**Sudan University of Science and Technology**

**College of Graduate Studies**

**Radio Link budget Calculation for Cube Satellite**

**Communication**

**حساب موازنةلرابط الإتصال للقمر الصناعي المكعب**

A Thesis submitted inpartial fulfillment of requirements for the

degree of M.Sc.in Electronics Engineering.

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قال "ص " من لايشكر الناس لا يشكر الله

إلي أمي الحبيبة مربية الاجيال .. إلى من عبرها رأيت النور  فكانت الهواء و النبض والنور ..  إلى من حملتني وهن على وهن ...إليك إنتي يا منبع الحنان وعبرك إلى كل من علمني حرف خلال مسيرتي التعليميةوعبرهم إلى كل معلمي ومعلمات السودان على إمتداد الوطن إلى أبي الحبيب صمام الأمان وملجأي حين جار الزمن.

وبكل حب

إلى زوجي ....إلى الذي سار معي في الطريق وسرت معه في الطريق .. إلى رفيق دربي نحو العلم خطوة بخطوة  .. سراج الأمل ومشعل النور ..  إلى من بذرناه معا وحصدناه معا .. وسنبقى معا بأذن الله

إلي الأخوان أيمن ومحمد  ... اليكم وانتم في البعد .. وأقرب الى الوجدان

إلي كل العاملين بمعهد  أبحاث الفضاء والطيران وعلى رأسهم الدكتور مؤتمن ميرغني مدير معهد أبحاث الفضاء والطيران.

I

# ACKNOWLEDGMENT

# ABSTRACT

The Communication link of CubeSat satellite suffers from Poor power of received signal, therefore, the link of CubeSat satellite is Susceptible to noise and interference and the signal may be lost because the CubeSat satellite transmit the signal to long distance at UHF, VHF frequency to increase the power received signal the gain of antenna most be increase so the slotted rectangular patch antenna is designed  by using trial and error method by using HFSS simulator The slots is made to increase gain and enhance the VSWR and return loss without changing the patch antenna dimensions .this is antenna instead of  the dipole antenna that is used in the CubeSat satellite it has gain of 2.5 dBi  the slotted patch antennais used because it has some advantages such as low cost, low profile, easily fabricated, small size. All of these specifications fit with small satellite (cube satellite) it gave us the gain about 8.5dBi ,this is the value of gain is added to power received signal after that the link budget is calculated by using MATLAB simulator and then the link performance is evaluated by calculating the $C\backslash N_o$ and $E_b\backslash N_o$ ratios.

# المستخلص

الأقمار الإصطناعية صغيرة الحجم دائما ما تعاني من ضعف الإشارة المستقبلة في المحطة الأرضية وذلك لأنها ترسل الإشارة علي مسافات بعيدة عند ترددات نوعا ما منخفضة مما يجعل الإشارة في بعض الأحيان تفقد أيضا عرضة للتضجيج والتداخل فيصعب تمييزها عند الإسقبال للتخفيف من المشكلة تم رفع مستوى قدرة الإشارة المستقبلة عن طريق زيادة كسب الهوائى دائما في الأقمار الإصطناعية صغيرة الحجم تستخدم هوائي ثنائي القطبية لإرسال وإستقبال الأشارة نسبة لأن حجم هذا الهوائي يتناسب مع حجم القمر الإصطناعي المكعب ولكن كسب هذا الهوائى بسيط جدا حوالى 2.5 ديسبيل لذلك تم تصميم هوائي الباتش لكن بإحداث شقوق صغيرة في طبقة الباتش هذه الشقوق تزيد من الكسب بدون التغيير في أبعاد الهوائي حتى لايؤثر حجمه علي وزن ال قمر الإصطناعي المكعب وتم إختيار هذا النوع من الهوائيات لصغر حجمه وسهولة تركيبه وقلة تكلفته حيث تم تصميمه بعدة أبعاد عشوائية للشقوق عن طريق إستخدام بر نامج محاكاة يسمى بنية الترددات العالية وبعد سبع محاولات تم الحصول علي كسب مقداره 8.5 ديسبيل ثم بعد ذلك تم إضافة قيمة الكسب إلى الأشارة المستقبلة لزيادة قدرتها وبعد ذلك تم حساب موازنة القدرة لرابط الإتصال للقمر الإصطناعى المكعب وتم تقييم أداء الرابط عن طريق حساب بعض المعدلات بإستخدام برنامج الماتلاب

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# Abbreviations

HFSS    high frequency structure simulator

CST    microwave studio

VSWR   voltage standing wave ratio

LAN    local area network

CP    circularly polarized

IE3D    integral equation three –dimensional

HAM    hertz Armstrong Marconi

UHF    Ultra high frequency

4NEC   numerical electromagnetic code

HPBW  half power beam width

RSSI    received signal strength indicator

EM    electromagnetic waves

3D    three dimensions

EIRP    effective isotropic radiated power

# Chapter One

# Introduction

## 1.1Overview

This is chapter generally talks aboutintroduction. It also illustrates Problem Statement and Proposed Solution, Objectives, Methodology, Thesis Outline.

Telecommunication technology facilitated our life we can now communicate with anyone around the globe through wire communication or wireless communication

A satellite communication is one of most important types of wireless communication because Satellite technology can thus become a solution for some of the most complicated access problems, connecting cities across a large landmass, where copper or fiber would be cost prohibitive it can use in other fields for example in earth imaging and measuring weather and space research Although the  Satellite offers many services but it still suffers from some problems such as large size and high cost of design and launching Some Experimenters developing satellites until they reached to invent small satellites. One reason for miniaturizing satellites is to reduce the size and cost.

## 1.2 Problem Statement

Communication link of cube satellite suffers from the following problems:

➢ The poor power of received signal or at least may be lost [2].

➢ The communication link of cube satellite Susceptible to noise because of unwanted signal energy injected into the link or from thermal noise generated within the link [2].

## 1.3 Proposed Solution

To enhance link of cube satellite we must increase thegain of theantenna to reduce the impact of losses and noise. In this research, the slotted rectangular patch antenna will be designed by using HFSS simulator.

The Patch antenna has some advantages such as low cost, low profile, easily fabricated, small size. All of these specifications fit with small satellite (cube satellite).the slotted rectangular patch antenna will be used to advance gain and bandwidth without change dimensions of thepatch antenna. To get high gain from slotted rectangular patch antenna the trial and error method will be used .some shapes of slotted patch antenna will be designed.

The antenna gain obtained from the abovesimulated results will be added to link budget equation to reliable performance of thesystem. Link budget equation will be calculated by MATLAB simulator and simulated results will be discussed.

## 1.4 Objectives

The main aim of this project is to link budget design for cube satellite, the objectives are**:**

1. To improve thereliability of link.

2. To enhance specifications of cube satellite to use in a wider area because it has asmall size and low cost.

## 1.5Methodology

In this research slot, patch antenna will be designed by HFSS simulator by using try and error method to specify slots position until we get advanced gain. The antenna gain obtained from the abovesimulated results will be added to link budget equation to reliable performance of thesystem. Link budget equation will be calculated by MATLAB simulator and simulated results will be discussed.

## 1.6Thesis Outline

The structure of Thesis will be written as follows:

**Chapter1: Introduction**: This is chapter generally talks about small satellites and its importance in our life also it talks about CubeSats satellites and it advantages and disadvantages and link budget of cube satellite. It also illustrates Problem Statement and Proposed Solution, Objectives, Methodology, Thesis Outline.

**Chapter 2: Literature review**: This is chapter discusses three review papers that related to enhancing power budget of CubeSat satellite by increasing the gain of theantenna.

**Chapter3: Methodology proposed solution**: This chapter illustrates how to calculate the link power budget of CubeSat depends on thedesign of slotted Rectangularpatch antenna to increase the gain and explain the methodologies to achieve that.

**Chapter4: Results and discussions**: This chapter discusses the results of slotted rectangular patch antenna design by using the HFSS simulator and discusses the results of link budget calculations and Evaluate link performance evaluate by using the MATLAB simulator and compare these results with power budget calculation when touse the dipole antenna.

**Chapter 5: Conclusions and Recommendations**: This last chapter summarizes the idea of this thesis and recommendations for future.

# Chapter Two

# LiteratureReview

## 2.1 Overview

This is sectiontalks about CubeSats satellites and it advantages and disadvantages it also illustrates the basic idea of link budget of CubeSat satellite and discuss problems that related to the link of CubeSat satellite and some technology Proposed solutions to enhance the link performance of CubeSat satellite.

## 2.2 Small Satellite

In the past few years, much of the attention of the space industry has shifted towards the development of small satellites. These satellites, often called picosats, nanosats, or microsats are generally less than 200 kg and, in many cases, are as little as 1 - 5 kg. Traditional space satellites are typified by geostationary communications satellites which range in mass from 500 to 7000 kg Such satellites require millions of dollars to develop and have historically been large expensive projects requiring five to ten years to construct. Because of the enormous costs and time allocated to such projects, very little risk tolerance exists.

Small satellites provide an amazing alternative to traditional space satellites. Such projects are driven by a "smaller, faster, better, cheaper, smarter"

Reduce the size, weight, and cost of the satellite, but also greatly increase the available functionality. SmallSatellite projects are also able to accept higher risk payloads, allowing for more interesting satellite experiments. Furthermore, as a result of resource limitations, small satellite developers are often forced to experiment with new and innovative designs, techniques, and procedures.

The low cost and limited time investment required to construct small satellites greatly reduce the cost of entry to space. Such projects make space much more accessible to amateurs, researchers, entrepreneurial efforts, and small governments. Over the past decade, an enormous variety of small satellites has been developed including a large number of educational efforts by universities [1].

## 2.3 CubeSat Satellite

A CubeSat is a standard Pico-satellite of 1000 cm³ and a mass of no more than 1.33 kg. CubeSatgives developer's standard specifications for size, weight, and basic construction, which enable parts to be built as a "one-size-fits-all" type of arrangement [2].

## 2.3.1 CubeSat Advantages

The CubeSats-class space craft's have the advantages of being able to serve as a test bed for new core space technologies and to carry small scientific payloads to be applied to larger space programs, for much lower cost, shorter schedule, and less risk. Due to these features, CubeSats have become an affordable way for educational and scientific initiatives to access space [2]

## 2.3.2 CubeSat Disadvantages

The cube sat suffers from some problems such as poorly received power this matter affects the performance of cubes. This problem also makes the CubeSat signal susceptible to noise and interference with other signals. Strong link design requires alleviating this problem.

## 2.4 CubeSat Link Budget

A link budget is an accounting of gains and losses throughout a system that is used as a design tool to provide sufficient power (or gain) to allow a satellite connection to be established.

A simple link budget equation is

$$Pr = Pt + Gt + Gr - Lp - Li \tag{1.2}$$

Where: $P_r$ is the received power (dBm),$P_t$ is the transmit power (dBm),$G_t$ is the transmit antenna gain (dBi),$G_r$ is the receive antenna gain (dBi),$L_p$ is the path loss (dB),$L_i$ is the implementation losses (dB).

Link budget in cube satellite is a method to evaluate the received power and noise power in a radio link and is the result of the summary of all gain and losses that affect the signal along the path, such as decibel units are more practical for those quantities. Link budget analysis is basically an estimation technique for evaluating

Communications system performance .Link budgets are especially useful for predicting system performance under established constraints, and for experimenting with various system design tradeoffs. In cube satellite, they received signal may degrade in one of two ways: through a loss in desired waveform power, or through the addition of noise to the signal. The cube satellite signal also interferes with the signals that are in the same frequency band like TV signal [2]. These disadvantages above make it difficult to detect signal in receive side or at least it may lose. There are many technology solutions to decrease these effects.

## 2.5 Technical Background

A link budget is an accounting of gains and losses throughout a system that is used as a design tool to provide sufficient power (or gain) to allow a satellite connection to be established.

In cube satellite link the received signal may degrade in one of two ways: through a loss in desired waveform power, or through the addition of noise to the signal .losses like (free space loss, antenna misalignment and polarization loss), it is also prone to noise from unwanted signal energy being injected into the link like terrestrial link (TV signal), or from thermal noise generated within the link. These all losses and attenuation lead to poor received signal power or at least maybe it lost [2].

There are many technology solutions to enhance the communication capability of CubeSat satellites by improving antenna system performance This is can be achieved by improving the gain and the directivity of theantenna .Cube Satellites currently use deployable dipole antennas because they can easily fit within cube satellite dimension [14].

These dipole antennas have an efficiency of 25%, radiate power in
A wider cone, and have a very low gain. These characteristics result in ahigh signal to noise ratio (SNR) making dipoles easily interfered with power inefficient Antenna.

## 2.6 Related Works

Recently the microstrip patch antenna began using in CubeSat satellite to increase the gain, therefore, the power received will be increased and the link performance is enhanced. The microstrip patch antenna is used because it has some advantages that  make the patch antenna is fit with the CubeSat size such as high

gain compare to adipole antenna, lightweight, low volume, low profile, easy fabrication [15].

In this section, some related works are illustrated.

MuhammadAamirAfridi in [6] has designed the simple microstrip patch antenna. to increase the gain is in CST Microwave Studio at a resonant frequency of 2.4GHz. The gain of the designed antenna is 8.27 dB and VSWR of 1.18.

AnwerSabahin [7] has designed a low profile, unidirectional, dual layer, and narrow bandwidth microstrip patch antennato increase the gain as well as reduce the size of the unidirectional patch antenna to resonate at 2.45 GHz. The proposed antenna is simulated and measured. According to the simulated and measured results, it is shown that the unidirectional antenna has a higher gain and a higher front to back ratio (F/B) than the bidirectional one. This is achieved by using a second flame-retardant layer (FR-4), coated with an annealed copper of 0.035 mm at both sides, with an air gap of 0.04λo as a reflector. A gain of 5.2 dB with thedirectivity of 7.6 dBi, F/B of 9.5 dB, and −18 dB return losses ($S_{11}$) are achieved through the use of a dual substrate layer of FR-4 with a relative permittivity of 4.3 and a thickness of 1.6 mm. The proposed dual layer microstrip patch antenna has an impedance bandwidth of 2% and the designed antenna shows very low complexity during fabrication.

Pampa Debnath in [8] has designed  rectangular patch antenna loaded with a semi-circular slot to operate at 5.25 GHz To enhance gain and bandwidth of rectangular patch antenna with moderate gain (about 8.53dBi),bandwidth (96.7 MHz) and a good matching( S11=-24.13dB) also describes the increment in Bandwidth andthe gain of Rectangular Microstrip Patch antenna with the Slot. Microstrip patch antenna is designed on a Duroid 5880 substrate with a dielectric constant of 2.2 the results of both the designs with and without slots are compared

and it was foundthat an increase in the bandwidth by33.82% and gain by 28.25% are being achieved. The antenna is designed based on extensive HFSS simulation studies.
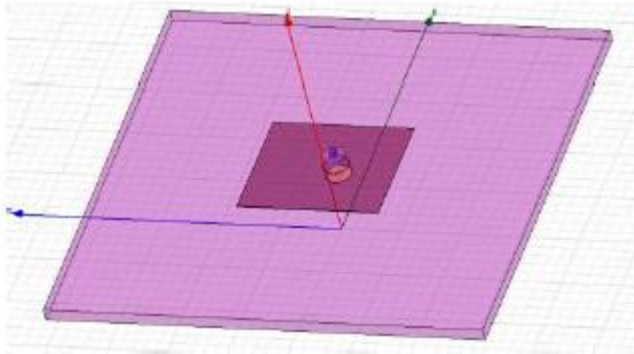


Figure (2.1): shows rectangular patch antenna model
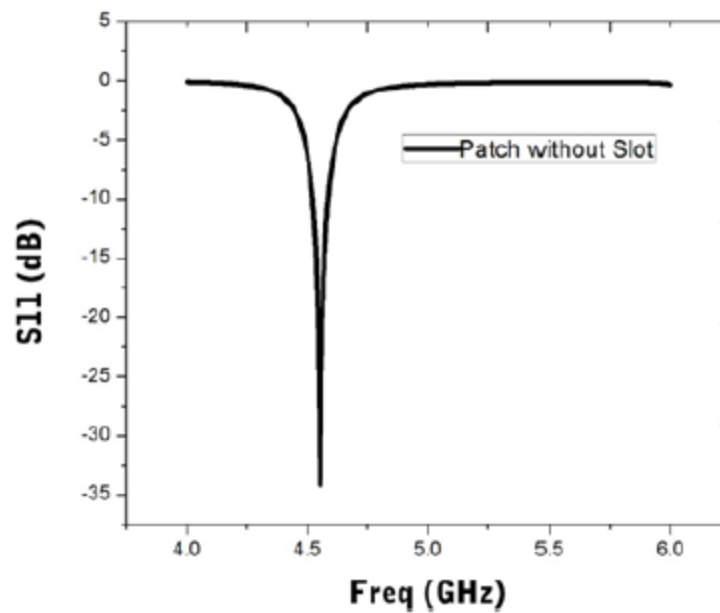


Figure (2.2): shows return loss curve
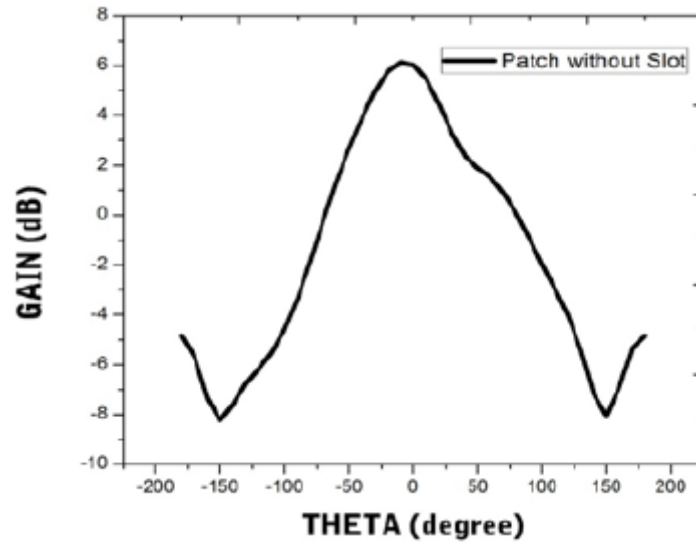
Figure (2.3): shows gain VS. Theta curve at 4.55 GHz
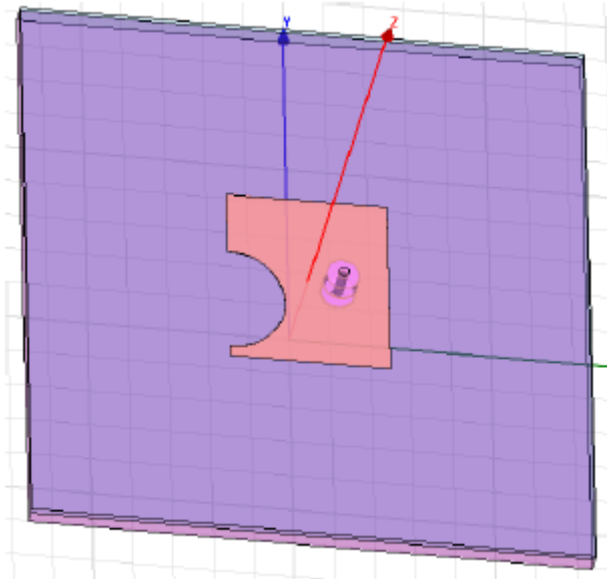


Figure (2.4): shows rectangular microstrip patch antenna with the shifted semi-circular slot
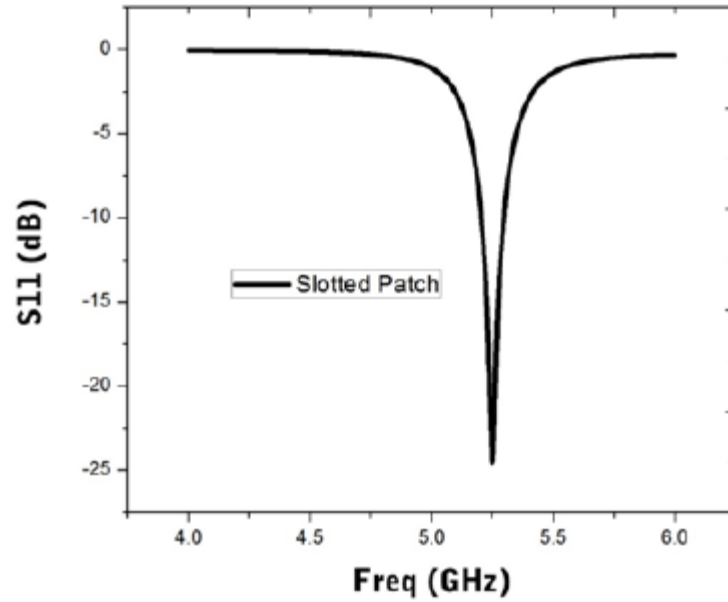
Figure (2.5): shows return loss curve of the slotted patch
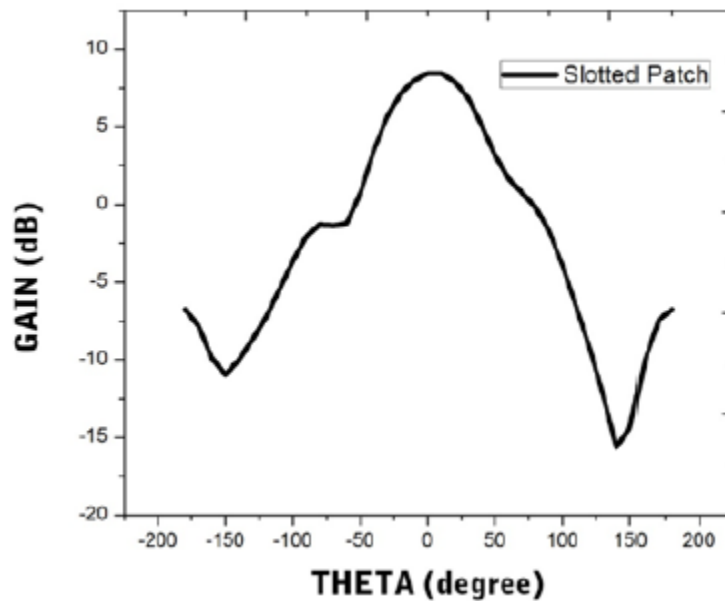


Figure (2.6): shows Gain VS. Theta curve of the slotted patch at operating frequency of 5.25 GHz

J. Chandrasekhar in [9] has designed a novel microstrip stacked patch antenna for enhancing the bandwidth and also for getting high gain of the antenna for the Wireless LAN and Bluetooth applications. The proposed antenna is excited by using the edge feed and double layer dielectric substrate are used the proposed

antenna is simulated by using the HFSS software. The return loss up to 36.1db and gain 8.6db is obtained in the frequency range from 2.32GHz-2.38GHz withacenter frequency of 2.35GHz. The VSWR<1dB at center frequency of 2.35GHz is obtained.

T. N. Chang and in [10] has designed 3 X3 and one 5 X5 antenna arrays to enhance gain and bandwidth. In each array, one probe-fed circularly polarized (CP) microstrip patch antenna is placed at the center as the driven antenna and is gapped coupled to the remaining elements. It is investigated that CP performance of the patch can be proved by properly arranging these parasitic elements. The driven patch is a perturbed square one with two diagonal corners truncated. The remaining elements are square patches slightly smaller than the driven patch. The proposed antennas have been constructed and measured .The 3*3 array has a measured

The gain of 7.7 dBic with a 3 dB axial ratio bandwidth of 3.3%. The 5 * 5 array has a measured gain of 9.3 dBic with a 3 dB axial ratio bandwidth of 8.1%.
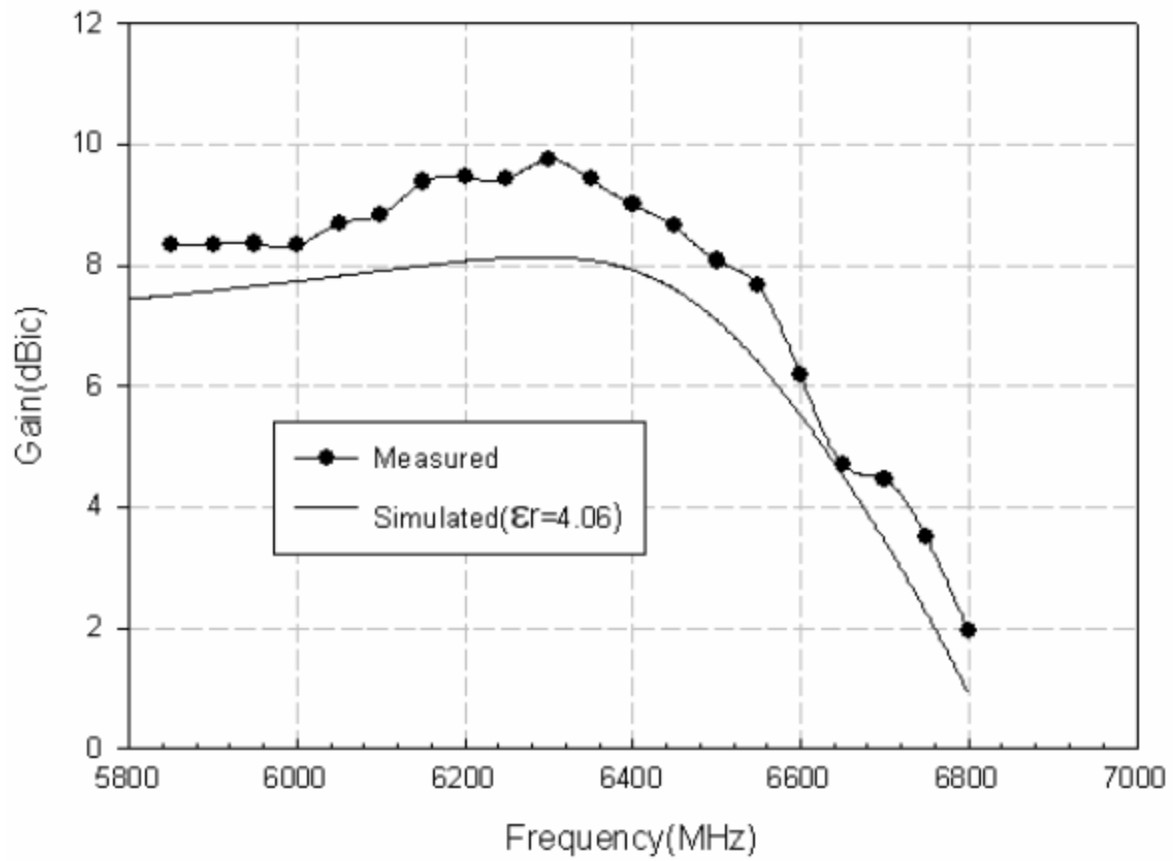
Figure (2.7): shows measured and simulated Gains of the 5X5 microstrip patch array
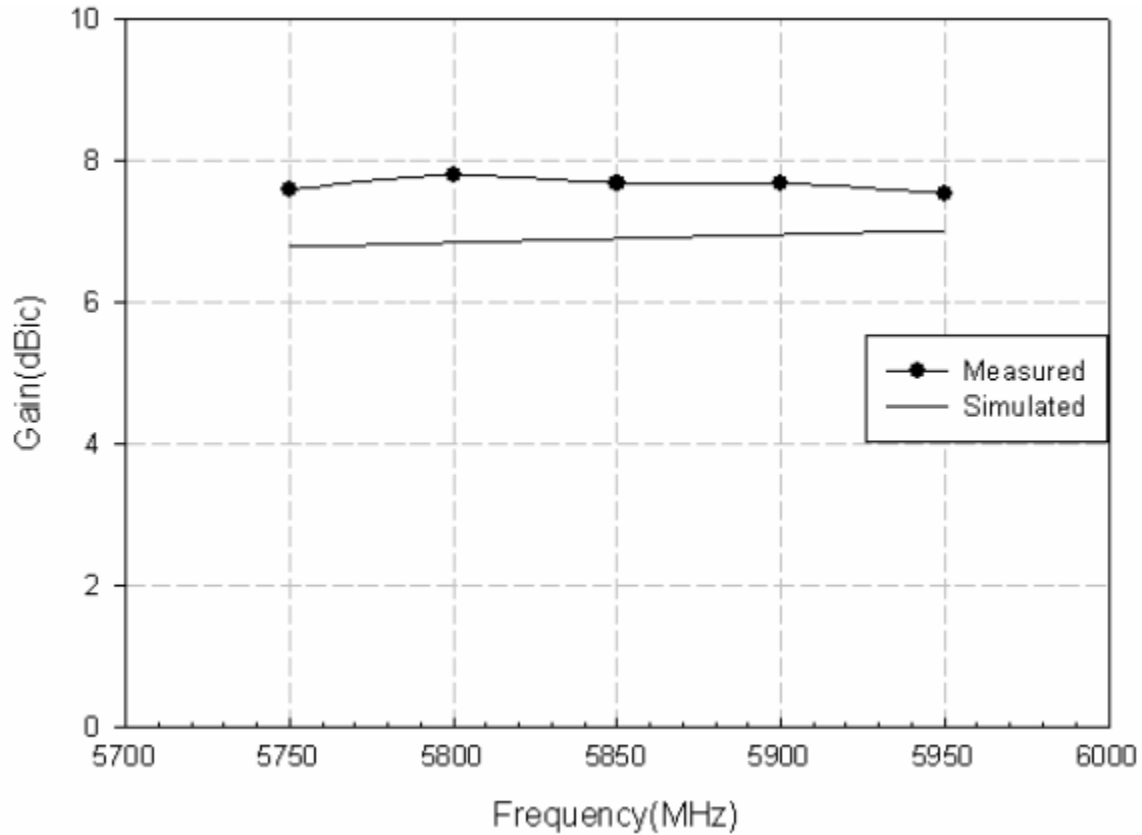
Figure (2.8): shows measured and simulated Gains of the 3X3microstrip patch array.

Ram Singh Kushwahain [11] has designed compact, wideband microstrip patch antenna with an E-shape slot for dual Frequency to increase bandwidth without change the dimensions .The proposed antenna operates at 1.95 GHz and 2.93 GHz bands. Theantenna size is very compact (40 mm x 60 mm x 1.6 mm) and is fed from a 50 Ω microstrip line. Using IE3D software package of Zeland, according to the set size, the antenna is simulated. The computer simulation results show that the antenna can realize wideband characters. The two operating bands exhibit broad impedance bandwidths (VSWR ≤ 2) of about 25% and 15%.

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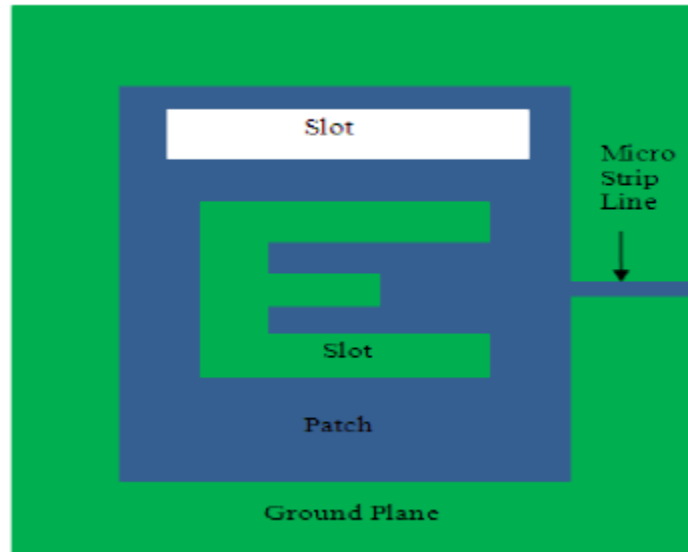
Figure (2.9): shows top view of the antenna
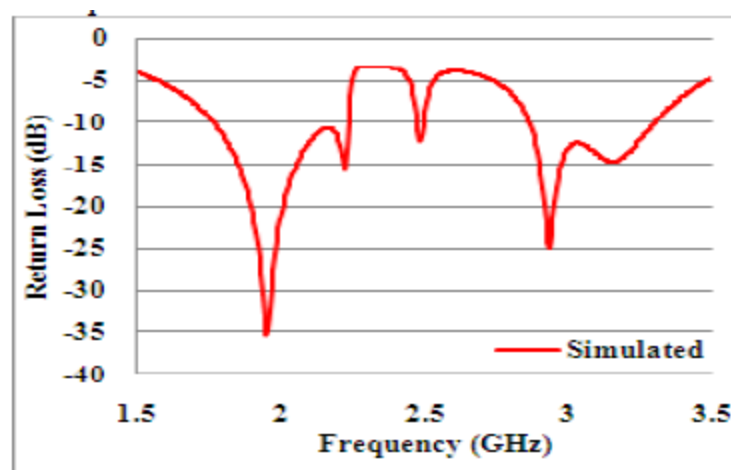


Figure (2.10):  shows simulated return loss of the proposed antenna

Bharat Rochaniin [12] has introduced a slot of a shape and using stacked configuration of microstrip patch antenna to increase thebandwidth of themicrostrip antenna. The antenna is fed by coaxial probe feeding technique. The designed antenna provides the bandwidth of 220MHz (3.86GHz-4.08GHz)

withreturn loss of -30.71db at 3.97GHz and 1.87 GHZ (9.8GHz- 11.67GHz) withreturn loss of -23.02db at 10.02GHz.
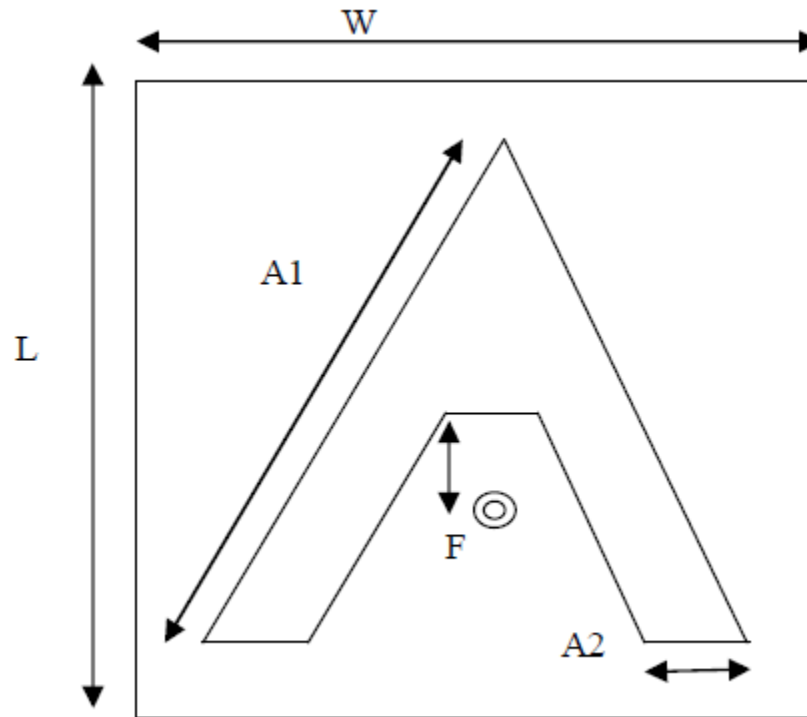


Figure (2.11): shows top view of slotted rectangular microstrip patch antenna
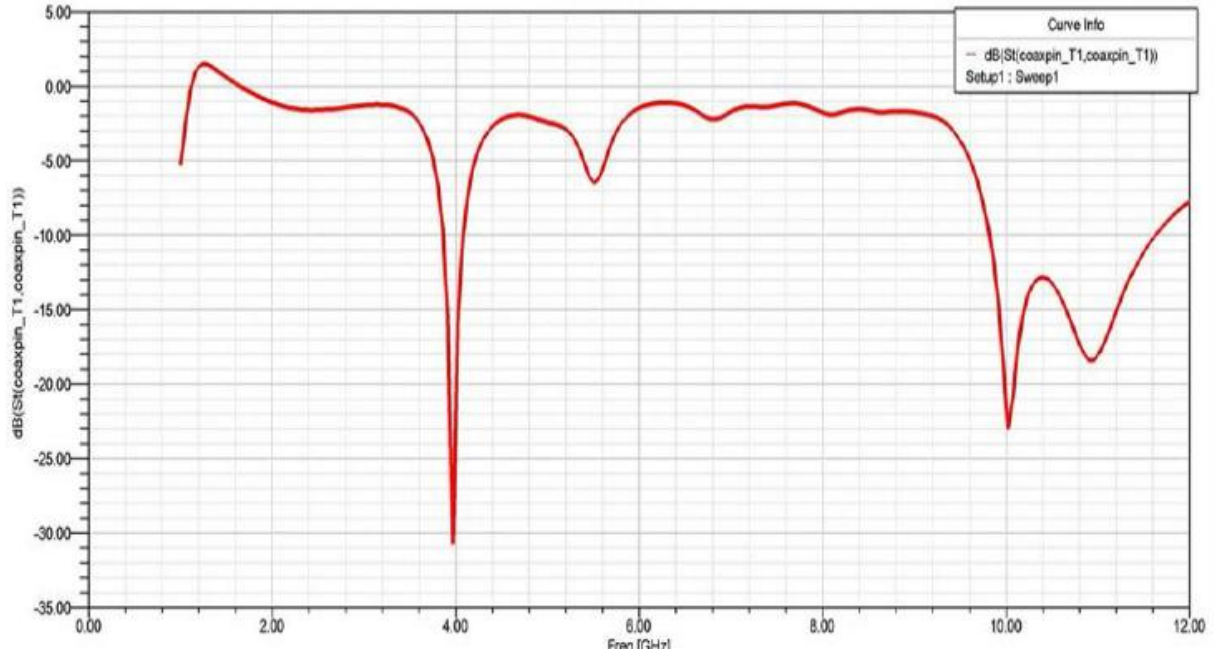
Figure (2.12): shows return loss VS. Frequencycurve for proposed antenna

Rupesh Lad in [13] has described the electrical simulations and the performance evaluation of the one unit, two units and four units circularly polarized crossed Yagi-Uda antenna array designed for communication with amateur radio (HAM) satellites operating over the 434 MHz to 438 MHz Amateur UHF band to improve upon the antenna system performance at the ground station used for the establishment of the links with the satellite This can be achieved by improving the forward gain, the forward to backward ratio and the directivity of the antenna. The electromagnetic Model has been developed using the 4NEC2 software.

The simulations have been validated with the practical field testing performed for estimating the SWR, antenna gain, the forward to backward ratio and radiation pattern for the antenna system shown in the Table   (2.1)

Table (2.1): shows results of the Comparison between antennas

| Parameter | Cross Yagi antenna | 2 unit array antenna | 4 unit array antenna |
|---|---|---|---|
| Gain | 15.5 dBi | 18.6 dBi | 20.9 dBi |
| SWR | 2.8 | 2.78 | 1.49 |
| HPBW | 32° | 32° | 16° |
| Front to Back ratio | 21.35 | 21.86 | 18.36 |
| Cable loss | 0.5dB | 1 dB | 2dB |
| Connector loss | 0.22dB | 0.44 dB | 0.88dB |

Paul Muri in [14] has studied several directional antenna types for a 2.45 GHz to enhance small satellite communication and larger bandwidth transmission. This higher frequency provides the bandwidth needed for increasing the data rate and A deployable antenna mechanism maybe needed because most directional antennas are bigger than the CubeSat size constraints. From the study, a deployable hemispherical helical antenna prototype was built. Transmission between two prototype antenna equipped transceivers at varying distances tested the helical performance. When comparing the prototype antennas maximum transmission distance to the other commercial antennas, the commercial antennas' RSSI for each distance was recorded and compared with the custom made helical prototype model shown in Figure (2.13).

Results on RSSI readings at various distances ranged from 0 to 900 meters. The 6dbi patch outperformed the other antennas in RSSI. Both the path and the custom made deployable helical performed well having a maximum transmission range of 900 meters. The commercial 9.6 dBi helical did worse than expected only

transmitting at a maximum distance of 500 meters. The two dipoles exhibited the worst performance and shortest range.
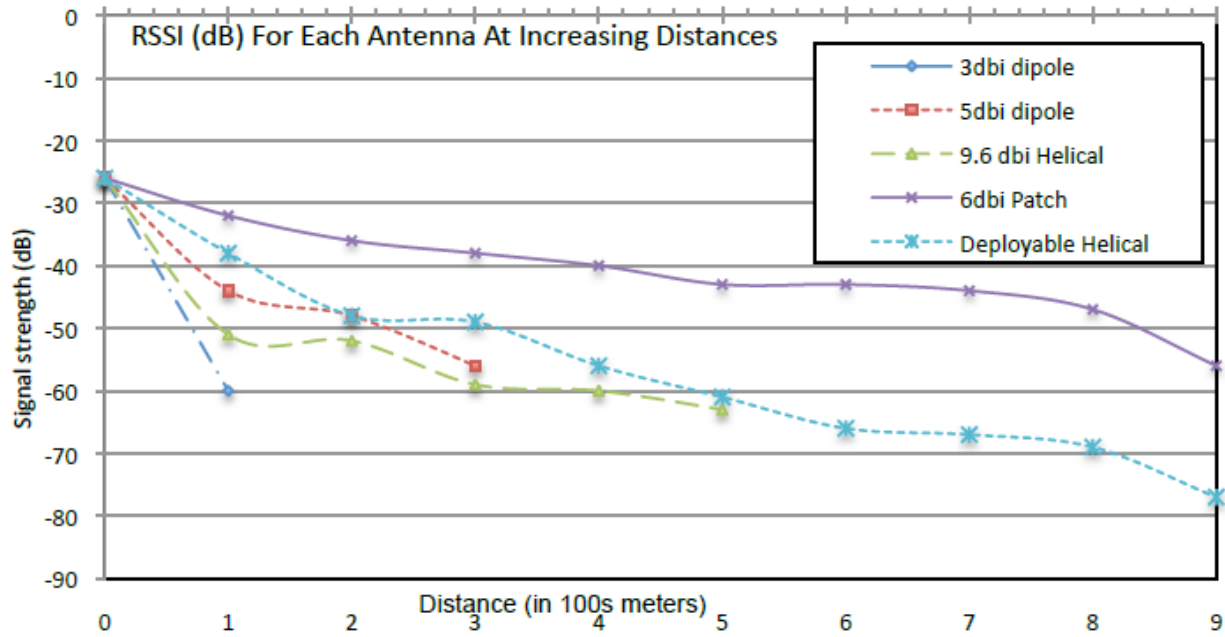


Figure (2.13): shows Deployable Helical Performances vs. Other Commercial Antennas.

The prototype outperformed all commercial antennas, except the patch antenna. The root cause was due to the helical antenna's narrow beam width.

Jianzhou Li in [15] has designed and simulated the two new circularly polarized printed antennas to broaden the impedance bandwidth, axial ratio bandwidth and increase the gain, reduce the dimensions and broaden the 3-dB axial ratio beamwidth.

Circularly polarized high-gain printed antennas for small satellite data downlink applications have been designed and simulated. The proposed antenna is composed of a dual feed is driven element to achieve circular polarization, an air gap to increase the impedance bandwidth, a parasitic element to enhance the gain and a rim to reduce the antenna dimensions and broaden the AR beamwidth the obtained gain is about 10dBi. Some advantages of the antenna, such as

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compactness, easy fabrication, and low cost make it very suitable for small satellite missions. The simulated results of the antenna mounted on the microsatellite demonstrate the reliable onboard performance.

## 2.7 Summary

the conclusions from this chapter that we can increase gain to enhance the communications link of CubeSat satellite we can achieve that by selection the antenna that fit with the size of CubeSat such as dipole antenna, patch, helical, we can so improve the structure of antennas to obtain high gain and directivity, when insert this enhanced gain in link budget equation the CubeSat link will be stable.

# Chapter Three

# Methodology and Proposed Solutions

## 3.1 Overview

In this chapter, the research methodology will be illustrated (simulators, tools, equations, parameters) to design slotted patch antenna that used in cube satellite to improve power received at ground station, therefore, thehigh performance of link communications. This chapter is divided into two parts: antenna design, link budget design of cube satellite. We will see slotted patch antenna effect on link performance.

## 3.2 System Model and Design

The flow chart in below illustrates the Methodology to antenna design and link budget calculations.
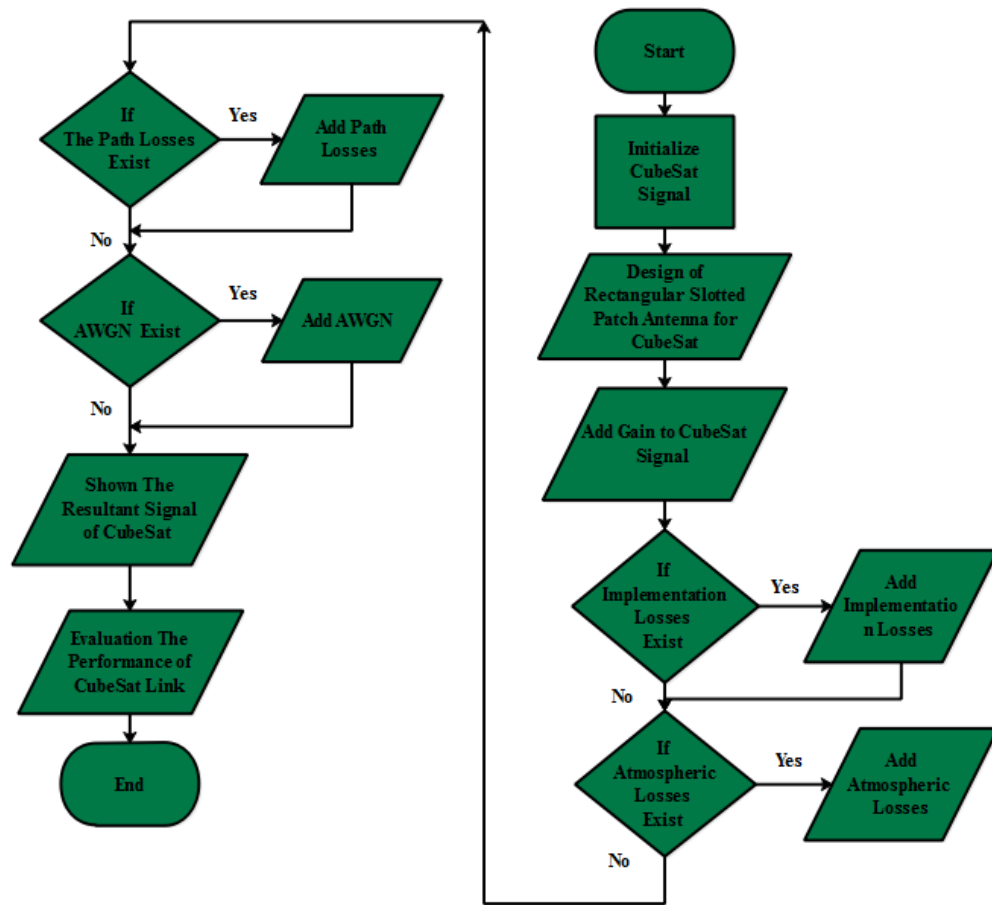
Figure (3.1): shows Methodology to antenna design and link budget calculations.

## 3.3 Antenna Design

The CubeSat belongs to Pico satellites/ Nano satellites. So the rectangular patch antenna is designed to fit with CubeSat size. The patch antenna is slotted with different shapes to get high gain and enhance the power budget of CubeSat link.

Adjust the location of the feed point is applied as the matching method to enhance return loss and VSWR.

Return loss must be less than -10dBand VSWR value must be between 1 and 2.

## 3.3.1 Rectangular Patch Antenna Design

To enhance link of cube satellite the gain of theantenna must be increased to achieve that the slotted patch antenna is used because the patch antenna has some advantages such as high gain compared to adipole antenna, lightweight, low volume, low profile; easy fabrication .patch antenna is designed by using HFSS simulator.

## 3.3.1.1 Design Specifications

The three essential parameters for the design of a rectangular Microstrip Patch Antenna:

1-Frequency of operation ($f_o$): the resonant frequency of the antenna must be selected appropriately the CubeSatfrequency range from 300MHz to 1100MHz.Hence, the antenna designed must be able to operate in this frequency range. The resonant frequency selected for my design is 900MHz.          2-Dielectric constant of thesubstrate ($\varepsilon_r$): based on material of substrate. Thedielectric

material that is selected for design is Teflon (tm) which has a dielectric constant of
(2.1)

3- Height of dielectric substrate (h): the height of the dielectric

The substrate is selected as 1mm.


## 3.3.1.2 Calculations of Parameters

The width (*W*) and length (*l*) of the patch antenna arecalculated to depend on adielectric substrate. The width *(W)* is calculated by using equation (3.1)

$$W = \frac{c}{2fo\sqrt{(\varepsilon r+1)/2}}(3.1)$$

The length of patch antenna is calculated below equations

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + \left(\frac{12h}{W}\right)\right]^{\wedge(-1/2)}(3.2)$$

$$\Delta L = \left[0.412h(\varepsilon reff + 0.3)\left(\left(\frac{W}{h}\right) + 0.264\right)/(\varepsilon reff - 0.258)\left(\left(\frac{W}{h}\right) + 0.8\right)\right](3.3)$$

$$L = (C_o/2f_r\sqrt{\varepsilon reff}) \tag{3.4}$$

Where:W is the width of thepatch antenna, $\varepsilon_r$ is the dielectric constant, h is the thickness of substrate (mm), ƒo is the frequency of free space (MHz), $\varepsilon_{reff}$ is the effective dielectric constant , ΔL is the length extension (mm).

For feeding the microstrip patch antenna, microstrip feeding is used. The method is used to match the patch antenna to the transmission line is to adjust the location of the feed (*y*0) [6].

### 3.3.2 HFSS Simulator Description

HFSS stand for high-frequency structure simulator .HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling .HFSS is used because that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to 3D EM problems are quickly and accurately obtained. HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency [5].
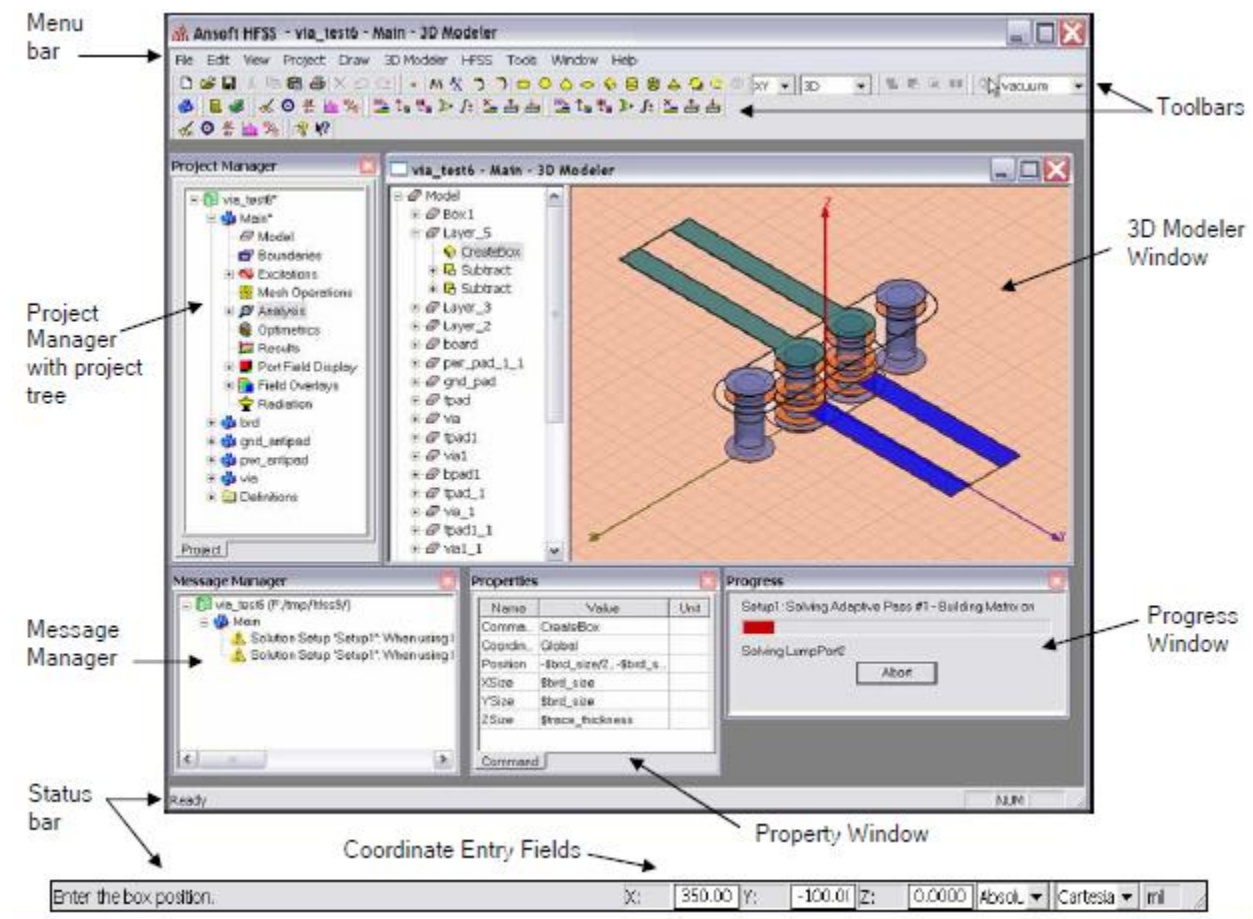


Figure (3.2): shows workspace of HFSS simulator

### 3.3.3 Slotted Rectangular Patch Antenna

The slotted rectangular patch antenna is designed by using trial and error method and the seven different shapes of theslotted antenna are designed to get high gain and suitable return loss &VSWR .each shape of slotted rectangular antenna has slots with specified dimensions the design of each shape is achieved by using HFSS simulator. The results of seven trials explained in chapter 4.

### 3.4 Link Budget Calculations of CubeSat Satellite (ISRA SAT1)

A link budget is an accounting of gains and losses throughout a system that is used as a design tool to provide sufficient power (or gain) to allow a satellite connection to be established.

### 3.4.1 Specifications of Design

In our CubeSat(ISRA SATE 1) the MHX920 transmitter is used that has specifications as shown in the table(3.1)

Table (3.1): shows specifications of MHX920 transmitter

| Frequency operation | 900MHz |
|---|---|
| Maximum transmits power | 1W=30dBm |
| Data rate | 230kbps |
| sensitivity | -110Db |
| Maximum distance | 450Km |
| Maximum gain of AH117 Power amplifier | 18.5dB at 900MHz |
| Modulation scheme | FSK |

### 3.4.2 Calculations of Parameters

Quality of link depends on:

- Transmitting power

- Losses

- Antenna gain

General link budget equation:

Received Power dBm = Transmit Power dBm + Antenna Gains dB − Link Losses dB.

$$Pr = Pt + Gt + Gr - Lp - Li \qquad (3.5)$$

Where: $P_r$ is the received power (dBm), $P_t$ is the transmit power (dBm), $G_t$ is the receive antenna gain (dBi), $G_r$ is the receive antenna gain (dBi), $L_p$ is the path loss (dB), $L_i$ is the implementation loss (dB).

### 3.4.2.1 Gain Calculation

- Antenna gain:

It is the ratio of the flux density in a specific direction at a distance d and the flux density from the same transmitter using a hypothetical isotropic antenna.

- Flux density:

An isotropic radio transmitter radiates its power $P_t$ equally in all directions. The transmitted power is distributed equally on the surface of a sphere with a radius d and an area $4\pi d^2$

The Flux density F in W/m2 of an isotropically radiating antenna at a given distance d can be calculated using the following formula:

$$F = \frac{P_t.G_t}{4\pi d^2}(3.6)$$

Where:F is flux density (w/m$^2$), d is the distance between the CubeSat and the ground station (km).

- Effective Isotropic Radiated Power

Effective Isotropic Radiated Power (EIRP) is the signal power level emitted from the transceiver.

The EIRP is the sum of the effect supplied to the antenna and the gain in the antenna.

$$EIRP = Pt.Gt = Pt + Gt \ (db)(3.7)$$

Where:EIRP is the effective isotropic radiated power.

The slotted patch antenna is designed to use in the CubeSat.

## 3.4.2.2 Losses Calculations

It contains all the losses suffered by power signals such as path loss and implementation loss.

## 3.4.2.2.1 Path Loss

It contains two parts

1-Free space loss:

The free space path loss is caused by the reduction of flux density due to the distance. The signal must travel and the receiving antennas ability to absorb the emitted energy .The free space path loss is determined by the maximum distance and the frequency of the radio signal.

It is calculated using below equation:

$$Lfs = 32.44 + 20log\frac{d}{1[km]} + 20log\frac{f}{1[MHz]}(3.8)$$

Where:$L_{fs}$ is the free space loss (dB), D is the distance (km), is the frequency (MHz).

2-Atmospheric loss:

Atmospheric losses are a generic term which includes several phenomena that can cause losses to a radio signal. Among them are polarization mismatch loss, rain attenuation, Gasses, and refraction. Gasses in the lower parts of the atmosphere absorb electromagnetic waves .atmospheric effect is not significant on UHF band [17]. This loss greatly depends on the rain rate, drop size, and frequency. In reality, these losses are about 2 to 3 dB in total, but especially the atmospheric attenuation varies greatly. The following calculations do not include these losses, they are ignored. But they are considered to be part of the link budgets remaining margin.

Path loss = free space loss +atmospheric loss.

## 3.4.2.2.2 Implementation Losses
itcontains two parts

1-Feeder losses :

Depend on the MXH920 transmitter the cable loss at the transmit side is 2dB.At the receive side, the cable loss is about 2 dB.

2-Antenna misalignment:

This loss occurs because the antennas are not aligned perfectly.

Our calculations do not include these losses, it is ignored.

### 3.4.2.3 Noise Calculation

- Noise temperature

It is the one way of expressing the level of available noise power introduced by a component or source.

The contributions of all noise sources can be lumped together and regarded as a level of thermal noise.

In the theory of thermodynamics, noise calculations are related to power considerations.

An ideal ohmic resistor in thermal equilibrium at an absolute temperature T will produce an "available noise power" $p_n$ given by:

$$Pn = KTW = NoW \quad (3.9)$$

Where: $P_n$ is noise power (w), K is Boltzmann's constant $=1.38062.10^{-23}$(J/K), W is the bandwidth of the frequency band containing the signal of interest (Hz), $N_0$ = K T is the noise spectral density (W/Hz).

- Noise Figure (F)

Ratio of the total system noise power to that part of the system output noise power generated by an input source at the reference

$$F = 1 + \frac{Te}{T0} \quad (3.10)$$

Where: $T_e$ is the noise temperature of a source at the input of the system (considered as noise –free)that produces the same contribution to the system output noise as the internal noise of the actual system itself.

$T_0$ is the reference noise temperature .

$$FdB = 10log\left(1 + \frac{Te}{To}\right) \qquad (3.11)$$

The system noise temperature (T) builds up from all contributions of noise:

- noise from anantenna.
- Noise generated as a result of feeder losses.
- Noise generated within the receiver.

These contributions are budgeted at the receiver input

$$Tsys = \frac{TA}{LFRX} + TF \left(1 - \frac{1}{LFRX}\right) + TR (3.12)$$

Where: $T_{sys}$ is the system noise temperature, $T_A$ is the antenna noise temperature, $T_F$ is the feeder noise temperature, $L_{FRX}$ is the power loss of feeder, $T_R$ is the receiver noise temperature [3].

### 3.4.3 Link Performance

The performance of link is evaluated by calculate SNR, C/ $N_0$, $E_b$/$N_0$ ratios and calculate the BER

### 3.4.3.1 Signal to Noise Ratio (SNR)

SNR is the ratio between the power of the information carrying signal and the power of the unwanted noise it uses to evaluate performance of analog and digital communications system [9]

$$SNR = \frac{Ps}{Pn} = Ps - Pn = Pt + Gt + Gr - (Lp + Li) - Pn \ (dB) \ (3.13)$$

Where: $P_s$ is the power signal (dBm), $P_n$ is the power noise (dB).

### 3.4.3.2 Carrier to Noise Power Spectral Density Ratio (C/ N0)

C/No is the ratio of the power level to the noise power spectral density (normalized noise level relative to 1 Hz) in a system.

Similar to C/N but C/No does not factor the actual noise bandwidth in. This simplifies analysis of systems where variation of the (utilized) BW

Where: C  is The carrier power of modulated signal may apply, $N_o$ is the Noise power spectral density (W/Hz).

$N_o = kT$ , where T is the system noise temperature (K).

$C/N_0 = (P_t . G_t)(1/L)(G/T)(1/k)$.

In dB :

$C/N_0 = Pt + Gt + Gr - L - 10logT - 10logK$ (3.14)

### 3.4.3.3 Energy Per Bit to Noise Spectral Density(Eb/N0)

We may now introduce the universal Signal-to-Noise Ratio for digital communication. This ratio uses to evaluate the digital communication system.

$E_b$ is Energy per information bit, Carrier power divided by actual information bits

$E_b = C / R$ , where  C is the carrier power and R is the actual information bit rate.

Using the $E_b$ rather than overall carrier power (C) allows comparing different modulation schemes easily.

$N_0$ is the noise spectral density.

$E_b/N_0$ Allows comparing bit error rate (BER) performance (effectiveness) of different digital modulation schemes. Both factors are normalized, so actual bandwidth is no longer of concern.

Modulation schemes are compared through BER plots against $E_b/N_0$

The modulation schemeis used in our CubeSatis FSK modulation

$$\frac{Eb}{No} = EIRP + \left(\frac{G}{T}\right) + 169.15 - Losses - 10\log(R)(dB)(3.15)$$

Where: R is the data rate of the system, T is ratio between gain at receive side and temperature at the receiver [4]

### 3.4.3.4 BER Estimation

To be able to assess the quality of our radio link relation between Eb/N0 and the error rate of the received the bits must be established the bit error rate must be low but at a reasonable cost only.

- FSK is used because it is simple and Consumes low power

BER of FSK modulation scheme is:

$$BER = 0.5e^{-(Eb/2No)}(3.16)$$

### 3.4.3.5 Link Margin

Link margin is the difference between the minimum received signal level and the actual received power the link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

Link margin = received powersensitivity of receiver

$$Lm = \mathrm{Pr} - S(3.17)$$

Where: $L_m$ is the margin (dB), $P_r$ is the power received (dBm), S is the sensitivity of the receiver (dB).

## 3.4.3.6 Link Feasible Formula

To determine if a link is feasible, compare the calculated receive signal level $(P_r)$ with the sensitivity of receive (S) sensitivity threshold.

The link is theoretically feasible if:

$$Pr \geq S$$

## 3.4.3.7 Fade Margin and Link Availability

Fade margin is difference between receive signal power level and receiver sensitivity threshold each link must have sufficient fade margin to protect against path fading that weakens the radio signals .fade margin is the insurance against unexpected system outages [12]

Fade margin is directly related to link availability, which is the percentage of time that the link is functional .the percentage of time that the link is available increases as the fade margin increases .a link will experience fewer system outages with a greater fade margin, a link with little or no fade margin may experience periodic outages due to path fading phenomena.

Time Availability % = $\{1-2.5abfd^3 \ (10^{-(F/10)}) \ (10^{-6})\}*100$         (3.18)

F is the fade margin in (dB), f is the frequency operation in (GHz),d is the distance between ground station and cube satellite in  mails ,a is the terrain factor = 0.25 for mountains , very rough or very dry terrain ,b is the climatic factor = 0.5 for hot , humid coastal areas.

The MATLAB simulator calculated all losses and gain, noise, power receive depend on link budget equation:

$$Pr = Pt + Gt + Gr - Lp - Li \qquad (1.1)$$

After that the link is evaluated by calculating the $(C/N_0)$ and $(E_b/N_0)$

Time availability % is calculated todepend on availability equation:

Time Availability % = {$1-2.5abfd^3 (10^{-(F/10)}) (10^{-6})$}*100

The fade margin is the variable to draw time availability VS fade margin

Finally, the MATLAB makes sure the link is feasible or not by using the following condition

$P_r \geq$ sensitivity of receiver

If the power receive $\geq$ sensitivity of receiver that means the link is feasible

If the power receive< sensitivity of receiver that means the link is abreakdown.

# Chapter Four

# Results and Discussions

## 4.1 Overview

The slotted microstrip rectangular patch antenna is designed by using trial and error method by using the HFSS simulator to get high gain needs to increase the power receive of the CubeSat to enhance the performance of the link to be more stable.

## 4.2 Antenna Design

The slotted rectangular patch antenna is designed with specifications as shown in The Table (4.1):

Table (4.1): shows specifications of slotted rectangular patch antenna

| Item | Quantity |
|---|---|
| Width of the patch (W) | 130mm |
| Length of the patch (L) | 100mm |
| Feeding of set position($y_o$) | 50mm |
| Height of the substrate (h) | 1mm |
| Length of the ground plane ($L_g$) | 200mm |
| Width of the ground plane($W_g$) | 230mm |
| Dielectric constant ($\varepsilon_r$) | 2.1 |
| Resonant frequency | 900MHz |

The dimensions of patch antenna are obtained from (3.1) and (3.4) equations

For feeding the microstrip patch antenna, transmission line feeding Method is used having offset feeding position as 50mm.The simulation is carried out in HFSS software.

## 4.2.1 HFSS Simulator Results

In the beginning, the rectangular patch antenna is designed by HFSS simulator after that the patch antenna is slotted with different shapes to get high gain.

## 4.2.1.1 Design of Patch Antenna

The size and position of patch antenna are selected as shown in the Table (4.2)

Table (4.2): shows size and position of the rectangular patch antenna

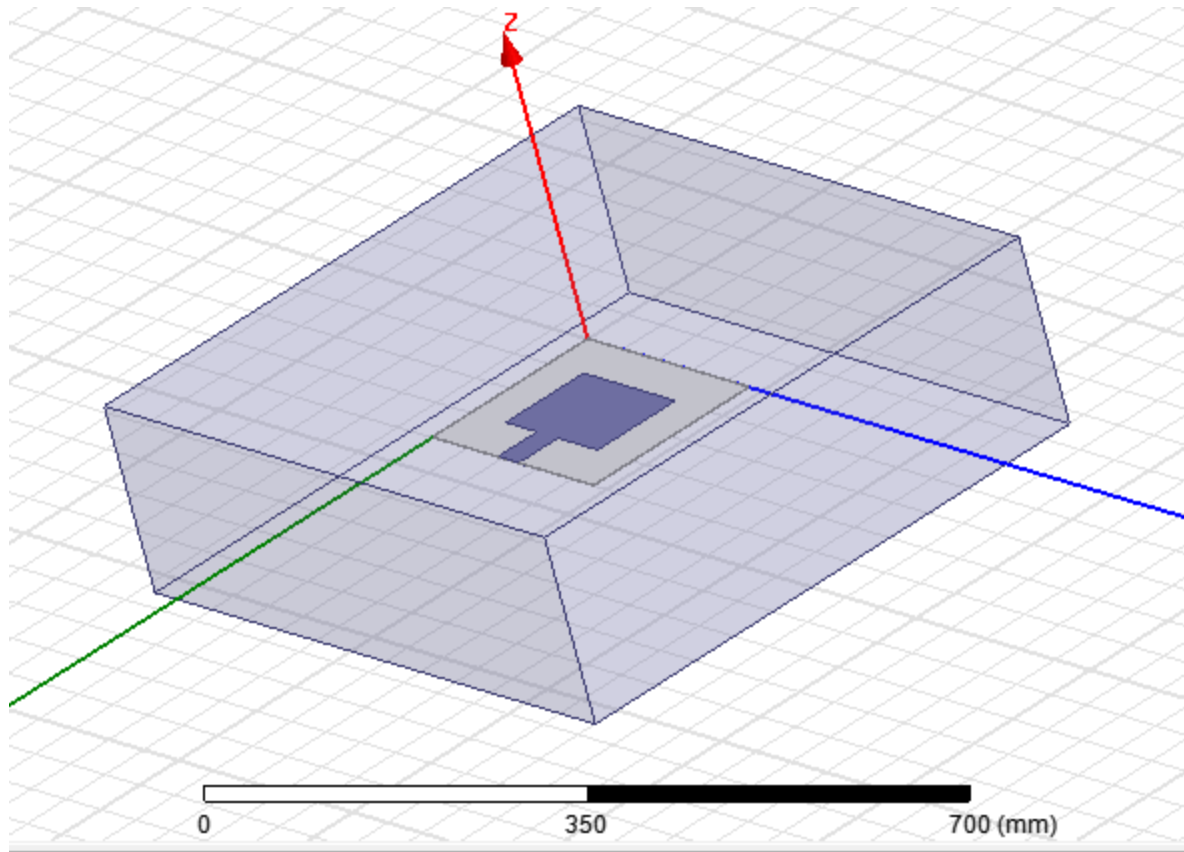| The name of box in HFSS | Size | position |
| --- | --- | --- |
| Patch | X=100mm<br>Y=132mm<br>Z=0.01mm | 50,50,1.02. |
| Substrate | X=200mm<br>Y=232mm<br>Z=1mm | 0, 0, 0.02 |
| Ground plane | X=200mm<br>Y=232mm<br> Z=1mm | 0, 0, 0.02 |
| Feed line | X=50mm<br>Y=30mm<br>Z=0.01mm | 150,95,1.02 |
| Air box | X=610mm<br>Y=632mm<br>Z=200mm | -200,-200,-100 |

Figure (4.1): shows patch antenna design

## 4.2.1.2 Slotted Rectangular Patch Antenna

In this section, the rectangular patch antenna is slotted in the seven scenarios with different shapes by using trial and error method to get high gain and suitable VSWR, return loss.

## 4.2.1.2.1 Scenario 1

5 slots are created in the patch antenna by specified dimensionas shown in the Table (4.3)

Table (4.3): shows dimensions of the shape 1

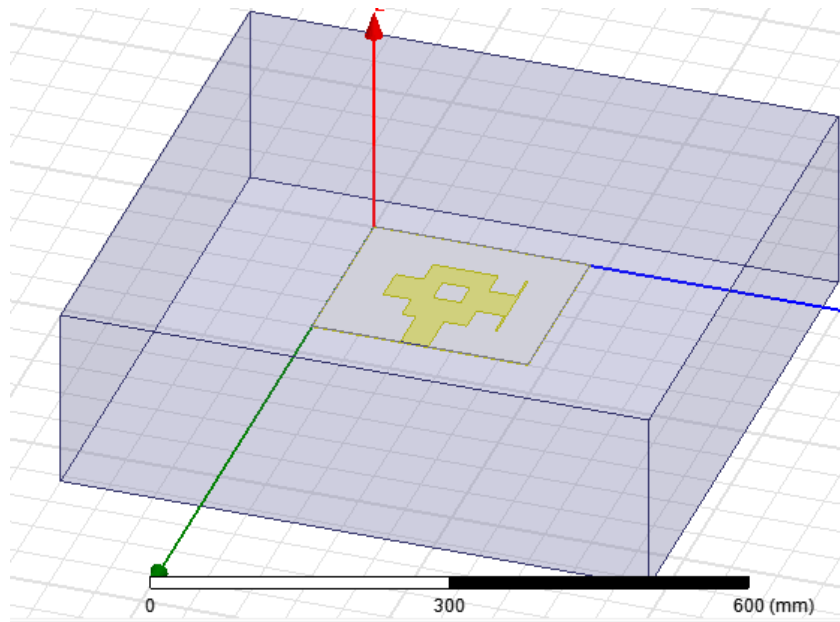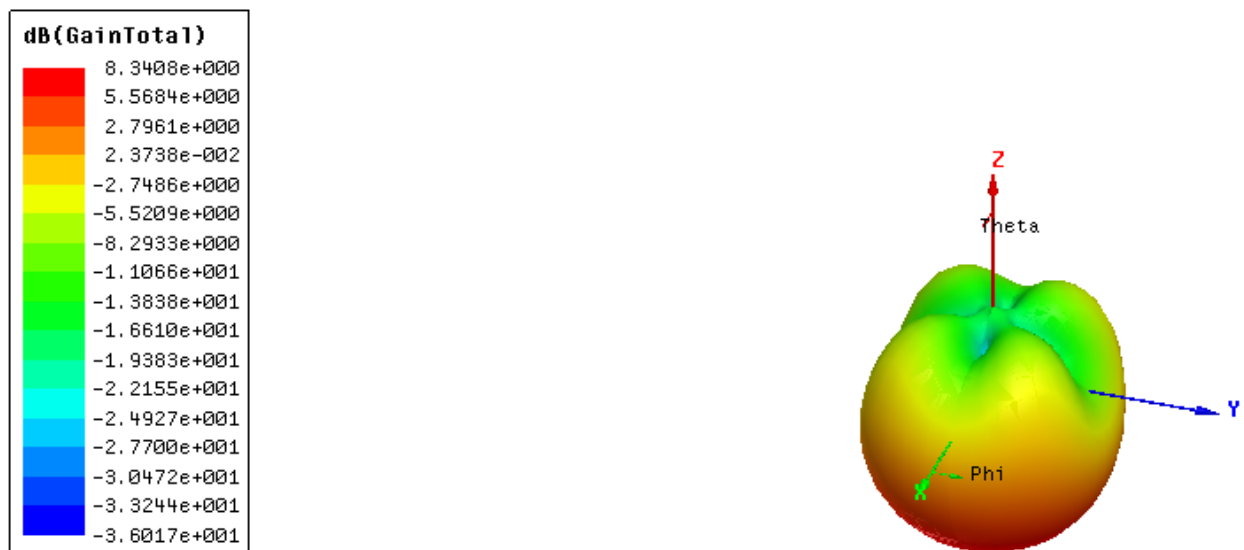| Slot number | size | Position |
| --- | --- | --- |
| Slot 1 | x= 30mm<br><br>y=30mm<br><br>z=0.01mm | 50, 50, 1.02mm |
| Slot 2 | x=30mm<br><br>y=30mm<br><br><br><br>z=0.01mm | 120, 150, 1.02mm |
| Slot 3 | x=30mm<br><br>y=30mm<br><br>z=0.01mm | 50, 150, 1.02mm |
| Slot 4 | x=30mm<br><br>y=30mm<br><br>z=0.01mm | 120, 50, 1.02mm |
| Slot 5 | x=30mm<br><br>y=30mm<br><br>z=0.01mm | 80, 100, 1.02mm |

Figure (4.2): shows shape1



Figure (4.3): shows Gain pattern of the shape 1 in the far field.
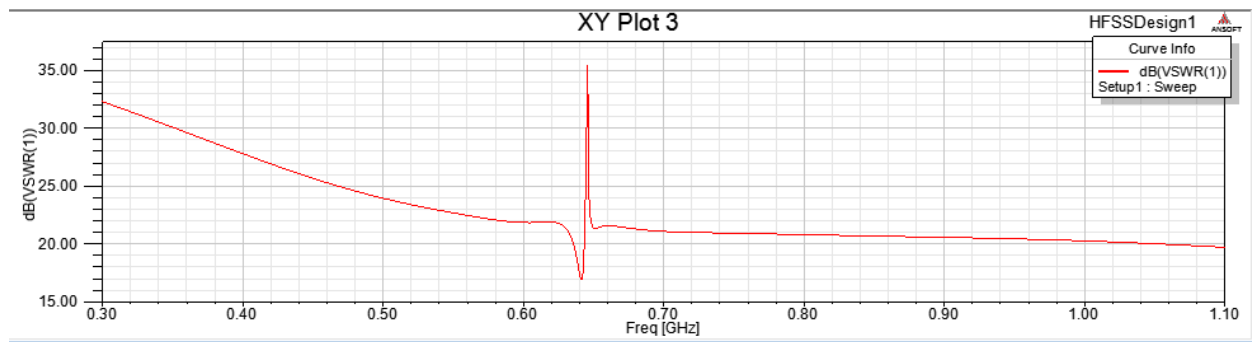
The maximum Gain of antenna is 8.34 dBi

Figure (4.4): shows S-parameter of the shape1

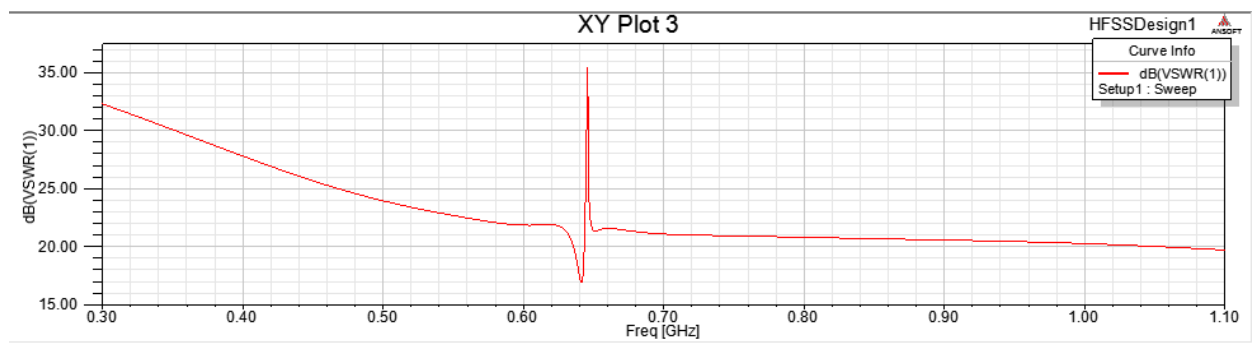The return loss at resonant frequency 0.9GHz is -1.625 dB



Figure (4.5): shows VSWR of the shape1

The VSWR at resonant frequency 0.9GHz is 20.5 dB

## 4.2.1.2.2 Scenario 2

5 slots are created in the patch antenna by specified dimensions as shown in the Table (4.4).

Table (4.4): shows dimensions of the slotted shape 2 antenna

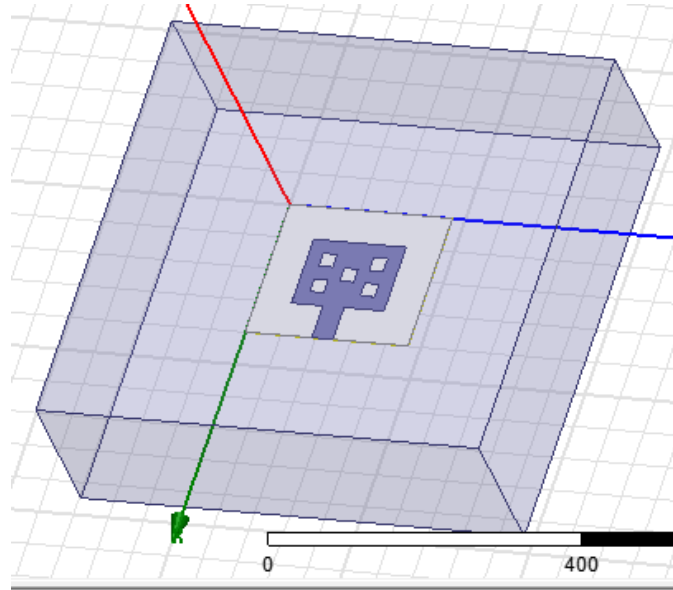| Slot number | size | position |
|---|---|---|
| Slot 1 | x=20mm<br>y=20mm<br>z=0.01mm | 70, 70, 1.02mm |
| Slot 2 | x=20mm<br>y=20mm<br>z=0.01mm | 70, 142, 1.02mm |
| Slot 3 | x=20mm<br>y=20mm<br>z=0.01mm | 110, 70, 0.01mm |
| Slot 4 | x=20mm<br>y=20mm<br>z=0.01mm | 110, 142, 0.01mm |
| Slot 5 | x=20mm<br>y=20mm<br>z=0.01mm | 90,106.1.02mm |

Figure (4.6): showsshape 2



Figure (4.7): shows Gain pattern of the shape 2 in the far field

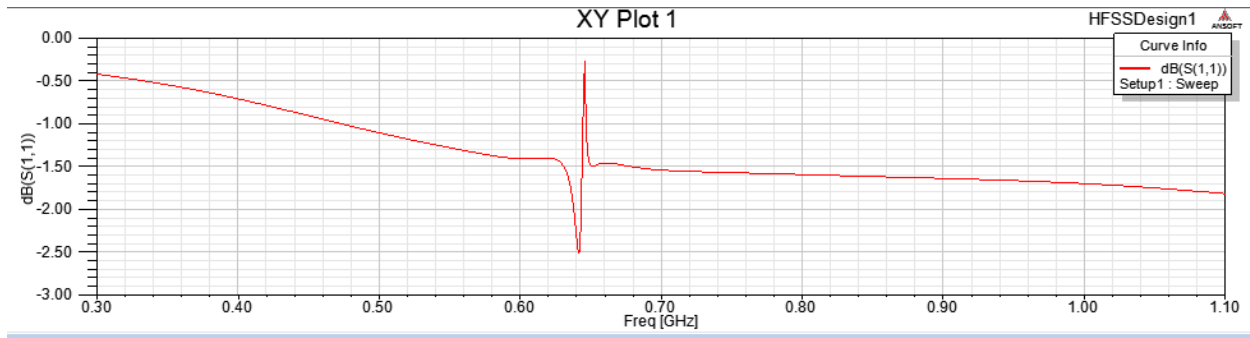The maximum Gain of antenna is 8.3842dBi

Figure (4.8): shows S-parameter of shape 2

The return loss at resonant frequency 0.9GHz is <u>-1.6dB</u>
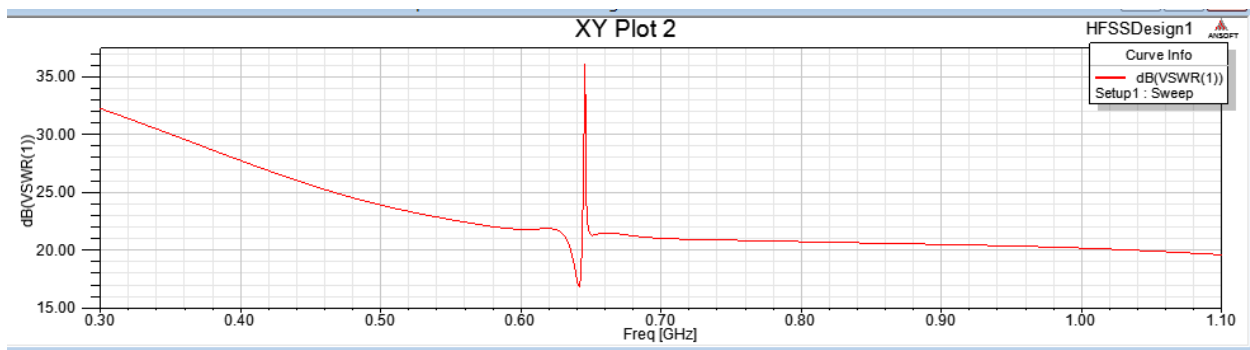


 Figure (4.9): shows VSWR of the shape 2

The VSWR at resonant frequency 0.9GHz is <u>20.5dB</u>

### 4.2.1.2.3 Scenario 3

2 slots are created in the patch antenna by specified dimensions as shown in the Table (4.5).

Table (4.5): shows dimensions of the shape 3

| Slot number | Size | position |
|---|---|---|
| Slot1 | x=10mm<br><br>y=80mm<br><br>z=0.01mm | 70, 76, 1.02mm |
| Slot2 | x=10mm<br><br>y=80mm<br><br>z=0.01mm | 110, 76.1.02mm |
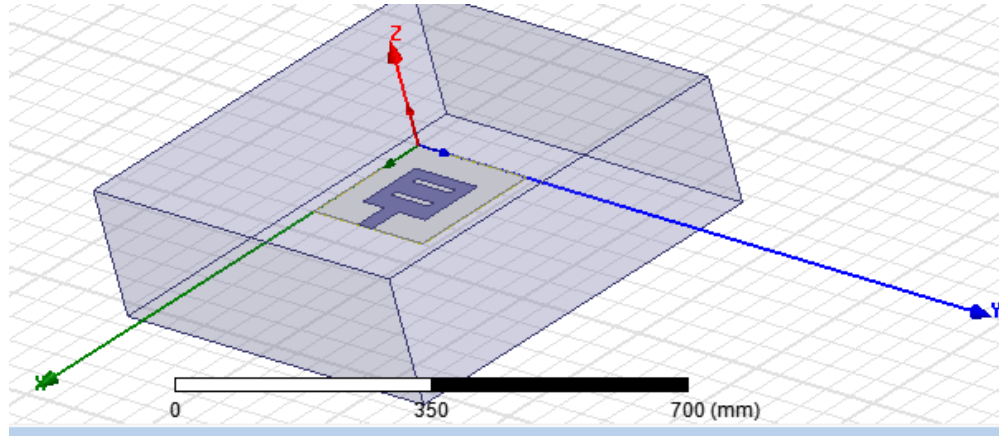
Figure (4.10): shows shape3



Figure (4.11): shows Gain pattern of the shape 3 in far field

The maximum Gain of antenna is <u>8.357 dBi</u>

Figure (4.12): shows S- parameter of the shape 3

The return loss of the antenna at resonant frequency 0.9GHz is -25.5dB



Figure (4.13): shows VSWR of the shape 3

The VSWR of the antenna at resonant frequency is 0.9GHz is 0.8dB =6.3

## 4.2.1.2.4 Scenario 4 (U shape)

U shape is created in the patch antenna by specified dimensions
As shown in the Table (4.6).

Table (4.6): shows dimensions of the shape 4(U shape)

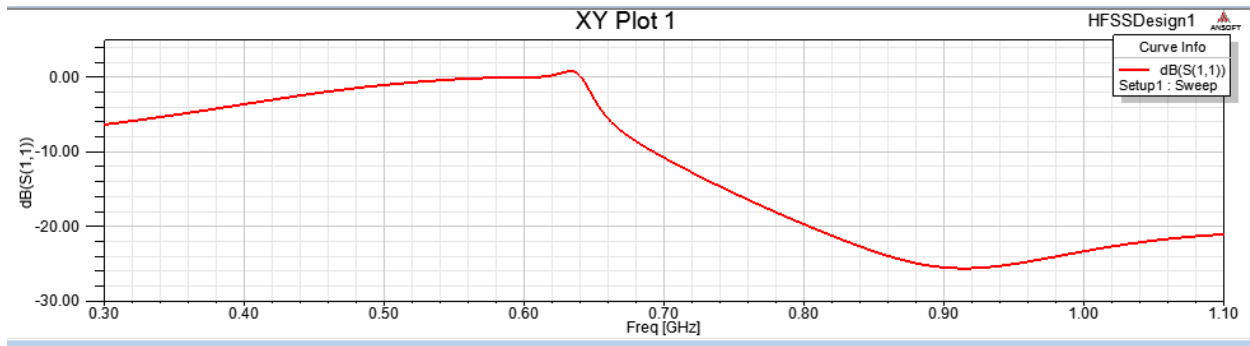| Slot number | Size | Position |
|---|---|---|
| Slot 1 | x=70mm<br><br>y=20mm<br><br>z=0.01mm | 60, 70, 1.02mm |
| Slot2 | x=20mm<br><br>y=20mm<br><br>z=0.01mm | 60,142.1.02mm |
| Slot3 | x=20mm<br><br>y=92mm<br><br>z=0.01mm | 110, 70, 1.02mm |
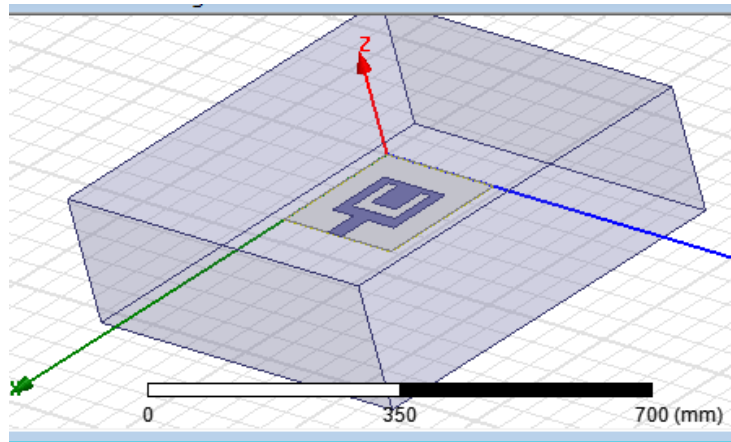
Figure (4.14): shows shape4 (U-shape)



Figure (4.15): shows Gain pattern of the shape 4(U shape) in the far field

The maximum Gain of antenna is 8.395dBi

Figure (4.16): shows S- parameter of the shape 4(U shape)

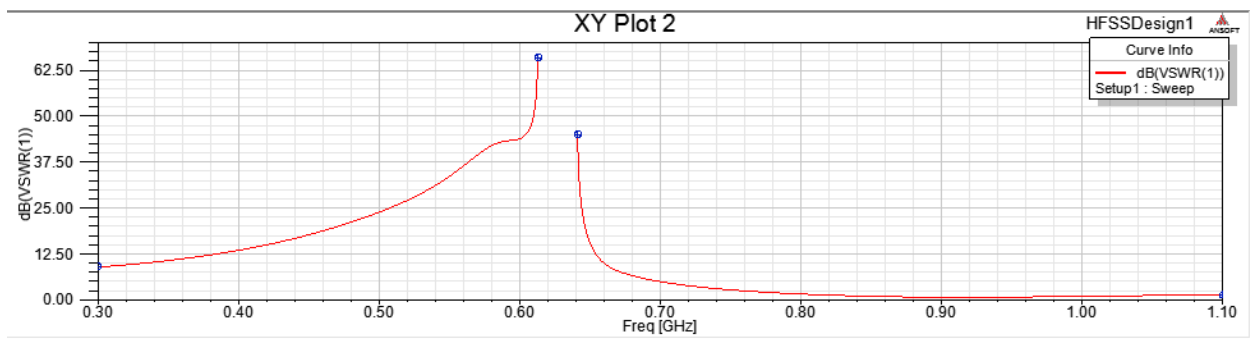The return loss of the antenna at resonant frequency 0.9GHz is -24dB



Figure (4.17): shows VSWR of the shape 4(U shape)

The VSWR of the antenna at resonant frequency is 0.9GHz is 0dB = 1

## 4.2.1.2.5 Scenario 5

4 slots are created in the patch antenna by specified dimensions as shown in the Table (4.7)

Table (4.7): shows dimensions of the shape 5

| Slot number | size | position |
|---|---|---|
| Slot1 | x=20mm<br><br>y=20mm<br><br>z=0.01 | 70, 70, 1.02mm |
| Slot2 | x=20mm<br><br>y=20mm<br><br>z=0.01mm | 70, 142, 1.02mm |
| Slot3 | x=20mm<br><br>y=20<br><br>z=0.01mm | 110, 70, 1.02mm |
| Slot4 | x=20m<br><br>y=20m<br><br>z=0.01mm | 110,142,1.02mm |

Figure (4.18): shows shape5



Figure (4.19): shows Gain pattern of the shape 5 in far field

The maximum Gain of antenna is 8.409dB
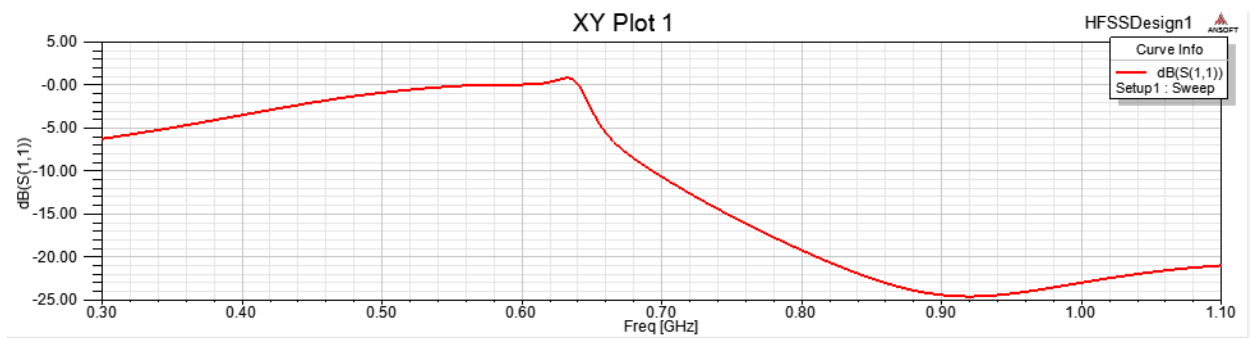
Figure (4.20): shows S- parameter of the shape 5

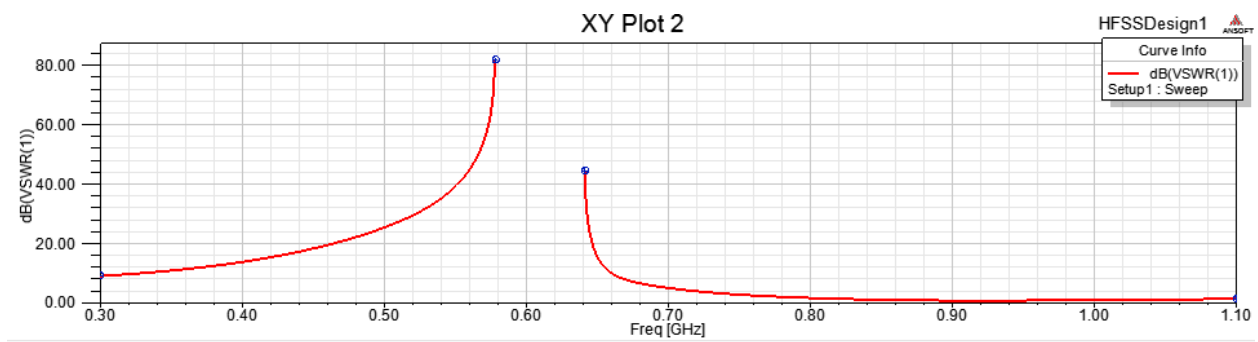The return loss of the antenna at resonant frequency 0.9GHz is -26dB



 Figure (4.21): shows VSWR of the shape 5

The VSWR of the antenna at resonant frequency is 0.9GHz is 0.8dB=6.3

### 4.2.1.2.6 Scenario 6(U shape)
U shape is created with 3slots different dimensions as shown in the Table (4.8) and the inset fed technique is used to match patch antenna with amicrostrip line.

Table (4.8): shows dimensions of the shape 6(U shape)

| Slot number | size | Position |
|---|---|---|
| Slot1 | x=50mm<br>y=10mm<br>z=0.01mm | 90, 60, 1.02mm |
| Slot2 | x=50mm<br>y=10mm,<br>z=0.01mm | 90, 152, 1.02mm |
| Slot3 | x=10mm<br>y=102mm<br>z=0.01mm | 80, 60, 1.02mm |

These slots are united to create U shape, Feed line position Xf=50mmYf=50mm



Figure (4.22): shows shape6

dB(GainTotal)

```
  8.4273e+000
  5.9486e+000
  3.4699e+000
  9.9112e-001
 -1.4876e+000
 -3.9663e+000
 -6.4451e+000
 -8.9238e+000
 -1.1403e+001
 -1.3881e+001
 -1.6360e+001
 -1.8839e+001
 -2.1317e+001
```
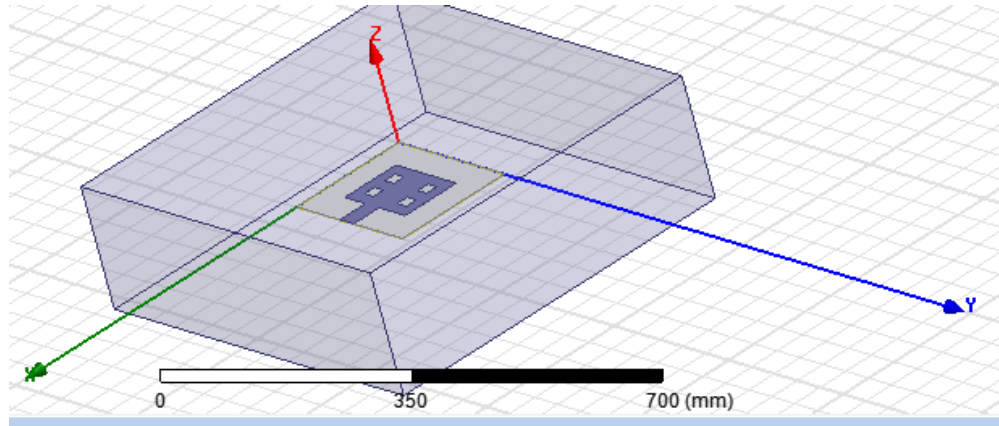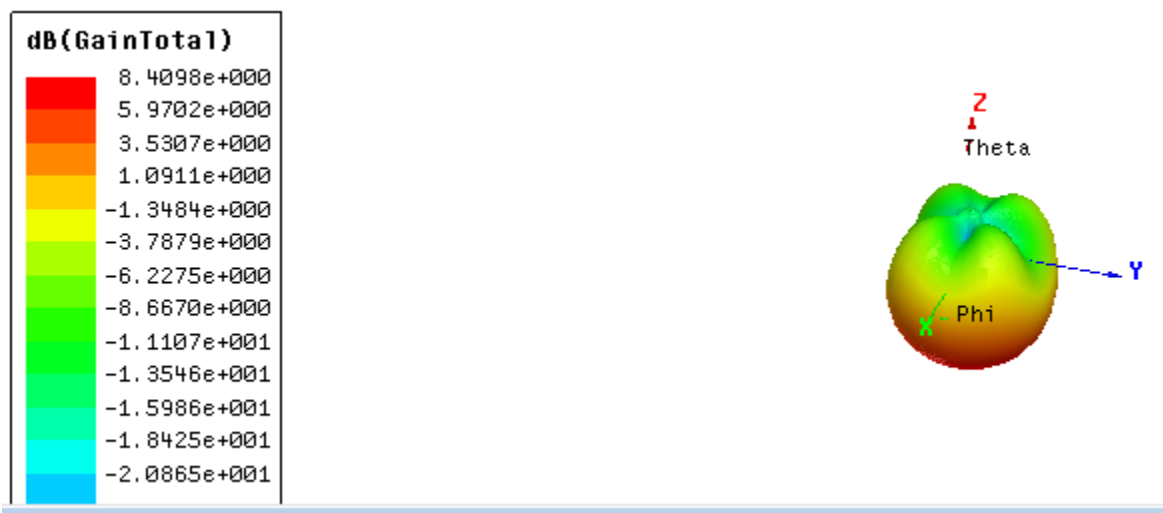
The Figure (4.23): shows Gain pattern of the shape 6 in far field

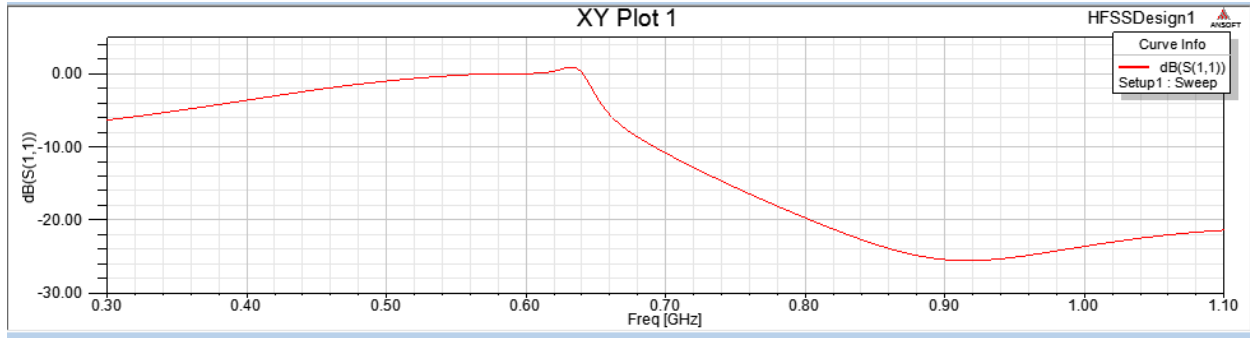The maximum Gain of antenna is 8.273 dBi



 Figure (4.24): shows S- parameter of the shape 6

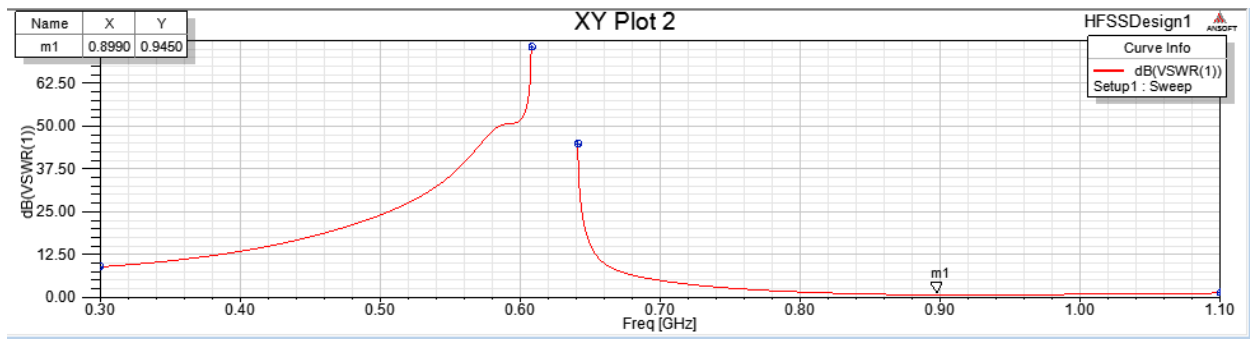The return loss of the antenna at resonant frequency 0.9GHz is -25.3dB



Figure (4.25): shows VSWR of the shape 6

**57**

The VSWR of the antenna at resonant frequency is 0.9GHz is <u>1dB=10</u>

## 4.2.1.2.7 Scenario7 (E shape)

E shape is created with 5slots different dimensions as shown in the Table (4.9)

Table (4.9): shows dimensions of the shape 7 (E shape)

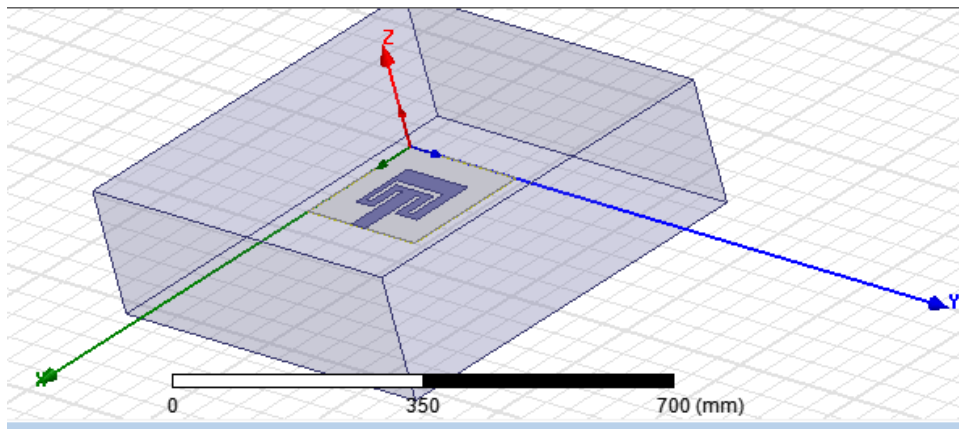| Slot number | size | position |
|---|---|---|
| Slot1 | x=50mm y=10mm z=0.01mm | 90, 60, 1.02mm |
| Slot2 | x=50mm y=10mm z=0.01mm | 90, 152, 1.02mm |
| Slot3 | x=10mm y=102mm z=0.01mm | 80, 60, 1.02mm |
| Slot4 | x=50mm y=10mm z=0.01mm | 100, 85, 1.02mm |
| Slot5 | x=50mm y=10mm z=0.01mm | 100, 125, 1.02mm |
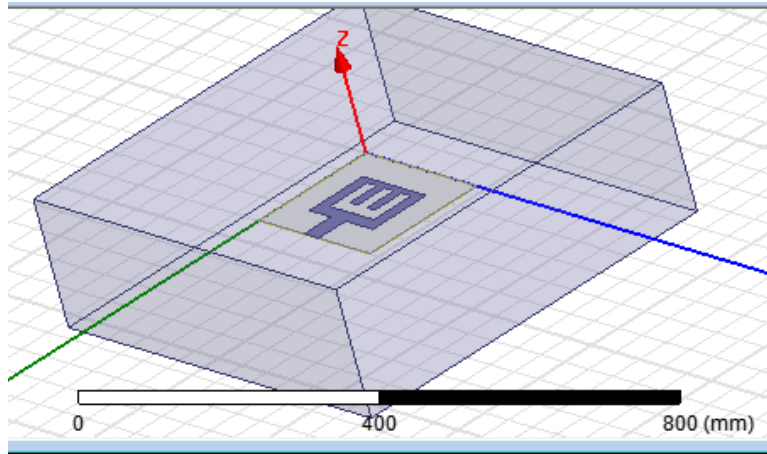
Figure (4.26): shows shape 7 (E shape)



Figure (4.27): shows Gain pattern of the shape 7 (E shape) in far field

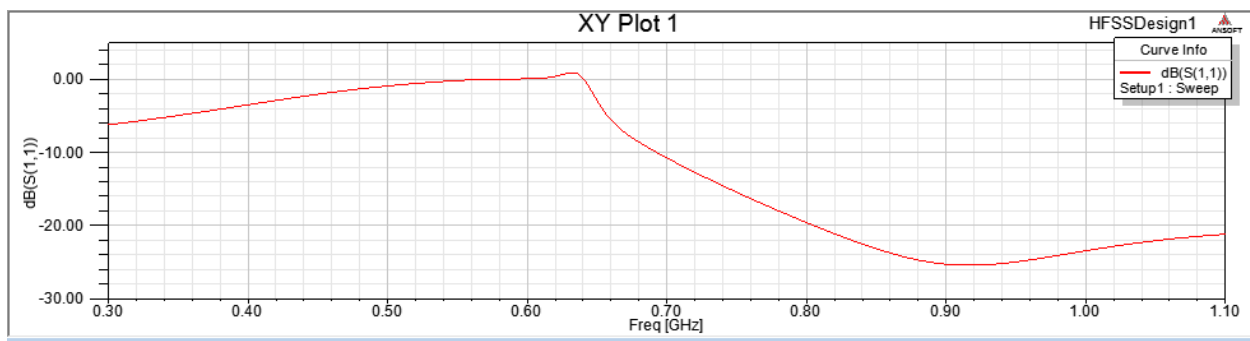The maximum Gain of antenna is 8.427dBi
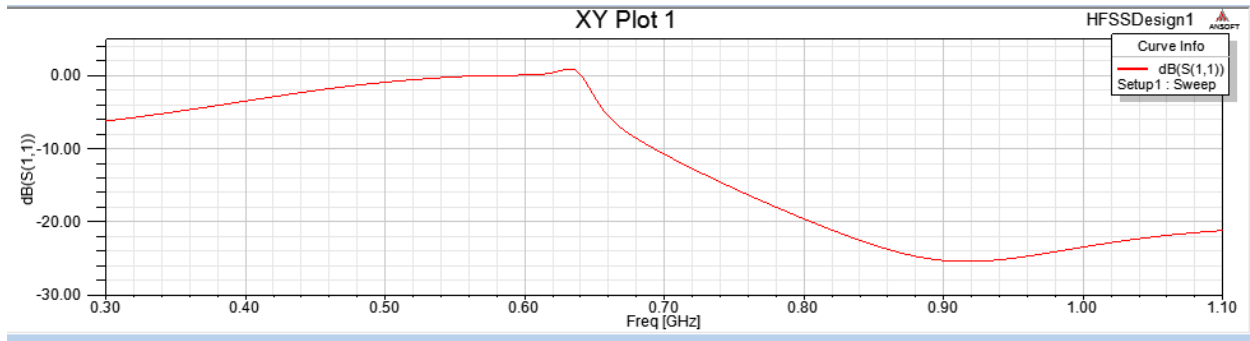
Figure (4.28): shows S- parameter of the shape 7 (E shape)

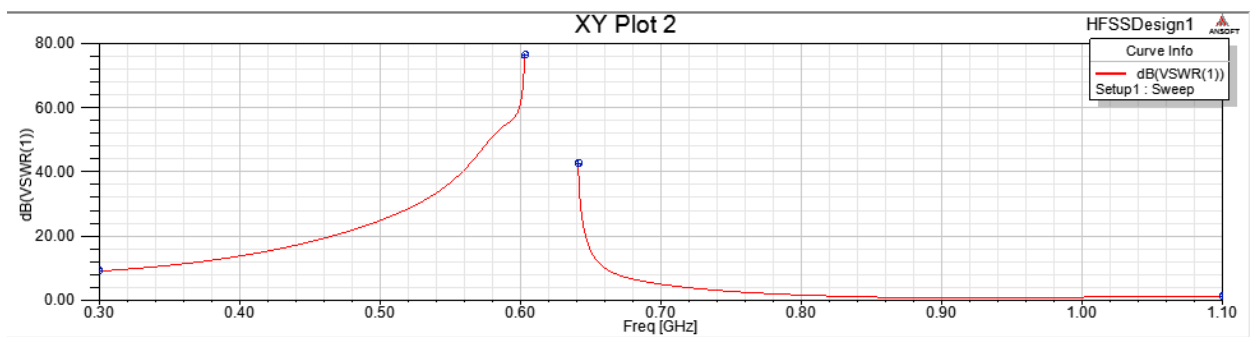The return loss of the antenna at resonant frequency 0.9GHz is -25.2dB
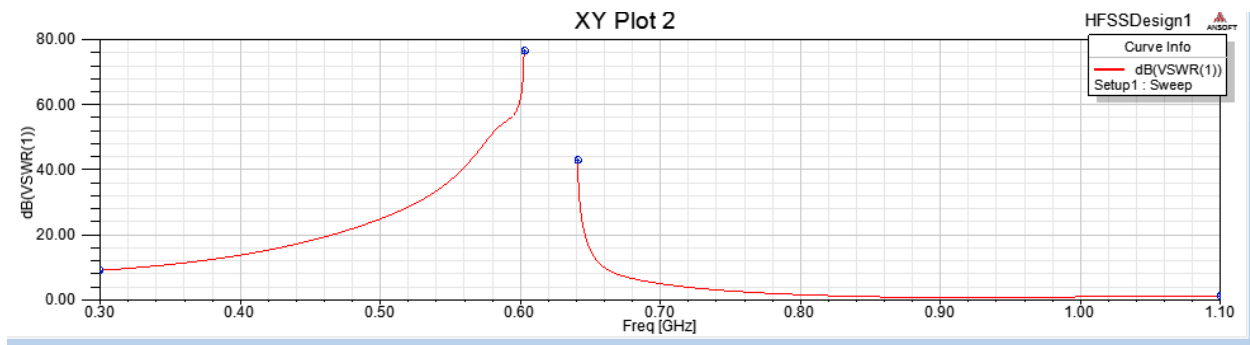


Figure (4.29): shows VSWR of the shape 7 (E shape)

The VSWR of the antenna at resonant frequency is0.9GHz is 0dB= 1

## 4.2.2 Discussions of the Antenna Design Results

Random seven shapes of slotted patch antenna are designed by using HFSS simulator to get high gain with suitable return loss and VSWR. Theslots are taken in specified sizes and position until getting highest gain with suitable return loss and VSWR.

The return loss of antenna must be at least -10dB

Ideally, the VSWR of antenna is from 1 to 2

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The obtained results are compared as shown in the Table (4.10)

Table (4.10): shows obtained results from the 7 shapes of theslotted patch antenna.

| trails | Gain | Return loss | VSWR |
|--------|------|-------------|------|
| Trial 1 | 8.34dBi | -1.625dB | 20.5dB |
| Trial 2 | 8.38dBi | -1.6dB | 20.5dB |
| Trial 3 | 8.35dBi | -25.5dB | 6.3=0.8dB |
| Trial 4 | 8.395dBi | -24dB | 1=0dB |
| Trial 5 | 8.409dBi | -26dB | 6.3 = 0.8dB |
| Trial 6 | 8.273dBi | -25.3dB | 10 = 1dB |
| Trial 7 | 8.427dBi | -25.2dB | 1 = 0 dB |

The highest gain in the table (4-1) is 8.427dBi≈8.5dBi

Return loss = -25.2dB

VSWR = 1= 0dB

This is gain is obtained from rectangular patch antenna slotted in E shape with size and position …… (1)

The matching between patch antenna and transmission line is enhanced by using the inset fed techniquewith specified position and size …..(2)

Our designed antenna satisfied these values, therefore, it suitable with the cube satellite (ISRA SATE 1) instead of dipole antenna that uses in cube satellites the obtained gain is added to power budget to enhance the link performance.

The gain of thedipole antenna is <u>2.5dB</u> this gain is not enough to enhance link performance of the cube satellite because the cube satellite susceptible tonoise and atmospheric losses and othersthat negatively affects the signal.

## 4.3 Calculations of Link Budget Parameters

The slotted rectangular patch antenna is designed to increase the gain to get high level of receive signal strength to enhance the performance of CubeSat link

The gain obtained from the antenna is about 8.5 dBi .this value is added to link budget equation:

$$Pr = Pt + Gt + Gr - Lp - Li \tag{3.5}$$

$G_t = G_r = \underline{8.5 \text{ dBi}}$

## 4.3.1 Losses Calculations

It contains all the losses suffered by power signals such as path loss and implementation loss

## 4.3.1.1Path Loss

Path loss = free space loss + atmospheric loss

$$Lfs = 32.44 + 20log\frac{d}{1[km]} + 20log\frac{f}{1[MHz]} \tag{3.8}$$

Free space loss = <u>144.58dB</u>.

Atmospheric loss = <u>0.5dB.</u>

Path loss =144.5 +0.5=<u>145.08dB.</u>

## 4.3.1.2 Implementation Losses

it contains feeder loss and antenna misalignment loss

- feeder loss:

    Depend on the MXH920 transmitter the cable loss at the transmit side is 2(dB).At the receive side, the cable loss is about 2 dB.

    Therefore the total cabe losses = feeder loss = 4dB.

- antenna misalignment loss:

    This loss occurs because the antennas are not aligned perfectly.

    Our calculations do not include these losses, it is ignored.

    Therefore the Pointing loss = 0dB.

    Overall losses $=Lp + Li$ =144.58+0.5+4+0 = 149.08dB.

    By substituted overall losses and antenna gain in (3.5) equation to obtain received power:

    $P_r$=30+8.5+8.5-149.08= -102.08dBm

    By adding the gain of power amplifier the result is:

    $P_r$ = -102.08+18.5= -83.58dBm

## 4.3.2 Noise Calculation

$$Pn = KTW = NoW (3.9)$$

$$Tsys = \frac{TA}{LFRX} + TF \left(1 - \frac{1}{LFRX}\right) + TR (3.12)$$

$T_A$ = 290 K  reference temperature

$T_F$ =290K reference temperature.

$L_{FRX}$ =2dB

$T_R$ =233.15 K.

Substituting in  (3.12) to obtain the system noise temperature

$T_{sys}$ = <u>523.15 K.</u>

The system noise temperature is substituted in (3.9) to obtain the noise power

$P_n$ = $T_{sys}$ K W

W is bandwidth of carrier

= 928-902 = <u>26MHz</u>

$T_{sys}$ = <u>523.15 K.</u>

K = <u>$1.38062.10^{-23}$(J/K).</u>

$P_n$ = $1.878*(10^{-13})$ W = <u>-127.26dB</u>

## 4.3.3 Signal to Noise Ratio (SNR) Calculation

$$SNR = \frac{Ps}{Pn} = Ps - Pn = Pt + Gt + Gr - (Lp + Li) - Pn \ (dB) \ (3.13)$$

SNR = -102.08-(-127.26) = -83.58+127.26= <u>25.18dB</u>

## 4.3.4 Carrier to Noise Power Spectral Density Ratio Calculation(C/N0)

$$C/N_0 = Pt + Gt + Gr - L - 10logT - 10logK \qquad (3.14)$$

$C/N_0$ = -102.08 –(27.18) –(-228.6) = <u>99.34dB</u>

## 4.3.5 Energy Per Bit To Noise Spectral Density Calculation(Eb/N0)

$$\frac{Eb}{No} = EIRP + \left(\frac{G}{T}\right) + 169.15 - Losses - 10log(R)(dB) \qquad (3.15)$$

(G/T) = $G_r$ - 10LOG (T) = 8.5-10LOG (523.15) = <u>-18.68dB.</u>

10log (R) =10log (230Kbps) =10log ($230*10^3$) = <u>53.6 dB.</u>

$E_b/N_0 =$ <u>13.29 dB</u>

## 4.3.6 BER Estimation

BER $=0.5\ e^{-(Eb/2No\ )}$(3.16)

BER = <u>0.26*(10$^{-2}$).</u>

## 4.3.7 Link Margin Calculation

Link margin = received powersensitivity of receiver

$$Lm = \text{Pr} - S \qquad (3.17)$$

Link margin = -102.08-(-110) = -102.08+110 = <u>7.92dB.</u>

Link margin after adding gain of amplifier =-83.58-(-110) = <u>26.42dB</u>

## 4.3.8 Link Feasible Formula

The link is theoretically feasible if:

**P$_r$> = S,** -102.08> -110.

Therefore the link of CubeSat is a feasible.

## 4.3.9 Fade Margin and Link Availability

Time Availability % = {1-2.5abfd$^3$ (10$^{-(F/10)}$) (10$^{-6}$)}*100 (3.18)

F = 26.42dB , f = 0.9 GHz

d = 0.45 mail

a = 0.25 for mountains, very rough or very dry terrain.

b = 0.5 for hot, humid coastal areas.

By substituting in (3.18)

Time Availability % = {1- 2.5*0.5*0.25*0.9*$(10^{-6})$*$(10^{-2.68})$}*100 = 0.99999 *100

= <u>99.999 %</u>

Table (4.11): shows calculations of the CubeSatdownlink budget

| Item | Quantity |
| --- | --- |
| $P_r$ | 30 dB |
| Gain of transmit antenna | 8.5dB |
| Gain of receive antenna | 8.5dB |
| <u>Free space loss</u> | 144.58dB |
| Pointing loss | 0dB |
| Atmospheric loss | 0.5dB |
| Cable loss | 4dB |
| Noise power | -127.26dB |
| $C/N_O$ | 99.34dB |
| $E_b/N_O$ | 13.29dB |
| BER | $0.26*10^{-2}$ |
| Fade margin | 26.42dB |
| Time availability% | 99.999% |

## 4.4 MATLAB Results of Link Budget Calculations

The parameters of thelink budget equation are acalculation by using MATLAB simulator (M-file)Depend on link budget equation. The MATLAB code plot the power receive ($P_r$) VS gain of theantenna set gain as a variable (2.5: 8.5) dBi.
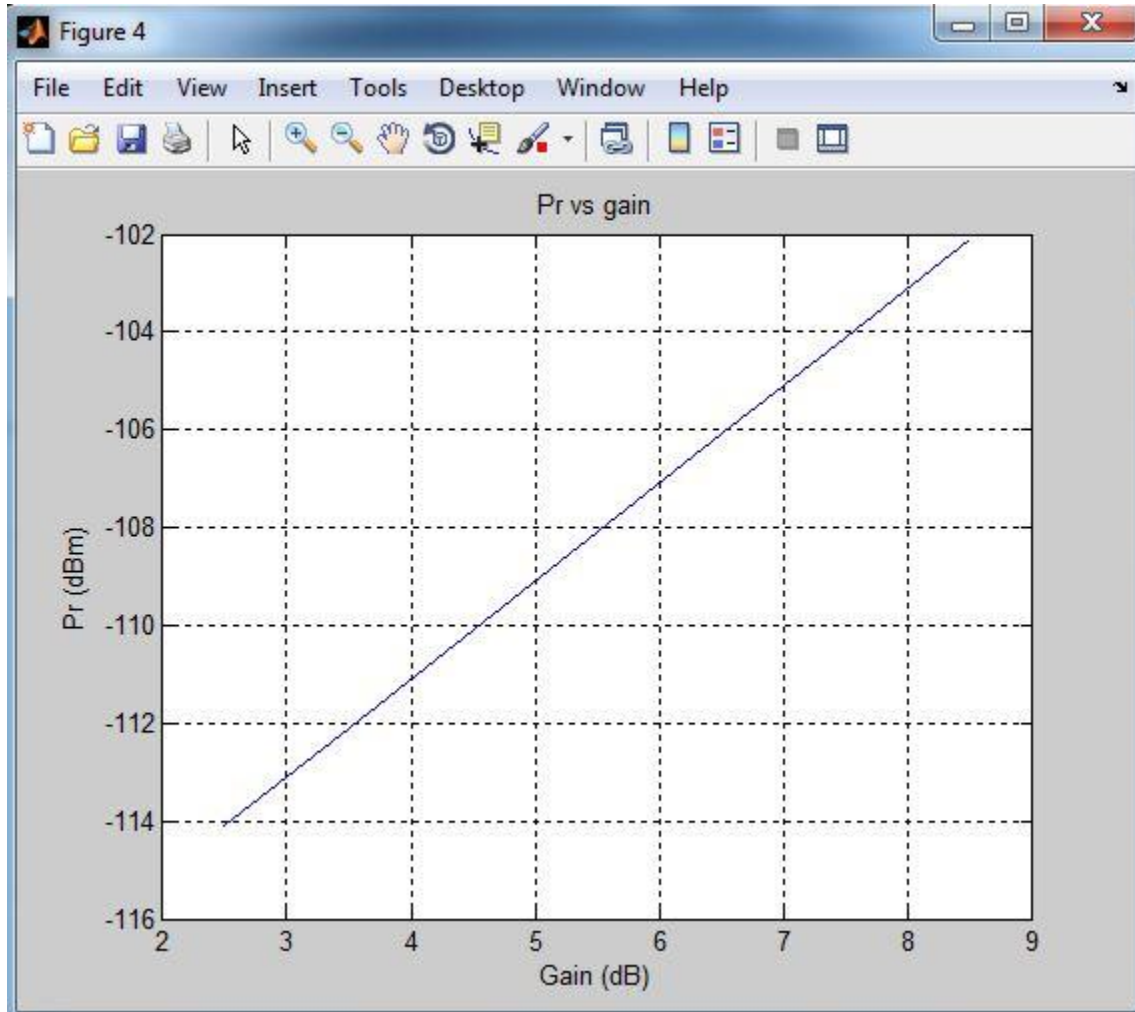


The Figure (4.30): shows power receive ($P_r$) VS .Gain of antenna

The Figure (4.31) illustratesthe gain (dB) VS carrier to noise spectral

Density($C/N_O$) depend on power received values that change with the gain (dB) variable as shown in the below equation

$C/N_0 = Pr - 10logT - 10logK$
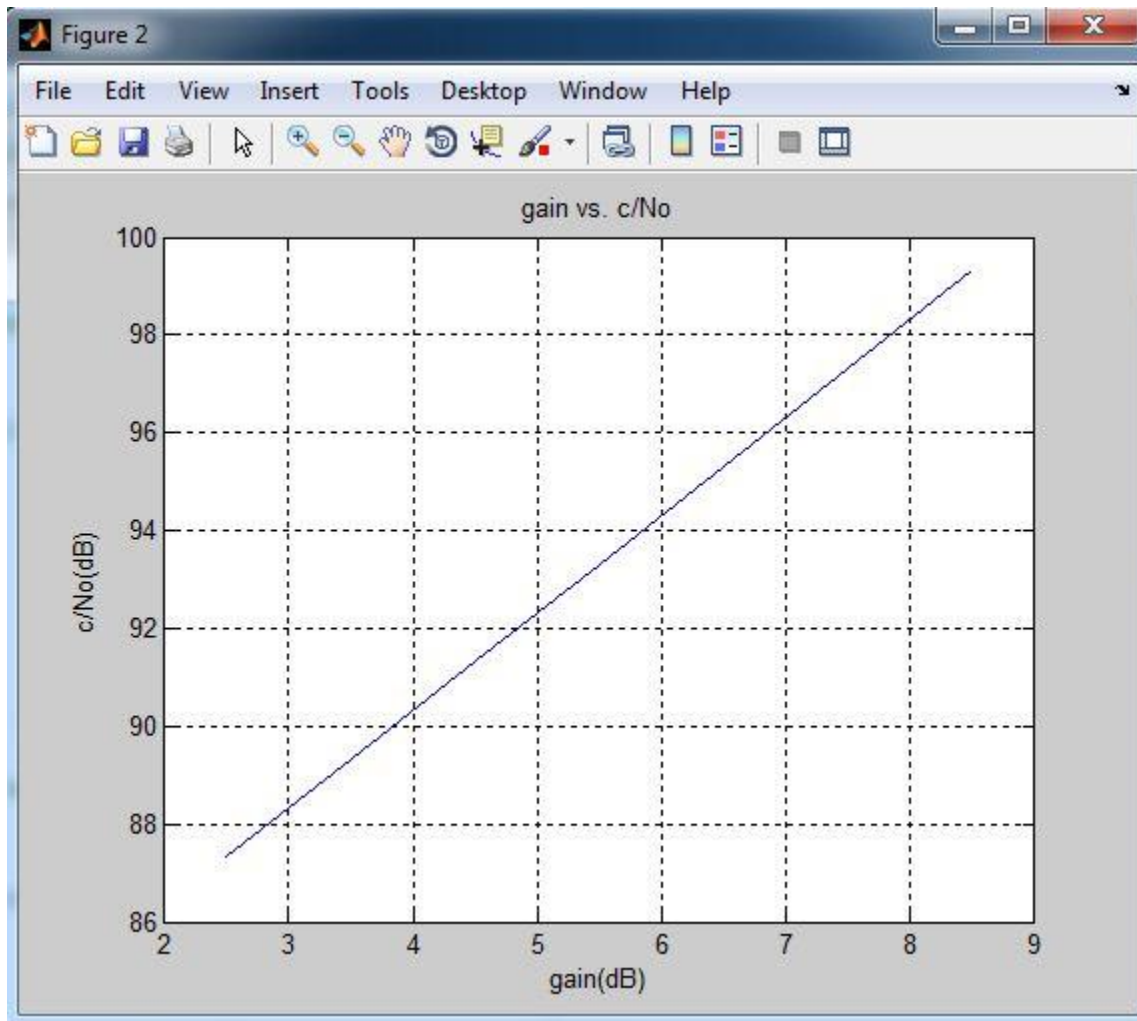


The Figure (4.31): shows Gain (dB) VS. C/N$_O$ (dB)

The Figure (4.32) illustratestheE$_b$/N$_O$ (dB) VS gain (dB) the MATLAB plot this Relationship depends on below equation:

$$\frac{Eb}{No} = EIRP + \left(\frac{G}{T}\right) + 169.15 - Losses - 10\log(R)(dB)$$
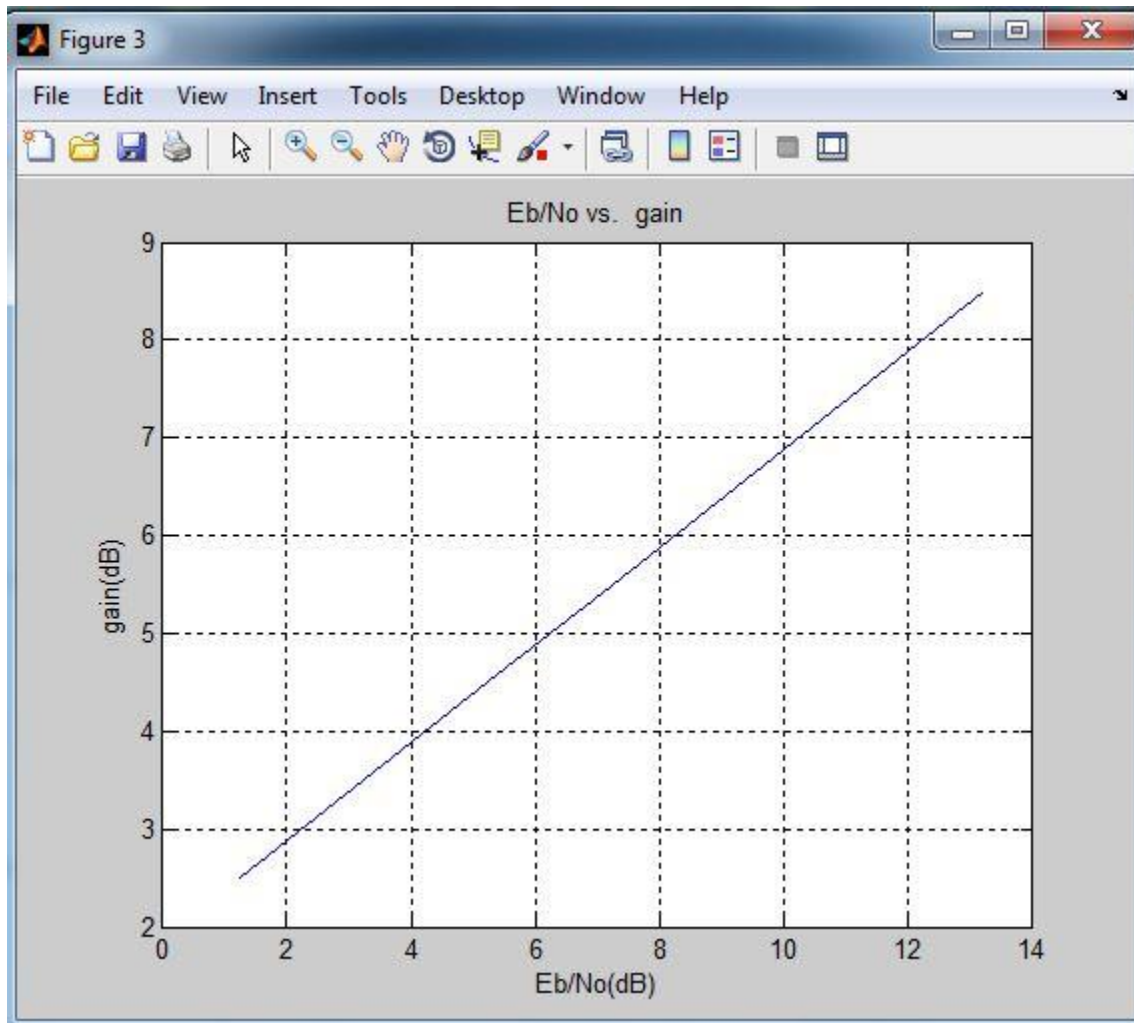


The Figure (4.32): shows E$_b$/N$_O$ (dB) VS. Gain (dB)

The Figure (4.33) illustrates $E_b/N_O$ (dB) VS BER. The MATLAB plot this relationship depends on FSK modulation BER equation

BER $=0.5\, e^{-(Eb/2No)}$
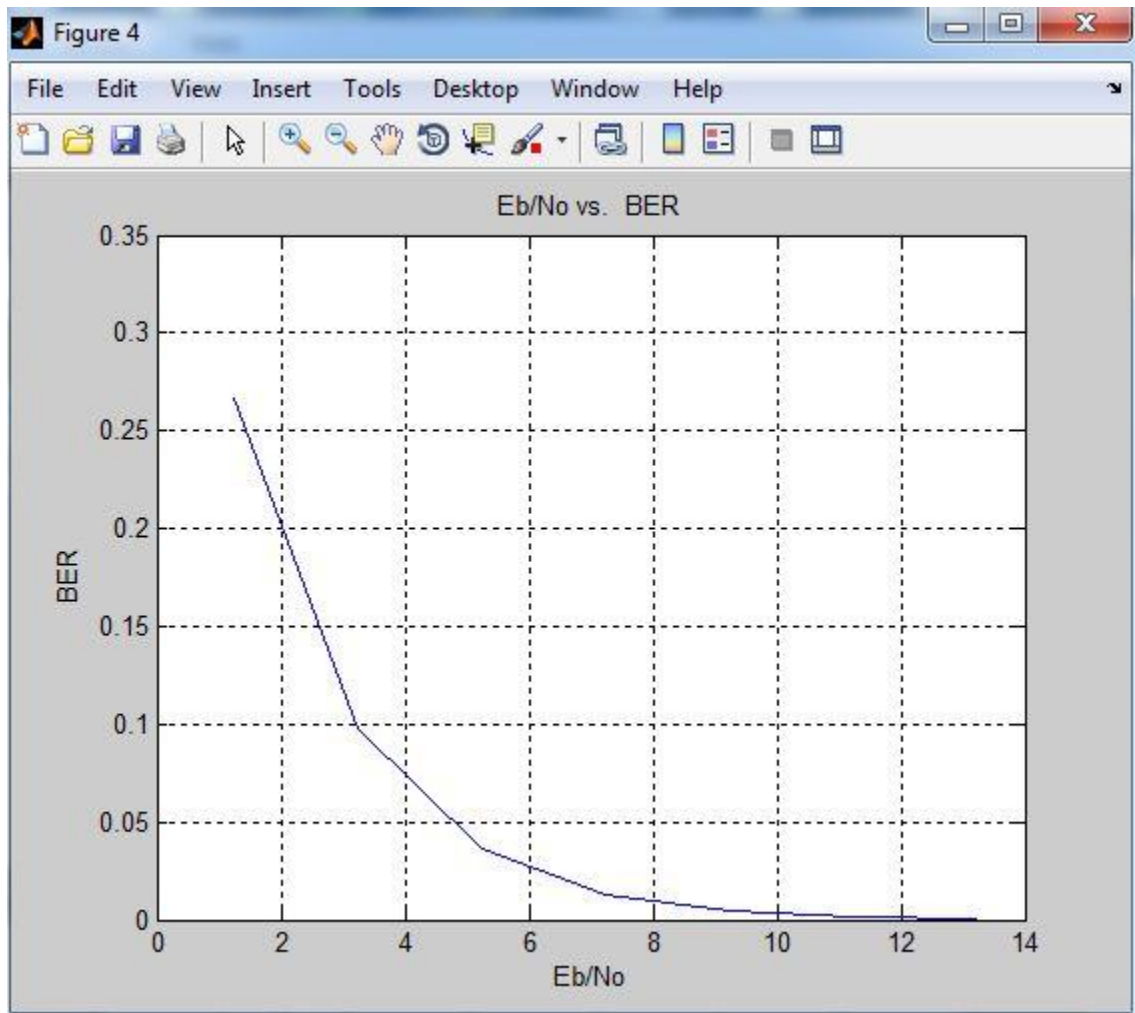


Figure (4.33): shows $E_b/N_O$ (dB) VS. BER

## 4.5 Discussion of Link Budget Calculations

- From Figure (4.30):

When the slotted rectangular patch antenna is used the CubeSat power receive is about -102.08dBm.

When the dipole antenna is used the CubeSat power receive is about

-115dBm.

The power receives value low when to use the dipole antenna to overcome the noise and interference.

Therefore, the slotted rectangular patch antenna is used because it gives us higher gain and therefore the power receive of the CubeSat is higher it is suitable to enhance theperformance of the CubeSat link.

- From Figure (4.31):

Whenthe slotted rectangular patch antenna is used the gain is 8.5 dB) therefore The $C/N_o$ is about 99.3(dB.

Whenthe dipole antenna is used the gain is 2.5dBtherefore The $C/N_o$ ratio is about 87 dB.

Therefore, the use of the slotted rectangular patches antenna gives us enhanced $C/N_o$ ratio for link stability.

- From Figure (4.32):

When the slotted rectangular patch antenna is used the gain is 8.5 dB, therefore, The $E_b/N_O$ is about <u>13.29dB.</u>

When the dipole antenna is used the gain is 2.5 dB, therefore The $E_b/N_O$ ratio is about <u>2.5dB.</u>

- From Figure (4.33):

When the $E_b/N_O$ ratio is <u>13.29dB</u> .depend on the BER of FSK equation the BER is <u>$0.26*(10)^{-2}$</u>

Depend on slotted rectangular patch antenna gain the link margin of CubeSat satisfied the feasible condition

Link margin $\geq$ sensitivity of the receiver

Link margin = power received–sensitivity of receiver

Link margin = -102.08 – (-110) = <u>7.92dB</u>

So the link of CubeSat satisfied the feasible condition because the value of link margin $\geq$ sensitivity of receiver

<u>7.92 dB)>-110dB</u>

When the gain of power amplifier is added to power signal of CubeSat

The power received will be:

-102.08 + 18.5 = <u>-83.58dB</u>

Therefore, the link margin will be:

-83.58 – (-110) = <u>26.41 dB</u>

The margin ≥ 10dB

Therefore, the link is good not break down.

- Availability of link:

The MATLAB code calculated the time availability of depending on the time availability equation:

Time Availability % = $\{1-2.5abfd^3 (10^{-(F/10)}) (10^{-6})\}*100$

The time availability % is calculated to depend onachange of link margin values.

When the slotted rectangular patch antenna is used the link margin is about 26.41(dB) at this value the time availability is about:

<u>99.999%.</u>

# Chapter Five

# Conclusion and Recommendations

## 5.1 Conclusion

The CubeSats suffer from some problems such as poorly received power this matter affects the performance of CubeSat. This problem also makes the CubeSat signal susceptible to noise and interference with other signals. The power signal of CubeSat is increased by enhancing the gain of CubeSat antenna. The dipole antenna used in the CubeSat has a low gain about 2.5 dB but we need to high gain to increase the power signal to enhance the performance of the CubeSat link.

In this research, we used the slotted rectangular patch antenna to increase the antenna gain because the patch antenna is fit with the CubeSat size the patch antenna has some advantages such as high gain compare to adipole antenna, lightweight, low volume, low profile; easy fabrication. To get high gain the try and error method is used.

Seven random shapes are designed by using HFSS. After seven trails we get a high gain about 8.5dB from (E shape design). This value of gain we obtained was suitable to increase the power signal of CubeSat about -102.08 dB this results in animpact on theperformance of the CubeSat link.

The performance of CubeSat link is evaluated by the calculation of some ratios such as ($C/N_O$, $E_b/No$, S/N).These ratios are enhanced by increasing the power signal and also the BER is the decreased about ($0.26*(10^{-2})$).

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Finally: when we use the slotted rectangular patch antenna in the CubeSat satellite. The obtained gain is high compared to dipole antenna the gain results oftheslotted patch antenna is good to enhance the power signal of CubeSat, therefore, enhancing the performance of thelink.

## 5.2 Recommendations

The dimensions (width, length) of rectangular patch antenna related to frequency operation depend on the patch antenna dimensions calculate equations (3.1) & (3.3). When the frequency operation is high the size of thepatch antenna is small but when the frequency operation is low the size of thepatch antenna is large. The use of patch antenna in the CubeSat satellite at low frequencies adversely affects the CubeSat Weightbecause the Weight of CubeSat is very small (10*10*10 cm) compare to large satellite.

In this research, a patch antenna is designed with dimensions 132*100 cm to fit with the CubeSat size at 900MHz .after that it is slotted to E shape slot antenna to get high gain about 8.5 dBi and suitable return loss.

When the slotted patch antenna is mounted on the CubeSat satellite we will expect some problems such as:

1- The size of patch antenna will increase the size of CubeSat, therefore, the cost is increased.
2- The patch antenna interferes with the solar cells which lead to increase the noise that affects the signal strength.
3- The patch antenna consumes high power.

Some of points recommended:

1- The Array rectangular patch antenna has a higher gain than single patch antenna when toget a very high gain from array patch antenna the above problems will be solved.

2- After the antenna designed it is important to find a specified way to put the array patch antenna on the CubeSat satellite so it doesn't cause interference with solar cells, therefore, it reduces the effect of noise on the signal strength.

The array antenna has a very high gain it increases the signal strength that affects the performance of CubeSat link it becomes much better and it reduces the effect of noise and interference and losses.

# References

[1] Traussnig,Wolfgangk" Design of a communication and navigation subsystem for a CubeSatmission"KarlFranzens University of Graz Austria, thesis, 2007.

[2] Kattia Flores Pozo"CubeCat-1: Implementation, testing, and integration of the communication subsystem"California Polytechnic State University, San Luis Obispo, thesis, July 2012.

[3] Carlos Jorge Rodrigues Capela"protocol of communication for VorsatNsatellite" FEUP, thesis, April 2012.

[4] Flemming Hansen "DTU Satellite Systems and Design Course CubeSat Communication" Danish Space Research Institute, August 2001.

[5] Pittsburgh "HFSSv10user guide" Ansoft Corporation, REV1.0, June 2005.

[6] Muhammad AamirAfridi"Microstrip Patch Antenna − Designing at 2.4 GHz Frequency"Biological and Chemical Research,

,March 2015, Volume (2015), pp.128-132.

[7] AnwerSabah"Gain Enhancement of a Microstrip Patch Antenna Using a Reflecting Layer"international journal of antennas and proposed propagation, March 2015, volume 501, p.975263.

[8] Pampa Debnath"Design and Enhancement of Gain & Bandwidth of Rectangular Patch Antenna Using Shifted Semi-Circular Slot Technique" 77International Journal of Advanced Research in Computer and Communication Engineering, April 2014,Volume 3, Issue 4, PP.6196-6199.

[9] Rao, J. Chandrasekhar "Performance Analysis of Double Layer Stacked Patch Antenna with Edge Feed, International Journal of Energy, Information and Communications" May 2013,Volume 4, Issue 5 (2013), pp.15-24.

[10]T. N. Chang "enhance gain and bandwidth of the circularly polarized microstrip patch antenna using gap-gap coupled method" 2009, volume 9, issue 6, pp.127-139.

[11] Ram Singh Kushwaha"a Multi-Slotted Wide Microstrip Patch Antenna for Dual-Frequency" International Journal of Computer Science and Information Technologies, 2012,Volume 3 (2), pp.3523-3525.

[12] Bharat Rochani"A- slotted rectangular microstrip patch antenna"International Journal of Application or Innovation in Engineering & Management (IJAIEM), November 2012,Volume 1, Issue 3,PP.40-43.

[13] Rupesh Lad "design and performance evaluation of two unit yagi –UDA array for UHF satellite Communication"International Journal of Wireless & Mobile Networks (IJWMN), October 2014, volume 6, issue5, pp.145-152.

[14] Paul Muri"Enhancing Small Satellite Communication through Effective Antenna System Design" military communications conference -unclassified program-waveform and signal processing track, October 2010,pp. 347-352.

[15] Jianzhou Li "Circularly Polarized High-Gain Printed Antennas for Small Satellite Applications" Microwave Technology and Computational Electromagnetics, ICMTCE International Conference on IET, 2009, pp. 76-79.

[16] Johan L. Tresvig "Design of a Prototype Communication System for the CubeSTAR Nano-satellite"university OF OSLO

Department of Physics, thesis, July 2010.

[17] Kattia Flores Pozo"Cubesat-1Implementation, testing, and integration of the communication subsystem" UniversitatPolitècnica de Catalunya,thesis, July 2012.

[18] Carlos Jorge Rodrigues Capela"protocol of communication for VorsatNsatellite" FEUP, thesis, April 2012.

[19] H. T. Hui"Design of a Small and Low-Profile 2 x 2 Hemispherical Helical Antenna Array for Mobile Satellite Communications" IEEE TRANSACTIONS

ON ANTENNAS AND PROPAGATION, January 2004, volume 52, issue 1, pp.346-348.

[20] Prof. KiranParmar"Design of Satellite Communications Toolbox for MATLAB®" International Journal of Electronics and Computer Science Engineering, pp. 356-363.

[21] Shin Youngjong"Design of satellite launcher antenna for efficient link budget" Antennas and Propagation Society International Symposium, 2004 IEEE, June 2004, volume 3,pp. 3237-3240.

[22] AlexandruBudianu"Inter-satellite links for CubeSats"Aerospace Conference, 2013 IEEE , march 2013,pp. 1-10.

[23] Ali Telli"Link Analysis for BILSAT-1" Aerospace Conference 2006 IEEE, 2006, pp. 6-pp.

[24]ShkelzenCakaj"Rain Attenuation at Low Earth Orbiting Satellite Ground Station" Multimedia Signal Processing and Communications, 48th International Symposium ELMAR-2006 focused on. IEEE, June 2006, pp. 247-250.

[25] Aderemi A. Atayero"Satellite Link Design" International Journal of Electrical & Computer Sciences IJECS-IJENS, Augustus 2011, Volume1, issue 4, pp.1-6.

[26] J. Costantine"UHF Deployable Antenna Structures for CubeSats"Radio Science Meeting (USNC-URSI NRSM), 2014 United States National Committee of URSI National. IEEE, 2014, pp.1-1.