SindhUniv. Res. Jour. (Sci. Ser.) Vol. 50 (002) 303-310 (2018)

http://doi.org/10.26692/sujo/2018.06.0051

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Analysis of Patch Antenna with two Different Substrate Materials for Ku-Band Communications

G. AHMAD, M. I. BABAR, M. IRFAN, R. EDWARDS*

Department of Electrical Engineering, UET Peshawar, Pakistan

Received 10rdFebruary 2017 and Revised 26th October 2017

Abstract: In this paper different characteristics of patch antenna with two different Substrates' materials have been analyzed. The initial antenna has been fabricated and tested. Rectangular slots have been etched in the radiating patch and ground. Two parasitic patches have been loaded to the antenna. Two different materials have been used in the substrate of the antenna and their impedance bandwidth and efficiency have been compared to each other. The Transmission Feed line is used to feed the antenna under consideration. The overall size of the final proposed antenna on Preperm L-450 is $10 \times 20 mm^2$. The impedance bandwidth of the proposed antenna is 5.44GHz and a return loss of 62.38 dB has been obtained at the center frequency of 16.93GHz. This antenna on the basis of its features can be used for Ku- Band communication.

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

1. INTRODUCTION

Microstrip patch antenna has the inherent features of low profile, light weight and it has planner size. The patch antenna has three layers, ground plane, and substrate and patch. The height and the dielectric constant of the substrate have a crucial role in the design of the antenna. The patch and the ground of the antenna are made of copper, while the substrate is made of dielectric material. The resonant frequency of the antenna can be calculated in terms of its length as well as width. In order to energize the patch antenna diverse feeding methods like coaxial feed line, Microstrip transmission line and indirect coupled transmission lines are reported in the literature. The feed line is connected to the patch and the ground plane of the antenna.

In (Nor, *et al.*, 2016) an antenna has been reported with an impedance bandwidth of 2.1GHz. The Gain of the antenna was 12.1dBi.

The fractional bandwidth of the patch antenna in (Bashar and Elias, 2013) was measured at the center frequency of 12.57 GHz and it was 13.3%. Howell, in 1975, has designed patch antennas and the shapes ofThese antennas were circular and rectangular(Howell, 1975). The author of the above mentioned antenna has concluded that the thickness and relative permittivity of substrate plays a crucial role in the antenna's bandwidth Different shaped antennas like Rectangular, circular, square, triangular and elliptical shaped antennas were explained in (Balanis, 2005) and he has concluded the patchantenna can also be designed from the combination of these shapes.

(Jana, *et al.*, 2013), (Sinhamahapatra, *et al.*, 2013) and (Saluja, *et al.*, 2008) have discussed different patch antennaswhich can be used for Satellite applications in the Ku band. (Azim, *et al.*, 2011) has made a patch antenna Ku band applications and this antenna has acheived a bandwidth of 0.95 GHz and peak gain of 7.6 dBi. The size of the substrate/ground was15 x 15 mm^2.

A rectangular shape, patch antenna has been suggested in (Dubey, *et al.*, 2011) has designed a multiband patch antenna having band width of 0.6 GHz, 0.52 GHz and 0.382 GHz for these bands and the size of the antenna was 7.6 × 10 mm^2.TheSubstrate has been made Teflon dielectric material and its thickness was 0.8. (Chodavadiya and Aggarwal, 2014) has reported micro strip patch antenna for Ku- band application on Teflon substrate having thickness of 0.8 mm. This antenna has achieved the bandwidth of 4.15 GHz. The area of the ground as well as substrate was 4.5 × 23.2 mm^2. This antenna has a gainof 6.906dBiand a Return loss of 26.55dB.

A microstrip antenna having a size of 9.5×10 mm^2 on Rogers RT/Duroid 5880 has been reported in (Misran, *et al.*, 2009). The thickness of the substrate was 0.254 mm and the antenna had an impedance bandwidth of 0.9GHz.The patches of A, E, M, U, hexagonal and defected shapes were designed and explained in (Sanjeev *et al.*, 2013), (Fan *et al.*, 2001), (Tapan and Das, 2016)

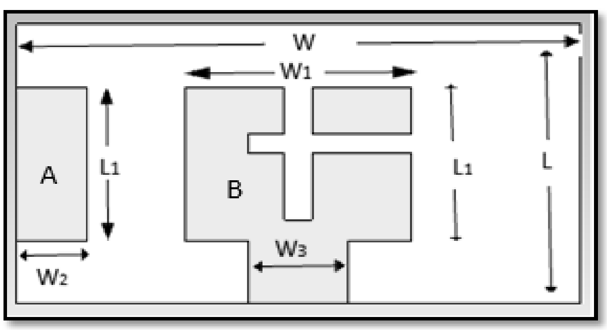
++Corresponding Author: Email: gulzar@uetpeshawar.edu.pk

* Department of Electrical & Electronic Engineering, Loughborough University, UK

and (Manoj *et al.*, 2015).(Samsuzzaman, *et al.*, 2013) has concluded an antenna for satellite communication in Ku-band. The material of the substrate was Rogers RT/Duroid 6010 and its thickness was 1.905 mm. The size of the antenna was 8.5 × 7.96 mm^2 and this antenna has obtained an impedance bandwidth of 0.576 GHz. The antenna of (Islam, *et al.*, 2010) with size of 9.50 × 10 mm^2has been concluded for Ku-band application and the thickness of the substrate was 0.254mm. The returnlosses of 23.83dB and 14.04 have been achieved by the mentioned antenna.

2. DESIGN OF INITIAL ANTENNA WITH FR-4 SUBSTRATE

Initially a patch antenna having FR-4 as substrate's material has been designed using the defected ground structure (DGS) as shown in **(Fig. 1)**. The patch has been loaded with two parasitic elements and the dielectric constant of the substrate was 4.3 and its height was 1.5mm. The overall size of the initial design is 10×20mm^2. The size of radiating patch B was 5.5×8mm^2, initially the main patch was rectangular and it then had been reshaped with the help of a horizontal and vertical rectangular slots S_1 and S_2. This rectangular man patch has been placed at the center of the substrate. The ground of the antenna has been converted to DGS by creating four rectangular slots G_1, G_2, G_3 and G_4 in it. The material used in all the patches and the ground plane is pure copper having a thickness of 0.035mm. The antenna has been excited with the help of Transmission Feed line. The parameters are given in **(Tables 1,2, 3)**.



(a)

(b)

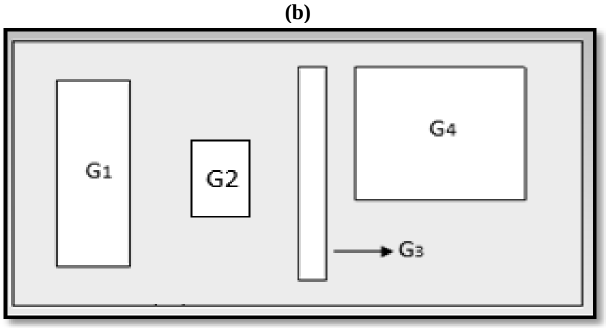


Fig.1. The InitialAntenna (a) Front View (b) Back View

Table.1. Parameters of the Initial Antenna

Symbol	Description of the Parameters	Values (mm)
L	Length of the antenna substrate and Ground	10
W	Length of the antenna substrate and Ground	20
L_1	Length of the left parasitic patches A	5.5
L_1	Length of the radiating patches B	5.5
W_1	Width of the radiating patches B	8
W_2	Width of the left parasitic patches A	2.5
W_3	Width of the feed line	3.4
L_3	Length of the feed line	2.25
T	Thickness of the ground plane and all the three patches	0.035
H	Height of the substrate	1.6

The dimensions of the Slots on the main patch are given in **(Table 2)**. For the Front view the x and y coordinates are given in **(Fig2)** and the origin of the coordinate system is at the center of the front view

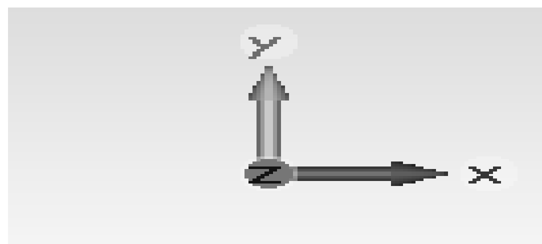


Fig.2. Rectangular Coordinates for the Front View.

Table 2: Slots on the Main Patch

Sy	Description of the Parameters	Values (mm)
X_1	X_{min} for vertical slot S_1 on the patch	-0.5
X_2	X_{max} for vertical slot S_1 on the patch	0.5
Y_1	Y_{min} for vertical slot S_1 on the patch	-2
Y_2	Y_{max} for vertical slot S_1 on the patch	$L_1/2$
X_3	X_{min} for horizontal slot S_2 on the patch	-1.8
X_4	X_{max} for horizontal slot S_2 on the patch	$W_1/2$
Y_3	Y_{min} for horizontal slot S_2 on the patch	0.4
Y_4	Y_{max} for horizontal slot S_2 on the patch	1.1

The dimensions of the Slots on the ground are given in **(Table 3)**. For the Front view the x and y coordinates are given in **(Fig 3)** and the origin of the coordinate system is at the center of the back view

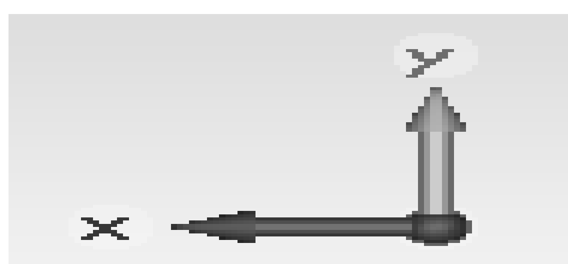


Fig. 3: Rectangular Coordinates for the Back View

Table 3: Slots on the Ground

Symbol	Description of the Parameters	Values (*mm*)
X_5	X_{min} for the ground slot G_1	6.5
X_6	X_{max} for the ground slot G_1	8
Y_5	Y_{min} for the ground slot G_1	-3.5
Y_6	Y_{max} for the ground slot G_1	3.5
X_7	X_{min} for the ground slot G_2	3
X_8	X_{max} for the ground slot G_2	5
Y_7	Y_{min} for the ground slot G_2	L -3
Y_8	Y_{max} for the ground slot G_2	-1
X_9	X_{min} for the ground slot G_3	1
X_{10}	X_{max} for the ground slot G_3	0
Y_9	Y_{min} for the ground slot G_3	-4
Y_{10}	Y_{max} for the ground slot G_3	4
X_{11}	X_{min} for the ground slot G_4	-8
X_{12}	X_{max} for the ground slot G_4	-2
Y_{11}	Y_{min} for the ground slot G_4	-1
Y_{12}	Y_{max} for the ground slot G_4	4

3. BANDWIDTH OF THE INITIAL DESIGN

The bandwidth of the initial design was 2.63GHz as shown in **(Fig4)**. The value of the return loss of this antenna was maximum at the center frequency of 17.56GHz and its value was 41.41dB.

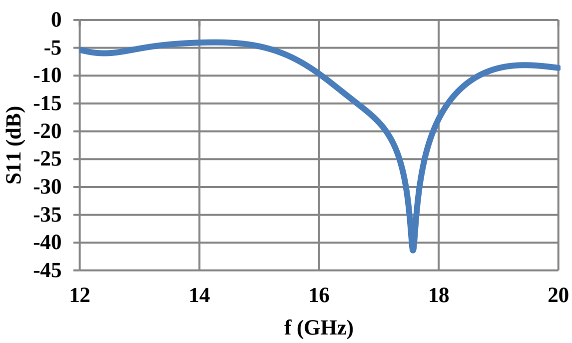


Fig 4: The Bandwidth of the Initial Design

VSWR of the initial design was 1.01 at the above mentioned center frequency. The antenna was fabricated and tested. The pictorial view of the fabricated antenna is given in **(Fig 5)** and its reflection coefficient is given in **(Fig 6)**.

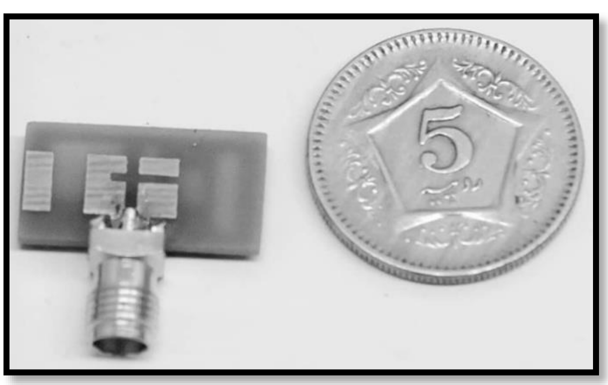


Fig. 5a: Front View of the Fabricated Antenna

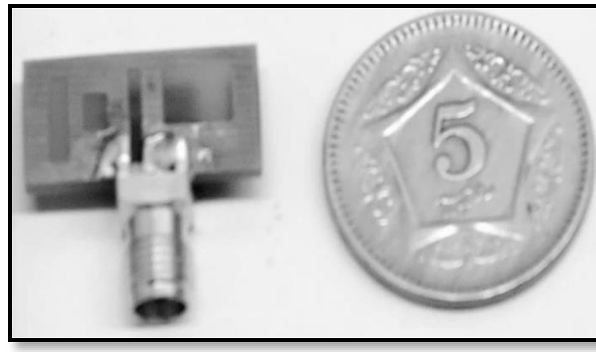


Fig. 5b: Back View of the Fabricated Antenna

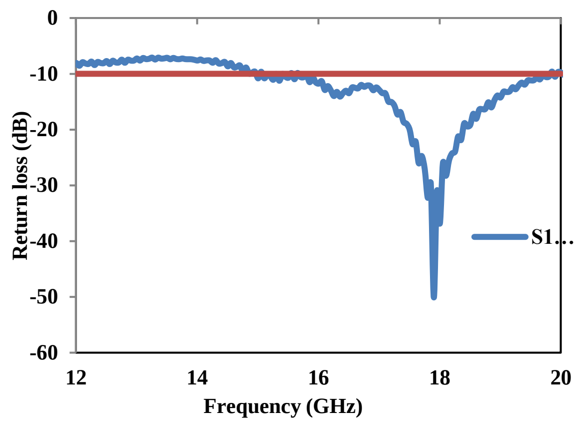


Fig. 6: The Bandwidth of the Fabricated Antenna

The Comparison of the bandwidth of the simulated antenna and that of the fabricated antenna indicate that the bandwidth of the fabricated antenna is better than the simulated one. The bandwidth as well as the return loss of this fabricated antenna is better than the one in **(Fig. 1)**.

In order to enhance the bandwidth of this initial design three ground slots G_1, G_2, G_3 and height of the substrate were modified as shown in **(Fig. 7)** and the parameters of the slots are given in **(Table 4)**.

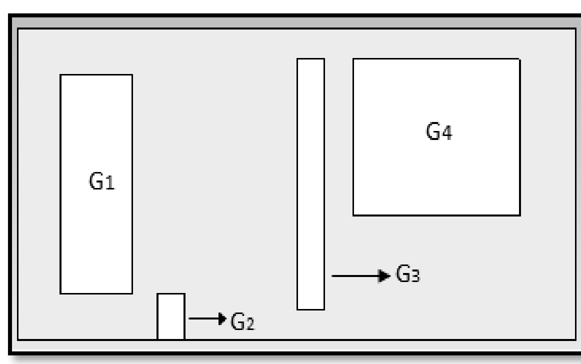


Fig.7 Modified Ground Structure of the Initial Design

Table 4: Modified Slots on the Ground

Symbol	Description of the Parameters	Values (mm)
X_5	X_{min} for the ground slot G_1	5.9
X_6	X_{max} for the ground slot G_1	8.5
Y_5	Y_{min} for the ground slot G_1	-3.5
Y_6	Y_{max} for the ground slot G_1	3.5
X_7	X_{min} for the ground slot G_2	4
X_8	X_{max} for the ground slot G_2	5
Y_7	Y_{min} for the ground slot G_2	-L
Y_8	Y_{max} for the ground slot G_2	-3.5
X_9	X_{min} for the ground slot G_3	-1
X_{10}	X_{max} for the ground slot G_3	0
Y_9	Y_{min} for the ground slot G_3	-4
Y_{10}	Y_{max} for the ground slot G_3	4
h	Height of the Substrate	1.6

4.BANDWIDTH AND RETURN LOSS OF THE MODIFIED GROUND STRUCTURE

The reflection coefficient (S_{11} dB) of this antenna with modified ground No further changes have been made in the parameters of the antenna and the bandwidth of this structure has been enhanced as shown in Fig. 8. The impedance bandwidth was 3.66GHz and the maximum Return loss was 25.04dB at the centre frequency of 16.57GHz.

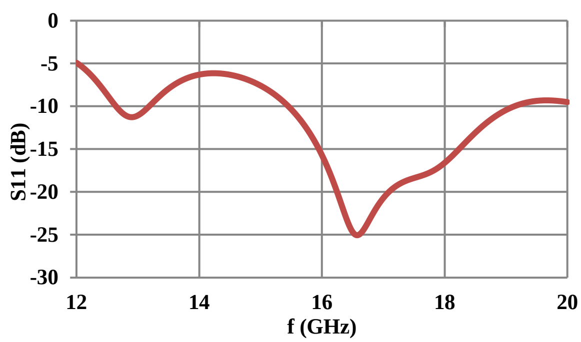


Fig. 8: Bandwidth of the Initial Antenna

5. VOLTAGE STANDING WAVE RATIO OF THE MODIFIED GROUND STRUCTURE

The Voltage Standing Wave Ratio of the proposed antenna is shown in **(Fig 9)**. The VSWR of the antenna is between 1 and 2 in the mentioned bandwidth.

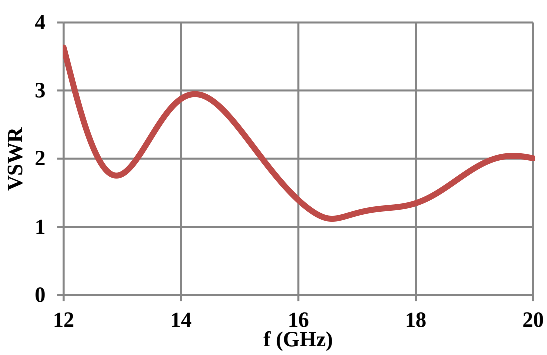


Fig. 9: VSWR of the Initial Antenna.

6. EFFICIENCY OF THE MODIFIED GROUND STRUCTURE

The total efficiency is shown in **(Fig10)**.The total efficiency varies from 50 to 65% the entire operating band. The maximum value has been obtained at the frequency of 17. 6 GHz. The efficiency of the antenna was low so another dielectric substrate has been investigated in the next antennas.

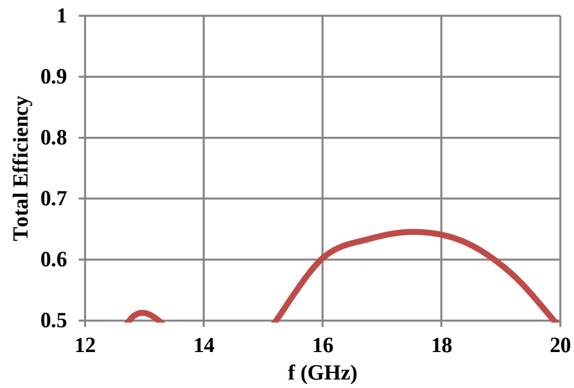


Fig 10: Efficiency of the Initial Antenna

7. DESIGN & RESULLTS OF 2ND ANTENNA WITH PREPERM L-450

The substrate material of the above mentioned antenna isreplaced by Preperm L-450 with dielectric constant of 4.5.

2nd antenna is shown in **(Fig11)**. The bandwidth of the antenna has been reduced but enhancement in the return loss has taken place. A bandwidth of 3.01GHz with return loss of 47.21dB has been achieved at the center frequency of 16.28GHz.

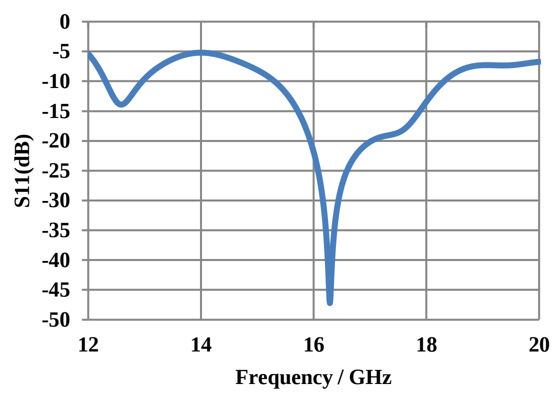


Fig.11. Bandwidth of the 2nd Antenna

The VSWR of 1.008 has been attained at the center frequency of 16.28GHz as shown in **(Fig12)**. The comparison of this ratio with the ratio of the previous antenna with FR-4 Substrate indicates that the 2nd antenna has been matched properly.

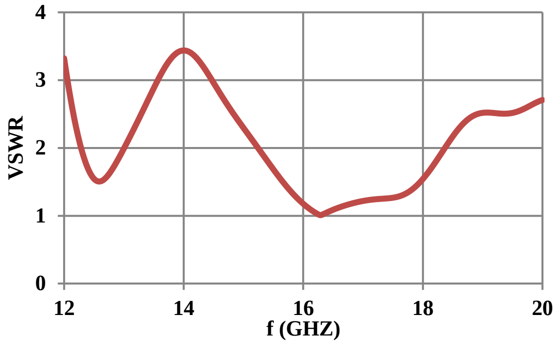


Fig. 12: VSWR of the 2nd Antenna

The material of the substrate was changed for investigation into the improvement of the antenna at high frequencies and enhancement in the total efficiency of the antenna can be observed in **(Fig 13)**. Variation from 79% to 83% has taken place due to the replacement of FR- 4 by Preperm L-450 and hence it is concluded that this dielectric substrate improves the efficiency of the antenna even at higher frequencies.

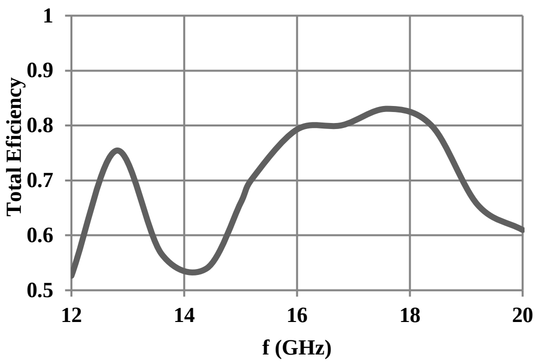


Fig. 13: Efficiency of the 2nd Antenna

8. <u>MODIFICATION IN 2nd ANTENNA</u>

Some parameters of the 2nd antenna were changed and the optimized values of these parameters are given in **(Table 5)**. The width W_3 of the transmission feed line has been change from 3.4mm to 3.44mm and the parameters of the rectangular horizontal slot on the patch have been changed in accordance with the following table. The remaining parameters were unchanged.

The bandwidth of the antenna was enhanced from 3GHz to 4.43GHz with lower frequency as 15.32GHz and higher frequency as 19.76GHz as shown in Fig.14.The return loss of 32.38dB can be observed at the center frequency 17.93GHz. Another narrow band can be seen in this figure but as the return loss of the band is not reasonable, this is why discussion has not been made on it. The voltage standing wave ratio was 1.04 at the mentioned center frequency. S_{11} represents the reflection coefficient of the antenna in dB.

Table 5: Parameters of the 3rd Antenna

Symbol	Description of the Parameters	Values (mm)
X_3	X_{min} for horizontal slot S_2 on the patch	0.5
X_4	X_{max} for horizontal slot S_2 on the patch	$W_1/2$
Y_3	Y_{min} for horizontal slot S_2 on the patch	0
Y_4	Y_{max} for horizontal slot S_2 on the patch	0.6

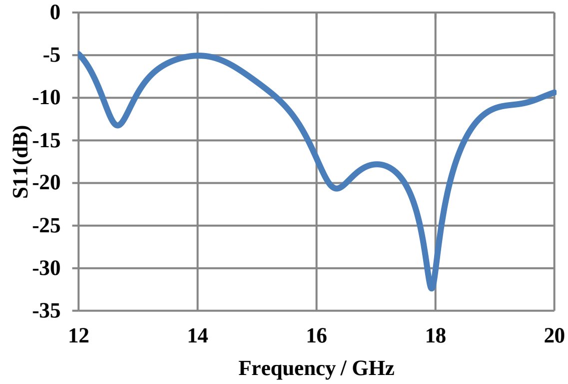


Fig.14: Refection Coefficient of 3rd Antenna

The total efficiency of the 3rd antenna was greater than 73% and its maximum value was 85%.less and this maximum value has occurred at 18.4GHz as shown in **(Fig. 15)**. Once again the total efficiency was far better that of the initial design. The comparison of **(Fig. 11)** with **(Fig. 12)** revealed that the difference in the 2nd antenna's efficiency and that of the 3rd one was not significant.

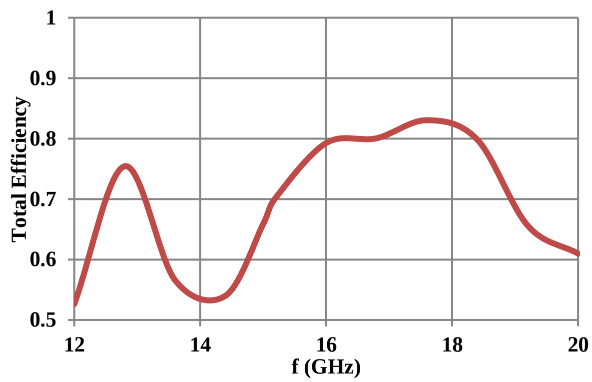


Fig. 15: Efficiency of the 3rd Antenna

9. <u>MODIFICATION IN 3RD ANTENNA</u>

The third antenna has been modified to enhance its bandwidth and return loss. The width W_3 of the transmission line has been increased from 3.44mm to 3.8mm and similarly the length L_1 of the left parasitic patch A and the main patch B has been increased from 5.5mm to 6.5mm and the width W_1 of the main patch has been 8mm to 9mm. All these parameters are given in **(Table 6)** and the remaining parameters are as those of 3rd antenna. The bandwidth of the antenna has been enhanced from 4.5GHz to 5.44GHz and the return loss has been increased up to 62.38dB at the center frequency 16.93GHz as shown in **(Fig16)**.The frequency bandwidth ranges from 15.16GHz to 20.6GHz.

Table 6: Parameters of 4th Antenna

Symbol	Description of the Parameters	Values (mm)
L_1	Length of the main and left parasitic patch	6.5
W_1	Width of the main patch	9
W_3	Width of the transmission line feed	3.8
X_3	X_{min} for horizontal slot S_2 on the patch	0.5
X_4	X_{max} for horizontal slot S_2 on the patch	$W_1/2$
Y_3	Y_{min} for horizontal slot S_2 on the patch	-0.2
Y_4	Y_{max} for horizontal slot S_2 on the patch	0.6

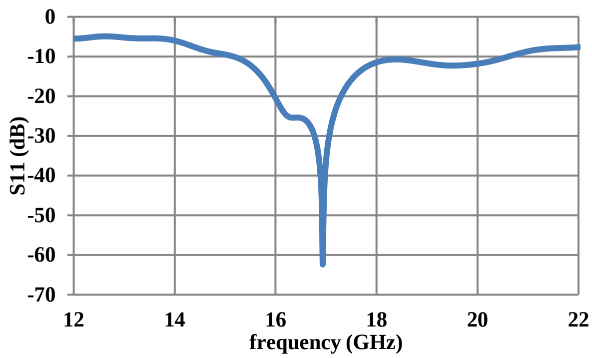


Fig.16: Reflection Coefficient of 4th Antenna

The voltage standing wave ratio of this 4th antenna is shown in **(Fig 17)**. The matching of the antenna has been improved and the VSWR of 1.001 has been achieved at the center frequency of 16.93GHz.

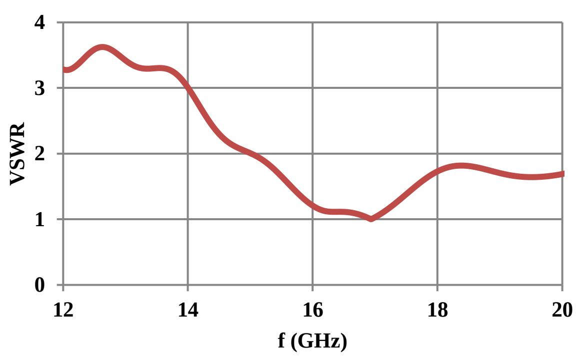


Fig.17: VSWR of 4th Antenna

The total efficiency of 4th antenna varies from 63.94% to 80.12% in the entire working spectrum of the antenna and the maximum value has occurred at 16.79GHz as shown in **(Fig 18)**.The gain of this antenna at the spot frequencies is shown in **(Fig 19)**. The gain of 5.08dBi has been confirmed at the spot frequency of 19.2GHz.

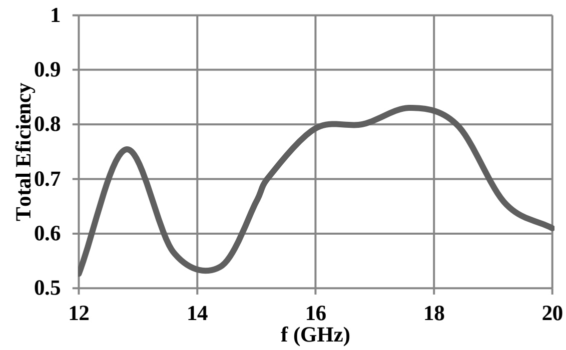


Fig. 18: Efficiency of the 4thAntenna

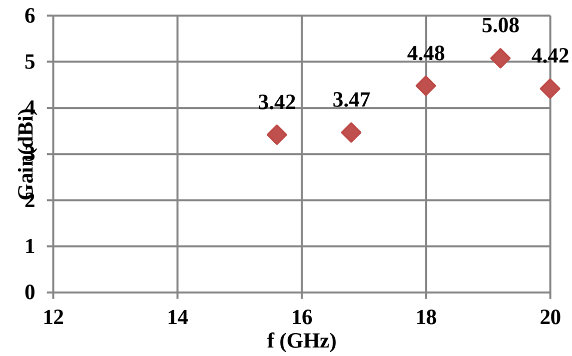


Fig.19: Gain of 4th Antenna

The radiation patterns of this final proposed design for implementation of Ku-band communication are shown in **(Fig20)** to **(Fig 23)**. The direction of the Main lob in Fig.20 is 32^0, its 3dB angular width is 171.8^0 and its side lob level is -3dB.

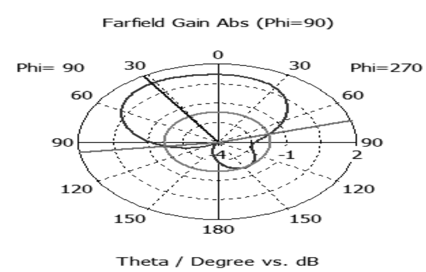


Fig .20: 2D Radiation pattern at 15.6GHz

The direction of the Main lob in Fig.21 is 57^0, its 3dB angular width is 95.6^0 and its side lob level is -3dB.

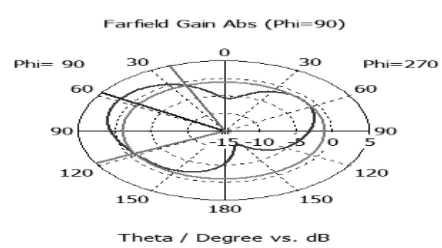


Fig .21: 2D Radiation pattern at 18 GHz

The direction of the Main lob in **(Fig 22)** is 48^0, its 3dB angular width is 71.5^0 and its side lob level is -3.4dB.

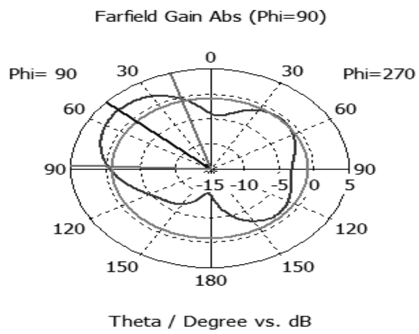


Fig .22: 2D Radiation pattern at 19.2GHz

The direction of the Main lob in **(Fig23)** is 59^0, its 3dB angular width is 99.5^0 and its side lob level is -1.3dB.

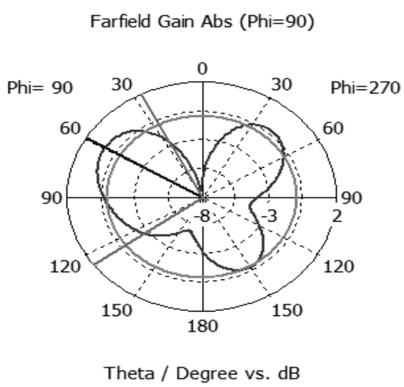


Fig .23: 2D Radiation pattern at 20GHz

10. <u>CONCLUSION</u>

The simple initial antenna has been simulated as well as fabricated and it is concluded that the bandwidth of the fabricated antenna is far better than that of the simulated one. The bandwidth of the FR-5 Initial antenna with modification was 3.66GHz and the maximum Return loss was 25.04dB at the center frequency of 16.57GHz. The total efficiency of this design was 65%.

The substrate of this design was replaced by Preperm L-450 with dielectric constant of 4.5.The bandwidth of the antenna was enhanced to 5.45GHz and the return loss has been increased up to 62.38dB at the center frequency 16.93GHz as shown in **(Fig 14)**.The frequency bandwidth ranges from 15.16GHz to 20.6GHz. VSWR of the proposed antenna was less than 2 and the value of 1.001 has been attained at the center frequency.The total efficiency of the final proposed antenna varies from 63.94% to 80.12% in the entire working spectrum of the antenna and the maximum value has occurred at 16.79GHz. The gain of 5.08dBi has been confirmed at the spot frequency of 19.2GHz. The overall size of the antenna was $10\times20mm^2$. The proposed antenna can be used in the Ku-band for satellite communications.

<u>**REFERENCES:**</u>

Azim, R., M. T. Islam, N. Misran, (2011). Dual polarized microstrip patch antenna for Ku-band application. Informacije MIDEM, 41(2), 114-117.

Bashar, B., Q. Elias, (2013). “A Wideband Microstrip Patch Antenna for KU-Band Applications” American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) (Online) . 2313-4402.

Balanis, C. A., (2005) “Antenna Theory Analysis and Design”. New York: Wiley, 3rd Edition.

Chodavadiya, V. V., S. S. Aggarwal, (2014). April. Microstrip Patch Antenna Design for Ku Band Application. In International Journal of Engineering Research and Technology Vol. 3, No. 4 IJERT.

Dubey, S. K., S. K. Pathak, K. K. Modh, (2011). December. High gain multiple resonance Ku-band microstrip patch antenna. In Applied Electromagnetics Conference (AEMC), IEEE, 1-3.

Fan Y., X. Zhang, X. Ye, Y. R. Samii, (2001). Wide band E- shaped patch antennas for wireless communications, IEEE Transactions on Antennas and Propagation, vol. 49, 1094-1101.

Howell, J. Q., (1975). “Microstrip antennas,” IEEE Transactions on Antennas and Propagation, AP-23.

Islam, M. T., A. T. Mobashsher, (2010). “Compact dual band microstrip antenna for Ku-band application,” Information Technology Journal, vol. 9, no. 2, 354–358.

Jana, S., B. Sinhamahapatra, S. Dey, A. Das, B. Datta, M. Mukherjee, S. Chatterjee, (2013). Single layer monopole hexagonal microstrip patch antenna for satellite television. International Journal of Soft Computing and Engineering (IJSCE), 2231-2307.

Misran, N., M. T. Islam, A. T. Mobashsher, (2009). August. Design of a compact dual band microstrip antenna for ku-band application. InElectrical Engineering and Informatics, ICEEI'09. International Conference Vol. 2, 699-702.

Manoj, K., A. K. Srivastava, B. K.Kanaujia, (2014). A M-shaped monopole- like slot UWB antenna, Microw. Opt. Technol. Lett., vol. 56, 127-131, Manoj, K., A. K. Srivastava, B. K.Kanaujia (2015). A novel A-shaped monopole like slot antenna for ultra wideband applications, Microw. Opt. Technol. Lett., vol. 54, 1826-1829.

Nor, N. M., M. H. Jamaluddin, M. R. Kamarudin, M. Khalily, (2016) "Rectangular Dielectric Resonator Antenna Array for 28GHz Applications", Progress in Electromagnetics Research C, Vol. 63, 53-61.

Sinhamahapatra, B., S. Jana, S. Dey, A. Das, B. Datta, M. Mukherjee, S. Chatterjee, S. Dual-Band, (2013).Size Deducted Un-Equal ArmY-Shaped Printed Antenna for Satellite Communication. International Journal of Engineering Research and Development (IJERD), 36-40,

Saluja, R., A. L. Krishna, P. K. Khanna, D. Sharma, P. Sharma, H. C. Pandey, (2008)."Analysis of Bluetooth patch antenna with different feeding techniques using simulation and optimization." In Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on, 742-744. IEEE.

Sanjeev D., A. Rawat, R. N. Yadav, (2013).Design of U-shape microstrip patch antenna for WiMAX applications at 2.5 GHz, Tenth International Conference on Wireless and Optical Communications Networks (WOCN), Bhopal, .1-5.

Samsuzzaman, M., M. T. Islam, B. Yatim, M. M. Ali, (2013).Dual frequency triangular slotted microstrip patch antenna for Ku band applications. PrzeglądElektrotechniczny, 89(1),275-279,

Tapan, M., S. Das, (2016). Ultra wideband printed hexagonal monopole antennas with WLAN band rejection, Microw. Opt. Technol. Lett., vol. 54, 1520-1523.