MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART, AND TECHNOLOGY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

DESIGN AND SIMULATION OF A HIGH GAIN ANTENNA FOR MILLIMETER-WAVE APPLICATIONS

Submitted by

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A final year project report was submitted to Makerere University in partial fulfillment of the requirements for the award of BSc in Telecommunication Engineering.

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Declaration

I James Ivan Wamoto declare that this work is my original work and efforts. It has never been submitted for the award of any degree at any university, college, or institution of learning.

I have abided by the Makerere university academic integrity policy on this assignment.

Signed ……………………………………………………………

Date …10/06/2026……………………………………………………

APPROVAL

This section of the report is to certify that this report has been accepted by the following Supervisors.

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Dedication

I dedicate this project to all my lovely parents, relatives and loving friends that we have been together in the struggle.

Acknowledgments

I would like to thank the almighty God for his continued guidance on this journey. Special thanks goes to my family and friends for their continued support in countless ways. With utmost gratitude I appreciate my main supervisor, Dr. Amitu David Martin for his guidance and continuous support throughout the process of writing this report. In the same respect, I acknowledge the guidance and effort extended by my co supervisor, Dr. Roseline Akol.

Abstract

As electronic devices continue to shrink in size, the antenna designers are pushed to reduce the antenna size. This has led to the invention of Microstrip antennas that are found to be compatible with today's manufactured devices and developed systems due to their low cost, low weight, and small size. With the desire to increase data rates and bandwidth by network service providers to meet the demands of their customers, mm-wave frequency bands have been explored and found to be a solution to overcome the bandwidth problem.

Different antenna designs have been proposed by many researchers with the aim of increasing the gain and bandwidth of the antennas. Some of these techniques include: the use of antenna arrays, multiple layersubstrate technique, parasitic patch, defective ground structure, and air gap method among others.

The main aim of this project is to design and simulate a high gain microstrip antenna through the use of an air gap method that is suitable for mm-wave applications while assessing the desired parameters like VSWR, bandwidth, radiation pattern, directivity, return loss, and antenna efficiency among others.

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List of abbreviations

5G	Fifth Generation
B/W	Bandwidth
dB	Decibel
dBi	Decibel with reference to isotropic antenna
EHF	Extremely High Frequency
EM	Electromagnetic
FR4	Flame Retardant 4
GHz	Gigahertz
HFSS	High frequency structural Simulator
ITU	International Telecommunication Union
MHz	Megahertz
MM/mm	Millimeter
MPA	Microstrip Patch Antenna
RF	Radio Frequency
RL	Return Loss
VSWR	Voltage Standing Wave Ratio

List of symbols

εr	Dielectric constant
λo	Operating Wavelength
fo	Center/Resonant/ Operating frequency

1 CHAPTER 1: INTRODUCTION

1.1 Background

The mm-waves have attracted significant interest in meeting the capacity system requirements due to wider bandwidth and high data rates. They are EHF defined by ITU as the band of frequencies in the EM spectrum from 30GHz - 300GHz. It lies between the High-Frequency band and the Far-Infrared band. Radio waves in this frequency band have wavelengths from 1mm - 10mm[1]. So it is also called the mm-band and radiation in this band is called mm-waves.

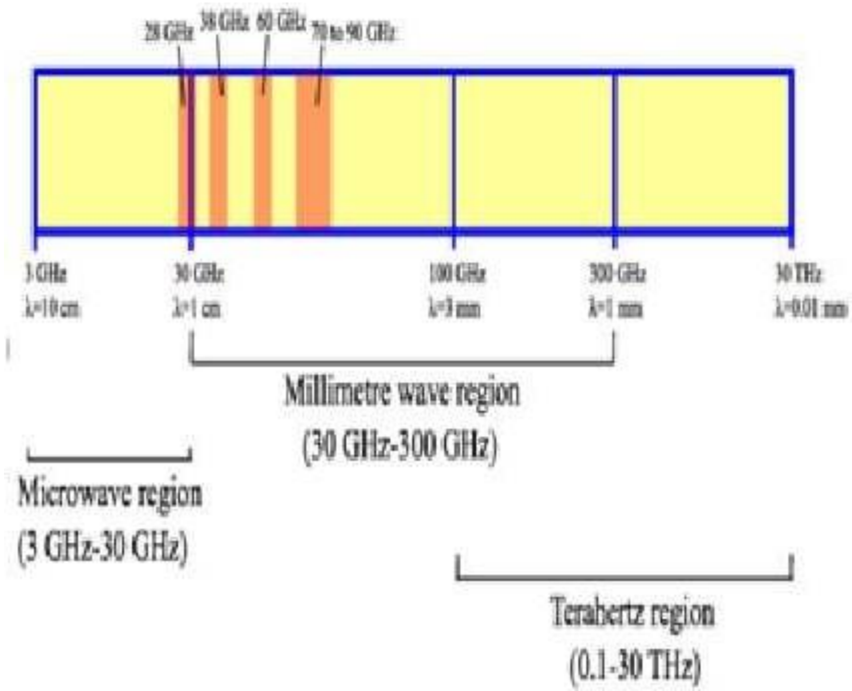

Figure 1: Frequency bands of millimeter waves

The mm-waves are used for short-range communication because they are attenuated over short distances due to the high path losses experienced as they propagate and their applications include radio astronomy, remote sensing, automotive radars, military applications, imaging, security screening, and telecommunications among others. Due to the corresponding smaller wavelength, mm-waves offer the advantage of physically smaller antennas and circuits. The mm-waves are capable of supporting the neededhigh data rate capacity and high speeds for HD video streaming used in Wireless Personal Area Networks. The planned 5G cellular network base stations and mobile devices will essentially make use of mm-wave frequency bands to meet users' evergrowing demand for high data rates. Also, mm-wave-based imaging systems have attractive characteristics including their effectiveness for explosive detection on personnel because the waves readily pass-through common clothing materials and reflect from the body and any concealed items, very low penetration for living tissues, less physical personal intrusion, and safer doses of radiation.

They are highly deployed in imaging and body penetrating applications such as homeland security, medicalimaging, and defense applications. These systems based on mm-waves could be used instead of traditional X-ray systems which have higher levels of radiation.

For a successful wireless communication system today, the antenna is one of the most critical components that should be considered; a good design of the antenna can relax system requirements and improve overall systemperformance.

An antenna is an EM transducer that converts electrical signal into EM waves. It radiates and receives EM waves and it should act as a directional device to optimize or accentuate the transmitted or received energy in some directions while suppressing it in others. These were published until they had to send signals not only concentrated in short distances but also delivered over long distances and this technology was primarily basedon wire-related radiating elements and frequencies up to about UHF. As technological advancements went on,A modern antenna was launched and new elements (such as waveguide apertures, horns, reflectors, etc.) wereprimarily introduced. A contributing factor was the invention of microwave sources (such as the klystron and magnetron) with frequencies of 1 GHz and above. Also, the advancement of computer architecture and technology had a great impact on the design of antennas.

To describe the performance of an antenna some important parameters have to be put into consideration: gain,directivity, bandwidth, return loss, radiation pattern, and antenna efficiency among others [3]. Gain shows the ability of the antenna to radiate power present at its input. It takes into account the losses exhibited within the antennastating the fact that it’s a conductor and is defined as the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna was radiated isotopically. Directivity is the ability of the antenna to concentrate the radiated power/ energy in a specific direction. It is defined as the ratio of the radiation intensity in a given direction from an antenna to the radiation intensity averaged in all directions. Antenna B/W is defined as the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth can be considered to be the range of frequencies, on either side of the f_o where the antenna characteristics are within an acceptable value of those at the f_o. The Return Loss is the ratio of the reflected power to the incident power ofan antenna. It indicates how well an antenna is Z matched. The radiation pattern of an antenna is a graphical representation of the radiation properties of an antenna as a function of space coordinates. In most cases it is determined in the far-field region often used to determine the direction of maximum radiation. It is often timesnormalized as field and power patterns. Antenna Efficiency relates to the gain of an antenna and its directivity.[3].

High-performance mm-wave applications like aircraft, spacecraft, satellite, and missile previously made use ofreflector antennas due to their high gains. As electronic devices continue to shrink in size, the antenna designersare pushed to reduce the antenna size but maintaining their special characteristics like gain. To meet these requirements, microstrip antennas are deployed. These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particularpatch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance. [3]. Microstrip antennas are planar resonant cavities that leak from their edges and radiate. A microstrip antenna (printed antenna) consists of a thin metallic patch (strip) like copper on a grounded dielectricmaterial called a substrate. They are designed so that $\lambda_o >> h$. The h of the dielectric ranges between $0.003\lambda_o \leq h \leq 0.05\lambda_o$, h is the thickness of the dielectric material. The radiating patches may be made of different shapesthough square, rectangular, dipole (2), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation and the substrates used in the design of these antennas have a dielectric constant ranging between $2.2 \leq \varepsilon_r \leq 12$. Both linear and circular polarization can be achieved with this antenna. Microstrip Antenna are commonly fed usingfour techniques: microstrip line, coaxial probe (coplanar feed), aperture coupled and proximity coupled feeding.The feeding can be defined as the means to transfer the power from the feed line to the patch. Patches radiate through the fringing effect around their edges.

1.2 Problem Statement

The rapid increase in mobile data growth and the increased demand for devices like smartphones has led to RFspectrum congestion. In the low-frequency bands, the spectrum is limited. This increases unintentional signal interference at the receiver, low speeds, dropped calls, and high delays leading to poor quality of communication among users.

1.3 Justification

The evolution in wireless communication systems has led to creation of compact small size devices. However,the antenna used is still large-sized compared to other components. Therefore, in order to reduce the size of theantenna to match the small sized devices being manufactured, microstrip antenna have been used due to manymerits such as small size, low profile, low cost, ease of installation, light weight, flexibility among others. Currently, microwave frequency bands with low data rates and low bandwidth are being deployed, butin this 5G era, lots of things such as electronic devices, vehicles, and the equipment in the offices and homes will be connected wirelessly and users will be able to access ultrahigh-definition multimedia streaming and services such as virtual reality and augmented reality which demands wide bandwidth and high data rates.

To achieve this, mm-wave frequency bands have to be deployed but they are faced with the challenge of highattenuations at shorter distances due to absorption by gaseous components (like O_2) in the atmosphere. This demands their amplification before they are radiated. This can be solved by the use of a high-gain antenna. Themm-wave band in combination with high gain antennas is beneficial for short-range small-cells backhauling which is very essential in the proposed 5G network architecture. And a microstrip antenna can be designed to meet all these requirements.

This project aims at designing and simulating a high gain microstrip antenna using the air gap method that canbe deployed in mobile communications and other mm-wave applications.

1.4 Project Objectives

1.5 Main Objective

To design and simulate a high gain antenna that operates effectively in the millimeter wave frequency range.

1.6 Specific Objectives

- To design an antenna with a gain of 10dB
- To maximize the antenna's directivity to focus energy in a specific direction
- To model the antenna and compare it with the existing literature.

1.7 Project Scope

The scope of this project is limited to the design and simulation of a high gain microstrip antennausing the air gap method operating in the X-band. This shall be achieved through:

1. Design and simulation of a high gain microstrip antenna in HFSS aimed to obtain a gain 10dB. This is because Millimeter wave applications often require high sensitivity and low noise figure thus a 10dB gain provides a good balance between signal enhancement and noise reduction.

2. Numerical assessment of the designed antenna performance with HFSS and comparison with antenna designs in the existing literature.

NOTE:

Fabrication/ Physical design of the antenna will not be carried out.

Outline

1. Chapter 1 presents the introduction. It includes the background, problem statement and justification, objectives and project scope.
2. Chapter 2 presents the literature review in which the key terminologies and related work used to describe the design are discussed.

3. Chapter 3 presents the methodology. Here, the design and analysis of the proposed model are discussed.

4. Chapter 4 presents the results and their corresponding analysis. The performance of the proposed design is compared with existing designs in literature previously reviewed.

5. Chapter 5 presents the conclusion and recommendations drawn from this project.

2 CHAPTER 2 LITERATURE REVIEW

This chapter provides a detailed review and analysis of the existing research that has been done to enhance the gain of microstrip antennas while maintaining optimum bandwidth, return loss, directivity, radiation patterns and other related characteristics. A comparison of the works is drawn up at the end of this chapter.

2.1 Antenna Theory

For wireless systems, the antenna is one of the critical components. Good antenna design can relax system requirements and improve overall system performance. An antenna is an electromagnetic transducer used to convert guided waves within transmission lines to radiated free-space waves (in the transmitting mode) or to convert free-space waves to guided waves (in the receiving mode).Antennas are used to transmit and receive nonionizing EM fields, which include radio waves, microwaves, infrared radiation (IR) and visible light.

The guiding device or transmission line may take the form of a coaxial line or waveguide and it is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. In addition to receiving or transmitting energy, an antenna can be used to optimize the radiation energy in a particular direction and suppress it in others. Thus the antenna must also serve as a directional device [5].

2.2 Types of Antennas

- **Aperture Antennas**

Aperture antennas find common application at microwave and higher frequencies due to their ease of excitation, large gain and good overall performance. They may take the form of a waveguide or a horn whose aperture is of any configuration. The horn is a hollow pipe that is tapered to a larger opening and is often used as a feed element for large radio astronomy, satellite tracking, and communication dishes. Aperture antennas are very practical for space applications due to their ability to be flush mounted on the surface of the spacecraft or aircraft. In addition, their opening can be covered with a dielectric material to protect them from environmental conditions. This type of mounting does not disturb the aerodynamic profile of the craft, which is crucial in high speed applications.

- ### Microstrip Antennas

Microstrip antennas are desired for their low profiles, conformability to planar and nonplanar surfaces, simplicity and low manufacturing costs using modern printed-circuit technology. This makes them suitable for high performance aircraft, satellite, and missile applications where size, weight and cost are constraints. The metallic patch can take many different configurations, however, the rectangular and circular patches are the most popular because of ease of analysis and fabrication[2].

- ### Wire Antennas

Wire antennas are some of the oldest, simplest and cheapest antennas. Their versatility makes them suitable for several applications and they may be seen almost everywhere e.g on automobiles, buildings, ships, aircrafts and so on. There are various shapes of wire antennas such as a straight wire (dipole), loop, and helix. Loop antennas may take the form of a rectangle, square, ellipse, or any other configuration. The circular loop is the most common because of its simplicity in construction.

- ### Reflector Antennas

Reflector antennas e.g the parabolic reflector find common application in long distance communication. Such antennas are constructed with diameters up to 305 m. These large dimensions are needed to achieve the high gain required to transmit or receive signals over long distances. The most commonly used shapes include the plane, corner, and curved reflectors.

2.3 Key parameters for Antenna performance

For the antenna to effectively operate some parameters are considered which include:

- ### Gain

Gain, G of an antenna (in a given direction) is the ratio of the intensity in that direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically. The gain of the antenna is closely related to the directivity, D by taking into account the efficiency, η of the antenna as well as its directional capabilities[4].

- **Directivity**

Directivity, D of an antenna is the ratio of the radiation intensity in a given direction from the antenna, U to the radiation intensity averaged over all directions, Uo. It gives an indication of the directional properties of the antenna as compared with those of an 19 isotropic source. The average radiation intensity is equal to the total power radiated, Prad by the antenna divided by 4π. For an isotropic source, directivity is 1 since its power is radiated equally in all directions. For other sources, the maximum directivity will always be greater than 1.

- **Bandwidth**

The bandwidth of an antenna is the range of frequencies over which an antenna exhibits optimum performance with respect to certain performance characteristics of a specified standard. The antenna characteristics often considered include input impedance, pattern, beamwidth, polarization, side lobe level, gain and radiation efficiency. These must be within an acceptable value of those at the center frequency. The bandwidth can be expressed as the ratio of the upper-to-lower frequencies of acceptable operation e.g in broadband antennas or as a percentage of the frequency difference (between the upper and lower) over the center frequency of the bandwidth.e.g in narrowband antennas[2].

- **Return Loss and VSWR**

The return loss, ρ is the ratio of the reflected power to the incident power of an antenna. It quantifies the portion of electromagnetic energy that is reflected at the antenna's input relative to that which was incident. In other words, it indicates how well an antenna is impedance matched. An antenna is said to be properly matched when the its input impedance, Zin is equal to the characteristic impedance, Zo of the transmission line. If a large portion of the incident power is reflected, then there is significant antenna mismatch which results in a loss in signal and thus antenna efficiency reduces. For optimum performance of the antenna, the return loss must meet the threshold of 10dB or more[2].

VSWR, also provides a measure of the mismatch between the load and the transmission line and is related to the return loss as shown below. A VSWR of unity indicates no mismatch loss. Generally, the value of VSWR should lie in between 1 and 2[5].

- **Efficiency**

The total antenna efficiency is used to take into account losses at the input terminals and within the structure of the antenna that may occur due to reflections as a result of the mismatch between the transmission line and the antenna or conduction and dielectric losses.

- **Radiation Pattern**

An antenna radiation pattern is a graphical representation of the antenna's radiation properties as a function of space coordinates and is generally determined in the far field region[5]. The radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. The portion of the radiation pattern bounded by regions of relatively weak radiation intensity is known as a radiation lobe and these can be classified into; major lobe (the radiation lobe containing the direction of maximum radiation), minor lobe(any lobe except a major lobe), side lobe(lobe in any direction other than the intended lobe and is usually adjacent to the main lobe) and back lobe(lobe whose axis makes an angle of approximately 180 degrees with respect to the beam of an antenna.) Minor lobes usually represent radiation in undesired directions, and thus should be minimized. The level of minor lobes is usually expressed in terms of side lobe ratio ratio(level) which is given as the ratio of the power density in the given minor lobe to that of the major lobe.

2.4 Gain Techniques in Microstrip Patch Antennas

To overcome the challenges in MPAs, various techniques have been investigated by researchers to enhance thegain of the antennas while assuring optimum bandwidth, return loss and radiation patterns. A number of thesetechniques are discussed below.

2.5 Gain Enhancement in Single Element Antennas

Single element antennas designed to use techniques such as the H-shaped slotted microstrip stacked antenna with ground plane slot reported in [7] and multiple dielectric substrates employed in [8] were ableto obtain reasonable bandwidth and moderate gains of 7.62 dB, 6.01 dB and 2.12 GHz, 610 MHz respectively.

A method to enhance the gain of a microstrip patch antenna by partial substrate removal was investigated byauthors in [9]. The effects of substrate removal in different configurations on the gain of the antenna were studied numerically and validated experimentally using an aperture coupled microstrip antenna operating at 2.4 GHz. The substrate surrounding the patch was removed in various configurations to synthesize a lower dielectric substrate with an open-air cavity with each of the cavities having the same depth. The authors reported the gain of the microstrip patch antenna to have improved in a range between 2.4–2.7 dB when the substrate surrounding the radiating edges of the patch antenna was fully or partially removed.

Although the authors in [7] and [8] were able to improve the gain of the MPA, the values obtained were still moderately low which still leaves a lot of potential for further enhancement of the antenna gain using MPA arrays. Furthermore, proper alignment of the substrate layers must be achieved which introduces complexity in the antenna's fabrication in both antenna designs. The work done in [9] was able to validate the effect of substrate removal on the gain of the MPA by reducing the surface wave losses. However, this work was carried out at much lower frequency of 2.4 GHz and thus does not satisfactorily address the effectiveness of this technique at mm wave frequencies

Gain Enhancement in Microstrip Patch Antennas using Arrays

A 2x1and 4x1 microstrip antenna array design for simultaneous improvement of band-width, gain and directivity using a two-layer substrate comprised of RT/ Duroid 5880 (sr = 4.4) andair comb (ε_r = 2.2) as dielectric materials was reported by the authors in [8]. The single element of the array was designed as a square patch proximity coupled multilayer antenna that achieveda gain, directivity, return loss and bandwidth of 6.94 dB, 8.26dB, -12dB and 172 MHz respectively. Different configurations of the multilayer antenna array were designed using 2, 4 and 8 rectangular patches in a 2x1and 4x1 arrangement to further enhance the antenna'sperformance. The element spacing was maintained at 0.8λ in all the configurations. The achieved antenna performance after simulation for each of the antenna arrays is tabulated below.

Table 1: Comparison between different array configurations

Parameters	Single element	2x1	4x1
Gain (dB)	6.94	10.05	11.5
Directivity (dB)	8.26	10.4	11.62
Bandwidth (MHz)	172	190	230

Authors in [10] presented a theoretical analysis of a single element microstrip antenna that was later extended into a 4x1 element antenna array to enhance its gain and bandwidth. The single element was designed with RT/ Duroid 5880 **as** the substrate material of thickness 1.85 mm and a rectangular patch loaded with slots as shownbelow. The minimum return loss was obtained as - 30 dB at 9.77 GHz with bandwidth between 9.55 GHz to
10.03 GHz. The VSWR, gain and directivity of the antenna were obtained as 1.06, 5.15 dBi and 5.95 dBi respectively. The 4 x 1 microstrip patch antenna array was then designed with the second and fourth rectangular patch elements having the same shape as the single element rectangular

The first and third rectangular patch elements had only one rectangular slot in a middle of each patch element. The dimensions and dielectric substrate of the array elements were maintained as those proposed for the first antenna design and the array was fed using the corporate-feeding technique. A return loss of -36.1 dB at 12.03 GHz was obtained after simulation. Furthermore, the antenna supported C- band applications between 6.22 GHz - 6.61 GHz with return loss of -25.7dB at 6.31 GHz. The gain and directivity obtained from the array were 10.88dB and 12.47 dB respectively. By using slotted patches, the proposed antenna was able to operate over a wide frequency range (8.99 GHZ - 14.02 GHz) that supports bothX-band and Ku-band applications.

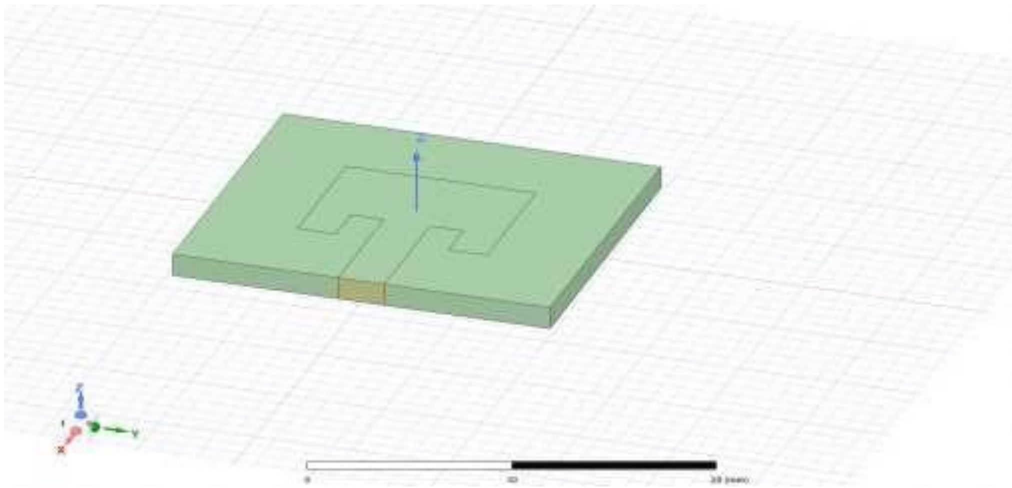

Figure 2: Single antenna design

2.6 Gain Enhancement techniques in MPAs using the air gap method

Authors in [4] proposed a compact air gap microstrip patch antenna. They used FR4 as a substrate with εr of 4.4 sandwiched in between patch and ground plane made up of copper. They used microstrip feedline technique and the Z of the antenna was matched to minimize the back reflections from the antenna. They used CST Microwave Studio 2014 to design and simulate the antenna. The Authors [4] observed that the antenna was resonant at 11.5 GHz with a B/W of 528 MHz and an operating frequency range of 11.532 GHz - 12.06 GHz.The proposed antenna had RL of -43.48 dB at *fo* of 11.5 GHz. The antenna had Gain of 8.58 dB and Directivity of 10.29 dBi. The designed antenna had applications in X-band for fixed satellite to earth downlink applicationsand could be suitably employed for mobile satellite to earth downlink applications ranging between 11.7GHz -12GHz.

The geometry of the proposed antenna including side view, top view and bottom view of antenna illustratingthe dimensions of patch, substrate and ground plane are shown below:

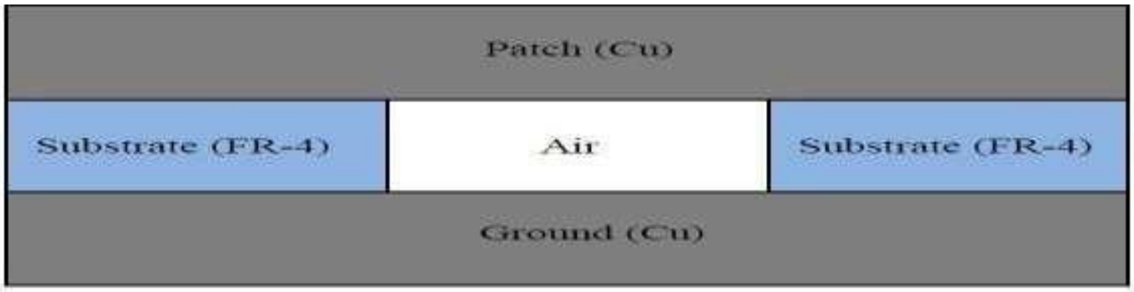

Figure 3: Side view of the proposed antenna

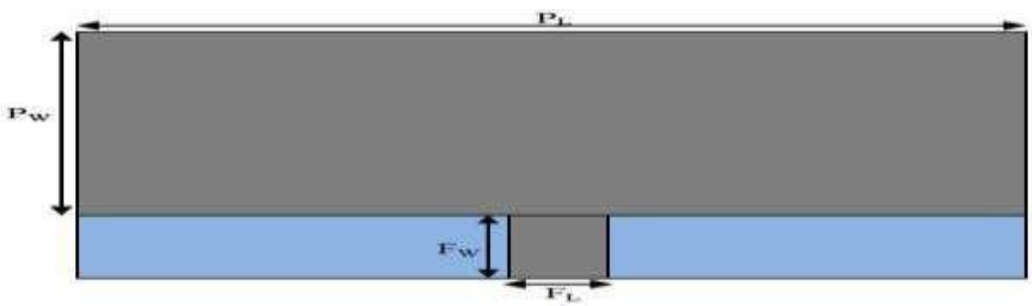

Figure 4 Geometry of the patch placed on top of the substrate(top view)

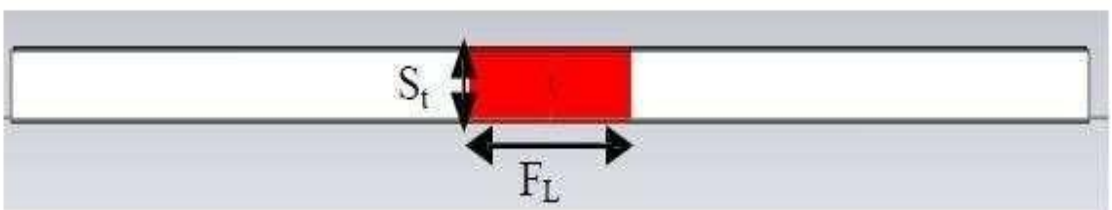

Figure 5: Geometry of feed of the proposed antenna (side view)

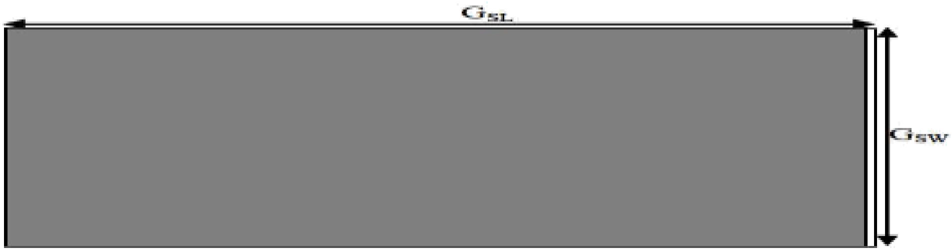

Figure 6 :Geometry of ground of the proposed antenna

Table 2: Antenna Dimensions

Parameter	Value (mm)
Width of the Patch	40
Length of the Patch	20
Length of the feedline	8
Width of the Feedline	4
Length of the ground	40
Width of the ground	20
Width of the feed	1.5

The proposed antenna was designed and simulated using CST Microwave Studio 2014. The analysis of proposed antenna design was done in terms of *fo* (GHz), RL(dB), Z(Ω), VSWR, B/W, G(dB) and D(dBi) and their results are tabulated:

Antenna Parameter	Magnitude
Gain	8.85dB
Return Loss	-42.45dB
Directivity	10.31dBi
Bandwidth	530MHz(11.6-12.5) GHz
Impedance	47.5Ω
VSWR	Less than 1.5
HPBW	50.62 deg

3 CHAPTER 3 METHODOLOGY

This chapter majorly introduces the research methods and process being used how the antenna model was done and the numerical that were used for the design.

3.1 Proposed antenna design

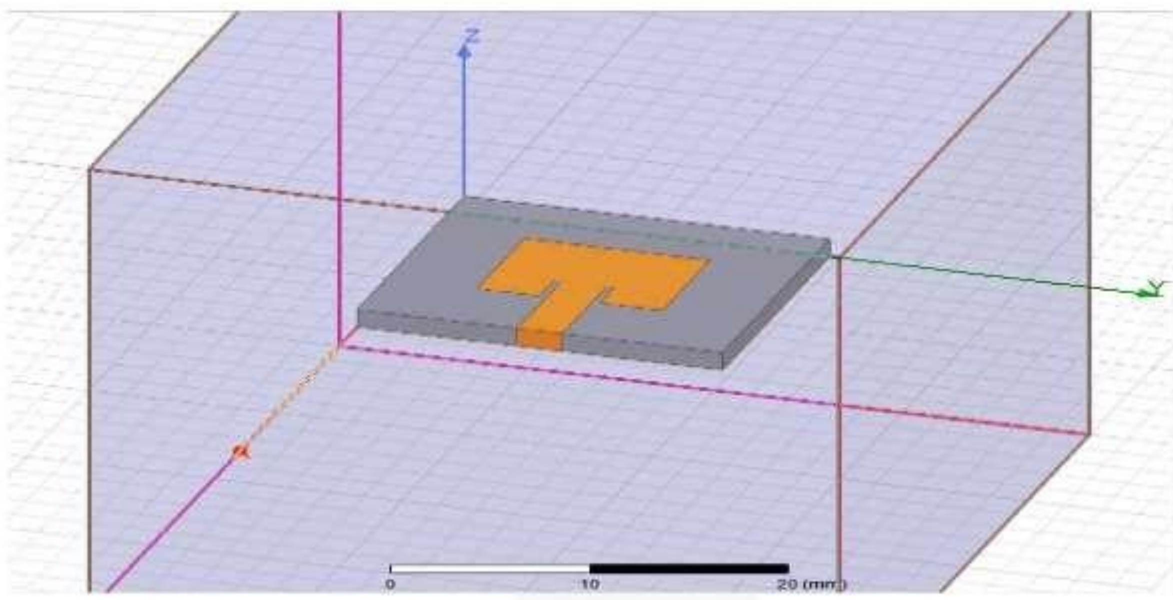

Figure 7: Antenna inside the radiation box

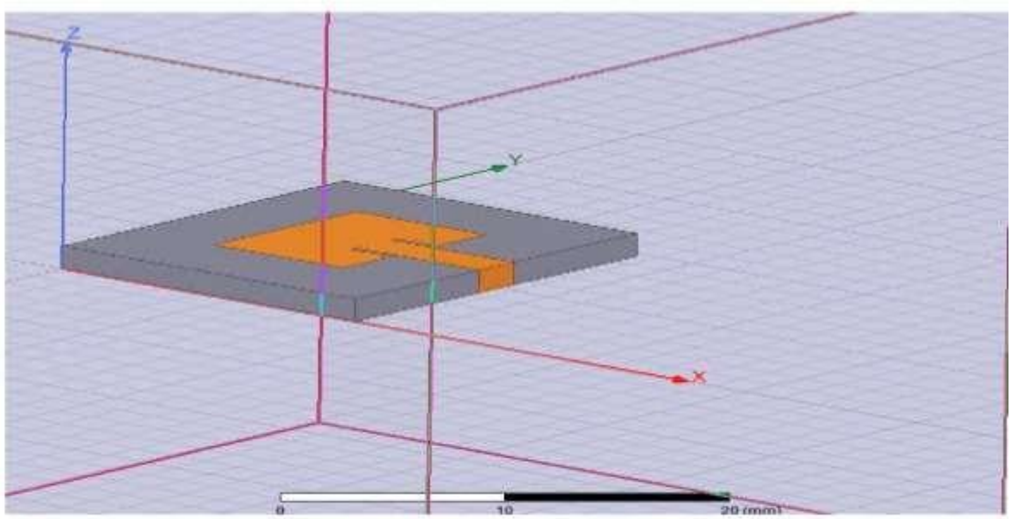

Figure 8: Antenna view outside the radiation box.

3.2 Air gap method of analysis

In this process the rectangular microstrip patch antenna added with air gap technique is used for the main purpose of gain enhancements of which the antenna is designed using the RT5880 substrate is used because of its low dielectric constant at 2.2 and it's a less lossy material when compared to the commonly used Flame retardant 4 (FR-4). The main reason of choosing an air gap method is due to the effect of reducing the dielectric constant of the radiating plane and the effect of reducing the electric field concentration on the lossy epoxy.

Frequency of operation, f

The antenna designed is operating at a frequency of 30GHz which is the frequency at which the millimeter waves lie as they tend to lie between 30-300GHZ frequency ranges.

Patch Dimensions

1. **Patch Width, W**

The values of the patch width are majorly got from the frequency of operation and the permittivity of the medium.

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where: c= speed of light (3×10^8)

ε_r = permittivity of the medium

2. **Patch Length, L**

To obtain the patch length one needs to attain the Effective permittivity, ε_{reff} since some waves travel in air as some require a medium for transmission which is the substrate. This is mainly obtaining from the expression below:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{\frac{1}{1 + \frac{12h}{W}}}$$

After this the Effective length, L_{eff} has also to be calculated in which is obtained from the formula as below:

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

Thus the Change in length, $2\Delta L$ is also obtained from the formula below:

$$\Delta l = 0.412h \left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\right) \left(\frac{\frac{W}{h} + 0.262}{\frac{W}{h} + 0.813}\right)$$

Then after the Patch length is thus obtained from the formula of having twice the Change in length, $2\Delta L$ being subtracted from effective dielectric length, L_{eff} as in the formula below:

$$L = L_{eff} - 2\Delta L$$

Ground Dimensions

1. Ground Width, L_g

   This is majorly obtained by having six times the substrate height, h and adding on the patch Length, L

$$L_g = 6h + L$$

   Where h=substrate height

   L=patch length.

2. Ground width, W_g

   This is majorly obtained by having six times the substrate height, h and adding on the patch Width, W

$$W_g = 6h + W$$

Substrate dimensions

Both the Substrate width, W_s and Substrate length, L_s are equal to the Ground width, W_g and Ground length, L_g respectively as shown below:

$$W_s = W_g$$

$$L_s = L_g$$

Feedline line Dimensions

The feed and the patch are united in order to create correct impedance matching, this is majorly having the input impedance which is equal to the output impedance. It is achieved using the formula as below:

$$d = 10^{-4}[0.001699\epsilon_r^7 + 0.13761\epsilon_r^6 - 6.1783\epsilon_r^5 - 93.187\epsilon_r^4 - 682.69\epsilon_r^3 + 2561.9\epsilon_r^2 - 4043\epsilon_r + 6697]\frac{L}{2}$$

4 NUMERICAL RESULTS AND DISCUSSION

In this section, we are going to discuss about the results obtained from the simulation sing HFSS software so as to validate that the antenna operates within the millimeter wave region.

4.1 Results

- Bandwidth.

The bandwidth of the antenna after the simulation in HFSS shows that the antenna resonates at exactly the 30GHz which is within the millimeter wave range.

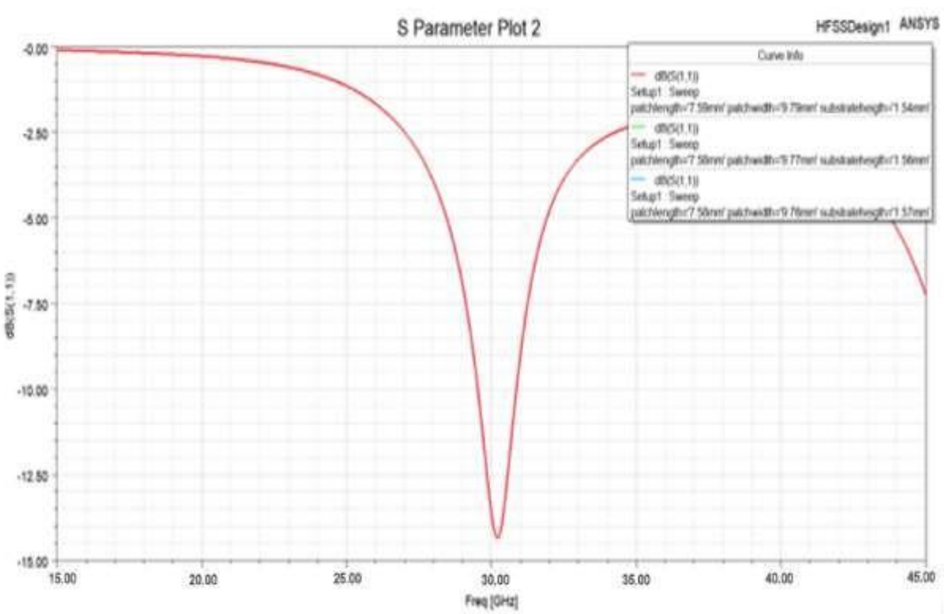

Figure 9: Band Width

- Gain

The antenna designed mainly shows that the gain is at the 10dB and why this gain is majorly because many millimeter wave applications, like 5G and radar, have specific requirements for antenna gain require high sensitivity and low noise figures thus a 10 dB gain provides a good balance between signal enhancement and noise reduction.

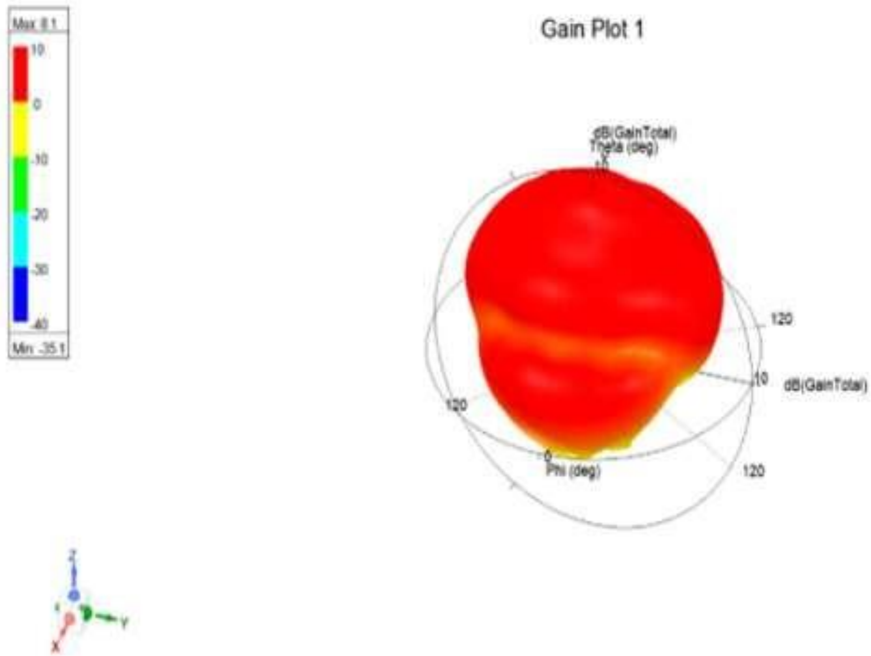

Figure 10: Antenna gain at 10dB

- Radiation Pattern

This simply shows how the power flux density is maximized so as most applications can be directed at that particular point.

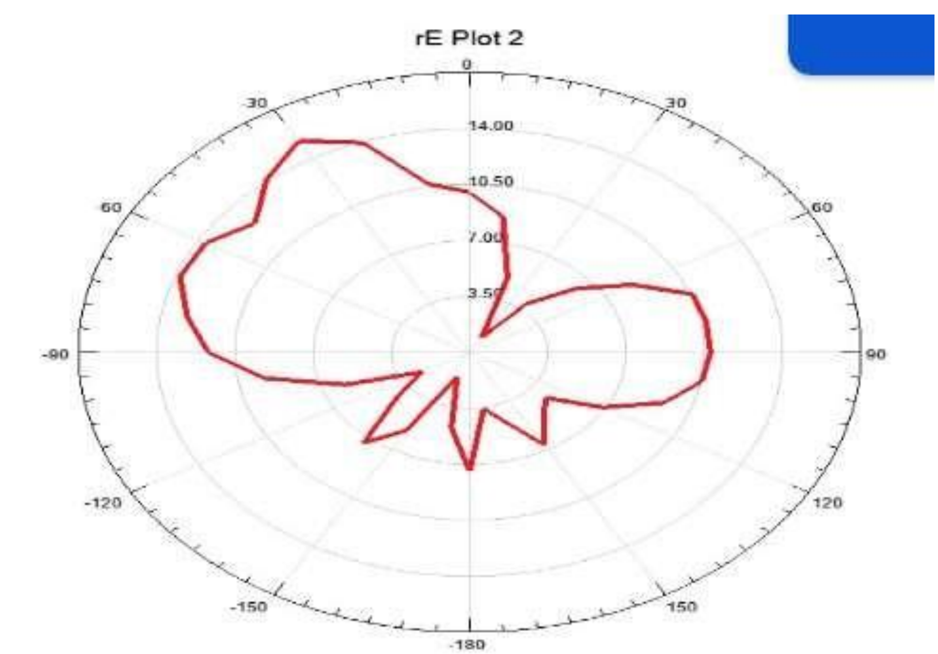

Figure 11: Radiation Pattern

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this, Microstrip high gain patch antenna was designed for millimeter wave applications as a contribution to the next generation of networks however the use of RT-Duroid can help to improve the gain of the antenna. It is also observed that the antenna designed within the millimeter wave region has better performance compared to those existing antenna designs but mostly suffers some draw backs in terms of energy losses

5.2 Recommendations

- Switching from one frequency to another can be done between the X band and the Ku band to increase the gain of the antenna such that it can be able to be applied in most millimeter wave applications.
- Further work can also be done to increase the gain of the antenna using antenna arrays than designing only one antenna but as well as varying the phase excitation.

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