Design and Simulation of Ku-band Microstrip patch antenna for satellite interchange application

Dissertation Project Report
M.Sc. in Physics

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under the guidance of
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DEPARTMENT OF APPLIED PHYSICS
DELHI TECHNOLOGICAL UNIVERSITY, DELHI
MAY 2021

DECLARATION

We, Purnima, (2K19/MSCPHY/26) and Shweta Sharma, (2K19/MSCPHY/27) hereby certify that the work which is presented in the Dissertation Project-II/Research work entitled **"DESIGN AND SIMULATION OF KU-BAND MICROSTRIP PATCH ANTENNA FOR SATELLITE INTERCHANGE APPLICATION"** in fulfilment of the requirement for the award of the degree of **Master of Science** in **Physics** and submitted to the **Department of Applied Physics, Delhi Technological University, Delhi** is an authentic record of our own, carried out during a period from August 2020 to May 2021, under the supervision of **Dr Kamal Kishor.**

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Purnima
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Place: Delhi
Date: 29th May 2021

CERTIFICATE

This is to certify that the report entitled **"DESIGN AND SIMULATION OF KU-BAND MICROSTRIP PATCH ANTENNA FOR SATELLITE INTERCHANGE APPLICATION"** submitted to the **Department of Applied Physics, Delhi Technological University, Delhi** in fulfilment of the requirement for the award of the Degree of **Master of Science** in **Physics** is a record of original research work done by **PURNIMA (University Roll No.: 2K19/MSCPHY/26) AND SHWETA SHARMA (UNIVERSITY ROLL No.: 2K19/MACPHY/27)** under my guidance. To the best of my knowledge, the above work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere. I further certify that the publication and indexing information given by the students is correct.

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Date: 29th May 2021

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ACKNOWLEDGEMENT

We would like to express our heartfelt gratitude to our project supervisor, Dr. Kamal Kishor for his valuable guidance throughout the course of this project. His constructive advice and constant motivation have been instrumental in the completion of our venture.

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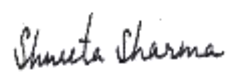
Last but not the least, thanks to our classmates for their constant support and valuable inputs at critical junctures during the completion of this project.



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ABSTRACT

In the satellite communication system, the Microstrip patch antenna are playing a very important role. This paper reports a novel design of Ku band microstrip patch antenna for satellite interchange application. The proposed antenna is compact with an overall size of 21.258 X 18.25 X 1.4 mm^3. The antenna design consist of RT/Duroid 5880 (dielectric constant 2.2) patch and substrate. A very thin layer of the metallic sheet has also been used below the substrate for the ground plane. The simulation have been done here in COMSOL Multiphysics.Various antenna parameters such as far-field radiation pattern, gain, directivity, input impedance, and VSWR have been obtained and analyzed. The designed antenna has been thoroughly analyzed by varying geometrical parameters of the patch to study their impact on return loss, gain, and directivity enhancement, which helps to optimize the design as per our application. The proposed antenna is excited by a 50 Ω microstrip transmission line, and the antenna has achieved good impedance matching. The reported antenna design has been optimized to operate in the Ku band at resonant frequency 12.75 GHz for a wide range of applications in satellite communications, direct-transmission satellites or satellite television, etc.

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1. ANTENNA AND KU-BAND

1.1. INTRODUCTION TO ANTENNA

The antennas form the key components of almost all wireless communication systems. An antenna is a device that allows electromagnetic waves to be transmitted and received. These devices convert the process of transferring a signal (in a wired system) to waves, which subsequently propagate over space and are received by a receiver antenna. The receiving antenna is in charge of the reciprocal process, which involves converting an electromagnetic wave into a signal that the receiver can access. Maxwell's equations comprehensively characterise the antenna structure's receiving and transmitting qualities and operation, making them well-known and easier to comprehend [1].

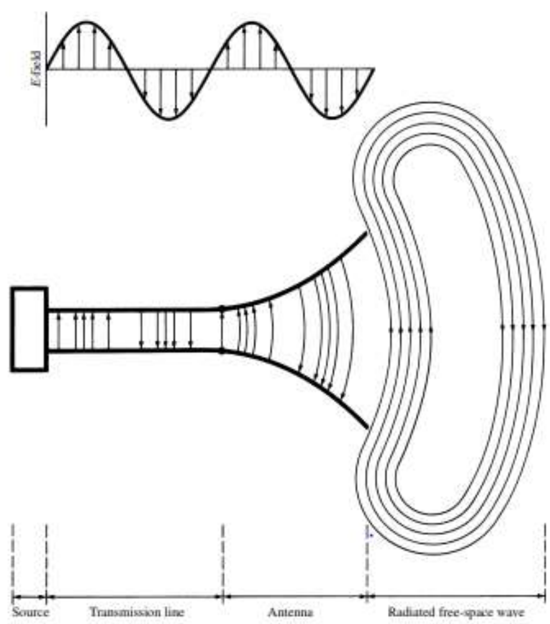


Figure 1.1 Diagram showing antenna transition[1]

Electromagnetic waves are often called radio waves. Most antennas that operate efficiently over a relatively narrow frequency band are thus called resonant devices. For efficient transmission and reception, the antenna should be matched(tuned) to the same frequency band. We talk about antenna size in terms of wavelength a lot. A 1/2 wave dipole, for example, is about half a wavelength long. A radio wave's wavelength is the distance it travels in one cycle [2].

1.2. ANTENNA CHARACTERISTICS

There are various characteristics that we study to determine the overall behavior of the antenna. During the optimization process, we change antenna dimensions and see its effect on the antenna characteristics. The figure below mentions all those characteristics which we have studied in our proposed paper.

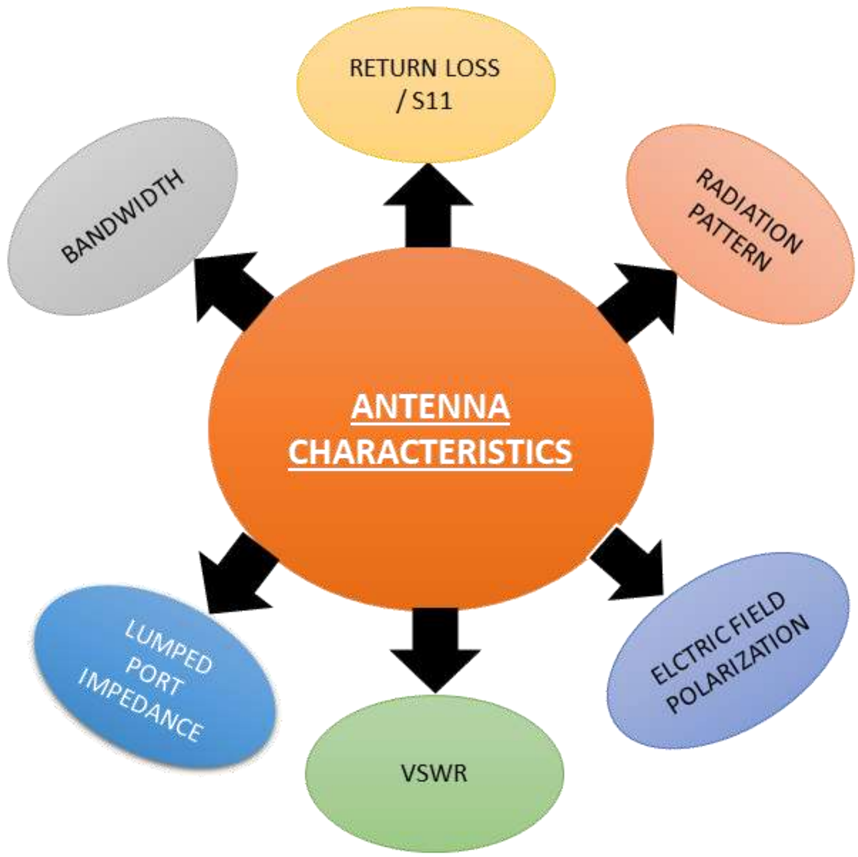


Fig 1.2. Diagram showing Antenna characteristics of proposed antenna

1.3. MICROSTRIP PATCH ANTENNA

Radar and satellite communication systems use these types of antennas. In today's world of wireless communication, low profile, lightweight, and low-cost antennas are required. The MPA is used recurrently because of its simple design, ease in installation, variety of shapes, and compatibility with microwave and Millimeter-Wave Integrated Circuit (MIMC)[3].

They consist of a radiating patch fixed over a dielectric substrate and fixed a ground plane on the other side. There can be various patches or radiating elements such as triangular, circular, semi-circular, or rectangular. However, rectangular is the most common one.

The microstrip patch antennas have their own set of constrains such as less power handling capability, narrow bandwidth and gain. There is a direct connection between all the parameters of antennas, as if we try to advance one parameter, it affects the other one[4]. There are vast applications for MPA such as mobile systems, Global Positioning System (GPS), satellite communication, Wi-Fi, WiMax, radar systems, biological imaging, and radio frequency identification.

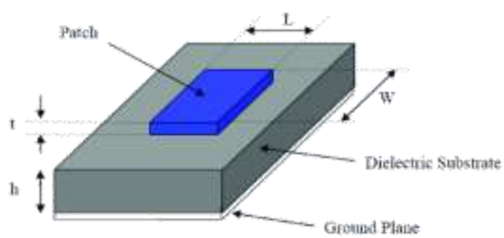


Figure 1.3 Rectangular Patch MPA[5]

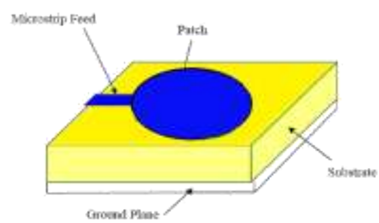


Figure 1.4 Circular Patch MPA[6]

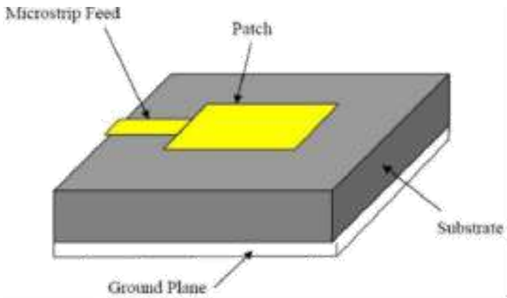
1.3.1. FEEDING TECHNIQUES FOR MPA

The feeding techniques are broadly divided into two categories:

1. Category Contacting In this method, a connecting microstrip is attached to the radiating element. It acts as a connecting element.
2. Without category contacting-Here, the electromagnetic coupling is used to connect the elements.

In most of the microstrip rectangular patch antennas, the following feeding techniques are used:

[1] Microstrip line technique- A conducting rectangular or circular patch is affixed to the radiating patch's edge in this technique. In comparison to the radiating patch, the conducting strap is narrower.



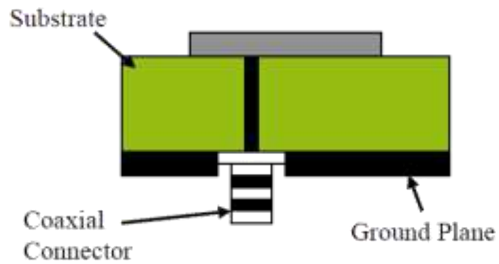
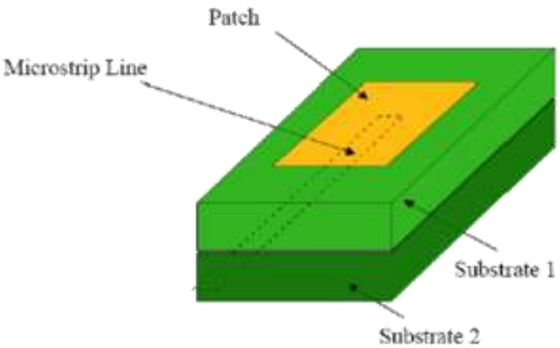


Figure 1.5 Microstrip feed Technique [7] **Figure 1.6 Coaxial Probe feed [8]**

[2] Coaxial Probe Feeding Techniques- A coaxial connector is used between the radiating patch and the ground plane that passes through the dielectric in this approach. However, the demerits of this method are it is difficult to fabricate and produce narrow bandwidth.

[3] Feeding Techniques with Proximity coupled- The feed lines are placed between two substrates in this technique, and the radiating patch is placed on top of the upper substrate.



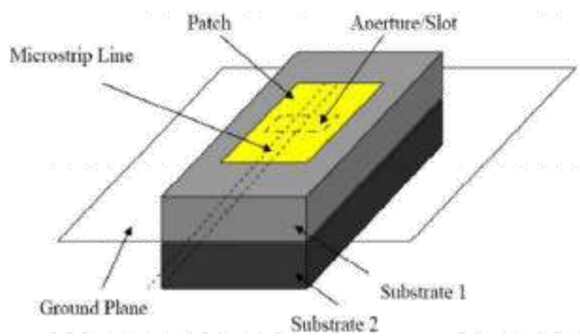


Figure 1.7 Proximity Coupled feed [9] **Figure 1.8 Aperture Coupled feed[5]**

[4] Aperture coupled feed- In this method, the conducting strip and the radiating element are connected through a slot or an aperture in the ground plane. The changes in the coupling depend on the width and length of the slot to improve the simulation result of bandwidths and return losses.

1.4. KU BAND

The electromagnetic spectrum in the frequencies in microwave band range from 12 to 18 gigahertz (GHz) is called the Ku band. Frequencies greater than 10 GHz have received wider attention for future wireless communication due to their wide bandwidth often unused due to this and other advantages like the control on rain attenuation, circuit size, and higher channel capacity compared to other bands like C-band and Ka-band. It is not restricted in power to avoid interference with other microwave systems, and its uplink and downlink power can also be increased compared to other bands like C-band. As a result, the higher power is also transmitted to smaller receiving dishes. There is also a relation between satellite transmission and a dish's size. The size of the antenna dish decreases as the power increases. If the waves have high power, then fewer of them are needed to achieve the same intensity at the dish. The dish element of the antenna collects the incident waves over an area and then converges them all towards the actual receiving element, which is fixed in front of the dish.

This frequency range is used in satellite service (broadcast, fixed, and mobile), mobile satellite service.

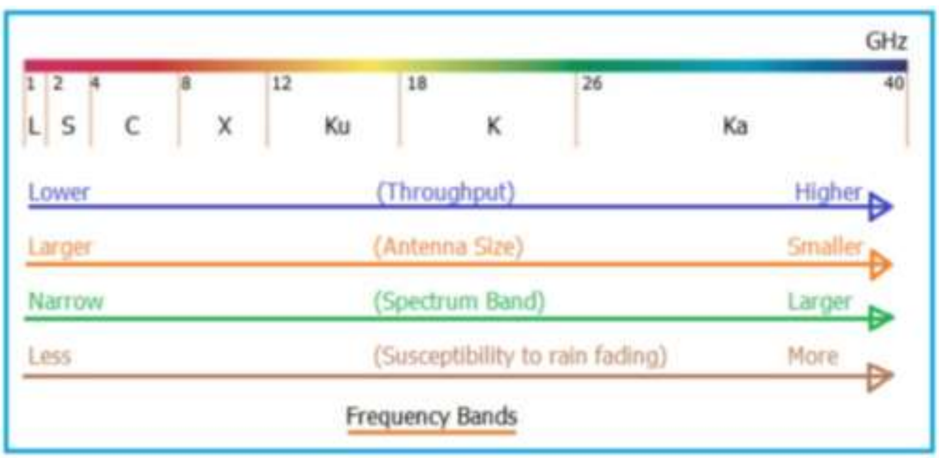


Figure 1.9. Frequency bands in satellite communication

(*https://www.everythingrf.com/community/ku-band)

2. DESIGN METHODOLOGY

This paper reports a novel design of Ku band microstrip patch antenna for satellite interchange application. The proposed antenna is simple and compact, with an overall size of 21.258 X 18.25 X 1.4 mm^3 and resonates at operating frequency 12.75 GHz. The dimensions of the different parts of the microstrip patch antenna must be chosen very carefully as they impact its parameters. As explained earlier, the rectangular microstrip patch antenna has three parts a dielectric substrate with one side having a ground plane and the other having a radiating patch. The formula to calculate these three parts has been discussed briefly in this chapter.

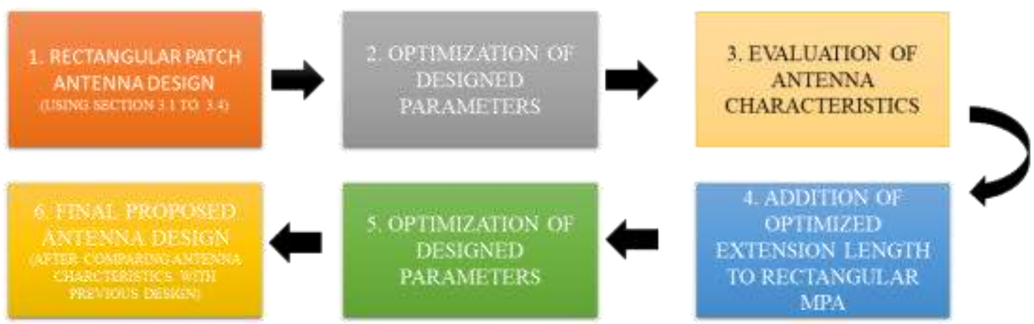


Figure 2.1 Flow chart for design methodology of the proposed microstrip patch antenna

2.1. PATCH DIMENSIONS

The radiating patch of the proposed antenna is designed using dielectric RT/Duroid 5880 (dielectric constant 2.2), having a thickness of 1.4 mm. The length and width of the patch is calculated using equations (1) and (5) where L and W are the patch length and width, c is the velocity of light, $\mathcal{E}_r$ is the dielectric constant of the substrate, h is the thickness of the substrate, f is the resonant frequency and $\mathcal{E}_{eff}$ is the effective dielectric constant[10]:

A. Width of the rectangular radiating patch element-

$$\mathrm{w} = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r}} \quad (1)$$

B. Effective dielectric constant of radiating patch element-

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

C. Fringe factor / Optimal extension length-

$$\triangle L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (3)$$

D. Effective length-

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \quad (4)$$

E. Total length-

$$L = L_{eff} - 2 \triangle L \quad (5)$$

Patch width in the microstrip patch antenna determines the input resistance and bandwidth, whereas it does not impact bandwidth and resonant frequency. Patch length affects the power radiated, and hence it influences the parameters such as resonant resistance, bandwidth, and radiation efficiency.

2.2. GROUND DIMENSIONS

The antenna design consists of a very thin layer of the metallic sheet as the ground here. During simulation in COMSOL, we have used a perfect electric conductor (PEC) for the ground plane whose behavior is similar to a metallic conductor. However, the ground plane is kept small as possible to limit the size of the antenna, but it should not affect the antenna's performance. The dimensions of the ground plane are evaluated using the equations (6) and (7):

A. Width of the ground plane-

$$W_g = 6h + W \quad (6)$$

B. Length of the ground plane-

$$L_g = 6h + L \quad (7)$$

2.3. SUBSTRATE DIMENSIONS

The substrate of the reported antenna is designed using the dielectric RT / Duroid 5880 (dielectric constant 2.2) with a thickness of 1.4 mm. Generally, the substrate's dimensions are equal to or greater than the microstrip radiating patch's dimensions. Further to improve the parameters of the antenna, the substrates dielectric constant ε_r should be low ($\varepsilon_r < 2.5$). The dielectric substrate provides mechanical strength to the antenna.

2.4. FEED POINT DIMENSIONS AND LOCATION

The position and dimensions of the feed point must be chosen very carefully because it affects various factors. While applying the feed, the most important thing to consider is the effective transfer between the radiating and feeding structures, and technically it is called impedance matching. The reduction of spurious radiation and its influence on the radiation pattern are also critical considerations when assessing the feed[11]. The most popular and widely used feeding techniques include coaxial probe feed, coplanar waveguide feed, microstrip line feed, aperture coupled feed, and proximity coupled feed. The proposed antenna is excited by a 50 Ω microstrip transmission line, the width of the transmission line and the position of the feed point is evaluated using the following equations (8), (9), and (10)[12]:

A. Width of the microstrip line (W_0) –

$$W_0 = \frac{7.48h}{e^{\left(z\frac{\sqrt{\varepsilon_r + 1.41}}{81}\right)}} - 1.25t \quad (8)$$

Where t = Thickness of the patch

B. Depth of the feed (G) –

The impedance of the patch, $$Z_0 = \frac{90}{\varepsilon_r - 1}\left(\frac{\varepsilon_r + L}{W}\right)^2 \quad (9)$$

Depth of the feed, $$Z = Z_0\left[\cos\left(\frac{\pi G}{L}\right)\right]^2 \quad (10)$$

The dimensions of the proposed antenna are calculated using the above formulas. However, due to the limitation of fabrications, the parameters calculated using the above-defined formulas need to be optimized to obtain minimum return loss parameter, maximum gain, and maximum directivity at the operating resonant frequency.

SUBSTRATE (mm)		PATCH (mm)		FEED (mm)	
W_g	L_g	W	L	W_0	G
BY CALCULATION					
18.30081	15.90670	9.30081	6.906709	1.88998	2.00655
OPTIMIZED PARAMETERS (WITHOUT ΔL)					
20	18.3	9.5	7	2.592	1.9888
OPTIMIZED PARAMETERS (WITH ΔL)					
21.258	18.25	9.3799	7+0.758853	1.05	2.8688

Table 1. Calculated and optimized parameters of microstrip patch antenna resonating at 12.75 GHz

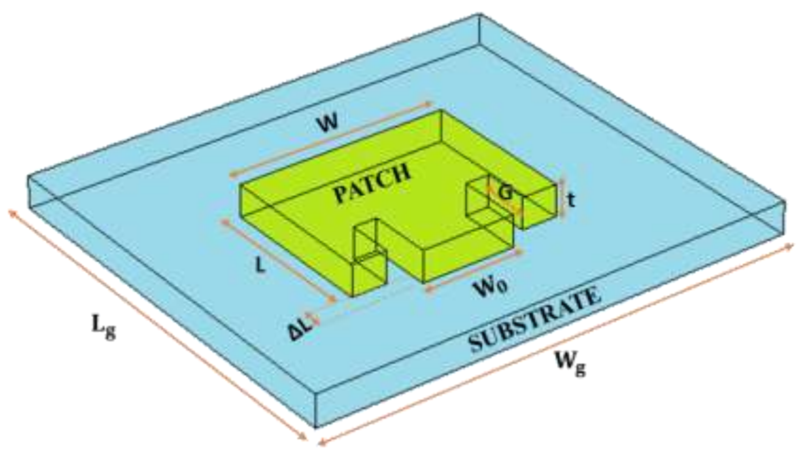
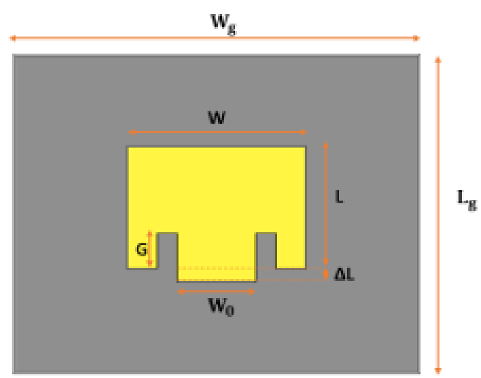
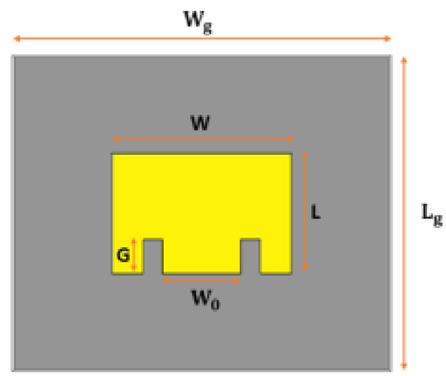


Figure 2.2 3-D structure of the proposed microstrip patch antenna with optimized extension length ΔL



(a)



(b)

Figure 2.3. (a) Top view of the reported microstrip patch antenna without optimal extension Length ΔL.
(b) Top view of the reported microstrip patch antenna with optimal extension Length ΔL.

The above-proposed antenna is designed using the finite element method in COMSOL Multiphysics software. On simulation, significant improvement was observed in various antenna parameters after optimizing extension length ΔL in the radiating patch.

3. RESULTS AND DISCUSSION

The reported antenna is designed and simulated in COMSOL Multiphysics, and various antenna characteristics were investigated at 12.75 GHz resonant frequency. The antenna is designed to operate in Ku-band for the application of satellite interchange.

3.1. ELECTRIC FIELD NORM (V/m)

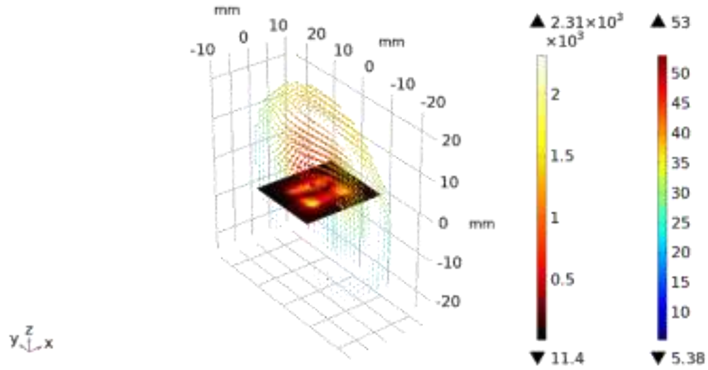


Figure 3.1 Electric field Norm (V/m) plot of reported microstrip patch antenna without optimized extension length ∆L

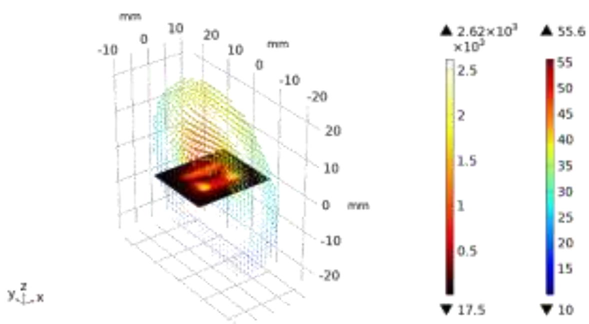


Figure 3.2 Electric field Norm (V/m) plot of reported microstrip patch antenna with optimized extension length ∆L

Figures 3.1 and 3.2 display the electric field vector within the antenna substrate. The electric field arrows indicate the dominant direction of polarization at antenna boresight. Using the scale given that the electric field is higher around the antenna's radiating edges can be seen. On comparing both the figures, we conclude that the electric field has become stronger, the maximum value has increased to 2.31 x 103 V/m from 2.62 x 103 V/m, and the minimum value has increased from 11.4 V/m to 17.5 V/m on the addition of the optimized extension length (Figure 3.2) in the microstrip patch antenna.

3.2. 2-D FAR-FIELD RADIATION PATTERN

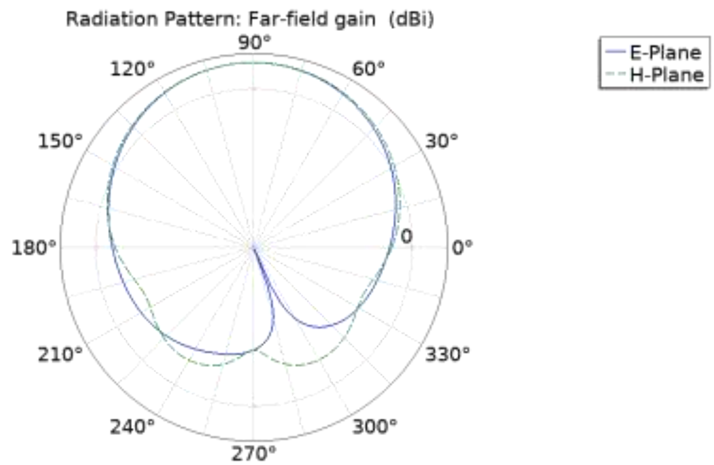


Figure 3.3 2-D far-field radiation pattern (gain in dBi) at E-plane and H-plane of microstrip patch antenna without optimized extension length ∆L.

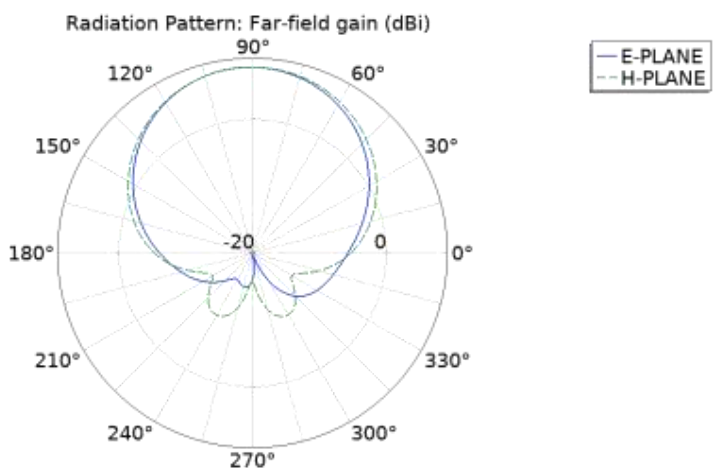


Figure 3.4 2-D far-field radiation pattern (gain in dBi) at E-plane and H-plane of microstrip patch antenna with optimized extension length ∆L.

Far-field radiation patterns at E-plane and H-plane at resonant frequency 12.75 GHz are described in figure 3.3 and figure 3.4 for both the microstrip patch antenna without and with optimized length ∆L, respectively. Because of the bottom ground plane, the above two far-field radiation patterns are guided upwards and are unidirectional. The antenna ground plane affects the gain and directivity of the antenna. Also, after comparing the two radiation patterns of the reported antenna, we can see that the antenna's directionality has improved due to reduction in the back lobe radiation (figure 3.4), and the far-field gain has improved from 7.7854 dB to 7.8709 dB on the addition of optimized extension length to the microstrip patch antenna.

3.3. 3-D FAR-FIELD RADIATION PATTERN

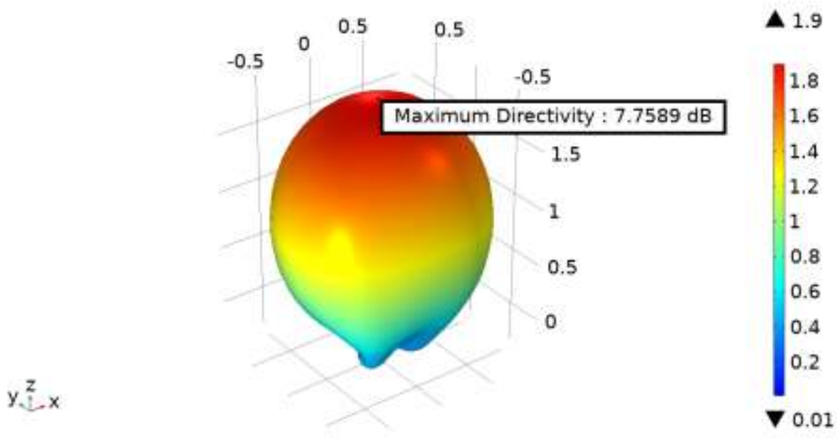


Figure 3.5 3-D Far-field radiation pattern of microstrip patch antenna without optimized extension length ΔL.

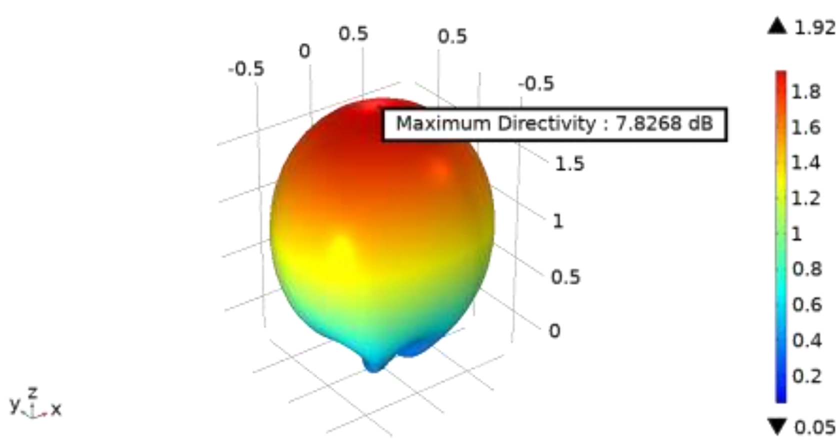


Figure 3.6 3-D Far-field radiation pattern of microstrip patch antenna with optimized extension length ΔL.

3D far-field radiation pattern is visualized in Figures 3.5 and 3.6. The ground plane prevents the radiation from reaching the bottom side, resulting in a directive beam pattern. Also, after adding extension length ΔL to the microstrip patch antenna, the antenna's directivity has improved from 7.7589 dB to 7.8268 dB.

3.4. RETURN LOSS / S11 VS FREQUENCY

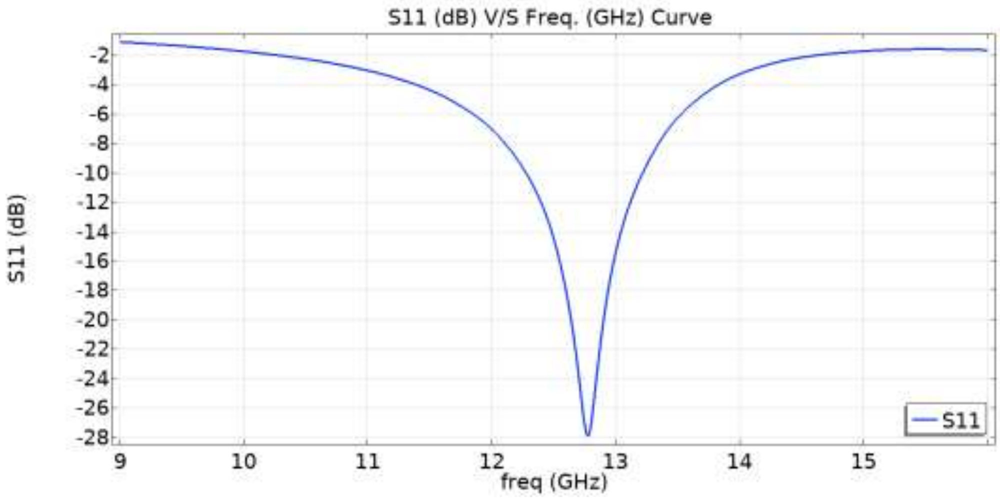


Figure 3.7 Variation of return loss with the frequency of proposed microstrip patch antenna without optimized extension length ΔL.

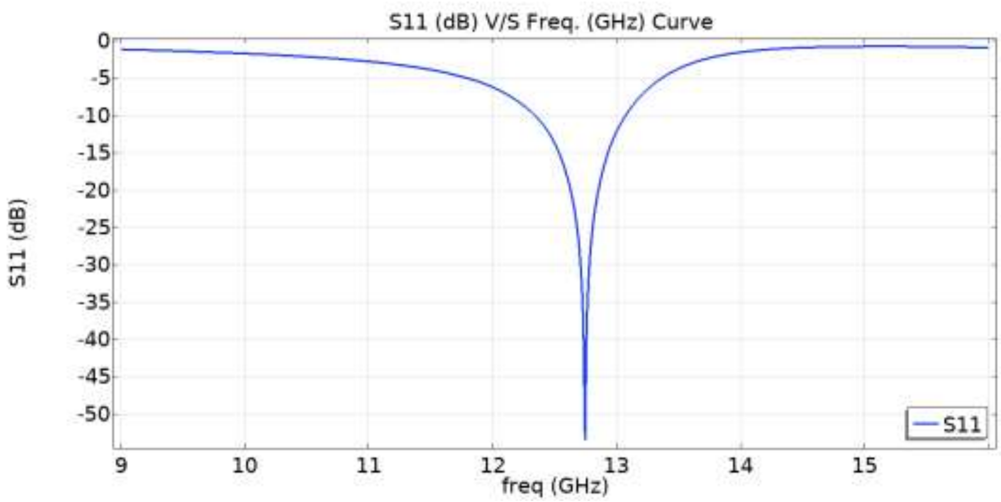


Figure 3.8 Variation of return loss with the frequency of proposed microstrip patch antenna with optimized extension length ΔL.

Return loss or S11 parameter, is a term that describes how much power is reflected from an antenna. Figure 3.7 and figure 3.8 show the variation of return loss or S11 parameter with frequency; after the addition of optimized length ΔL to the microstrip patch antenna, the return loss parameter has improved from -28.926 dB to -47.135 dB. By looking at both the figures, we can conclude that after adding optimized length ΔL to the MPA, the quality factor of MPA has significantly improved, which gives us better impedance matching at resonant frequency 12.75 GHz.

3.5. VSWR VS FREQUENCY

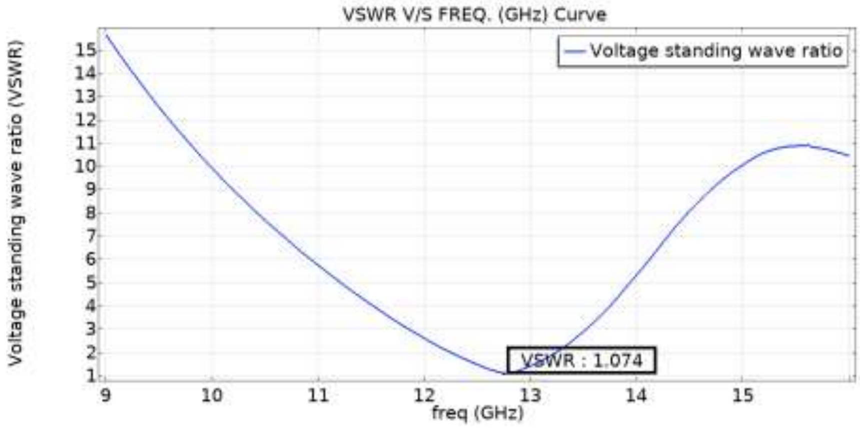


Figure 3.9 Variation of VSWR with the frequency of proposed microstrip patch antenna without optimized extension length ∆L resonating at 12.75 GHz.

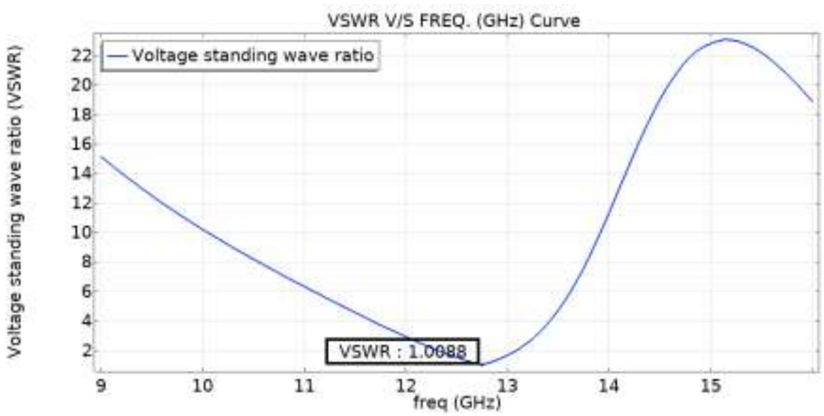


Figure 4.0 Variation of VSWR with the frequency of proposed microstrip patch antenna with optimized extension length ∆L resonating at 12.75 GHz.

The VSWR describes how much power is transferred from the transmission line to the antenna, and the better the matching more is the transferred power. The VSWR must be at least 1.0. which directly means all power is radiated and nothing is reflected, which is perfect. Figure 3.9 and figure 4.0 show the variation of VSWR with frequency. Here, in addition of optimized extension length ∆L to the microstrip patch antenna, the VSWR has improved from 1.072 to 1.0088, thus gives better impedance matching.

3.6. LUMPED PORT IMPEDANCE VS FREQUENCY

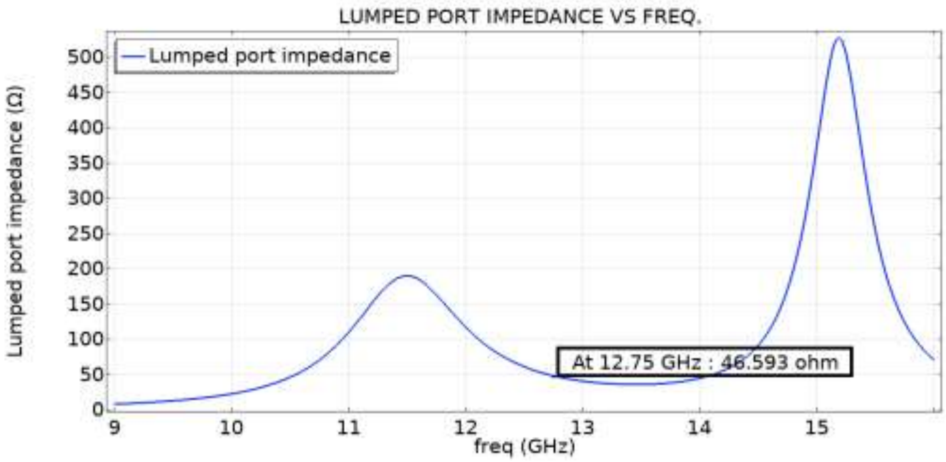


Figure 4.1 Variation of lumped port impedance (Ω) with the frequency of proposed microstrip patch antenna without optimal extension length ΔL resonating at 12.75 GHz.

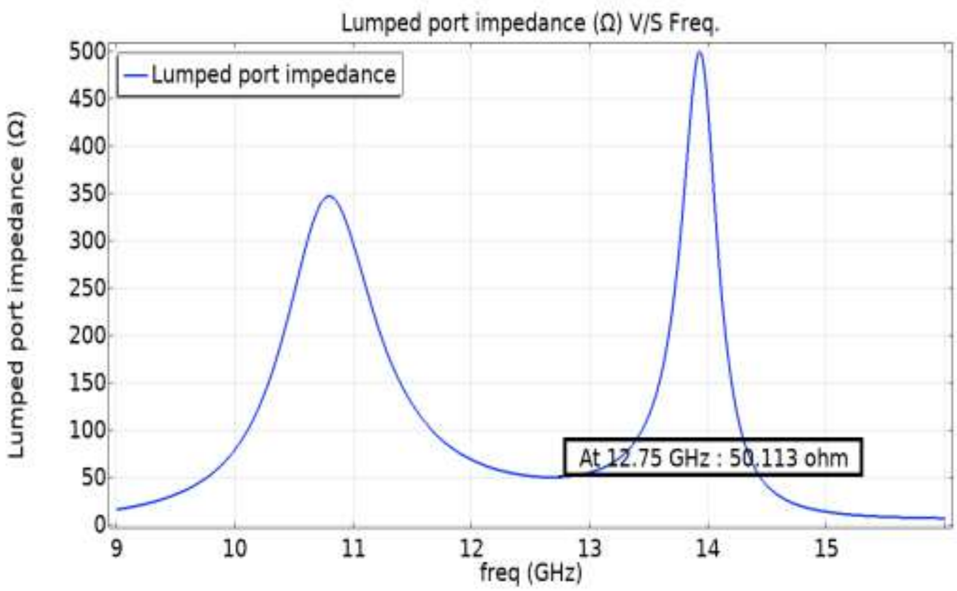


Figure 4.2 Variation of lumped port impedance (Ω) with the frequency of proposed microstrip patch antenna with optimal extension length ΔL resonating at 12.75 GHz.

Here figure 4.1 and figure 4.2 describe the variation of lumped port impedance with frequency. The proposed antenna is excited by a 50 Ω microstrip line and optimized to operate in Ku-band at resonant frequency 12.75 GHz. On the addition of optimized extension length ΔL to the microstrip patch antenna, the lumped port impedance value has improved from 46.593 Ω to 50.113 Ω. Hence, better the antenna is matched to the 50 Ω transmission line excited by lumped port.

ANTENNA PARAMETER	WITHOUT OPTIMIZED EXTENSION LENGTH ∆L	WITH OPTIMIZED EXTENSION LENGTH ∆L
Return Loss / S11 (dB)	-28.926	-47.135
Gain (dB)	7.7854	7.8709
Directivity (dB)	7.7589	7.8268
VSWR	1.0742	1.0088
Lumped Port Impedance (Ω)	46.593	50.133

Table 2. Simulated results of the microstrip patch antenna resonating at 12.75 GHz with and without extension length ∆L

4. CONCLUSION AND FUTURE WORK

The proposed antenna is simple and compact, with an overall size of 21.258 X 18.25 X 1.4 mm^3. Designed and optimized to operate in the Ku-band at resonant frequency 12.75 GHz for a wide range of satellite communication applications, direct transmission satellite, or satellite television. The optimal extension length ΔL has been added to the patch for improving the return loss, gain, VSWR, directivity, and impedance matching between the antenna and transmission line.

In the future, we are planning to design a microstrip patch antenna using metamaterial, having multiband operation operating in THz frequency band as nowadays THz frequency band is becoming popular in wireless communication system due to surge in smartphone users and internet.

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Design and Simulation of Ku-band Microstrip patch antenna for satellite interchange application

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ABSTRACT

This paper reports a novel design of Ku band microstrip patch antenna for satellite interchange application. The antenna design consists of RT/Duroid 5880 (dielectric constant 2.2) patch and substrate. Various antenna parameters such as far-field radiation pattern, gain, directivity, input impedance, and VSWR have been obtained and analyzed. The designed antenna has been thoroughly analyzed by varying geometrical parameters of the patch to study their impact on return loss, gain, and directivity enhancement, which helps to optimize the design as per our application. The proposed antenna is excited by a 50 Ω microstrip transmission line, and the antenna has achieved good impedance matching. The reported antenna design has been optimized to operate in the Ku band at resonant frequency 12.75 GHz for a wide range of applications in satellite communications, direct transmission satellites or satellite television, etc.

Keywords: Microstrip Patch antenna, Ku-band, Microstrip Transmission line, Satellite Interchange.

1. INTRODUCTION

Over the time, with the rapid advancement of technology, the implementation of different technologies has managed to overcome the various communication barriers such as climate, geographic location, etc., allowing in this way that transmission and reception have become an easier and more practical process. For satellite communication, the frequencies range from 0.03-0.3 GHz (VHF) to 27-40 GHz (Ka-band) and beyond. With wavelengths at the order of one meter down to below one centimeter, these frequencies constitute microwaves. The Ku-band is the electromagnetic spectrum portion ranging from 12 to 18 GHz frequency and is utilized for satellite interchanges. The downlink, for example, is used by direct broadcast satellites. Ku-band frequency is also used for various communication applications in ISRO's Geostationary Satellites such as GSAT-9, GSAT-18, INSAT-4A, etc., whose coverage is over South Asian countries and NASA's Tracking Data Relay Satellite, which is used for communications with the International Space Station (ISS). Fixed service (microwave towers), mobile service, radiolocation service (such as radar guns used by law enforcement), amateur radio service, and radio navigation are some of the other services that use the Ku-band frequency. Advantages of Ku-band includes[1]:

1. Ku band satellites are typically smaller than C band satellites due to their higher power.
2. Uplink and downlink power can be increased as needed.
3. It is immune to signal interference from other communication systems.
4. Dependable, cheap and efficient, thus attractive to small networks.
5. Delivers spot beam coverage from the satellite.

Antennas are the key to satellite communication and are used for both receiving and sending signals. There is a wide variety of satellite antenna types, and one amongst them is the microstrip patch antenna (MPA). MPA is a planar antenna consisting of a dielectric substrate with a ground plane on one side and a radiating patch on the other. They have become widely popular due to their various advantages: lightweight, compact size, inexpensive, ease of fabrication, high reliability, and multiband. However, it has disadvantages as well, such as narrow bandwidth, low gain, low power handling, and low radiation efficiency. These limitations can be overcome by employing a variety of enhancement techniques.

In this paper, extension length ΔL has also been added to the patch to enhance the antenna's return loss parameter, gain, and directivity. The proposed antenna's detailed design and simulation results are briefly shown. This MPA is attractive due to its low-profile, conformal design and very narrow bandwidth, which covers the maximum satellite application of Ku-band.

2. DESIGN METHODOLOGY

The proposed antenna design consists of a very thin layer of the metallic sheet for the ground plane, RT/Duroid 5880 (dielectric constant 2.2) patch, and substrate. Generally, the substrate dimensions are equal to or larger than the dimensions of the microstrip patch, and to improve the fringe fields that account for the radiation, the substrate's dielectric constant, ε_r, should be low[2], (ε_r < 2.5). The MPA is excited by a 50 Ω microstrip transmission line fed by a lumped port. The antenna is drawn from the origin of the cartesian coordinate.

To achieve the design requirements, a rectangular microstrip patch antenna is first designed using standard design procedures. For the design and simulation of antenna parameters, the finite element method (FEM) has been used in the COMSOL Multiphysics simulation tool. The length and width of the patch of the MPA has been calculated using equation (1) and (5), where L and W are the patch length and width, c is the velocity of light, ε_r is the dielectric constant of the substrate, h is the thickness of the substrate, f is the resonant frequency and ε_{eff} is the effective dielectric constant[3]:

2.1 Patch dimensions

A. Width of the rectangular patch element:

$$w = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r}} \tag{1}$$

B. Effective dielectric constant:

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

C. Fringe factor / Optimal extension length:

$$\triangle L = 0.412h \frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{3}$$

D. Effective length:

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \tag{4}$$

E. Total length:

$$L = L_{eff} - 2 \triangle L \tag{5}$$

2.2 Ground plane dimensions

A. Width of the ground plane:

$$W_g = 6h + W \tag{6}$$

B. Length of the ground plane:

$$L_g = 6h + L \tag{7}$$

2.3 Feed point dimensions and location

A variety of factors influence the choice of feeding techniques. The most important thing to consider is the effective transfer of power between the radiating and feeding structures, also known as impedance matching. The reduction of spurious radiation and its effect on the radiation pattern are also critical considerations when assessing the feed. The most popular and widely used feeding techniques are coaxial probe feed, coplanar waveguide feed, microstrip line feed, aperture coupled feed, and proximity coupled feed. Here we have used microstrip line feed, it is simple to design, and impedance matching is easier.

Generally, a feeding patch antenna from the edge is avoided since it results in high input impedance, creating an undesirable mismatch if a typical 50 Ω line is directly attached. Therefore, feed point location must be carefully selected. There are two possible solutions to this problem: the first is to use a quarter-wave transformer matching network between the 50 Ω transmission line feed point and the patch, but this will increase the antenna's size. The second choice is to use microstrip lines with a high characteristic impedance, but this will be narrower than the possible fabrication width[4]. So apart from these two methods, we've taken the feed point between the center and edge. The feed point dimensions are calculated as follows[5]:

A. Width of the microstrip line (W_0):

$$W_0 = \frac{7.48h}{e^{\left(z\frac{\sqrt{\varepsilon_r+1.41}}{81}\right)}} - 1.25t \tag{8}$$

Where t = Thickness of the patch

B. Depth of the feed (G):

The impedance of the patch, $$Z_0 = \frac{90}{\varepsilon_r - 1}\left(\frac{\varepsilon_r + L}{W}\right)^2 \tag{9}$$

Depth of the feed, $$Z = Z_0\left[\cos\left(\frac{\pi G}{L}\right)\right]^2 \tag{10}$$

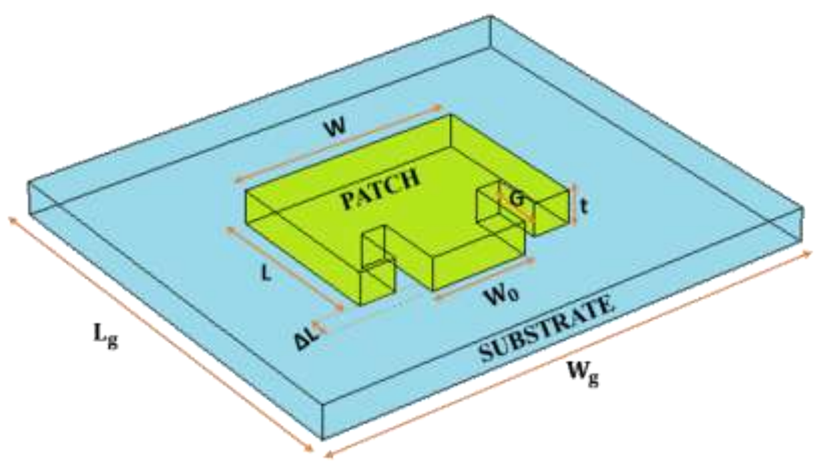
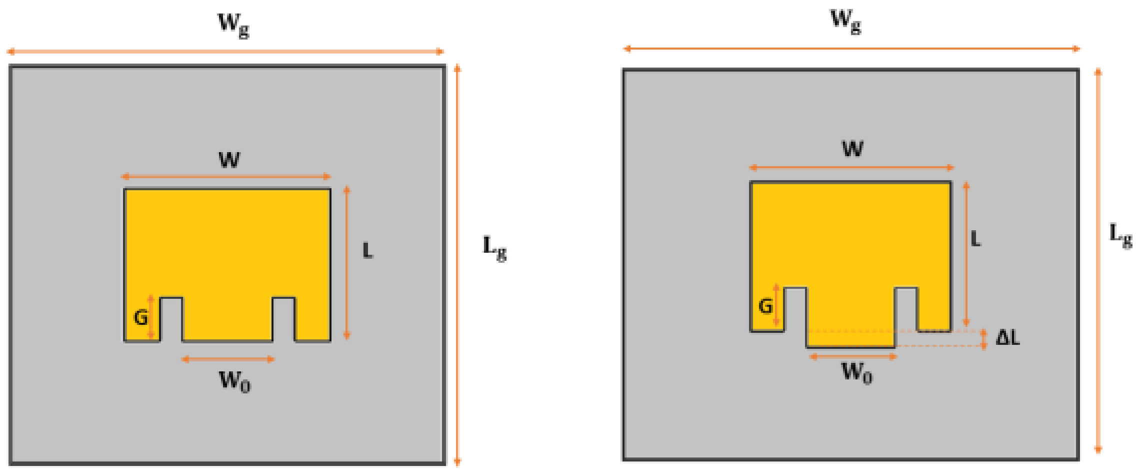


Figure 1. Dimensions of rectangular microstrip patch antenna with optimal extension length L.



(a) (b)

Figure 2. (a) 2D image of rectangular microstrip patch antenna without optimal extension length ΔL.

(b) 2D image of rectangular microstrip patch antenna with optimal extension length ΔL.

However, due to fabrication limitations, the parameters calculated using the above-defined formulas need to be optimized to obtain minimum return loss parameter, maximum gain, and maximum directivity at the operating resonant frequency.

Table 1. Calculated and optimized parameters of microstrip patch antenna resonating at 12.75 GHz

SUBSTRATE (mm)		PATCH (mm)		FEED (mm)	
W_g	L_g	W	L	W_0	G
BY CALCULATION					
18.30081	15.90670	9.30081	6.906709	1.88998	2.00655
OPTIMIZED PARAMETERS (WITHOUT ΔL)					
20	18.3	9.5	7	2.592	1.9888
OPTIMIZED PARAMETERS (WITH ΔL)					
21.258	18.25	9.3799	7+0.758853	1.05	2.8688

3. RESULTS AND SIMULATION

The antenna reported here is designed and simulated using the finite element method in the COMSOL multiphysics tool. Various antenna parameters such as electric field norm, far-field radiation pattern, gain, directivity, input impedance, and VSWR have been obtained and analyzed by varying the patch's geometrical parameters. The antenna operates in the Ku-band at a resonant frequency of 12.75 GHz.

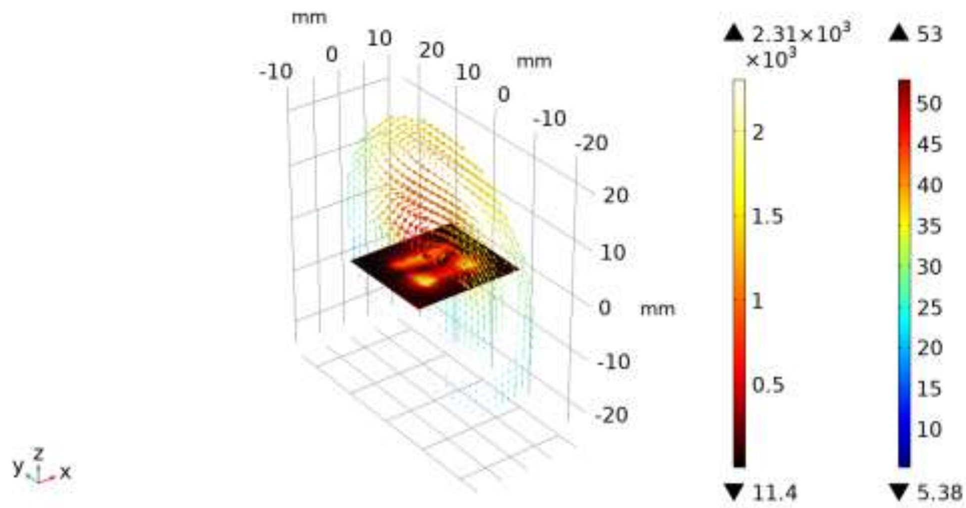


Figure 4. Electric field Norm (V/m) plot of reported microstrip patch antenna without optimized extension length ΔL

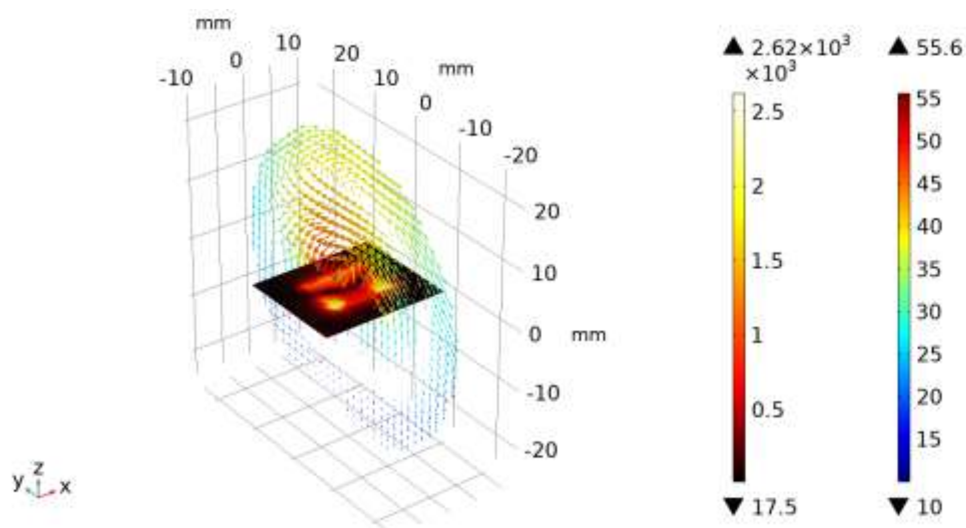


Figure 5. Electric field Norm (V/m) plot of reported microstrip patch antenna with optimized extension length ΔL

Figures 4 and 5 display the electric field vector within the antenna substrate. The dominant polarization direction at the antenna boresight (i.e., the axis of maximum gain of a directional antenna) is indicated by the direction of the electric field arrows. Using the scale given that the electric field is higher around the antenna's radiating edges can be seen. On comparing both the figures, we conclude that the electric field has become stronger, the maximum value has increased to 2.31 x 10^3 V/m from 2.62 x 10^3 V/m and the minimum value has increased from 11.4 V/m to 17.5 V/m on the addition of the optimized extension length (Figure 5) in the microstrip patch antenna.

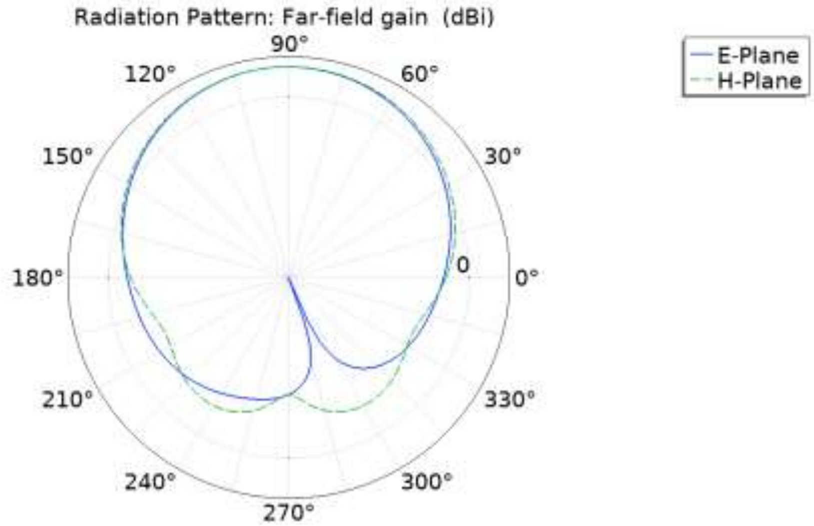


Figure 6. 2-DFar-field radiation pattern (gain in dBi) at E-plane and H-plane of microstrip patch antenna without optimized extension length ΔL.

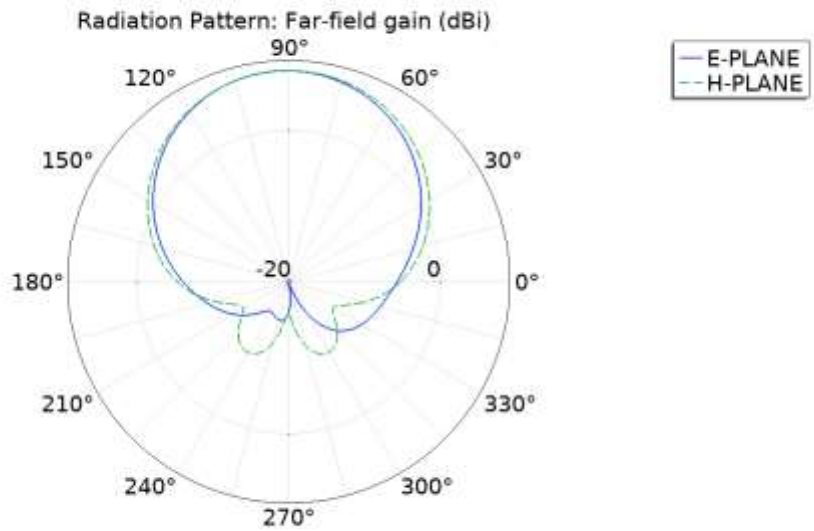


Figure 7. 2-D Far-field radiation pattern (gain in dBi) at E-plane and H-plane of microstrip patch antenna with optimized extension length ΔL.

Far-field radiation patterns at E-plane and H-plane at resonant frequency 12.75 GHz are described in figure 6 and figure 7 for both the microstrip patch antenna without and with optimized length ΔL, respectively. The E-plane is characterized by the dominant antenna polarisation or radio wave orientation; it is the plane containing the electric field vector (also known as the E aperture) and the maximum radiation direction. The magnetic field is primarily polarised in the H-plane, which typically coincides with the horizontal/azimuthal plane. Because of the bottom ground plane, the above two far-field radiation patterns are guided upwards. Also, after comparing the two radiation patterns of the reported antenna, we can see that the antenna's directionality has improved due to reduction in the back lobe radiation (figure 7), and the far-field gain has improved from 7.7854 dB to 7.8709 dB on the addition of optimized extension length to the microstrip patch antenna.

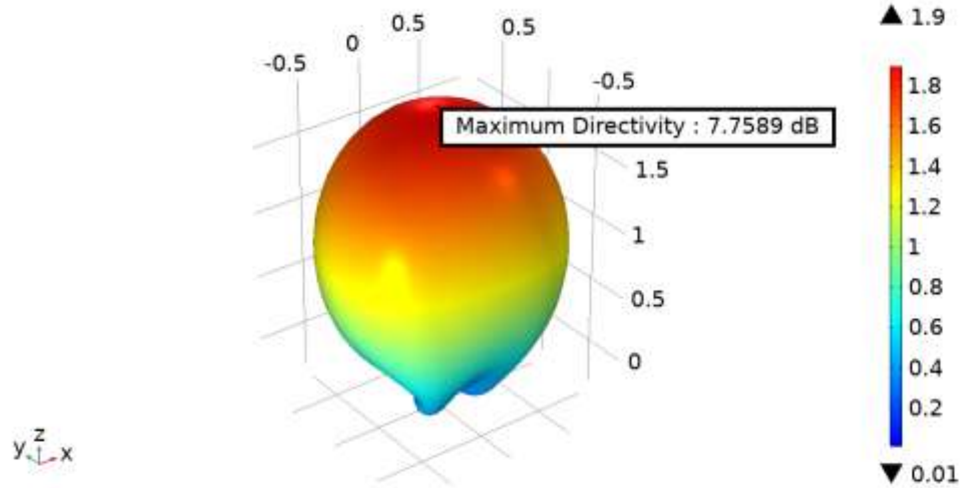


Figure 8. 3-D Far-field radiation pattern of microstrip patch antenna without optimized extension length ΔL.

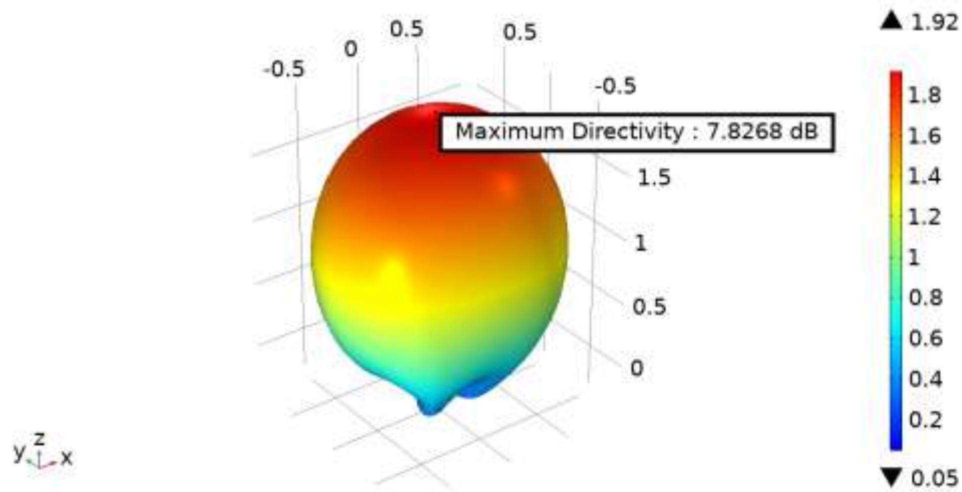


Figure 9. 3-D Far-field radiation pattern of microstrip patch antenna with optimized extension length ΔL.

3D far-field radiation pattern is visualized in Figures 8 and 9. The ground plane prevents the radiation from reaching the bottom side, resulting in a directive beam pattern. Also, after adding extension length ΔL to the microstrip patch antenna, the antenna's directivity has improved from 7.7589 dB to 7.8268 dB.

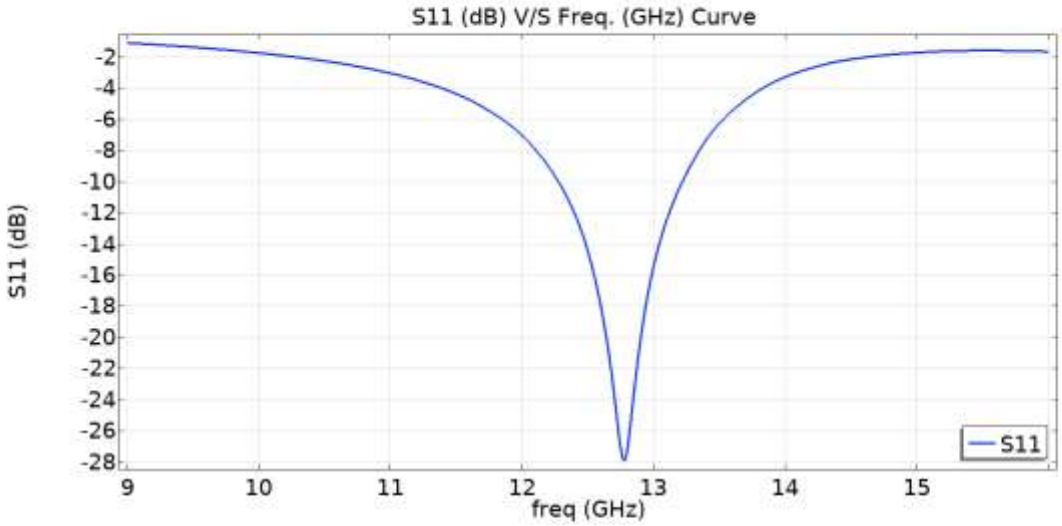


Figure 10. Variation of return loss with the frequency of proposed microstrip patch antenna without optimized extension length ΔL.

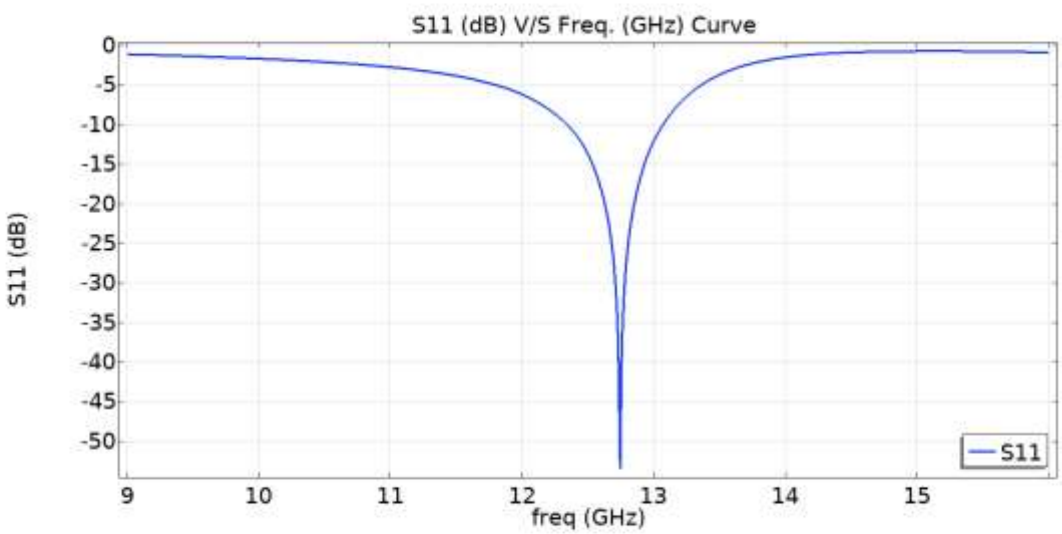


Figure 11. Variation of return loss with the frequency of proposed microstrip patch antenna with optimized extension length ΔL.

The reflection coefficient is also known as the return loss or S11 parameter, representing how much power is reflected from the antenna. When S11=0 dB, the antenna reflects all of the power and radiates none. Figure 10 and figure 11 show the variation of return loss or S11 parameter with frequency; after the addition of optimized length ΔL to the microstrip patch antenna, the S11 parameter has improved from -28.926 dB to -47.135 dB. By looking at both the figures, we can conclude that after adding optimized length ΔL to the MPA, the quality factor of MPA has significantly improved, which gives us better impedance matching at resonant frequency 12.75 GHz.

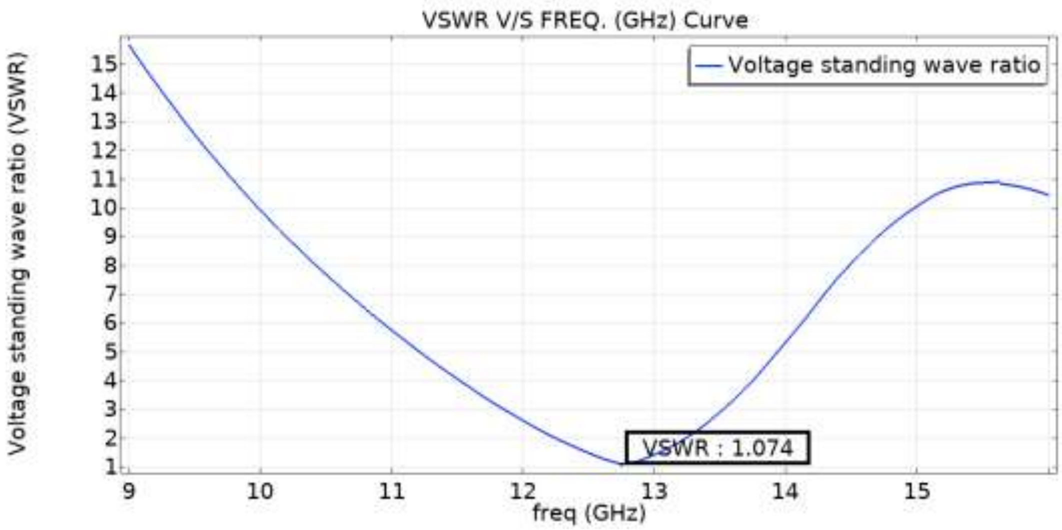


Figure 12. Variation of VSWR with the frequency of proposed microstrip patch antenna without optimized extension length ΔL resonating at 12.75 GHz.

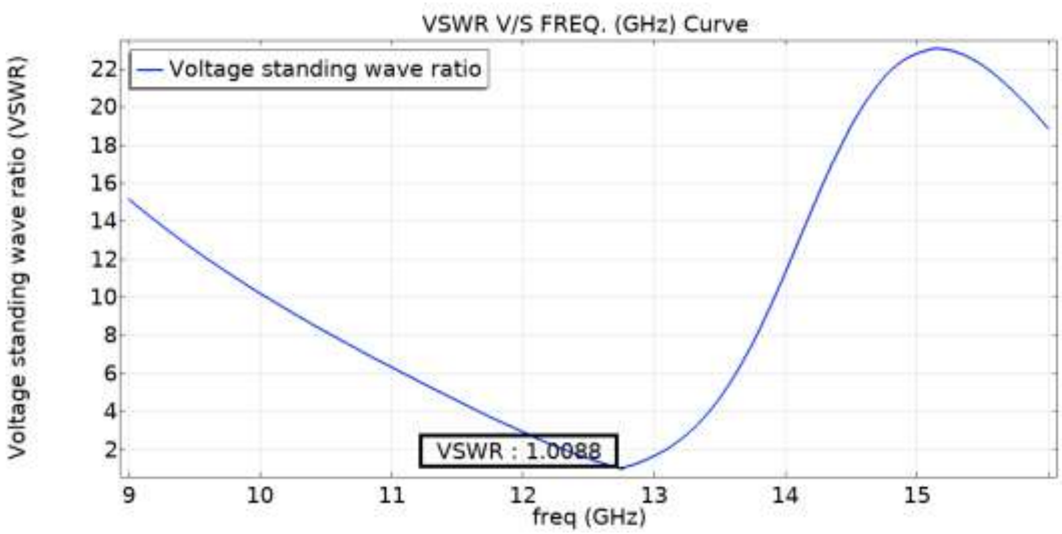


Figure 13. Variation of VSWR with the frequency of proposed microstrip patch antenna with optimized extension length ΔL resonating at 12.75 GHz.

The radio and transmission lines impedances must be well matched to the antenna's impedance for a radio transmitter or receiver to provide power to an antenna. The VSWR parameter is a numerical measure of how well the antenna's impedance matches to that of the radio or transmission line to which it is attached. The VSWR of an antenna is always a real and positive number. The lower the VSWR, the better the antenna is matched to the transmission line and the more power it receives. The lowest value of VSWR must be 1.0 for no power to be reflected from the antenna, which is ideal. Figure 12 and figure 13 show the variation of VSWR with frequency. Here, in addition to optimized extension length ΔL to the microstrip patch antenna, the VSWR has improved from 1.072 to 1.0088, thus gives better impedance matching.

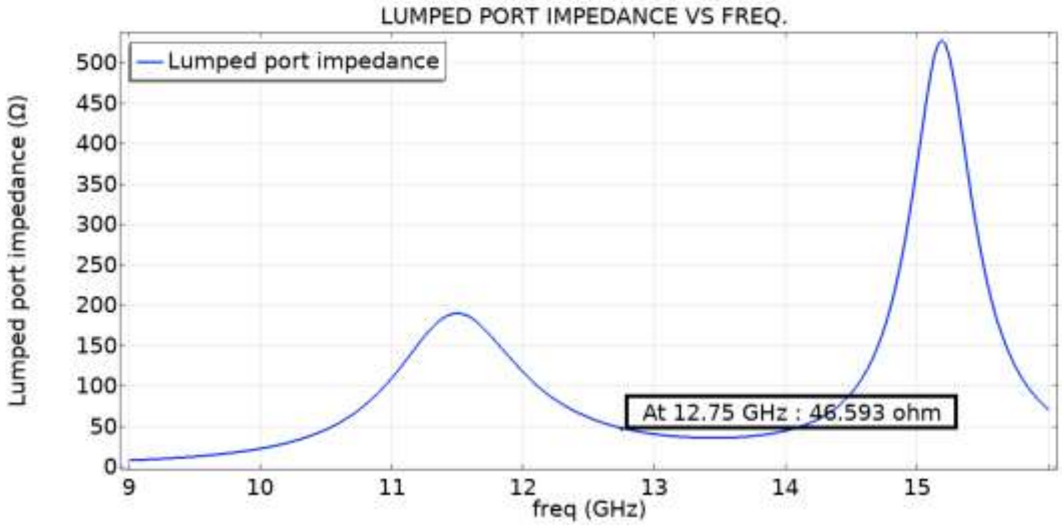


Figure 14. Variation of lumped port impedance (Ω) with the frequency of proposed microstrip patch antenna without optimal Extension length ΔL resonating at 12.75 GHz.

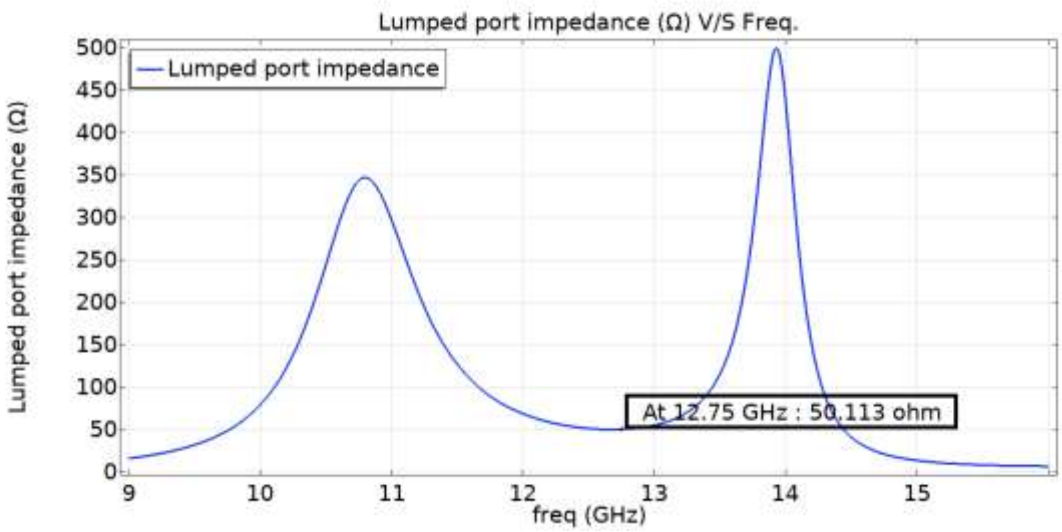


Figure 15. Variation of lumped port impedance (Ω) with the frequency of proposed microstrip patch antenna with optimal extension length ΔL resonating at 12.75 GHz.

The power transmitted to the antenna by the transmission line depends on the impedance matching of the feed point and the antenna, which depends on the position of the feed point, as described earlier. To reduce the reflection loss, the impedance of the inset feed must match with the antenna, thereby improving the antenna performance[6]. Here figure 14 and figure 15 describe the variation of lumped port impedance with frequency. The proposed antenna is excited by a 50 Ω microstrip line and has been optimized to operate in Ku-band at resonant frequency 12.75 GHz, on the addition of optimized extension length ΔL to the microstrip patch antenna, the lumped port impedance value has improved from 46.593 Ω to 50.113 Ω, and hence better the antenna is matched to the 50 Ω transmission line excited by lumped port.

Table 2. Simulated results of the microstrip patch antenna resonating at 12.75 GHz with and without extension length ΔL

ANTENNA PARAMETER	WITHOUT OPTIMIZED EXTENSION LENGTH ΔL	WITH OPTIMIZED EXTENSION LENGTH ΔL
Return Loss / S11 (dB)	-28.926	-47.135
Gain (dB)	7.7854	7.8709
Directivity (dB)	7.7589	7.8268
VSWR	1.0742	1.0088
Lumped Port Impedance (Ω)	46.593	50.133

The comparison of the proposed antenna and previously reported antenna has been done in table 3. The proposed antenna demonstrates minimum return loss, high gain, high directivity, VSWR around 1, and satisfactory bandwidth in Ku-band and simple design.

Table 3. Comparison of the proposed antenna with previous reported MPA in Ku-band

REFS.	DIMENSIONS (mm)	RETURN LOSS / S11	VSWR	BANDWIDTH (MHz)	GAIN	DIRECTIVITY
[7]	17 x 17	15.8 GHz = -25 dB	<= 1.1	1240	4.45 dB	5.17 dB
[8]	9.50 X 7.96	15.33 GHz = -19.20dB 17.61 GHz = -16.045dB 18.90 GHz = -6.42 dB	1.246 1.374 2.828	528 576 804	4.80 dB 6.42 dB 3.91 dB	---
[9]	20 X 20	15.56 GHz = -32.56 dB 20.41 GHz = -31.13 dB	1.048 1.057	1070 940	---	---
[10]	10 X 7.6	12.41 GHz = -23.60 dB 14.44 GHz = -21.40 dB 16.64 GHz = -24.61 dB	1.088 1.098 1.084	600 520 382	6.626 dB 7.771 dB 4.808 dB	---
[11]	12.56 X 12.56	16 GHz = -30 dB	~ 1	4500	6.0 dBi	---
PROPOSED ANTENNA **(WITH ΔL)**	21.258 X 18.25	- 47.135 dB	1.009	12.75 GHz = 900 (approx.)	7.8709 dB	7.8268 dB
PROPOSED ANTENNA **(WITHOUT ΔL)**	20 X 18.3	-28.926 dB	1.074	12.75 GHz = 900 (approx.)	7.7854 dB	7.7589 dB

4. Conclusion

The proposed antenna is simple and compact, with an overall size of 21.258 X 18.25 X 1.4 mm^3 . Designed and optimized to operate in the Ku-band at resonant frequency 12.75 GHz for a wide range of satellite communication applications, direct transmission satellite, or satellite television. The optimal extension length ΔL has been added to the patch for improving the return loss, gain, VSWR, directivity, and impedance matching between the antenna and transmission line.

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