.84dB has been demonstrated at the centre frequency of16.77GHz. The impedance bandwidth is reported from 11.34 to 17.46GHz.The fractional bandwidth of 36.49% has been obtained with the help of this antenna.

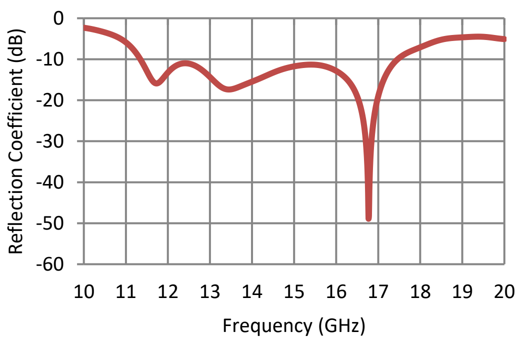


Fig. 3: Return Loss of the proposed antenna

B. Voltage Standing Wave Ratio

When the reflection of the signal takes place from the antenna, the interference of the incident and reflected signal results in the standing wave pattern. The ratio of the maximum voltage to the minimum voltage of the standing wave pattern is known as Voltage Standing Wave Ratio. It is represented by VSWR. The antenna is perfectly matched if the reflection coefficient is zero and the VSWR is one.

The Voltage Standing Wave Ratio of the antenna under discussion is shown in **(Fig. 4).** The ratio of 1 has been achieved at the center frequency of 16.77GHz as shown in the following figure. VSWR is less than 2 in the entire working spectrum of the antenna.

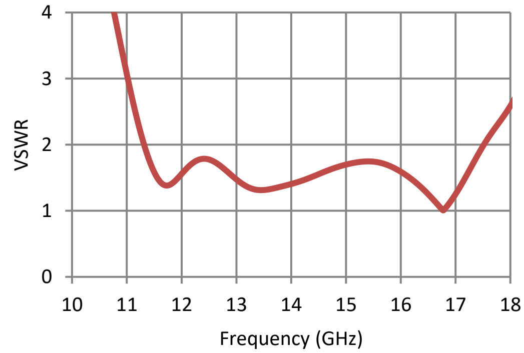


Fig. 4: Voltage Standing Wave Ratio.

C. Efficiency

The ratio of the power radiated by the antenna to the power delivered to the antenna is known as total efficiency. The total efficiency as well as the radiation efficiency of the antenna is shown in **(Fig. 5).** The total efficiency has reached the maximum value of 74.25% at the frequency of 13.99GHz. The radiation efficiency has reached the maximum value of 78.04% at the frequency of 15GHz.

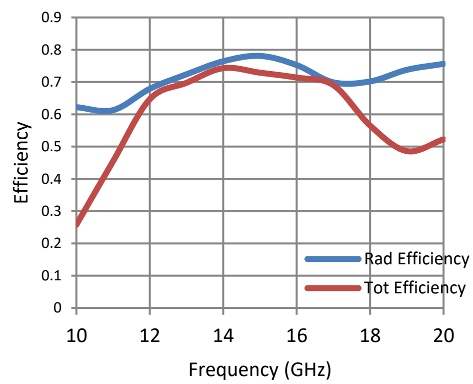


Fig. 5: Efficiency of the proposed antenna.

D. Radiation Pattern

The 2-D radiation patterns of the antenna at different frequencies are shown in **(Fig. 6).**

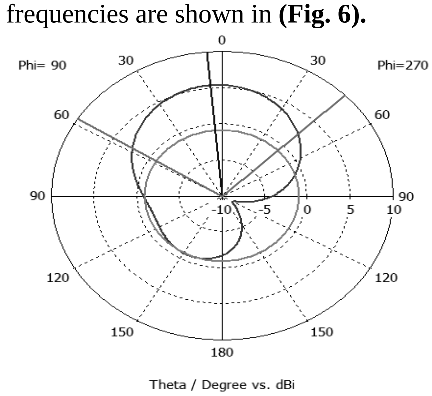


Fig.6a. Radiation Pattern at 12GHz

The angular width of the above radiation pattern is 103.5 deg and the side lob level is -6.2dB.

The radiation pattern at frequency of 13GHz has been shown in **(Fig.6b).** The 3dB angular width of the pattern is 92.4deg and the side lob level is -6.1dB.

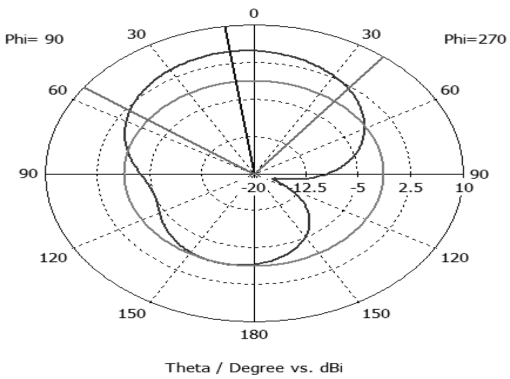


Fig.6b. Radiation Pattern at 13GHz

The radiation pattern at frequency of 14GHz has been shown in **(Fig.6c).** The 3dB angular width of the pattern is 92.7deg and the side lob level is -7.8dB.

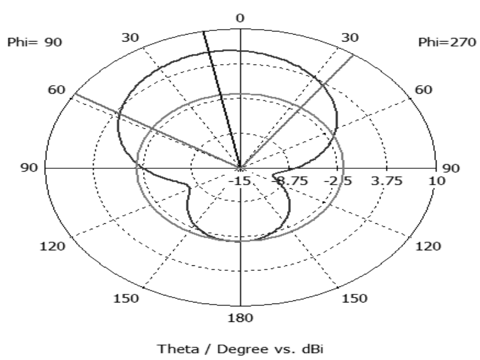


Fig.6c. Radiation Pattern at 14GHz

The radiation pattern at frequency of 15GHz has been shown in **(Fig.6d)**. The 3dB angular width of the pattern is 94.8deg and the side lob level is -8.3dB.

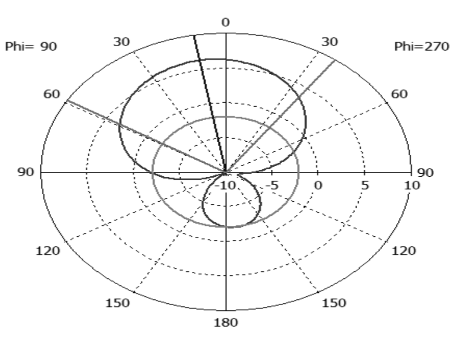


Fig.6d. Radiation Pattern at 15GHz

The radiation pattern at frequency of 16GHz has been shown in **(Fig.6e).** The 3dB angular width of the pattern is 102deg and the side lob level is -8.6dB.

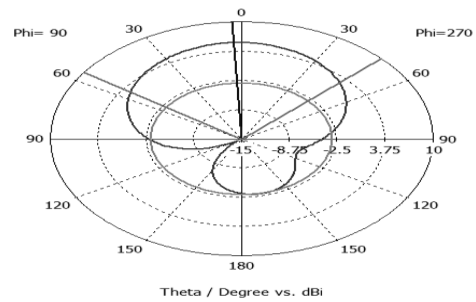


Fig.6e. Radiation Pattern at 16GHz

Finally the radiation pattern at frequency of 17GHz has been shown in **(Fig.6f).** The 3dB angular width of the pattern is 100deg and the side lob level is -12.5dB.

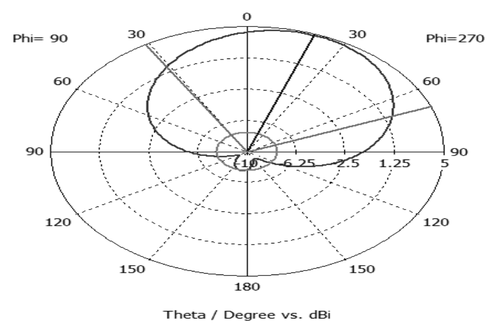


Fig.6f. Radiation Pattern at 17GHz

E. Gain

The power per unit solid angle is known as radiation intensity of the antenna. Its unit is watt per ste radians. The ratio of the radiation intensity of an antenna to the radiation intensity of the isotropic antenna is known as Gain. The same powers are applied to both the practical antenna and the hypothetical lossless isotropic radiator. The gain of the isotropic antenna is 0dB and the gain of a practical antenna with reference to isotropic antenna is greater than o dB. The gain will be large if the of the radiated beam of the antenna is small.

The gain of the proposed antenna is shown **(Table 2).** The sketch for the gain with respect to frequency is shown in **(Fig.7).**

Table.2. Gain of the antenna

Frequency (GHz)	Gain (dBi)
12	5.5
13	4.95
14	6.16
15	6.30
16	5.59
17	4.92

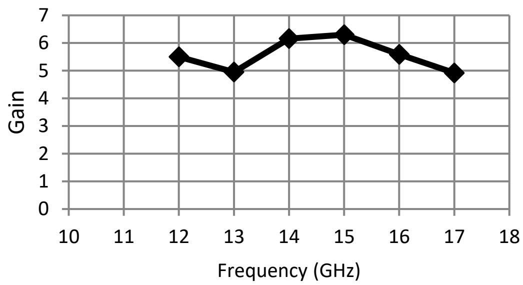


Fig. 7: Gain of the proposed antenna.

4. CONCLUSION

The impedance bandwidth of the proposed antenna is 6.12GHz from 11.34 to 17.46GHz.The return loss of 48.84dB at the center frequency of 16.77GHz has been obtained with the help of this antenna. VSWR of the antenna is in the desirable range between 1 and 2 and the value of 1 has been obtained at the center frequency. The maximum value of the total efficiency is 74.25% at a frequency of 13.99GHz.The minimum value of Gain is 4.92dBi and its maximum value is 6,30GHz. The maximum value of Gain has occurred at a frequency of 15GHz. Due to these characteristics, the proposed antenna can be used in the Ku-band for satellite communications.

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