DESIGN AND IMPLEMENTATION OF VIVALDI ANTENNA

A Dissertation
Submitted in the Partial Fulfillment for the Requirement for the Award of the Degree of

Master of Technology
Microwave and Optical Communication

Submitted by:
SONY
(2K17/MOC/08)

Under the supervision of

Dr. Priyanka Jain
Associate Professor
Department of Electronics and Communication Engineering
Delhi Technological University

Department of Electronics and Communication Engineering

Delhi Technological University

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

June 2020

Department of Electronics and Communication Engineering

Delhi Technological University

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

Candidate's Declaration

I, Sony, 2K17/MOC/08, student of M.Tech (Microwave and Optical Communication Engineering), hereby declare that the project Dissertation entitled "Design and Implementation of Vivaldi Antenna", is submitted by me to the Department of Electronics and Communication Engineering, Delhi Technological University, Delhi in partial fulfillment for the requirement for the award of the degree of Master of Technology in Microwave and Optical Communication Engineering is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition.

Place: New Delhi **Sony**

Date: **(2K17/MOC/08)**

Department of Electronics and Communication Engineering

Delhi Technological University

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

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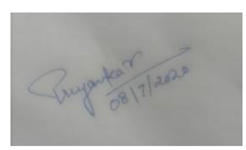
I hereby certify that the Project Dissertation entitled "Design and Implementation of Vivaldi Antenna", is submitted by Sony (2K17/MOC/08), Department of Electronics and Communication Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirements for the award of the degree of Master of Technology (Microwave and Optical Communication Engineering), is a bonafide record of the project work carried out by her under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.



Place: New Delhi

Date:

Dr. Priyanka Jain

SUPERVISOR

Associate Professor

Deptt. Of Electronics & Communication Engineering

Delhi Technological University

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Sony

(2K17/MOC/08)

Abstract

In the recent years the development in communication systems requires the development of low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. This technological trend has focused much effort into the design of a Vivaldi Antenna.

Since the release by the Federal Communications Commission (FCC) of a bandwidth of 7.5 GHz (from 3.1 GHz to 10.6 GHz) for ultra wideband (UWB) wireless communication UWB is rapidly advancing as a high data rate wireless communication technology. The objective of the design is to achieve return loss better than -10 dB over the desired frequency range of WiMAX, with a gain ranging from 4-9 dB. The minimum half power beam width required in both Azimuth and Elevation planes is 50^{o}, so that the designed Vivaldi Antenna element can be used for wide angle scanning. The designed Vivaldi Antenna has been fed by a strip line that helps in efficient coupling of microwave power to slot line. The triplicate structure of Vivaldi Antenna helps in reducing the spurious radiations from strip line feed. All the designs, simulations and analysis have been done in CST Microwave Studio Suite 2018. The Vivaldi Antenna is then fabricated. The simulated and fabricated results are compared. The Research Paper on “Design and Implementation on Vivaldi Antenna for Wi-MAX Applications” has been presented in the e-conference in National Conference on Recent Trends in IOT, Machine Learning, Artificial Intelligence and its Applications (NCRIMA 2020) organized by Department of Electronics and Communication Engineering on 19-20 June, 2020.

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List of Abbreviations

DBS-TV	Direct Broadcast Satellite Television
Wi-MAX	Worldwide Interoperability for Microwave Access
MAN	Metropolitan Access Network
BS	Base Station
WLAN	Wireless Local Area Network
RFID	Radio Frequency Identification
WPAN	Wireless Personal Area Network
SNR	Signal to Noise Ratio
AWGN	Additive White Gaussian Noise
TSA	Tapered Slot Antenna
IEEE	Institute of Electrical and Electronics Engineers
LTSA	Linearly Tapered Slot Antenna
CWSA	Constant Width Slot Antenna
FCC	Federal Communications Commission
VSWR	Voltage Standing Wave Ratio
FRC	Federal Radio Commission
DARS	Digital Audio Radio Service
CD	Compact Disk
RF	Radio Frequency
HF	High Frequency
UHF	Ultra High Frequency
SNIR	Signal to Interference plus Noise Ratio

VHR	Very High Frequency
PIFA	Planar Inverted-F Antenna
EM	Electro Magnetic
RHCP	Right Hand Circularly Polarized
LHCP	Left Hand Circularly Polarized
LP	Linearly Polarized
CP	Circularly Polarized
PLF	Polarization Loss Factor
VLF	Very Low Frequency
PCS	Personal Communications System
GPS	Global Positioning Satellite
GPR	Ground Penetrating Radar
UWB	Ultra Wide Band
OFDM	Orthogonal Frequency Division Multiplexing
CDMA	Code-Division Multiple Access
DSL	Digital Subscriber Line
VoIP	Voice over Internet Protocol
LPD Antenna	Log Periodic Dipole Antenna
HPBW	Half Power Beam Width
ESM	Electronic Support Measures
Fig.	Figure

CHAPTER 1

INTRODUCTION

Today, mobile and satellite communications permeate all aspects of our lives. The number of mobile and cellular phones has skyrocketed in recent years while satellite communication traffics including international telephone calls and DBS-TV (direct broadcast satellite television) has also increased substantially.

Commercial cellular and PCS mobile communications [1] currently occupy the 800 MHz-2 GHz spectral regions. Military and commercial satellite communications [2] including voice, data, and DBS-TV operate at higher frequencies ranging from 4-30 GHz, and are moving up higher to 60 GHz and beyond in order to facilitate higher data rates and a wider range of services. While the initial technological achievements in both mobile and satellite communications were geared to provide reliable service with wide functionality, there is a current focus on lowering the cost of service while maintaining superior quality. One of the main approaches to reducing system and operating costs is the conservation of system power resources and minimization of power wasted as heat. Of the approximately 250W of power produced by the solar-cell arrays on a typical satellite, more than 125W is dissipated as heat due to inefficient operation of the transmitter power amplifiers [2].

Micro strip patch antennas are the most common form of printed antennas. They are popular for their low profile geometry, light weight and low cost. These antennas have many advantages when compared to conventional antennas and hence have been used in a wide variety of applications ranging from mobile communication to satellite, aircraft and other applications [1]. The IEEE 802.16 working group has established a new standard known as WiMAX (Worldwide Interoperability for Microwave Access) which can reach theoretically up to 30 mile radius coverage. Moreover, in the case of WiMAX, the highest theoretically achievable transmission rates are possible at 70 Mbps. As currently defined through IEEE Standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with central radio base stations (BSs). Micro strip antennas are widely used in many applications due to their low profile, low cost and ease of fabrication. In some applications it is desired to have a dual band or multiband characteristics. These characteristics can be obtained by coupling multiple radiating elements. Single handset to access several different services such as voice, data, and video, at the same time in any place [3]-[4]. The objective of the new generations of wireless mobile radio systems is to provide flexible data rates and a wide variety of applications to the mobile users while serving as many users as possible [5]. The main target for today's communication system is to provide high bandwidth. So for that high band width antenna with small size should be required.

Present scenario of wireless communication system required compact and multiple band antenna design. Since many systems are operating at multiple frequency range, requiring dual and triple band antenna for various applications such as WLAN, WiMAX, RFID, satellite communication, etc. Presently, many printed monopole antenna are proposed. Serve for wireless applications to cover the wireless standards for Wireless local area network (WLAN: 2.4 GHz – 2.48 GHz, 5.15 GHz – 5.35 GHz, and 5.75 GHz – 5.825 GHz) and worldwide interoperability for microwave access (WiMAX: 3.4 GHz – 3.69 GHz) are two among the available wireless standards which allow interconnections of devices for communication.

Wireless communication technology has changed our lives during the past two decades. In countless homes and offices, the cordless phones free us from the short leash of handset cords. Cell phones give us even more freedom such that we can communicate with each other at anytime and in any place. Wireless local area network (WLAN) technology provides us access to the internet without suffering from managing yards of unsightly and expensive cables. The technical improvements have also enabled a large number of new services to emerge. The First - generation (1G) mobile communication technology only allowed analogue voice communication while the second-generation (2G) technology realized digital voice communication. Currently, the third-generation (3G) technology can provide video telephony, internet access, video/music download services as well as digital voice services.

In recent years, more interests have been put into wireless personal area network (WPAN) technology worldwide. The future WPAN aims to provide reliable wireless connections between computers, portable devices and consumer electronics within a short range.

Furthermore, fast data storage and exchange between these devices will also be accomplished. This requires a data rate which is much higher than what can be achieved through currently existing wireless technologies.

The maximum achievable data rate or capacity for the ideal band-limited additive white Gaussian noise (AWGN) channel is related to the bandwidth and signal-to-noise ratio (SNR) by Shannon – Nyquist criterion [7, 8], as shown in Equation 1.1.

$$C = B \log2 (1 + SNR) \tag{1.1}$$

Where
C: denotes the maximum transmit data rate,
B: stands for the channel bandwidth.

Equation 1.1 indicates that the transmit data rate can be increased by increasing the bandwidth occupation or transmission power. However, the transmission power cannot be readily increased because many portable devices are battery powered and the potential interference should also be avoided. Thus, a large frequency bandwidth will be the solution to achieve high data rate.

The tapered slot antennas (TSA) offer a wide bandwidth, significant gain and symmetric patterns in both co-polarization and cross-polarization. TSAs are efficient and light weight. In addition, TSAs are appreciably simple in geometry making them more advantageous. The most commonly used class of TSA is Vivaldi antenna. Vivaldi antenna, first introduced by Gibson [9] in 1979, has an exponentially tapered slot line. As a member of the class of TSA, Vivaldi antenna provides broad bandwidth, low cross polarization and directive propagation at microwave frequencies. Vivaldi antennas are low cost, easy to fabricate and fairly insensitive to dimensional tolerances in fabrication process due to printed circuit technology used for the construction of these antennas. Moreover, Vivaldi arrays are small size and low weight enabling compact arrays. It shall be also noted that the beam width and directivity of a Vivaldi antenna might be considerably improved varying the design parameters.

IMPORTANCE

Vivaldi antennas belong to the class of tapered slot antennas (TSA), and have several advantages such as light weight, easy fabrication, high efficiency, wide bandwidth and end fire radiation. This antenna has good performance in the band of 3.4 GHZ to 3.69 GHZ which is assigned to WiMAX wireless communication by IEEE. They are used for many applications such as, broadband internet, multimedia, cellular alternative, etc.

Micro strip antennas have some attractive advantages such as small volume, very low-profile, light weight, easy fabrication, and constant directional radiation patterns, which have been widely used in designing miniaturized antennas. Since the development of tapered slot technology, many traditional antennas could be made into corresponding printed antennas, such as printed Vivaldi antennas [10] and printed log-periodic dipole antennas [11].

BRIEF REVIEW OF PREVIOUS WORK

Lewis et al. [12] introduced tapered slot antenna as a broadband strip line array element capable of multi octave bandwidths in his study in 1974. Following TSA, Vivaldi antenna, an exponentially tapered slot antenna, was originated by Gibson [9] in 1979. Gibson stated that Vivaldi antenna had significant gain and linear polarization in a frequency range from below 2 GHz to above 40 GHz. Gibson's Vivaldi antenna with an asymmetric one sided micro strip to slot line transition was constructed on alumina using microwave photolithographic thin film techniques. It served fairly well as an 8-40 GHz video receiver module.

Yngvesson et al. [13] compared three different TSAs, linearly tapered slot antenna (LTSA), constant width slot antenna (CWSA) and Gibson's exponentially tapered slot antenna, Vivaldi antenna. Yngvesson found that Vivaldi antenna had the smallest side lobe levels followed by CWSA and LTSA whereas it had the widest beam width and CWSA had the narrowest one. He also investigated the effect of dielectric substrate thickness and the length of Vivaldi antenna on the beam width.

E. Gazit [14] proposed two important changes to the traditional Vivaldi design. He used a low dielectric substrate instead of alumina and an antipodal slot line transition. The antipodal slot line transition was constructed by tapering the micro strip line through parallel strip to an asymmetric double sided slot line. This type of transition offered relatively wider bandwidth which was restricted by the micro strip to slot line transition of the traditional design. However, antipodal slot line transition had the problem of high cross polarization.

Langley et al. [15] improved the antipodal transition of E. Gazit with a new and balanced structure in order to improve the cross polarization characteristics. This type of structure, known as balanced antipodal transition, consists of three layers of tapered slots fed directly by a strip line. E-field distribution of the antipodal transition is balanced with the addition of the mentioned layer. The tapered slots on both sides of the antenna serve as ground planes. The balanced antipodal transition offered 18:1 bandwidth with fairly well cross polarization characteristics. Then, Langley et al. [16] also constructed a wide bandwidth phased array using this balanced antipodal Vivaldi antenna. He achieved good cross polarization levels as well as wideband wide angle scanning.

The cross polarization of the antipodal Vivaldi antenna was also improved using different techniques. Kim et al. [17] placed the antipodal antenna and its mirror image alternately in the Cross-polarization. The cancellation of cross polarization fields was aimed in this study and more than 20 dB reduction of cross polarization level at broadside was obtained. Schuppert [18] came up with circular stubs applied to micro strip to slot line transitions in order to offer an easier fabrication whereas Sloan et al. [19] used radial stubs instead of circular ones and improved the bandwidth of these kinds of transitions.

Schaubert [20] used both circular and radial stubs in order to design a strip line - fed, metal fins placed on both sides of the element, Vivaldi antenna. He stated in his study that the bandwidth of the antenna was improved with these non uniform stubs and also noted that radial stub was more advantageous regarding the overlapping between circular strip line and slot line stubs. It was also shown in this study that the strip line feeding increased the antenna bandwidth compared with the micro strip feeding.

OBJECTIVE OF THE PROJECT

- To design an antipodal tapered slot Vivaldi antenna
- Operating frequency range to be 3.2 GHz to 3.8 GHz for Wi-MAX application
- To achieve return loss better than -10 dB over the desired frequency range
- To attain a gain between 4 dB – 9 dB
- The minimum half power beam width required in both Azimuth and Elevation planes is 50°, so that the designed Vivaldi Antenna element can be used for wide angle scanning.
- The simulated results will be taken
- To fabricate the antenna
- Compare the simulated and fabricated results

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

The original problem in telecommunications is transferring the information signals from one place to another place. In other words, to establish communication between various telecommunication units by and through the communication media, so called transmission interface. Generally, several different natural and man-made transmission interfaces exist nowadays, which have the ability of transporting signals; examples are: twisted wires, coaxial cables, waveguides, fibre optics, air interface or vacuum and etc. Each of them has its own properties and different influences over the signals transmitting through them. Hence it follow that we need to build the information carrying signals to be suitable for transmitting in an exact transmission interface considering the characteristics of the media. But, when signals pass from one transmission interface to another transmission interface they become sacrifice from dissimilar transmitting characteristics of the media and they do not feel comfortable without exceptional modification. In most of the cases the communication system uses not only one interface at a time when building a network, which pushes out the need of using the special technique to establish the 'right' communication between different media; i.e. changing signal properties step by step (or interface by interface) properly.

Here comes the term of matching, which carries a 'bridge' function between two different interfaces. To make the concept clear, better to have a simple characterization of the transmitting interface. In electronics point of view it can be thought, that every media have their own characteristic impedance, which describes how resistive it is towards the signal transmission. When signals are passing through the different transmission interfaces with different characteristic impedances the reflections appear at the connection points and some of the power is reflected back to the source interface, which is perceived as a power loss. To avoid power losses during signal transmission the "perfect" matching between different transmission interfaces are required.

Matching networks provide a transformation of impedance so that they maximize the signal transfer and minimize reflections between two communication media. There exists high variety of electrical matching networks used between different communication units to connect them to each other. Here, the focus will be on the communication between wired (coaxial cable) and wireless (free space) interfaces. As long as the wireless communications come into view, the requirement for signal transmission in the air or in a free space interface becomes extremely important. The idea is to leave the cables and closed transmission interfaces and to go out through the space. An electrical communication unit responsible for the matching between wired and wireless media is called an antenna.

Definition

Antenna is an electrical circuit used in microwave/RF networks to match the signal transmission line (coaxial cable, waveguide, etc.) to the signal propagation interface (air, vacuum, etc.). Antenna transforms the signals formed by the electrical currents inside the cable to the electromagnetic waves propagating in a free space. It's an electrical device that sends or receives radio signals. By the *IEEE Standard Definitions of Terms for Antennas* (IEEE Std. 145-1993) an antenna is defined as "a part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves". There are several different sources for the definitions of antennas; all of the definitions come from the functions that antenna carries and from the basic working principles they do. The detailed description of antenna behavior and functionality is discussed in the following part of the report. In general, antenna in both transmitting and receiving modes acts upon the same principles and obeys the same functionality, that's why the following pages does not show separate discussions for transmission and reception modes of antennas.

PROPAGATION PRINCIPLES

To clarify the job antenna we need to go through the theory of electromagnetism, Maxwell's equations and propagation principles. First, describe the signals passing through the cable and signals travelling in free space and then define a theory of signal transformation done by an antenna. Electric and magnetic phenomena at the microscopic level are described by Maxwell's equations, as published by Maxwell in 1873 [28]. In a cable, signals are transmitted by the electric currents moving through it. An electric current presents an electromagnetic field, since the current is the flow of charged particles and any charged particle presents an electromagnetic field itself. Time-varying electromagnetic fields produce electromagnetic waves. Generally, we talk about alternating currents as an information carrying signals and such currents produce time-varying electromagnetic fields. And here we reach the point, that the alternating currents are the source of radiation; so, any current carrying single wire radiates.

In a cable, used for signals transmission, we simply keep the two currents close together, to neglect or reduce radiation, because whenever a current becomes separated in a distance from its return current, it radiates [29]. As surprising it can be seen, the more effort is needed to prevent unnecessary radiations from the currents, since the currents are the radiators themselves.

We can agree that it is a simple task to make a device, which radiates; and we call it an antenna. But, the main task of the antenna device is to control propagating electromagnetic waves (or it can be said: to control currents) so, that we can obtain radiation in a desired frequency range, or in a desired direction in a space, or in a certain power levels, or certain polarization and etc. For that entire purposes antenna designers have created thousands of different types and styles of antennas with different practical solutions, different shapes and dimensions, with different functions and etc. But, still the essential part is to achieve specific current distributions through the antenna shape.

BASIC PARAMETERS OF ANTENNA

Radiation pattern

The radiation pattern of an antenna is a graphical description of the field strength transmitted from or received by the antenna. The patterns are generally represented in polar or rectilinear form with a dB strength scale.

The two types of antenna fields are:

• Reactive field – the portion of the antenna field characterized by standing waves which represent stored energy.

• Radiation field – the portion of the antenna field characterized by radiating waves which represent transmitted energy.

Antenna field regions are of two types:

• Near-Field – it is expressed as R< 2D2 / λ, and D is the maximum antenna dimension. It shows the region between the reactive near field and the far-field where the radiation fields are dominant and the field distribution is dependent on the distance from the antenna.

• Far-Field – it is expressed as R> 2D2 / λ, which shows the region extreme away from the antenna where the field distribution is independent of the distance from the antenna.

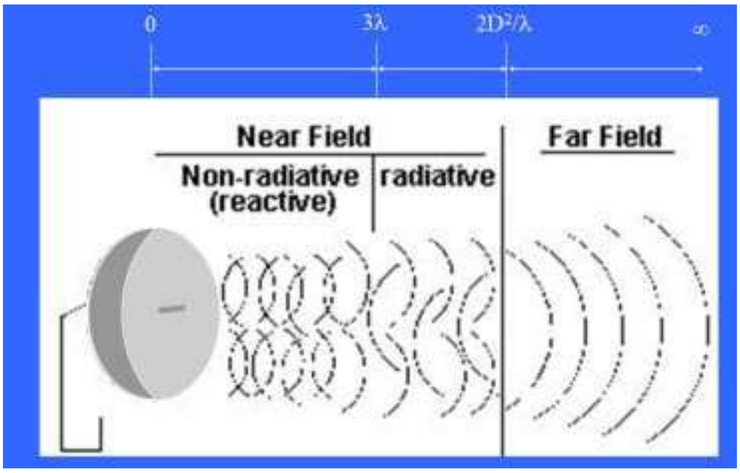


Figure 2.1: Antenna Field Regions

Directivity and Gain

To describe the directional properties of antenna radiation pattern, directivity *D* is introduced and it is defined as the ratio of the radiation intensity *U* in a given direction from the antenna over that of an isotropic source. It's a dimensionless quantity and is usually expressed in dBi. The radiation pattern helps in estimating the directivity of the antenna. The directivity of the antenna with narrow main lobe would be greater than the one which has a broad main lobe.

For an isotropic source, the radiation intensity U_0 is equal to the total radiated power P_{rad} divided by 4π. So the directivity can be calculated by:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{2.1}$$

If not specified, antenna directivity implies its maximum value, i.e. D_0.

$$D_0 = \frac{U|_{max}}{U_0} = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}} \tag{2.2}$$

Antenna gain G is closely related to the directivity, but it takes into account the radiation efficiency e_{rad} of the antenna as well as its directional properties, as given by:

$$G = e_{rad} D \tag{2.3}$$

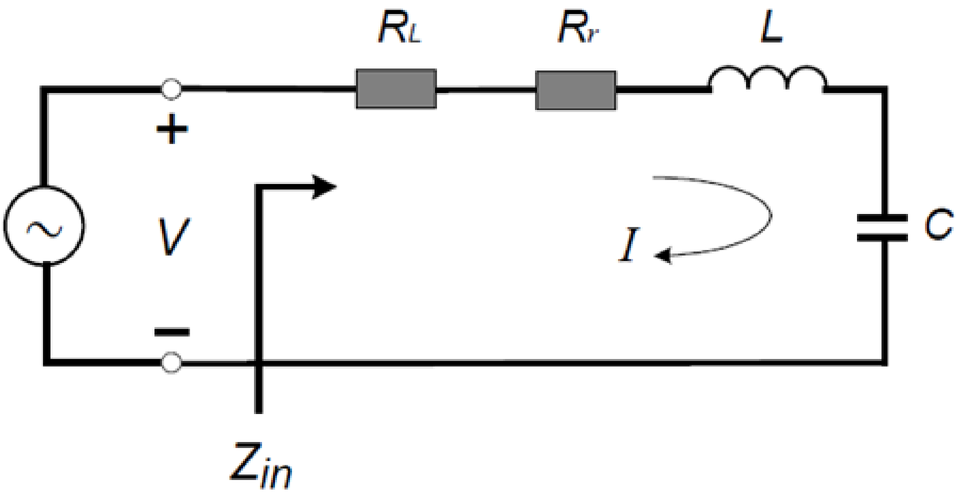


Figure 2.2: Equivalent circuit of Antenna

Figure 2.2 shows the equivalent circuit of the antenna, where R_r, R_L, L and C represent the radiation resistance, loss resistance, inductor and capacitor, respectively.

The radiation efficiency e_{rad} is defined as the ratio of the power delivered to the radiation resistance R_r to the power delivered to R_r and R_L. So the radiation efficiency e_{rad} can be written as:

$$e_{rad} = \frac{\frac{1}{2}|I|^2 R_r}{\frac{1}{2}|I|^2 R_r + \frac{1}{2}|I|^2 R_L} = \frac{R_r}{R_r + R_L} \tag{2.4}$$

An antenna that radiates badly has low "gain". And it emits radiation with about the same power in all directions, whereas a higher-gain antenna will radiate in particular directions. Gain of an antenna is the increase in signal strength as the signal is routed by the antenna for a certain incident angle. It is expressed in dB and it can be negative. It is a passive phenomenon; antenna does not add the power but it redistributes to supply further radiated power in a particular direction than the power transmitted by an isotropic antenna. Thus being dependent on the total power send to the antenna input terminals, antenna gain accounts for the ohmic losses in the antenna while being dependent on the total radiated power, the antenna directivity does not include the effect of Ohmic losses.

Similarly, the maximum gain G_0 is related the maximum directivity D_0 by:

$$G_0 = e_{rad} D_0 \tag{2.5}$$

Antenna efficiency

It is a measure of antennas ability to transmit the input power into radiation. It is basically a ratio of transmitted power to the input power. Different types of efficiencies contribute to the total antenna efficiency. The total efficiency is a multiple of all these efficiencies. Efficiency is affected by the losses within the antenna itself and the reflection due to the mismatch at the antenna terminal. The total power send to the antenna terminals is less than that offered from the generator given the effects of mismatch at the source / transmission line connection, losses in the t-line, and mismatch at the t-line / antenna connection. Radiation in antenna is caused by radiation resistance, which can only be measured as part of total resistance, including loss resistance. Loss resistance results in heat generation rather than radiation and reduces efficiency. Efficiency is mathematically calculated as radiation resistance divided by total resistance.

Bandwidth

The Bandwidth of an antenna is the range of frequencies in which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The Bandwidth of a broadband antenna is the ratio of the upper frequency to the lower frequency of suitable operation. The Bandwidth of a narrowband antenna is the percentage of the difference in frequency over the center frequency.

Return loss

An antenna's Return Loss is a figure that indicates the proportion of radio waves arriving at the antenna input that are rejected as a ratio against those that are accepted. It is specified in decibels (dB) relative to a short circuit (100 percent rejection).

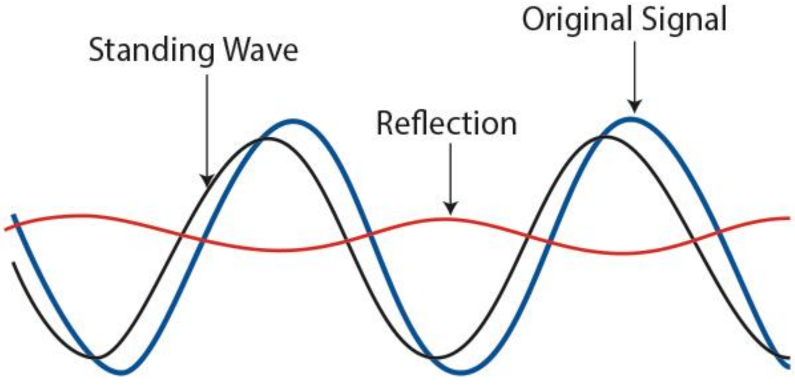


Figure 2.3: Antenna Signal

Consider the antenna being used in transmit mode. The radio waves from the transmitter are routed via a transmission line to the input flanges of the antenna feed. At all waveguide junctions there is a mechanical mismatch, the size of which will determine the size of the consequential electrical mismatch.

Thus, a proportion of the radio waves will be reflected back down the transmission line from the antenna input flange connection. The remainder will continue into the feed system. However any imperfections within the feed system will again cause small amounts of the incident radio waves to be reflected back again towards the input flange.

Finally, the radio waves will emerge from the feed aperture to be radiated onto the parabolic reflector, prior to being directed into the atmosphere towards their intended target. Again, a small percentage of the radio waves will be reflected back from the reflector into the feed system and back towards the input flange.

The sum of all the reflected components at the input flange represents the total reflected signal. Return Loss is significant to radio system designers for a number of different reasons:

- If a large proportion of the incident radio waves are rejected by the antenna, this represents a loss of signal and the antenna efficiency is therefore reduced.

- In a transmitting system where, for example, the antenna is remote from the radio equipment, rejected radio waves returned from the antenna will travel back down the transmission line to the radio. From there, they will be reflected and returned back up the transmission line to the antenna. A percentage of this returned signal will be radiated and, once again, a proportion routed back to the radio. This secondary radiated component will be a delayed version of the primary signal - the delay being set by the time taken for the signal to travel back down the transmission line to the radio equipment and back again.

- Secondary radiation will look like an echo signal on the main signal, and this can cause errors in the detection of the desired information at the remote receiver. If the reflected radio waves back into the transmitter are of sufficient magnitude, the transmitter performance can be severely degraded.

Polarization

Polarization is one of the fundamental characteristics of any antenna. Let us understand the polarization of plane waves first.

Linear Polarization

A plane electromagnetic (EM) wave is characterized by electric and magnetic fields traveling in a single direction (with no field variation in the two orthogonal directions). In this case, the electric field and the magnetic field are perpendicular to each other and to the direction the plane wave is propagating. As an example, consider the single frequency E-field given by equation 2.6, where the field is traveling in the +z-direction, the E-field is oriented in the +x-direction, and the magnetic field is in the +y-direction.

$$E = \cos\left(2\pi f\left(t - \frac{z}{c}\right)\right)\hat{x} \tag{2.6}$$

In equation (2.6), the symbol $\hat{x}$ is a unit vector (a vector with a length of one), which says that the E-field "points" in the x-direction.

A plane wave is illustrated graphically in Figure 2.4.

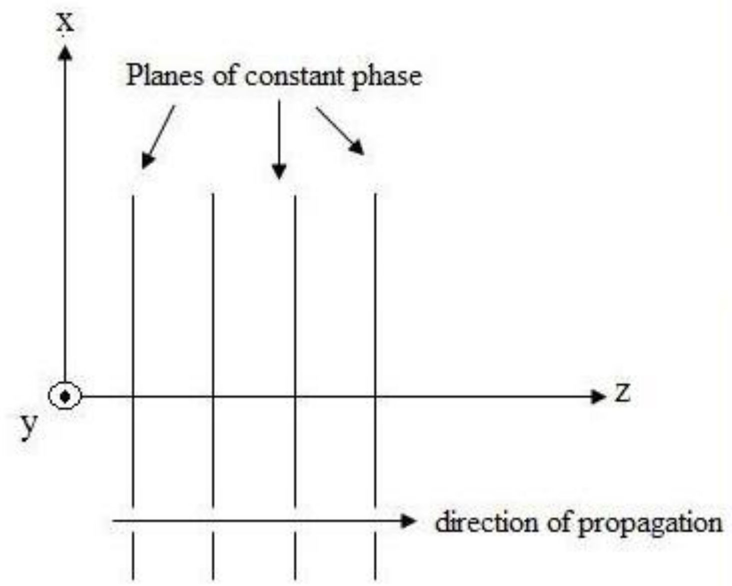


Figure 2.4: Graphical representation of E-field travelling in +z-direction.

Circular Polarization

Suppose now that the E-field of a plane wave was given by equation (2.7):

$$E = \cos\left(2\pi f\left(t - \frac{z}{c}\right)\right)\hat{x} + \sin\left(2\pi f\left(t - \frac{z}{c}\right)\right)\hat{y} \qquad (2.7)$$

In this case, the x- and y- components are 90 degrees out of phase. If the field is observed at (x, y, z) = (0, 0, 0) again as before, the plot of the E-field versus time would appear as shown in Figure 2.5.

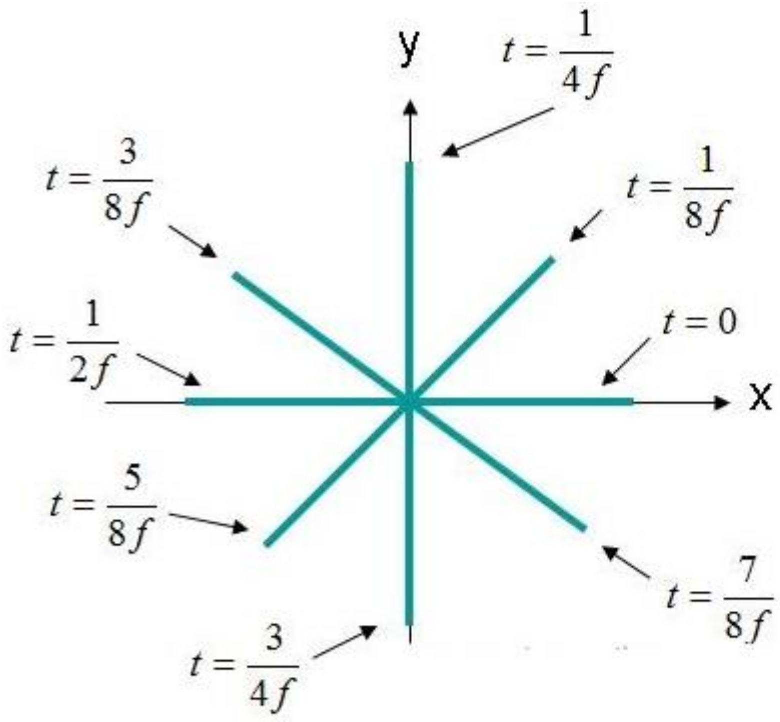


Figure 2.5 : E-field strength at (x,y,z)=(0,0,0) for field of equation (2.7).

The E-field in Figure 2.5 rotates in a circle. This type of field is described as a circularly polarized wave. To have circular polarization, the following criteria must be met:

1. E-field must have two orthogonal (perpendicular) components.
2. The E-field's orthogonal components must have equal magnitude.
3. The orthogonal components must be 90 degrees out of phase.

If the wave in Figure 2.5 is travelling out of the screen, the field is rotating in the counter-clockwise direction and is said to be Right Hand Circularly Polarized (RHCP). If the fields were rotating in the clockwise direction, the field would be Left Hand Circularly Polarized (LHCP).

Elliptical Polarization

If the E-field has two perpendicular components that are out of phase by 90 degrees but are not equal in magnitude, the field will end up Elliptically Polarized. Consider the plane wave travelling in the +z-direction, with E-field described by equation (2.8):

$$E = \cos\left(2\pi f\left(t - \frac{z}{c}\right)\right)\hat{x} + 0.3\sin\left(2\pi f\left(t - \frac{z}{c}\right)\right)\hat{y} \tag{2.8}$$

The locus of points that the tip of the E-field vector would assume is given in Figure 2.6.

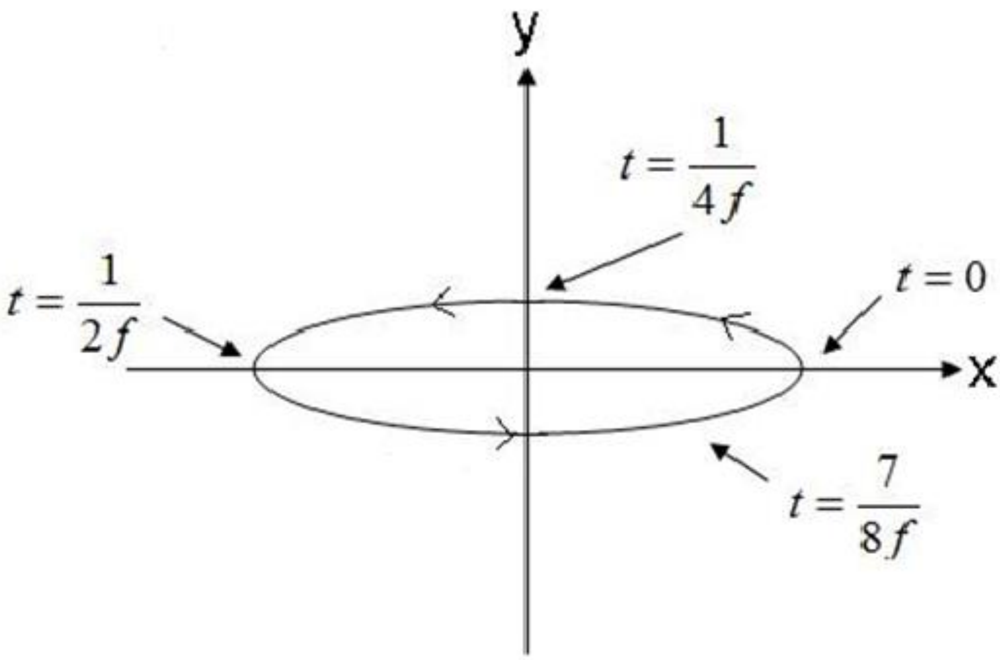


Figure 2.6: Tip of E-field for elliptical polarized wave of Eq. (2.8).

The field in Figure 2.6 travels in the counter-clockwise direction, and if travelling out of the screen would be Right Hand Elliptically Polarized. If the E-field vector was rotating in the opposite direction, the field would be Left Hand Elliptically Polarized.

TYPES OF ANTENNAS

Table 1: Antenna Types

Antenna Type/ Parameters	Monopole	Slot	Micro strip Patch	PIFA
Radiation Pattern	Omni directional	Roughly omni-directional	Directional	Omni directional
Gain	High	Moderate	High	Moderate to high
Modeling and fabrication	Modeling is difficult	Fabrication on PCB can be done	Easy to fabricate and model	Easier fabrication using PCB
Applications	Radio broadcasting, vehicular antenna	Radar, cell phone base stations	Satellite communication, Aircrafts	Internal antennas of mobile phones
Merits	Compact size, low fabrication cost and easy to manufacture, large bandwidth support	Radiation characteristics remains same due to tuning, design simplicity	Low cost, low weight, easy to integrate	Small size, low cost, reduced backward radiation for minimizing SAR
Demerits	Difficult to fabricate at higher freq (>3GHz)	Size constraint for mobile handheld devices	No band pass filtering effect, surface-area requirement	Narrow bandwidth characteristic

FEED METHODS

There are mainly four basic methods for the feeding to these antennas:

1.) Probe Coupling Method
2.) Micro strip Line Feeding Method

3.) Aperture Coupled Micro strip Feed Method
4.) Proximity Coupling Method

Table 2 summarizes the advantages and disadvantages of the four feeding methods:

	Advantages	Disadvantages
Proximity Coupled	No direct contact between feed and patch. Can have large effective thickness for patch substrate and much thinner feed substrate.	Multilayer fabrication required.
Micro strip Line	Monolithic. Easy to fabricate. Easy to match by controlling. Insert position. Easy to match. Low spurious radiation.	Spurious radiation from feed line, especially for thick substrate when line width is significant.
Coaxial Feed	Easy to match. Low spurious radiation.	Large inductance for thick substrate. Soldering required.
Aperture Coupled	Use of two substrates avoids deleterious effect of a high dielectric constant substrate on the bandwidth and efficiency. No direct contact between feed and patch avoiding large probe reactance or width micro strip line No radiation from the feed and active devices since a ground plane separates them from the radiating patch.	Multilayer fabrication required. Higher back lobe radiation.

Wi-MAX Technology

Antennas are essential elements, especially in UWB systems. Not only beam width, gain, and side - lobes, but also their pick amplitude, width of pulses, ringing, and spatial correlation are of major interest. There are several generic ideas for the width of the channel to the maximum value available, or equivalently in a fixed channel bandwidth by increasing the signal.

Wi-MAX, the **W**orldwide **I**nteroperability for **M**icrowave **A**ccess, is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from point-to-point links to full mobile cellular type access. It is a wireless digital communications system that is intended for wireless "metropolitan area networks". This technology can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3-10 miles (5-15 km) for mobile stations. Wi-MAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL. In a typical cell radius deployment of three to ten kilometers, Wi-MAX Forum Certified systems can be expected to deliver capacity of up to 40 Mbps per channel, for fixed and portable access applications.

Many companies are closely examining Wi-MAX for the "last mile" connectivity at high data rates. The resulting competition may bring lower pricing for both home and business customers or bring broadband access to places where it has been economically unavailable. Prior to Wi-MAX, many operators have been using proprietary fixed wireless technologies for broadband services.

The bandwidth and reach of Wi-MAX make it suitable for the following potential applications:

- Connecting Wi-Fi hotspots with each other and to other parts of the Internet.
- Providing a wireless alternative to cable and DSL for last mile broadband access.
- Providing high-speed data and telecommunications services.
- Providing a diverse source of Internet connectivity as part of a business continuity plan. That is, if a business has a fixed and a wireless Internet connection, especially from unrelated providers, they are unlikely to be affected by the same service outage.
- Providing nomadic connectivity.

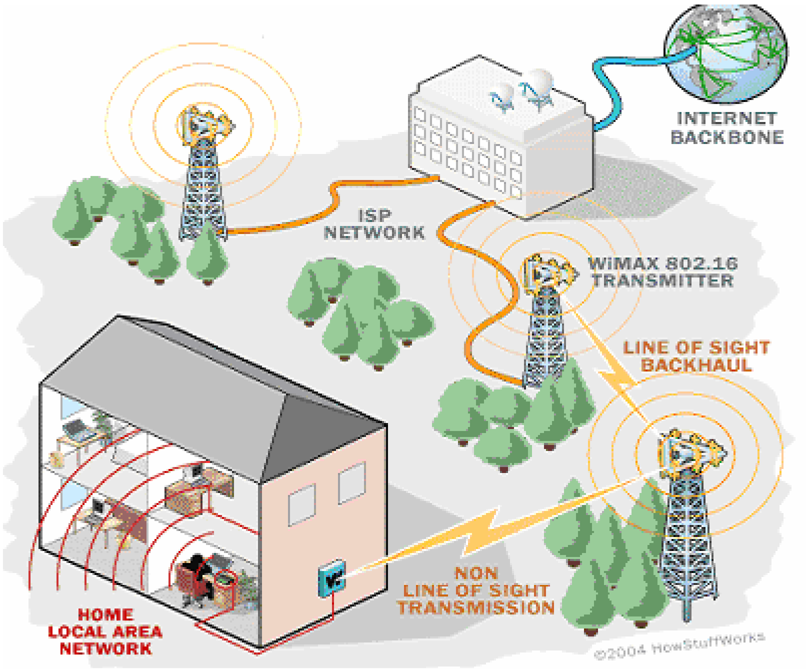


Figure 2.7: Overview of Wi-MAX Technology

Standard of Wi-MAX

Wi-MAX technology is based on the IEEE 802.16 standard, which is also called Wireless MAN. The IEEE 802.16 group was formed in 1998 to develop an air interface standard for wireless broadband. The group's initial focus was the development of a LOS-based point-to-multipoint wireless broadband system for operation in the 10 GHz–66 GHz millimeter wave band. The IEEE 802.16 group subsequently produced 802.16a, an amendment to the standard, to include NLOS applications in the 2 GHz–11 GHz band, using an orthogonal frequency division multiplexing (OFDM)-based physical layer. Additions to the MAC layer, such as support for orthogonal frequency division multiple access (OFDMA), were also included. Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004, which replaced all prior versions and formed the basis for the first Wi-MAX solution. These early Wi-MAX solutions based on IEEE 802.16-2004 targeted fixed applications. In December 2005, the IEEE group completed and approved IEEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support. The IEEE 802.16e-2005 forms the basis for the Wi-MAX solution for nomadic and mobile applications and is often referred to as mobile Wi-MAX.

Spectrum Allocation

From a global perspective, the 2.3 GHz, 2.5 GHz, 3.5 GHz, and 5.7 GHz bands are most likely to have Wi-MAX deployments. The WiMAX Forum has identified these bands for initial interoperability Certifications. A brief description of these bands follows.

- Licensed 2.5 GHz: The bands between 2.5 GHz and 2.7 GHz have been allocated in The United States, Canada, Mexico, Brazil, and some Southeast Asian countries. In many countries, this band is restricted to fixed applications; in some countries, two-way communication is not permitted. Among all the available bands, this one offer the most promise for broadband wireless, particularly 2.495 GHz and 2.690 GHz. Regulations allow a variety of services, including fixed, portable, and mobile services. Both FDD and TDD operations are allowed. Licenses were issued for eight 22.5MHz slices of this band, where a 16.5 MHz block is paired with a 6 MHz block, with the separation between the two blocks varying from 10 MHz to 55 MHz. The rules of this band also allow for license aggregation. Sprint, Nextel, and Clearwire control a majority of this spectrum in the United States. Regulatory changes may be required in many countries to make this band more available and attractive, particularly for mobile Wi-MAX.

- Licensed 2.3 GHz: This band, called the WCS band. This is available in many countries such as US, Australia, South Korea, and New Zealand. In fact, the WiBro services being deployed in South Korea uses this band. In the United States, this band includes two paired 5 MHz bands and two unpaired 5 MHz bands in the 2.305 GHz to 2.320 GHz and 2.345 GHz to 2.360 GHz range. A major constraint in this spectrum is the tight out-of-band emission requirements enforced by the FCC to protect the adjacent DARS (digital audio radio services) band (2.320 GHz to 2.345 GHz). This makes broadband services, particularly mobile Services, difficult in the sections of this band closest to the DARS band.

- Licensed 3.5 GHz**:** This is the primary band allocated for fixed wireless broadband access in several countries across the globe. In the United States, the FCC has recently allocated 50 MHz of spectrum in the 3.65 GHz to 3.70 GHz band for high-power unlicensed use with restrictions on transmission protocols that preclude Wi-MAX. The available bandwidth varies from country to country, but it is generally around 200 MHz. The available band is usually split into many individual licenses, varying from 2.5 MHz to 2.56 MHz. Spectrum aggregation rules also vary from country to country.

- UHF bands: UHF band spectrum has excellent propagation characteristics compared to the other microwave bands and hence is valuable, particularly for portable and mobile services. The larger coverage range possible in this band makes the economics of deployment particularly attractive for suburban and rural applications.

Wi-MAX Working

The Wi-MAX network uses an approach that is similar to that of cell phones. Coverage for a geographical area is divided into a series of overlapping areas called cells. Each cell provides coverage for users within that immediate vicinity. When subscriber travels from one cell to another, the wireless connection is handed off from one cell to another.

A Wi-MAX system consists of two parts:

- A Base station, similar in concept to a cell-phone tower - A single Wi-MAX tower can provide coverage to a very large area -- as big as 3,000 square miles (~8,000 square km).is mounted on a tower or tall building to broadcast the wireless signal.

- A Wi-MAX subscriber device, these could be Wi-MAX enabled notebook, mobile Internet device, or even a Wi-MAX modem by using the subscriber receives the signals. The user pays the service provider for wireless Internet access, just as they would for a normal Internet connection via a cable network. The service provider provides the end user with the software, a login and a password. Most of the laptop manufacturers today equip high-end models with a built in antenna bundled with the required software for the unit to be Wi-MAX compatible. The service provider beams the internet signals from the base station. The antenna at the user end catches the signals, providing uninterrupted internet as long as the signal is available. With a laptop equipped with an antenna you could be connected to the Internet wherever the signal is available from the base station.

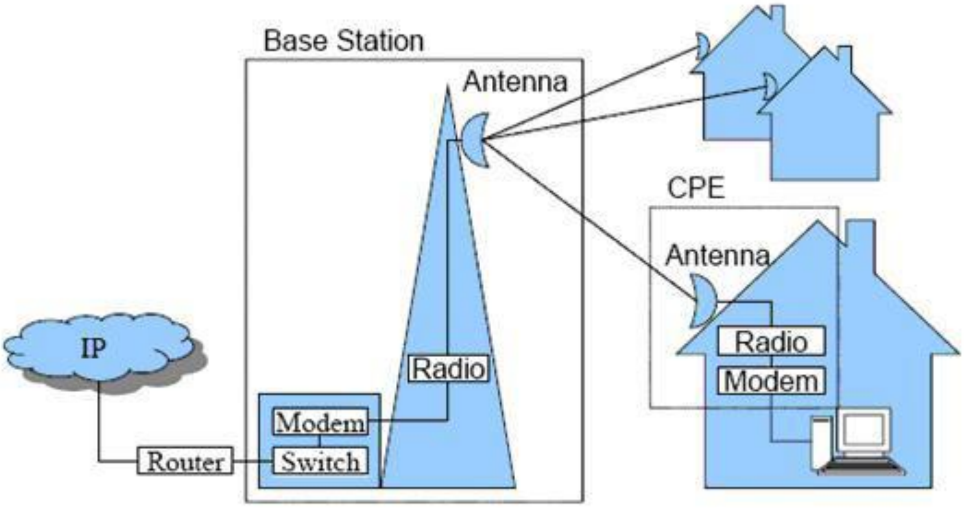


Figure 2.8: Fixed Wi-MAX

Features of Wi-MAX

- OFDM-based physical layer
- Scalable bandwidth and data rate support
- Adaptive modulation and coding
- Link-layer retransmissions
- Support for TDD and FDD
- Orthogonal Frequency Division Multiple Accesses
- Flexible and dynamic per user resource allocation
- Support for advanced antenna techniques
- Quality-of-service support

Vivaldi antennas

The Vivaldi antenna is slow-wave, leaky, end-fire, traveling-wave antenna. Theoretically, the Vivaldi antenna has an unlimited operating frequency range, with constant beam width over the entire bandwidth. The Vivaldi antenna is a type of a traveling-wave antenna of the “surface-type”. The waves travel down the curved path of the flare along the antenna. In the region where the separation between the conductors is small when compared to the free-space wavelength, the waves are tightly bound and as the separation increases, the bond becomes progressively weaker and the waves get radiated away from the antenna.

Vivaldi antenna Introduction

With the development of communication technologies, the usage of UWB (Ultra Wide Band) wireless communications system gets more and more extensive, while requirements of the ultra - wideband antenna are brought forward. The Vivaldi antenna has a history of twenty eight years dating back to Gibson in which he introduces the antenna as an amalgamation of slot and Beverage (traveling wave) antenna design, with a theoretically unlimited instantaneous band width. The first major modification of the Gibson design was developed by Langley et al in which a balanced design was created to reduce cross-polarization, while maintaining the wide bandwidth behavior.

Guillanton et al improved the low frequency cutoff to 1.3 GHz by increasing the dimensions of the metallization at the distal portion of the radiating elements of the antenna. [41]. Vivaldi antenna is a kind of slot-line UWB antennas, which is a slot with smoothly transition from narrow end to another wide end. The slot curve on the medium board gradually changes wider in terms of index, leading to a horn receiving or transmitting electromagnetic (EM) waves. At various frequencies, it radiates or receives electromagnetic wave using corresponding part of the horn. The planar aperture of the different parts of a horn in the Vivaldi antenna has constant electric size for the relevant frequency. This is the reason why this kind of antenna has so wide working frequency band. Theoretically, it has an infinite wide frequency band. What's more, Vivaldi antenna is a kind of high-gain and linearly polarized antenna. And its gain remains constant with frequency change.

Vivaldi antenna is a kind of high-gain and linearly polarized antenna. And its gain remains constant with frequency changed. Compared with Twin Cone antenna, cone shaped LPD antenna, and other ultra-wideband antenna, Vivaldi antenna has more compact shape and it is more suitable for portable devices. In addition, Vivaldi antenna, which has the features of low side lobe, moderate gain, beam width adjustable, small size, low cost, simple structure, easy to be processed and others, is very suitable for printing circuits [32].

Vivaldi antenna has been widely used from the beginning when it was brought out. It has been applied in many areas, such as:

1.) Satellite communications
2.) Earth-detection radar
3.) EM measurements

Overview of Vivaldi antenna design

Construction

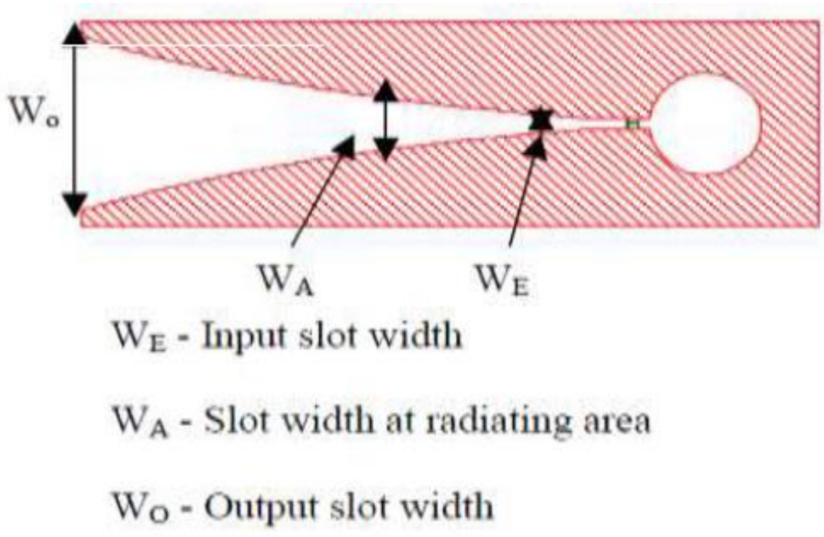


Figure 2.9: Structure of Vivaldi antenna

Taper slot antenna

The Vivaldi antenna is a member of a class of a-periodic continuously scaled traveling wave antenna structure. The terms “tapered-notch”, “flared-slot”, “tapered slot” antennas have been used interchangeably in the literature. These antennas consist of a tapered slot etched onto a thin film of metal. This is done either with or without a dielectric substrate on one side of the film. Besides being efficient and lightweight, the more attractive features of TSAs are that they can work over a large frequency bandwidth and produce a symmetrical end-fire beam with appreciable gain and low side lobe. An important step in the design of the antenna is to find suitable feeding techniques for the Vivaldi.

Understanding the characteristics of the Vivaldi is fundamental and would help a great deal in designing the antenna. From research journals on the TSA, we can confirm that TSAs generally have wide bandwidth, high directivity and are able to produce symmetrical radiation patterns. The feature that is common to all the different designs of this antenna is the exponentially flared slot. This aspect is particularly analogous to the standard TEM horn antenna, the width of the flare increases with distance from the antenna feed. In fact, we could say that the Vivaldi is the printed circuit equivalent of the horn. The wave-guiding structure here is the printed slot line that is tapered exponentially outwards [23]. The distinctive feature of TSA is a slot line widening with distance from the feed forming the radiating section of the antenna. The profile of radiating section or taper specifies the different types of TSA. The best known types of TSA which are linearly tapered slot antenna

(LTSA), constant width slot antenna (CWSA) and exponentially tapered slot antenna (Vivaldi) are shown in Figure 2.10 below.

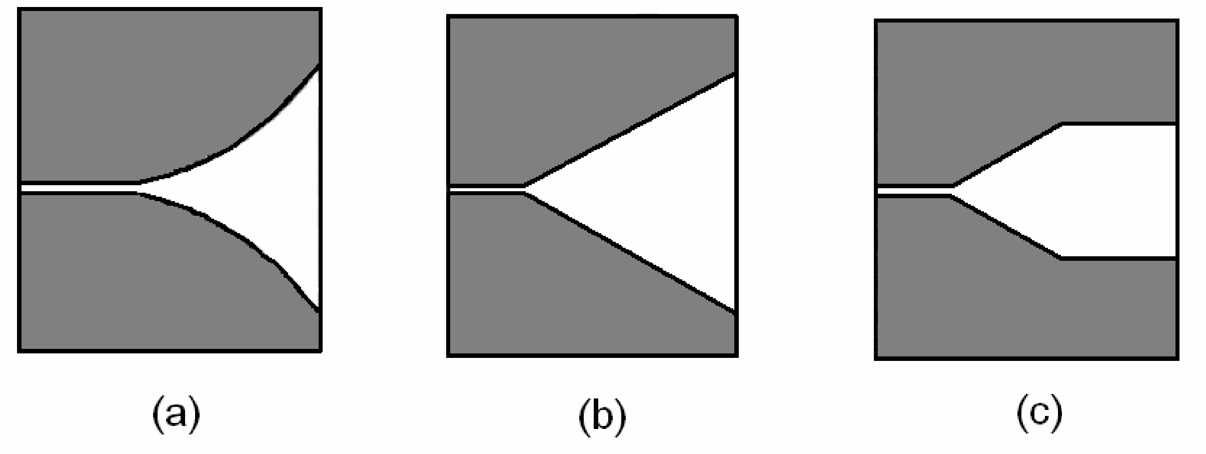


Figure 2.10: Types of TSA; (a) exponentially tapered (Vivaldi), (b) linearly tapered (LTSA) and (c) Constant width slot antenna (CWSA)

TSAs are efficient and geometrically simple with significant gain and wide bandwidth and appreciably light weight as mentioned before. Moreover, this kind of antennas produce symmetrical radiation patterns with high directivity and low side lobe levels.

The principle of operation

The Vivaldi antenna belongs to the surface wave class of traveling wave antennas (the other traveling wave antenna type is the leaky wave antenna). In order to describe principle of operation, the surface wave antennas can be divided into two sections: propagating section and radiating section.

The slot width (separation between the conductors) is smaller than one-half free space wavelength and the waves traveling down the curved path along the antenna are tightly bound to the conductors in the propagating section. The bond becomes progressively weaker and the energy gets radiated away from the antenna coupling to the air in the radiating section where the slot width is increasing beyond the one-half wavelength [40].

The waves are traveling along the antenna surface until the limiting case of phase velocity is equal to the free space velocity of light (c=3x108). The limiting case intends the antenna with air as dielectric. That is to say, radiation from low dielectric substrates is considerably high and crucial for the antenna operation.

Tapered profiles

Types

Many taper profiles exist for a normal TSA. Figure shows different planar designs and we can observe that each antenna differs from the other only in the taper profile of the slot. Planar tapered slot antennas have two common features. The radiating slot acts as the ground plane for the antenna and the antenna is fed by a balanced slot line. However, drawbacks for a planar TSA come in the form of using a low dielectric constant substrate and obtaining an impedance match for the slot line. By fabricating on a low dielectric constant substrate, relatively high impedance is obtained for the slot line. If a micro strip feed is chosen, it makes matching very difficult. Thus, the micro strip to slot transition will limit the operating bandwidth of the TSA.

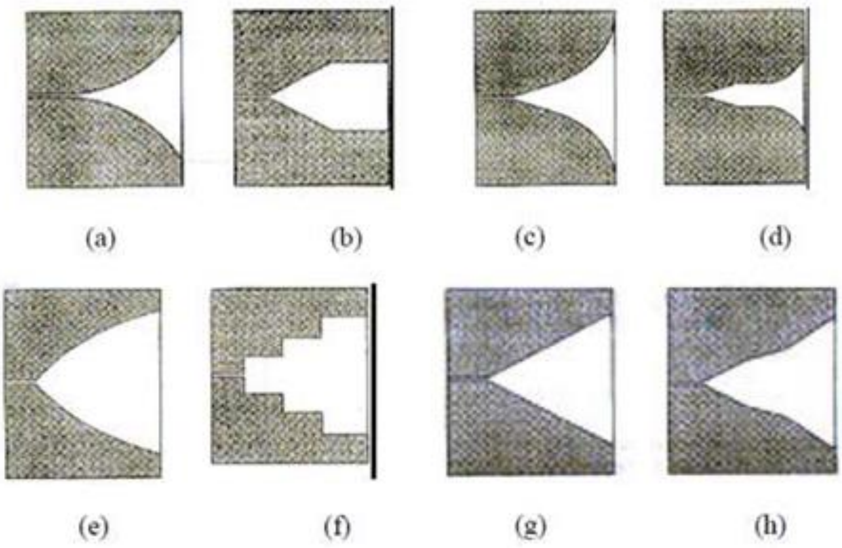


Figure 2.11: Different taper-styles of the TSA: (a)Exponential Vivaldi; (b) Linear-constant; (c) Tangential; (d) Exponential-constant; (e) Parabolic; (f) Step-constant; (g) Linear; (h) Broken – linear.

Taper styles

Experiments have shown that the curvature of tapered profile has a significant impact on the gain, beam width and bandwidth of tapered slot antennas. In fact, it was shown that the half-power beam width (HPBW) on the E-plane increases with a decrease in the radius of curvature while the opposite is true on the H-plane [35].

Effect of curvature on the TSA

Previous Experiments have shown that the curvature of tapered profile has a significant impact on the gain, beam width and bandwidth of tapered slot antennas. In fact, it was shown that the half-power beam width (HPBW) on the E-plane increases with a decrease in the radius of curvature while the opposite is true on the H-plane. The cross polarization is generally improved with the decrease in the radius of the curvature except for the E-plane, which will not show any improvement.

Feeding techniques

The Vivaldi antenna, as a member of class of TSA, is most effective with a slot line feeding. Thus, a transition shall be designed to couple signals to the slot line of Vivaldi from the transmitter or receiver circuitry. The transition shall be low loss over a wide frequency range so as not to limit operating bandwidth. It shall also be compact and easy to fabricate.

The feeding techniques may be divided into two types mainly as directly coupled transitions and electromagnetically coupled transitions.

1. Directly Coupled Transitions

A wire or a solder connection can act as the direct current path providing the electrical contact for this type of transition. The best known directly coupled transition type is coaxial line to slot line transition.

2. Coaxial to Slot line Transition

In this type of transition, the signals are coupled to the slot line from the actual antenna feed through a coaxial line. An open circuited slot and a coaxial line placed perpendicular to it form the transition. The electrical connection of the coaxial cable to the ground plane is provided by the outer conductor on one side of the slot while the inner conductor of the cable is placed over the slot forming a semicircular shape [17].

The characteristic impedance of the slot line is too high to get an adequate matching characteristic with the slot line etched on single side of the substrate. A better matching, thereby a wider bandwidth, is obtained etching the slot line on both sides of the substrate. However, coaxial feeding is still unfavorable to implement successfully due to etching difficulties.

3. Electromagnetically Coupled Transitions

The coupling of signals to the slot line is through the electromagnetic fields in this type of transition. Micro strip to slot line, strip line to slot line, antipodal slot line and balanced antipodal slot line are the best known types of electromagnetically coupled transitions.

4. Micro strip to Slot line Transition

The basic micro strip to slot line transition is constructed with micro strip and slot line crossing each other at a right angle. The micro strip is etched on one side of the substrate and the slot line on the other side of the substrate. The micro strip crosses the slot line and extends one quarter of a wavelength further from the slot line in the same way as the slot line extending one quarter wavelength further from the micro strip. The quarter wavelength micro strip stub is opening circuited but appears as a short circuit at the crossing with slot line. The slot line stub is bonded to the ground plane and short circuited but obviously it appears as an open circuit at the crossing. This mechanism makes electro-magnetic coupling between the micro strip and the slot line possible.

5. Strip line to Slot line Transition

The strip line to slot line transition consists of slots etched on both sides of the substrate and a strip line feeding the slot lines at the center of the substrate. The quarter wavelength stub mechanism of micro strip to slot line transition is also used for this structure. The most important advantage of strip line over the micro strip is the increased bandwidth. Non-uniform stubs may be used for both strip line to slot line and micro strip to slot line transitions in order to increase the bandwidth. The first idea was to use circular quarter-wavelength stubs. Then, it was found out that radial stubs would be the best to increase the bandwidth and reduce overlapping between the micro strip / strip line and slot line at the same time. Figure 2.12 shows this latter application; radial quarter-wavelength stubs.

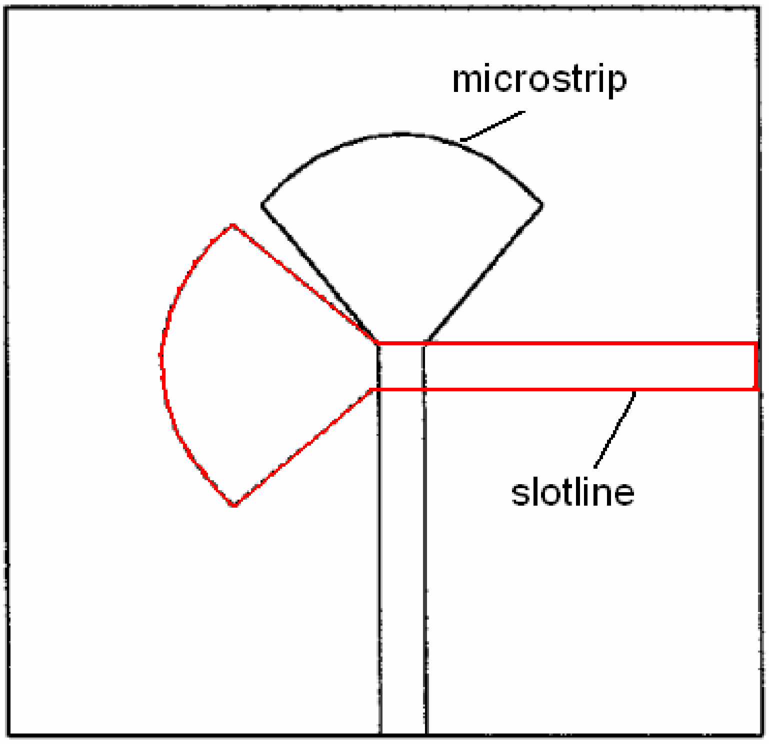


Figure 2.12: Radial quarter-wavelength stubs

Vivaldi exponential flare

The shape of the conventional Vivaldi exponential flare is defined by the equation,

$$\boldsymbol{y} = \boldsymbol{aebx} + \boldsymbol{c} \quad (2.9)$$

At a wavelength λ, the antenna radiates from a point on the exponential flare defined by,

$$y = \lambda/4 \quad (2.10)$$

In practice, the antenna does not radiate from a single point for a given frequency, but from a small section along the curve of the flare. The requirement for constant beam width is that the length of this section be in direct proportion to the wavelength.

Thus, the gradient of the flare must be proportional to wavelength. The exponential flare of the Vivaldi antenna satisfies this requirement [36].

Applications of Vivaldi Antenna

1.) The Vivaldi antenna is attractive as a lightweight, low-cost versatile antenna.

2.) A Vivaldi with known performance can be used as an instrumentation or multi-service antenna.

3.) A single installed antenna element that can be connected to a variety of systems operating at any frequency across a wide spectrum will reduce installation and upgrade costs.

4.) The antenna may be connected to multiple narrow-band receivers for a multipurpose system.

With increasing pressure on the spectrum from both radar and communications, ultra-wideband systems will be important in the future and an ultra-wideband antenna is an important enabling technology.

1.) A move towards low-power ultra-wideband systems using, for example, Direct Sequence coding spread spectrum techniques to provide high processing gain will allow the spectrum to be shared by many users, each using different coding techniques.

2.) It should be noted that the Vivaldi is a dispersive antenna. The point of radiation changes depending upon frequency.

3.) Antipodal Vivaldi antenna has many application-specific uses where a small lightweight antenna is important, for example, highly mobile ESM systems [32].

CHAPTER 3

EXPERIMENTAL WORK AND RESULTS

A Taper Slot Antenna (TSA) is a special class of Antenna in which a slot line is flared to provide an aperture for microwave radiations in free space. The flare for widening of slot line can be provided with the help of straight line, exponential, elliptical or parabolic curve equation. For some specific application, a combination of two curves is also used to achieve the desired antenna characteristics. A Taper Slot Antenna (TSA) in which the slot line is flared using an Exponential curve equation is termed as "Vivaldi Antenna" [22]. Vivaldi Antenna belongs to the end fire travelling wave antenna hence guide wavelength and the phase velocity are dependent on the substrate height, dielectric constant and taper rate. The length, width and taper profile affect the radiation characteristics of a Vivaldi Antenna as the gain of the Vivaldi Antenna is proportional to the $L/\lambda g$ [23].

The tapered slot is etched out from the thin metal layer deposited on to the substrate. Dielectric based or dielectric free Vivaldi Antenna can be fed through coaxial line, micro strip line, strip line or coplanar waveguide. The strip line or micro strip line fed Vivaldi Antenna can work over large bandwidths with symmetric beam width and high radiation efficiency. Vivaldi Antenna can be designed to achieve the bandwidth of 10:1. To achieve a wider bandwidth, the Vivaldi Antenna should have perfect impedance matching at both the feed slot line and slot line - free space transition. Hence, the most important design aspect is to provide a suitable feeding and reduction in wave reflection at the transition regions [29].

Transition Regions and Impedance Matching

A coaxial fed Vivaldi Antenna cannot provide broadband impedance bandwidth which is required in many broadband applications. Hence other alternative feeding techniques like micro strip to slot line or strip line to slot line is used and has been reported in literature [20]. In Micro strip slot line transition, the micro strip feed acts as an impedance transformer and it matches 50Ω coaxial line to a high impedance slot line. The performance of Vivaldi Antenna depends on smoothness of the transition. It is therefore essential for a designer to look into the matching aspect of transition. Transition regions in a Vivaldi Antenna are shown in Figure 3.1.

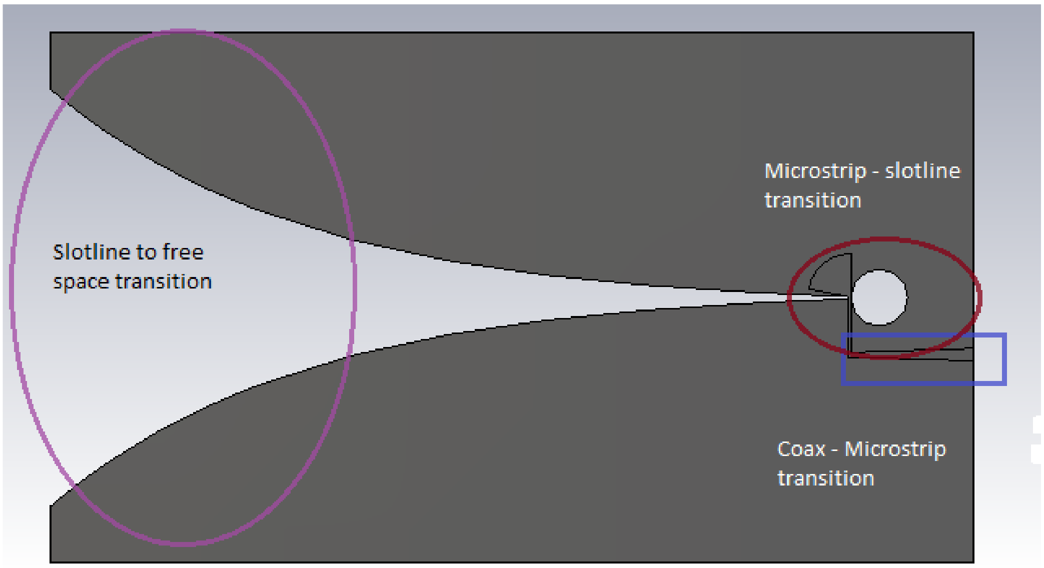


Figure 3.1: Transition Regions in Vivaldi Antenna

The broadband impedance matching for Vivaldi Antenna employs orthogonal crossover of micro strip and slot line with radial stub at the end of micro strip and circular cavity at the end of slot line. This cavity acts as a virtual open circuit while the stub acts a virtual short at higher frequencies. This type of transition is commonly used for ultra broadband matching [16].

Design of Exponential Flare

The slot line to free space transition (as shown in Figure 3.1) is governed by exponentially flared slot line. The return loss of a Vivaldi Antenna is greatly affected by this transition. Hence, in order to get efficient radiation in free space, the width of the open end is generally kept greater than $\lambda_0/2$ [27]. This criterion plays an important role in lowering the reflections at the slot line - free space transition. Moreover, the flare and the rate of flare also affect the VSWR of the Antenna. An exponential flare [28] is selected and the equation of the flare is mentioned in equation 3.1.

$$y = C_1 e^{Px} + C_2 \tag{3.1}$$

Where,

$$C_1 = \frac{(y_2 - y_1)}{\left[e^{Px_2} - e^{Px_1}\right]} \tag{3.2}$$

$$C_2 = \frac{\left(y_1 e^{Px_2} - y_2 e^{Px_1}\right)}{\left[e^{Px_2} - e^{Px_1}\right]} \tag{3.3}$$

P = flare or taper factor

(x_1, y_1)= flare start point coordinates
(x_2, y_2)= flare end point coordinates

The flare opening rate is controlled by flare factor P.

Strip line - Slot line Matching

The exponentially opened slot line is generally fed by a micro strip feed because it is impossible to achieve an impedance of 50Ω for a slot line and hence various matching networks are employed to feed slot line with micro strip. To overcome this problem the concept of balanced slot line is used and instead of micro strip feed, strip line feed is used. As the strip line transmission line requires ground plane on both the sides hence the slot line printed on both the sides appear in parallel and can be matched with a 50Ω strip line. As explained earlier, for a broadband performance the slot line is terminated by a circular cavity and the strip line is terminated with a radial stub. This cavity-stub model is useful for designing broadband Vivaldi Antenna especially for Microwave frequencies. Cavity and radial stub cancel the reactance of each other which facilitates the impedance matching. The design of Strip line – Slot line transition is shown in Figure 3.2.

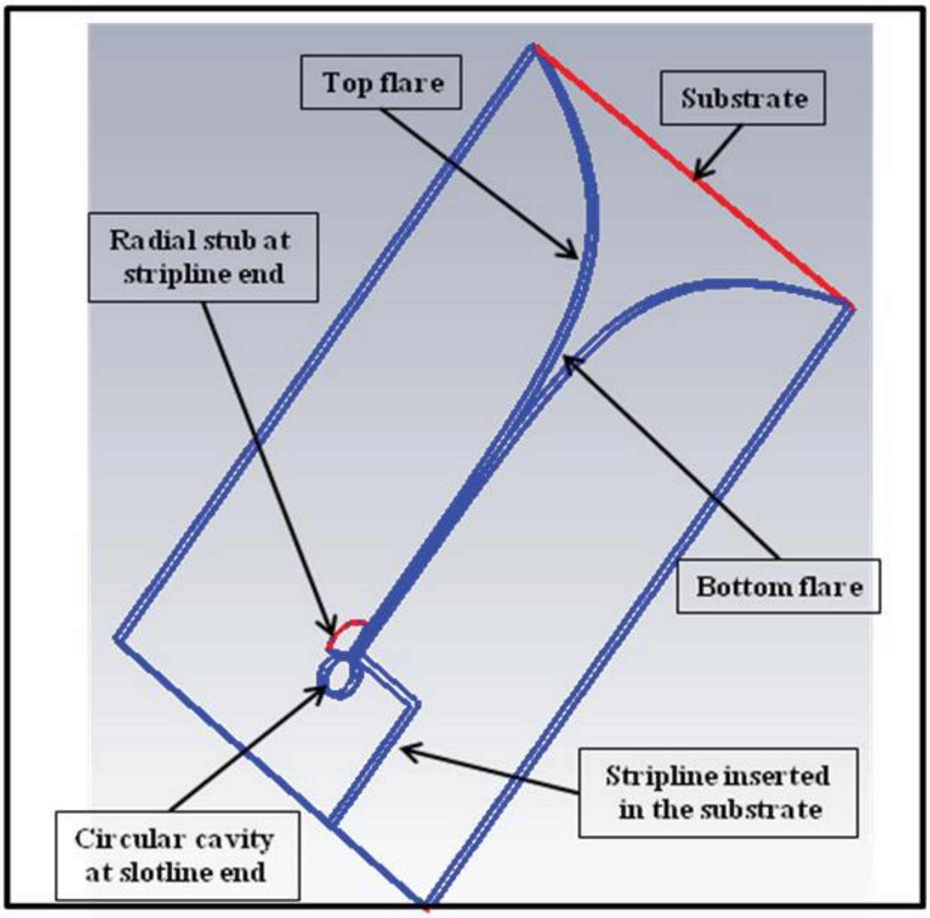


Figure 3.2: Triplicate Vivaldi structure and Strip line – slot line transition

Design of Vivaldi Antenna

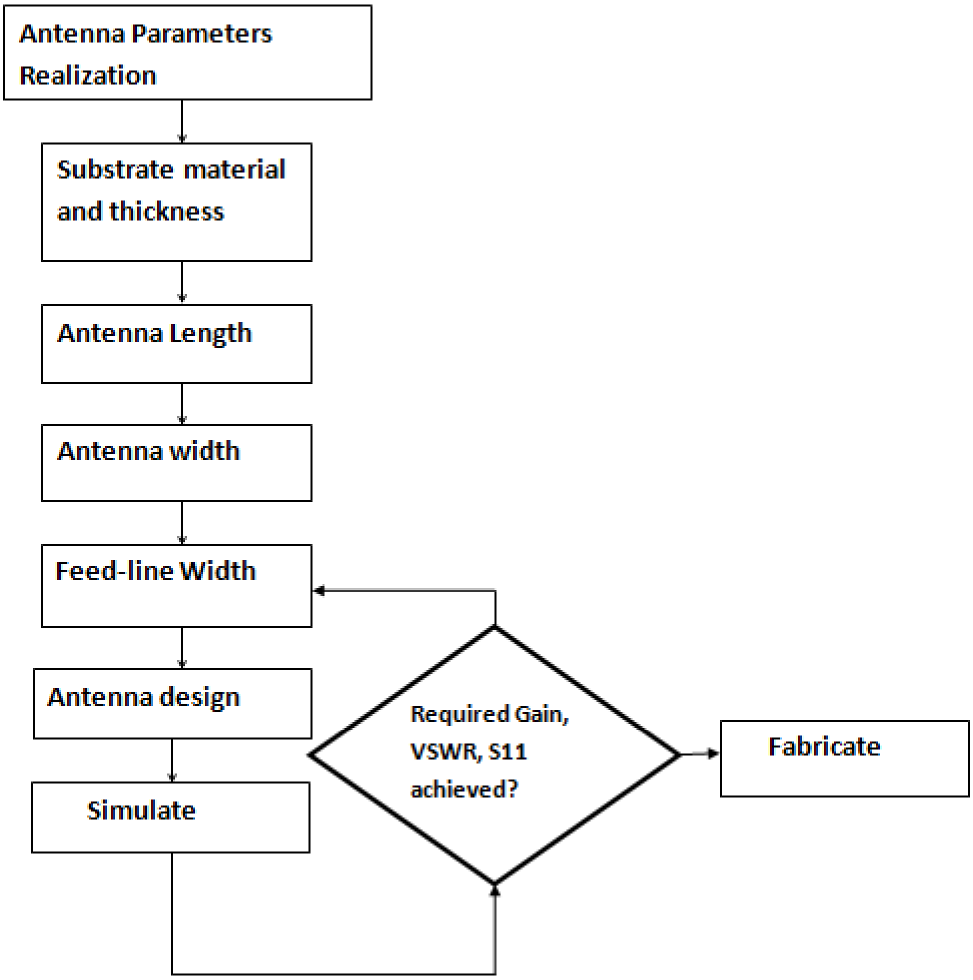


Figure 3.3: Flowchart of Design Methodology

The mechanical dimensions for a Vivaldi Antenna has been obtained by using design equations and a model has been designed simulated and optimized using CST Microwave Studio Suite 2018. As stated earlier, the substrate height and dielectric constant plays an important role in impedance matching hence FR4 substrate (ε_r = 4.3) has been found appropriate to achieve the desired bandwidth [29].

The design parameters are given in table 3:

Antenna length	88.34 mm
Antenna width	153.92 mm
Taper length	132.71 mm
Widest distance between two flares	67.70 mm

Slot line impedance	100 Ω
Slot line width	0.39 mm
Strip line impedance	50 Ω
Strip line width (maximum)	2.09 mm
Strip line width (near stub)	0.6 mm
Circular cavity	Open circuit
Diameter of circular cavity	9.37 mm
Radius of circular cavity	4.69 mm
Radial stub angle	110°
Radial stub radius	6.32 mm

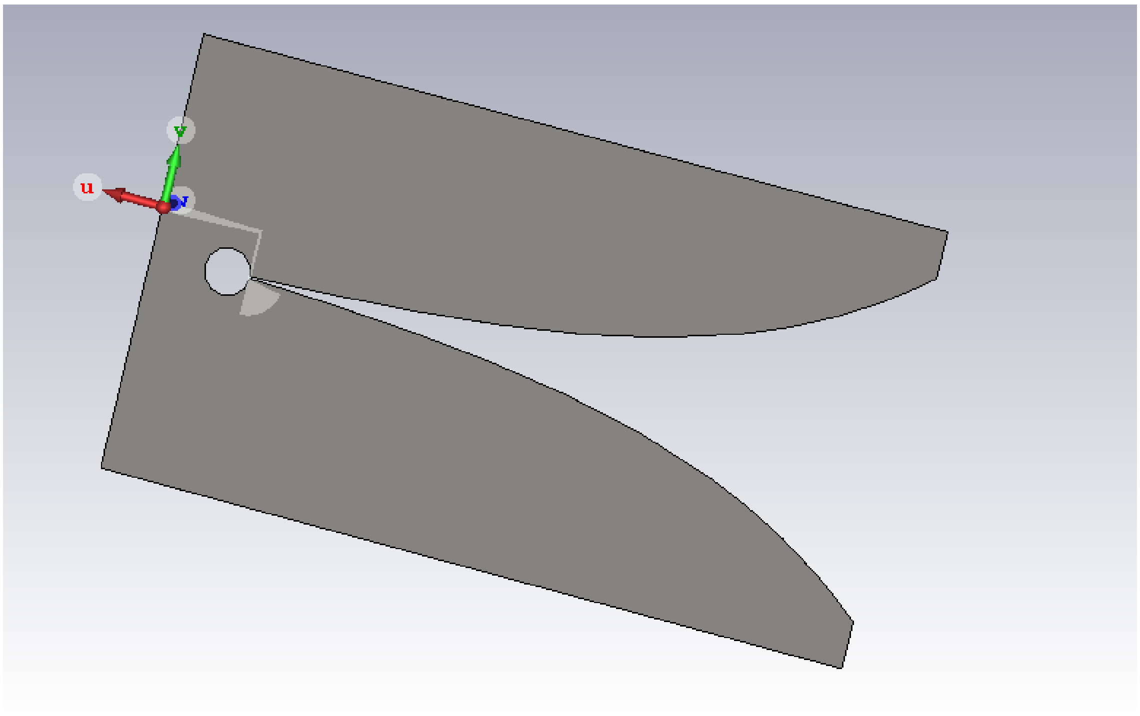


Figure 3.4: Antenna Design (I)

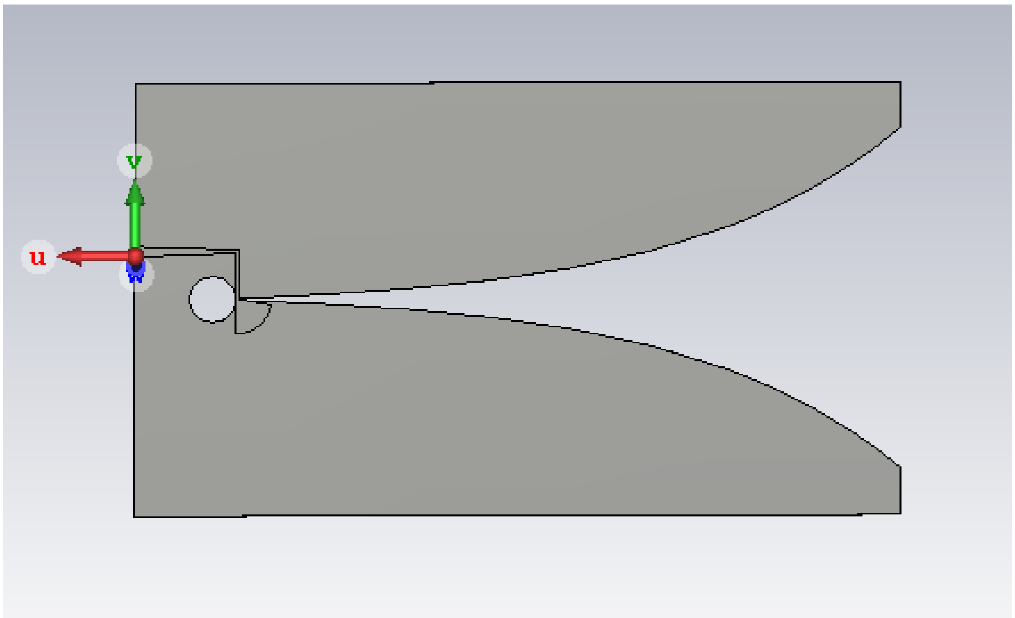


Figure 3.5: Antenna Design (II)

Figure 3.6: LKPF ProtoMat S64

The antenna is fabricated using LKPF ProtoMat S64. It is used in the manufacturing of high-performance PCBs. The high speed of the low maintenance milling spindle guarantees the production of fine structures and allows the formation of multi-layers. The high speed of the low-maintenance milling spindle guarantees the production of fine structures down to 100 µm and allows the production of multi layers. The extensive equipment, including dispenser and vacuum table, makes the ProtoMat S64 the perfect addition to any development environment.

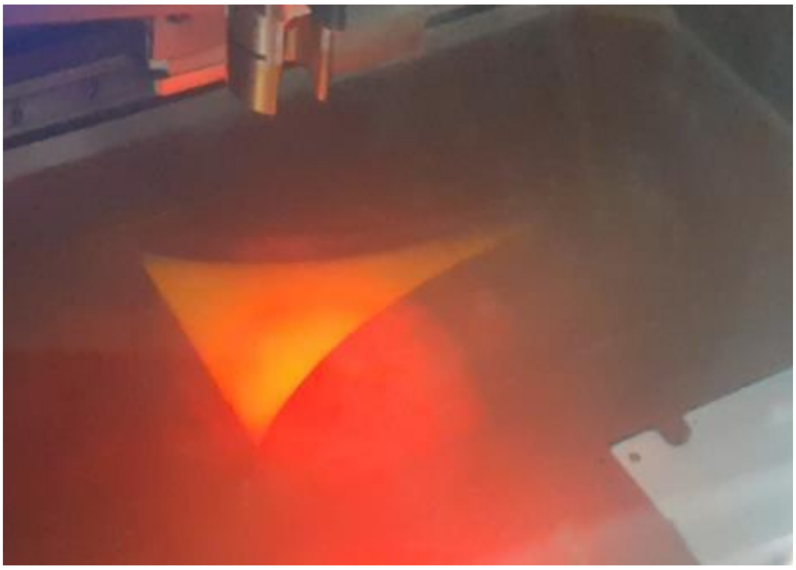


Figure 3.7: Vivaldi Antenna Fabrication Process

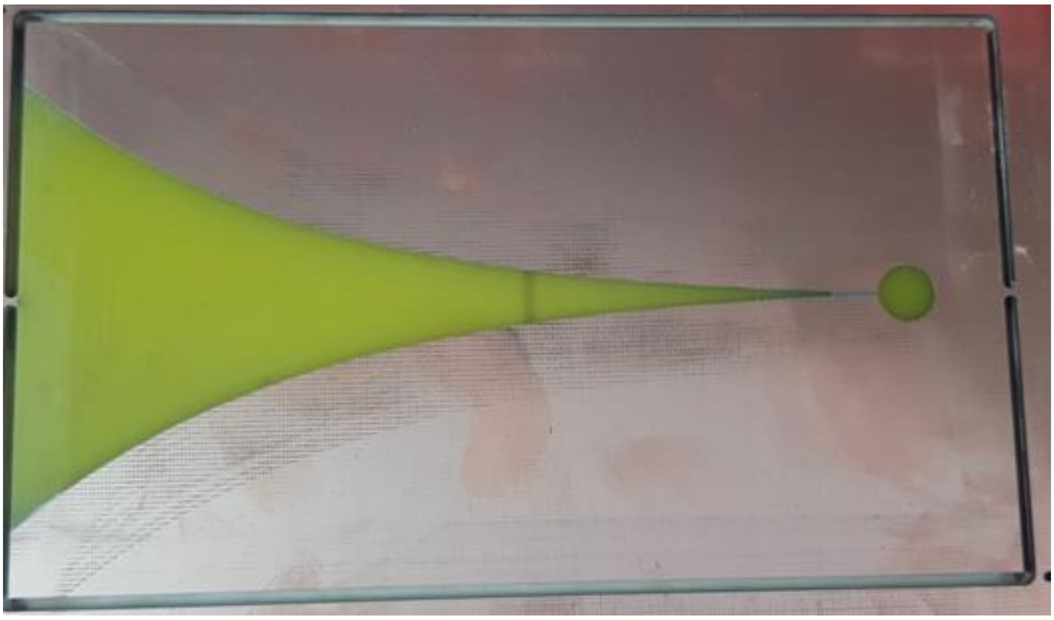


Figure 3.8: Fabricated Antenna

The taper length of the Antenna is chosen as $0.7*\lambda_0$ where λ_0 is the free space wavelength calculated at 3.2 GHz to work as a travelling wave Antenna and the opening width of the Antenna is chosen as $0.66*\lambda_0$ at lowest frequency of operation [40]. These dimensions provide an efficient radiation from the Vivaldi Antenna in 3-4 GHz frequency range. In the optimization process, the length width and the other parameters are varied in the ±10% range to check the effects of parameters on the Antenna characteristics [22].

The objective is to achieve the return loss better than -10 dB for the selected frequency range.

The strip line fed Vivaldi Antenna is a complex structure and can give errors in simulated results. To ensure the accuracy of simulated results, we use adaptive meshing feature available in CST Microwave Studio Suite 2018. This feature helps in enhancing the accuracy of simulated results by using finer mesh cells. The S-Parameter, VSWR, and gain of the simulated antenna are shown below.

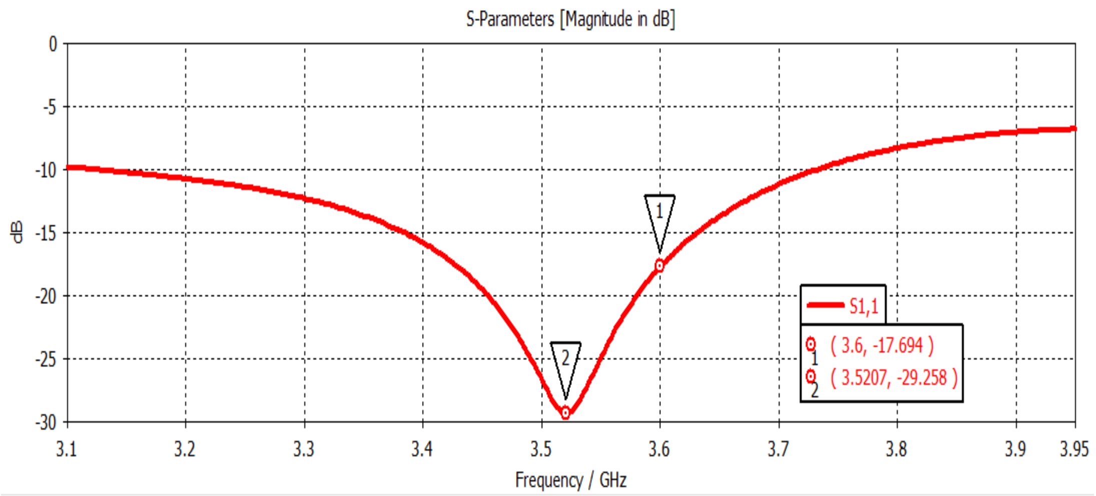


Figure 3.9: S-parameter

The S-parameter is -17.694 which is obtained at 3.6 GHz.

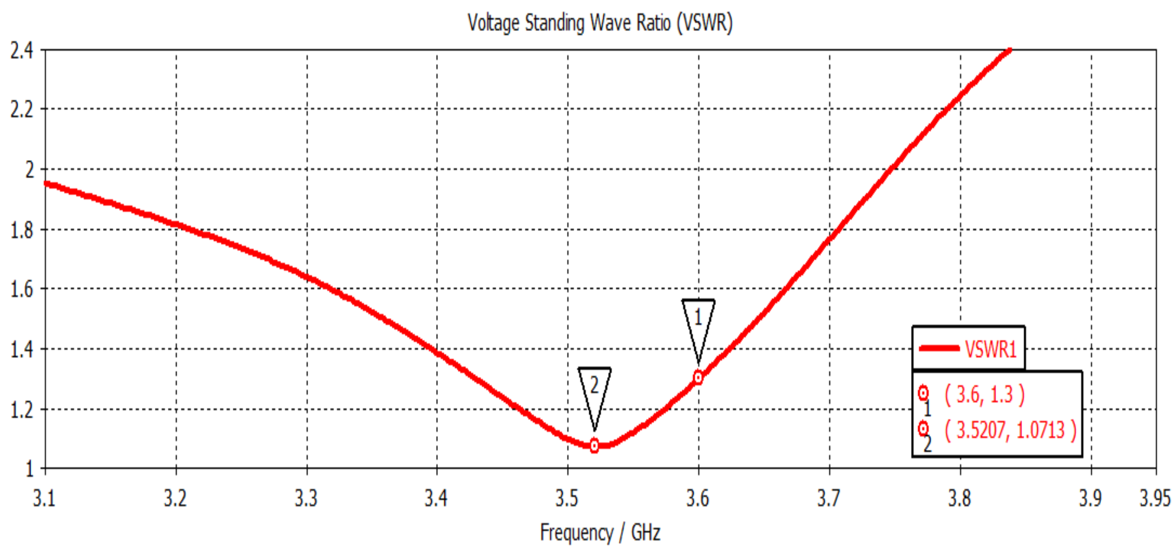


Figure 3.10: VSWR

The magnitude of VSWR is 1.3 dB at 3.6 GHz.

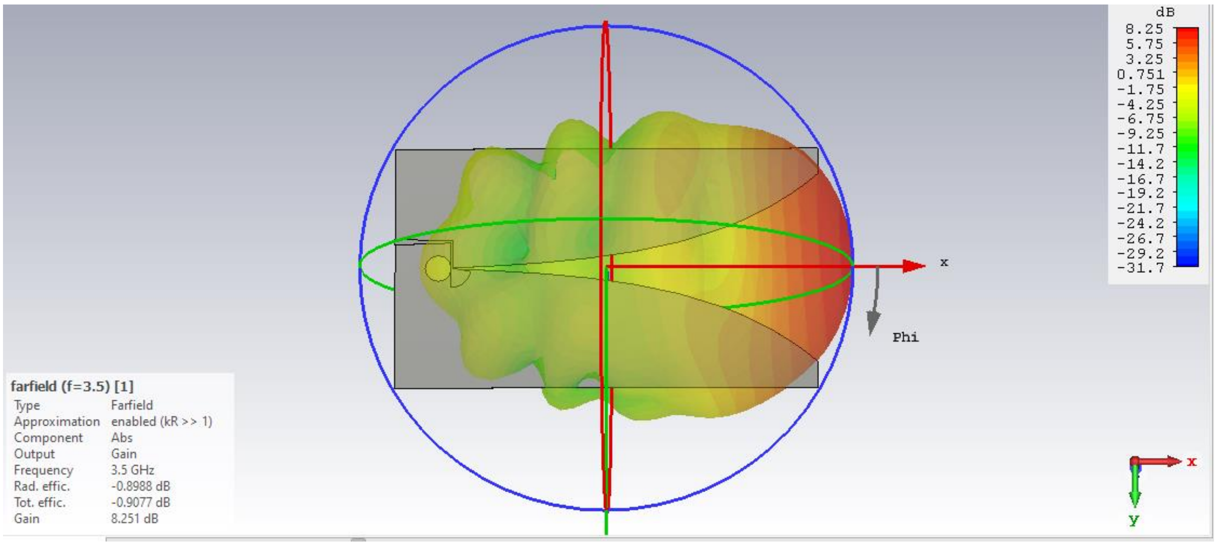


Figure 3.11: 3-D Gain at 3.5 GHz

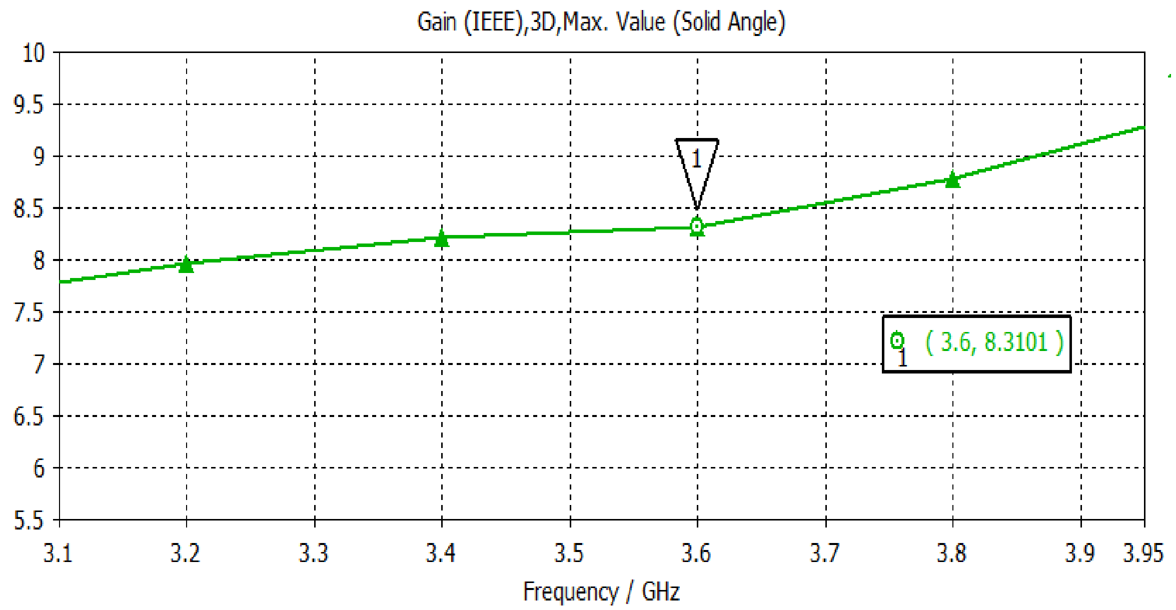


Figure 3.12: Gain (IEEE) at 3.6 GHz

After taking down the simulated results, the antenna is fabricated and the results of the fabricated antenna have been noted down using Keysight Technologies Field Fox RF Network Analyzer N9914A. The images of S-parameter and VSWR from the Network Analyzer are shown below in figure 3.13 and figure 3.14 respectively.

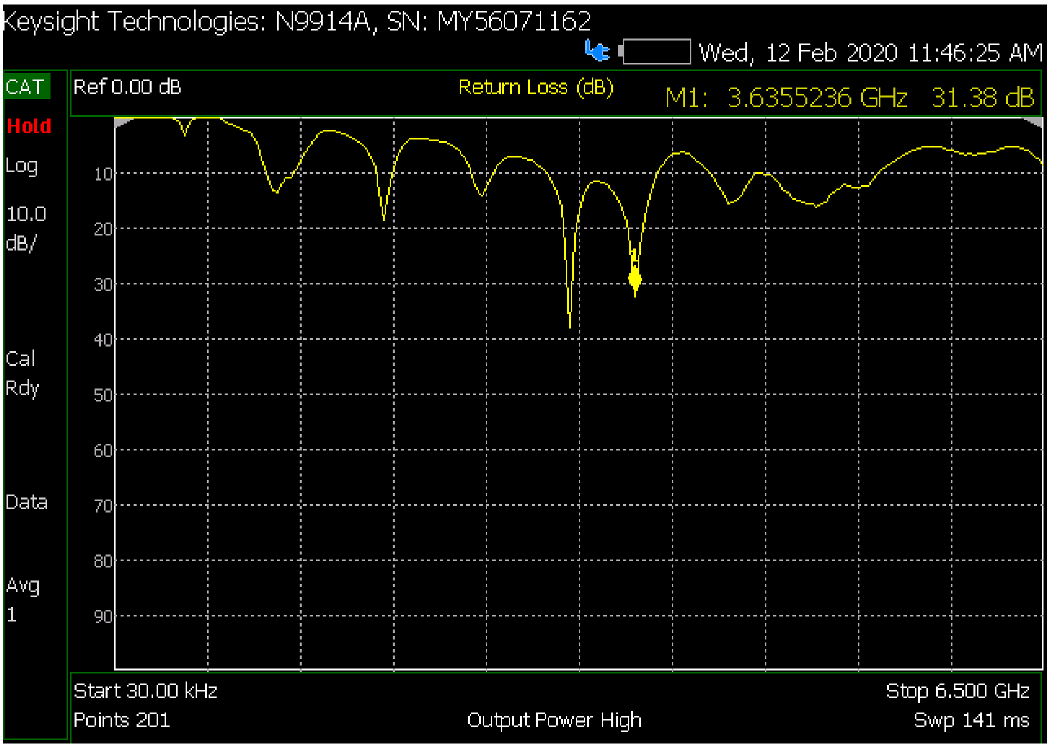


Figure 3.13: S-Parameter obtained from Network Analyzer

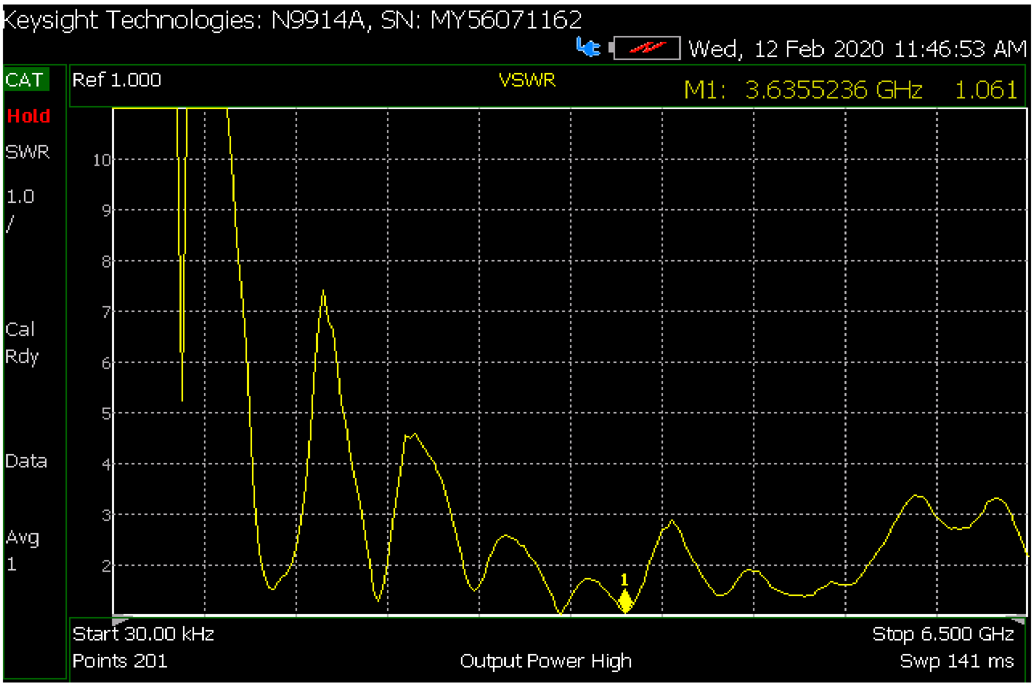
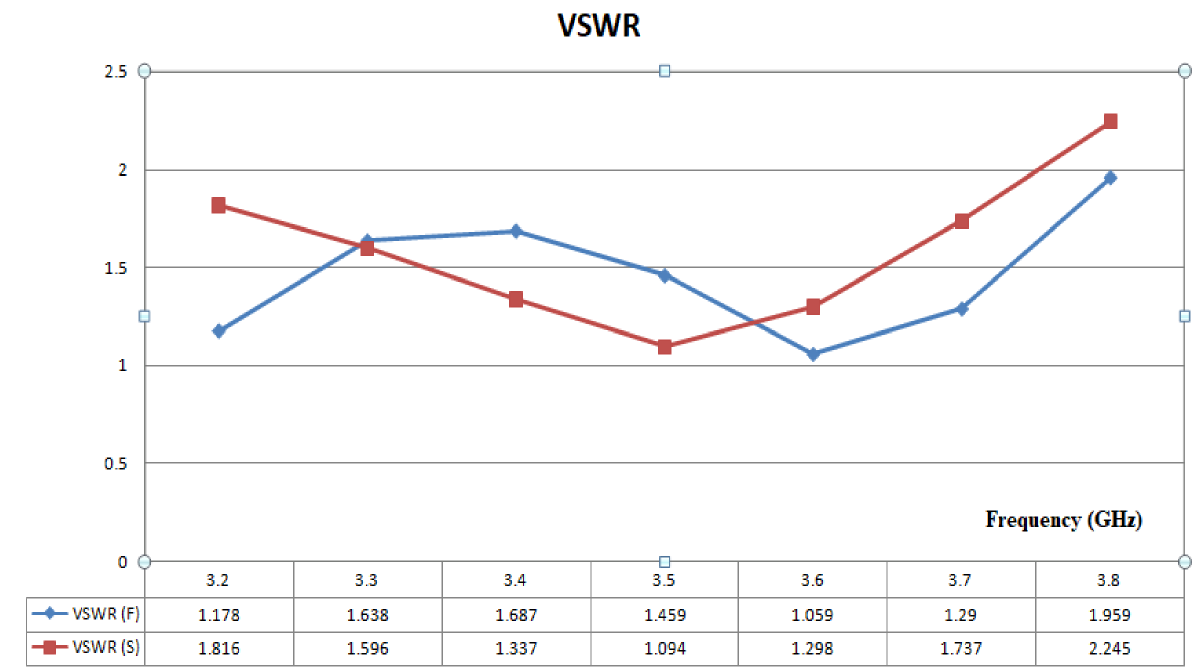


Figure 3.14: VSWR obtained from Network Analyzer

The results obtained from simulated Vivaldi antenna and fabricated Vivaldi antenna is then compared using graphs.

	3.2	3.3	3.4	3.5	3.6	3.7	3.8
Magnitude (dB) (F)	-21.75	-12.345	-11.594	-14.572	-31.289	-18.944	-9.785
Magnitude (dB) (S)	-9.531	-12.773	-16.803	-27.105	-17.741	-11.394	-8.317

Figure 3.15: Comparison of S-Parameter



	3.2	3.3	3.4	3.5	3.6	3.7	3.8
VSWR (F)	1.178	1.638	1.687	1.459	1.059	1.29	1.959
VSWR (S)	1.816	1.596	1.337	1.094	1.298	1.737	2.245

Figure 3.16: Comparison of VSWR

The comparison graphs show that the Vivaldi antenna has a return loss better than -10 dB and the maximum dip of the simulated antenna is -27.105 at 3.5 GHz frequency. Once the element is fabricated the maximum dip obtained is -31.289 dB at 3.6 GHz.

CONCLUSION

- We started with the literature survey on antenna design, Tapered-slot antennas, Vivaldi antenna and Wi-MAX applications.
- We designed a Vivaldi antenna with proper mathematical equations in CST Microwave Studio Suite 2018 to get the desired results.
- Vivaldi antenna was simulated successfully and the results are saved. We concluded that Vivaldi antenna provides broad bandwidth, and directive propagation at microwave frequencies.
- We converted the Vivaldi antenna design into gerber file format.
- The Vivaldi antenna is then fabricated using LKPF ProtoMat S64 Circuit Board Plotter.
- SMA Coaxial Connector (straight jack), 50 ohm is soldered at the feeding point of the antenna.
- Fabricated antenna is then tested using Keysight Technologies Field Fox RF Network Analyzer N9914A. The results are captured.
- Vivaldi Antenna for Wi-MAX application simulations have given expected results in terms of VSWR, return loss and gain.
- Simulated and fabricated results show good agreement with each other.
- The Research Paper on "Design and Implementation on Vivaldi Antenna for Wi-MAX Applications" has been presented in the e-conference in National Conference on Recent Trends in IOT, Machine Learning, Artificial Intelligence and its Applications (NCRIMA 2020) organized by Department of Electronics and Communication Engineering on 19-20 June, 2020.

FUTURE SCOPE

- The Vivaldi Antenna can be converted to 5X1 H-plane array to find out the effect of array environment on the characteristics of Vivaldi Antenna.

- The parametric study of Vivaldi Antenna and arrays might be extended observing their effects on antenna and array performance in a broader bandwidth.
- The micro strip to slot line, antipodal, and balanced antipodal transitions as well as the strip line to slot line transitions with non-uniform stubs might be considered in order to observe the effects of parameters on the designs with different antenna feeding techniques.

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Design and Implementation of Vivaldi Antenna for Wi – MAX Applications

Dr. Priyanka Jain and Sony

Department of Electronics & Communication Engineering,
Delhi Technological University (DTU), Delhi-110042, India

priyajain2000@rediffmail.com; sonyatakecare@gmail.com

***Abstract*: A novel Vivaldi Antenna has been designed for Wi-MAX application with a frequency range of 3.2 GHZ – 3.8GHz. The objective of the design of Vivaldi Antenna is to achieve return loss better than -10 dB over the entire range of frequency with a moderate gain ranging from 4 dB to 9 dB. The designed antenna has been fed by a stripline which helps in efficient coupling of microwave power to slotline. A triplicate structure of Vivaldi Antenna is designed that helps in reducing the spurious radiation from stripline feed. The Vivaldi Antenna is then fabricated and measured to show good agreement with the simulated results. All the designs, simulations, and analysis have been done in CST Microwave Studio Suite 2018.**

Keywords: Vivaldi Antenna, Return Loss, Tapered Slot Antenna, Wi–MAX

I. INTRODUCTION

Tapered Slot Antenna (TSA) is a unique class of antenna within which a slotline is flared to supply an aperture for microwave radiations in free space. The flare for widening of slotline will be supplied with the assistance of straight line, exponential, elliptical or parabolic curve equation. A combination of two curves is additionally used to achieve the specified antenna characteristics. A TSA during which the slotline is flared using an exponential curve equation is termed as 'Vivaldi Antenna'. The Vivaldi Antenna is a slow wave, leaky, end-fire, traveling wave antenna. This antenna consists of two parts: *radiator*–the part of antenna body - shape responsible for creating radiation by the currents flowing through it, and *matching* part–which makes impedance transition from radiator to the system impedance at which antenna is designed. Radiator part can also be considered as a matching between transmission line and the free space. Theoretically, the Vivaldi antenna has a limitless operating frequency range, with uniform beam width over the complete range of bandwidth. It could be a sort of traveling-wave antenna of the 'surface-type'. The waves travel down the curved path of the flare along the antenna. Within the region where the separation between the conductors is small as compared to the free-space wavelength, the waves are bound and because the separation increases, the bond becomes progressively weaker and also the waves get radiated far away from the antenna. The length, width, and taper profile affect the radiation characteristics of Vivaldi Antenna because the gain of Vivaldi Antenna is proportional to $L/\lambda g$. [1]. Etching out of the tapered slot is done from the thin metal layer which is deposited on the substrate. Dielectric based or dielectric free Vivaldi antenna may be fed through coaxial line, micro strip line, strip line, or coplanar waveguide. The stripline or microstrip fed Vivaldi antenna can operate upto large bandwidths with high radiation efficiency and consistent beam width. Vivaldi Antennas are often designed to attain the bandwidth of 10:1. Vivaldi antenna needs to have perfect impedance matching at both the feed slotline as well as slotline free transition to attain a wider bandwidth. Hence, the foremost important design aspect is to provide an appropriate feeding and reduction in wave reflection at the transition regions. In this paper a Vivaldi antenna is designed, fabricated, and tested in the frequency range of 3.2. to3.8 GHz range

II. TRANSITION REGIONS AND IMPEDANCE MATCHING

The matching is crucial for the operation of an antenna, since antenna is a part of the system and the affective power delivery to the antenna radiator is essential for successful communication.

Matching also affects the radiation properties of the radiator of the antenna. Microstrip to slot line or stripline to slotline has been used as the feeding techniques for the broadband application purpose [1]. In microstrip – slotline transition, the microstrip feed acts as an impedance transformer and it matches 50Ω coaxial line to a high impedance slotline. Better the smoothness of the transition better will be the performance of the Vivaldi Antenna. Hence, the matching aspect of transition is very essential to design a Vivaldi Antenna. Transition regions in Vivaldi Antenna are shown in figure 1.

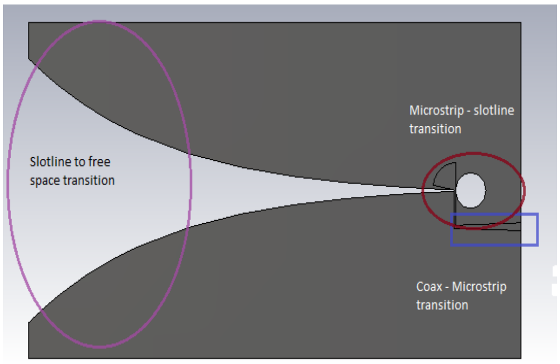


Figure 1: Transition Regions in Vivaldi Antenna

The broadband impedance matching for Vivaldi antenna engage orthogonal crossover of microstrip and slotline with radial stub at the end of microstrip and circular cavity at the end of slotline. At higher frequencies, this circular cavity at the end of slotline behaves as a virtual open circuit and the radial stub acts as a virtual short circuit. This sort of transition is often used for ultra-broadband matching.

III. DESIGN OF EXPONENTIAL FLARE

The exponentially flared slotline governs the slot line to free space transition. This transition substantially influences the return loss of a Vivaldi Antenna. Hence, in order to get efficient radiation in free space, the width of the open-end is usually kept greater than $\lambda_0/2$. This criterion plays a very important role in lowering down the reflections at the slotline – free space transition. Besides, the flare, the rate of flare also influences VSWR of the antenna. Equation of the exponential flare is mentioned in equation 1 [2]:

$$y = ae^{Px} + b$$

Where,

$$a = \frac{(y_2 - y_1)}{(e^{Px_2} - e^{Px_1})}$$

$$b = \frac{(y_1 e^{Px_2} - y_2 e^{Px_1})}{(e^{Px_2} - e^{Px_1})}$$

P = flare or taper factor

(x_1, y_1) = flare start point coordinates

(x_2, y_2) = flare end point coordinates

The flare opening rate is directed by the flare factor P.

It is impossible to attain an impedance of 50 Ω for a slotline hence the exponentially opened slotline is usually fed by a microstrip feed line. Consequently, various matching networks are used to feed slotline with microstrip. The theory of balanced slotline is used to bridle this problem and stripline feed is employed rather than microstrip feed. Stripline transmission line requires ground plane on both the sides. Hence, the slotline is printed on both the sides appear in parallel and can be matched with a 50 Ω stripline. As mentioned before, for a broadband performance the slotline is terminated by a circular cavity and consequently the stripline is terminated with a radial stub. This cavity stub model is used to design broadband Vivaldi Antenna particularly for microwave frequencies. Cavity and radial stub cancel the reactance of each other which results in the impedance matching.

IV. DESIGN OF VIVALDI ANTENNA FOR Wi – MAX BAND

The mechanical dimensions for a Vivaldi Antenna operating for Wi – MAX Mid Band frequency range of 3.2 GHz to 3.8 GHz has been acquired by using design equations and a model has been designed, simulated and optimized using CST Microwave Studio Suite 2018. As mentioned before, the height of the substrate and dielectric constant plays a major role in impedance matching, hence, FR4 substrate (εr = 4.3) with loss tangent 0.02, has been found suitable to attain the desired bandwidth[3].

Table I.Design parameters of Vivaldi Antenna for Wi – MAX

Widest distance between two flares	67.70 mm
Slot line impedance	100 Ω
Slot line width	0.39 mm
Stripline impedance	50 Ω
Stripline width (maximum)	2.09 mm
Stripline width (near stub)	0.6 mm
Circular cavity	Open Circuit
Radius of circular cavity	4.69 mm
Radial Stub Angle	110°

These dimensions provide an efficient radiation from the Vivaldi Antenna in 3.2 GHz – 3.8 GHz frequency range. In the optimization process, the length, width and also the other parameters are varied within the ± 10 % range to test the effects of parameters on the antenna characteristics [4].

The objective is to attain return loss better than -10 dB for 3.2 GHz – 3.8 GHz frequency for Wi – MAX applications.

The stripline fed Wi – MAX Vivaldi Antenna is a complex structure and may give errors in simulated results. Adaptive meshing feature is used to ensure the accuracy of simulated results, which is available in CST Microwave Studio Suite 2018. Adaptive meshing feature uses finer mesh, which helps in enhancing the accuracy of simulated results. The antenna is fabricated using LKPF ProtoMat S64. It is used in the manufacturing of high-performance PCBs. The high speed of the low maintenance milling spindle guarantees the production of fine structures and allows the formation of multi-layers. The LKPF ProtoMat S64 is shown in figure 2.

Figure 2: LKPF ProtoMat S64

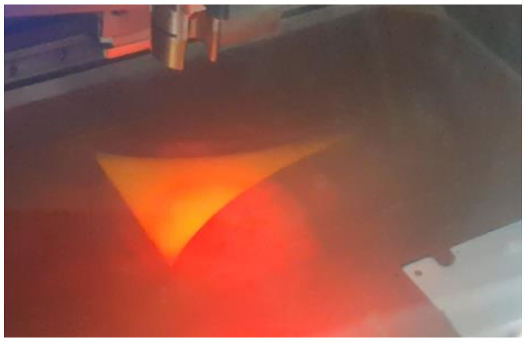


Figure 3: Vivaldi Antenna fabrication process

V. RESULTS AND DISCUSSION

A single Wi – MAX mid band Vivaldi Antenna have been designed and simulated. After taking down the simulated results, the antenna is fabricated with the specification mention in table 1.The fabricated antenna is shown in figure 4.

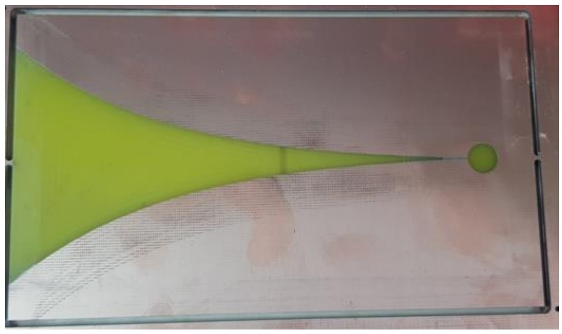


Figure 4: Fabricated Antenna

The results of the fabricated antenna have been tested through Fox RF Network Analyzer N9914A from Keysight Technologies Field. Maximum return loss of -27.105 dB is obtained at 3.5.GHz and -31.38 dB at 3.635GHz, as can be seen in figure 5. Figure 6 shows the measured VSWR is 1.06 at 3.635GHz and it shows good impedance matching. The comparison of return loss and VSWR for both the simulated and fabricated results has been done and is shown in figure 7 and 8 respectively.

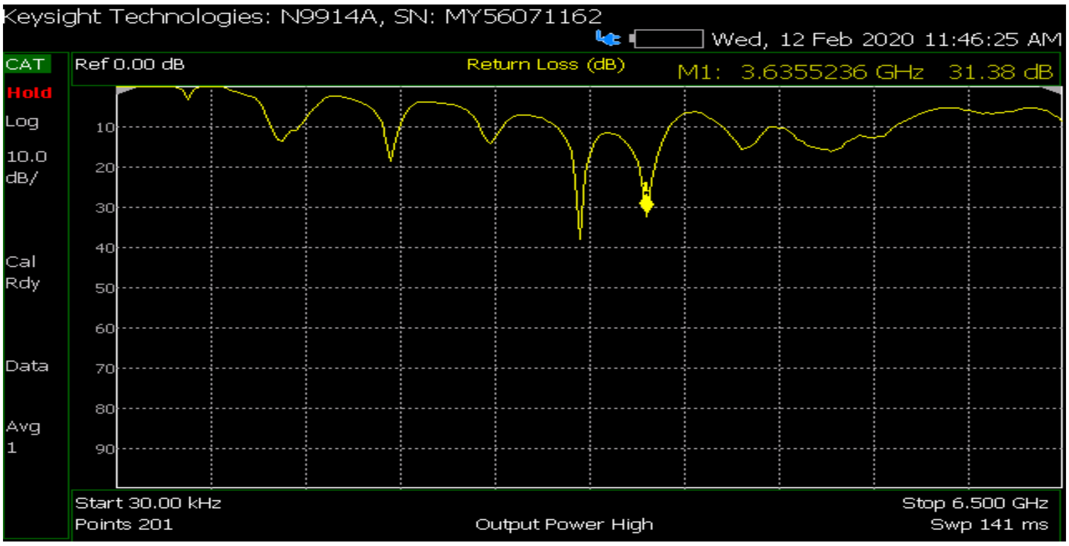


Figure 5: S-Parameter obtained from Network Analyzer

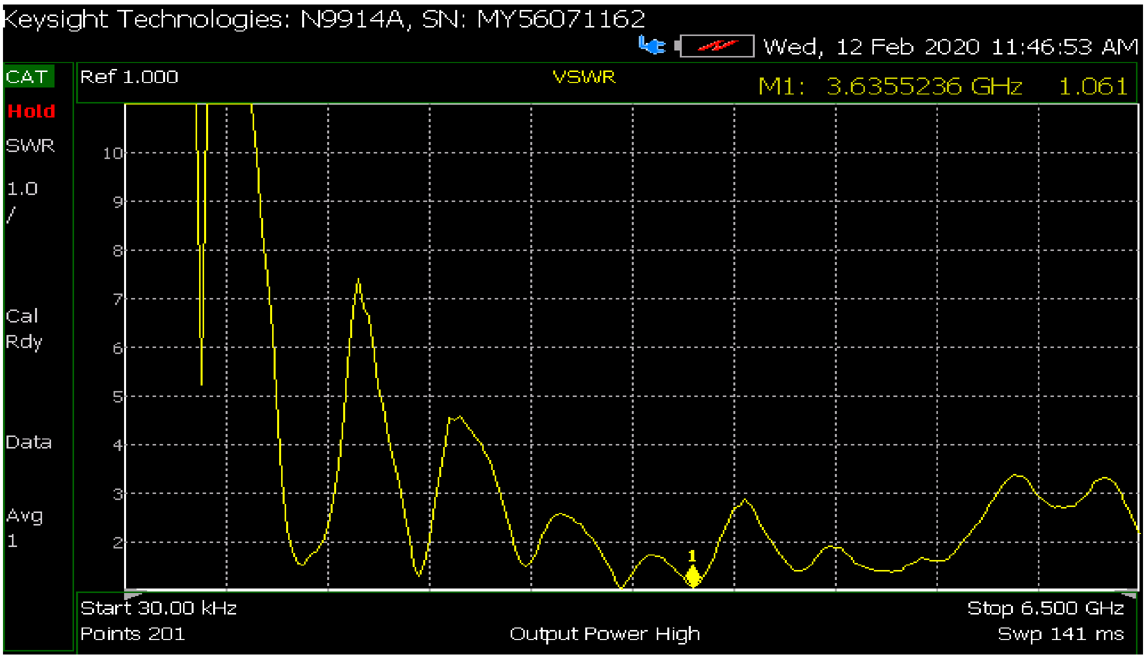
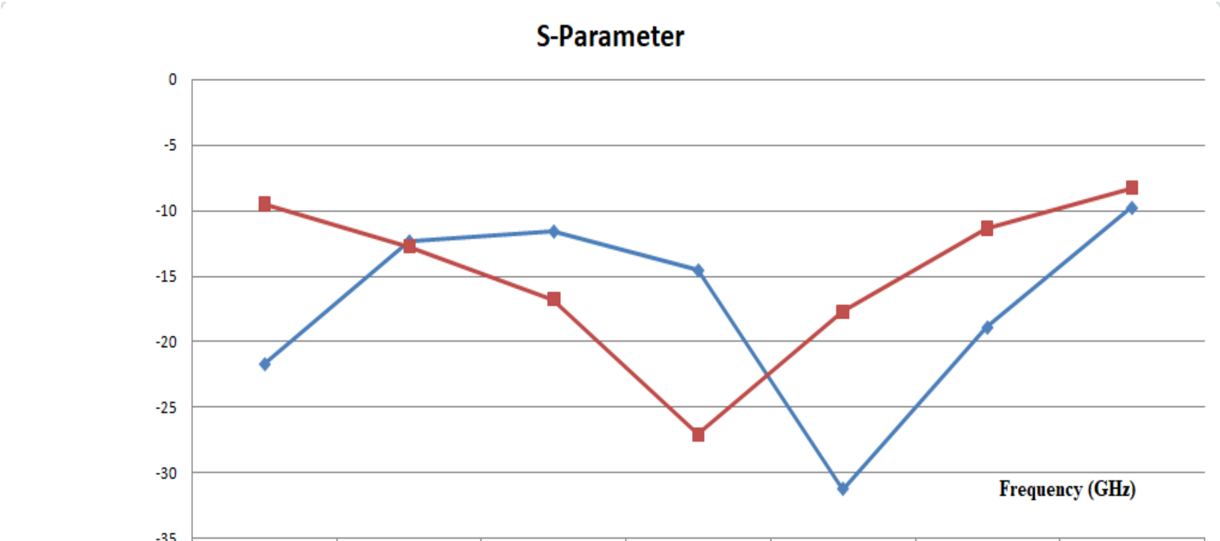


Figure 6: VSWR obtained from Network Analyzer

The graphs of compared results of simulated and fabricated Vivaldi Antennas are shown:



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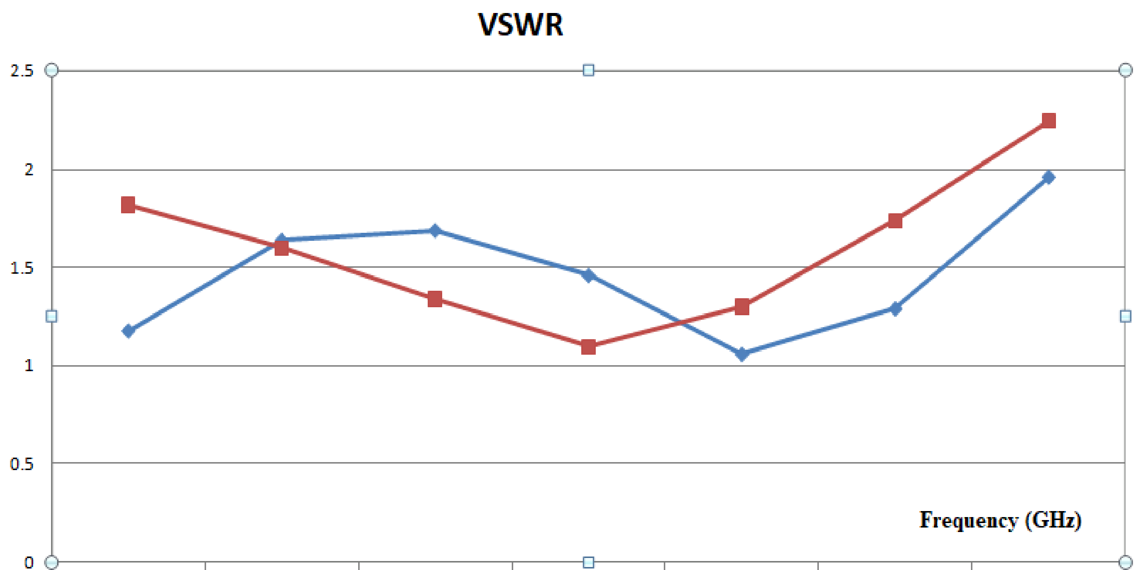
Magnitude (dB) (S)	-9.531	-12.773	-16.803	-27.105	-17.741	-11.394	-8.317

Figure 7: Comparison of S-Parameter of simulated and fabricated antenna



	3.2	3.3	3.4	3.5	3.6	3.7	3.8
VSWR (F)	1.178	1.638	1.687	1.459	1.059	1.29	1.959
VSWR (S)	1.816	1.596	1.337	1.094	1.298	1.737	2.245

Figure 8: Comparison of VSWR of simulated and fabricated antenna

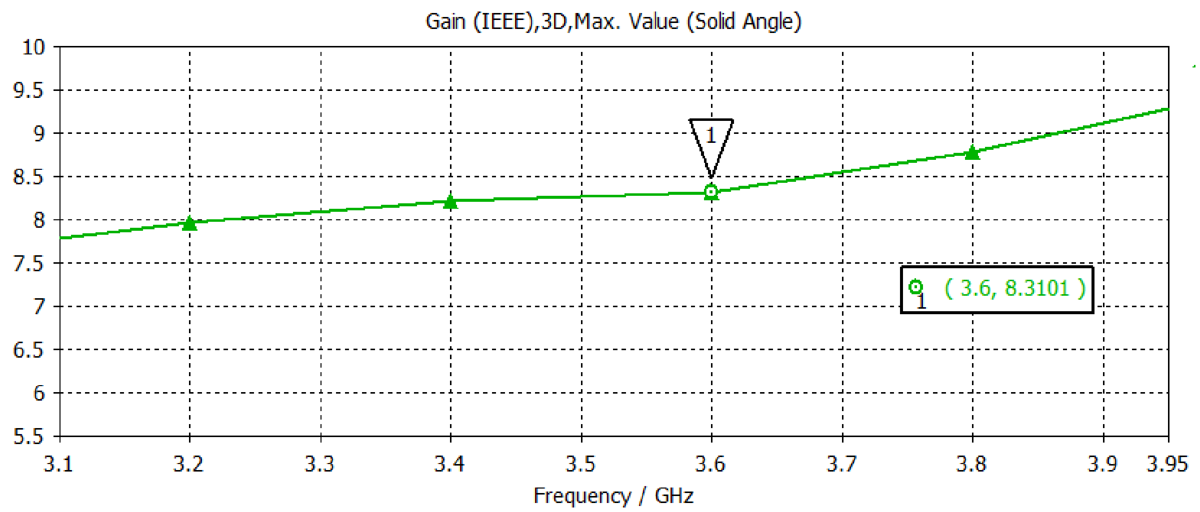


Figure 9: IEEE Gain at 3.6 GHz

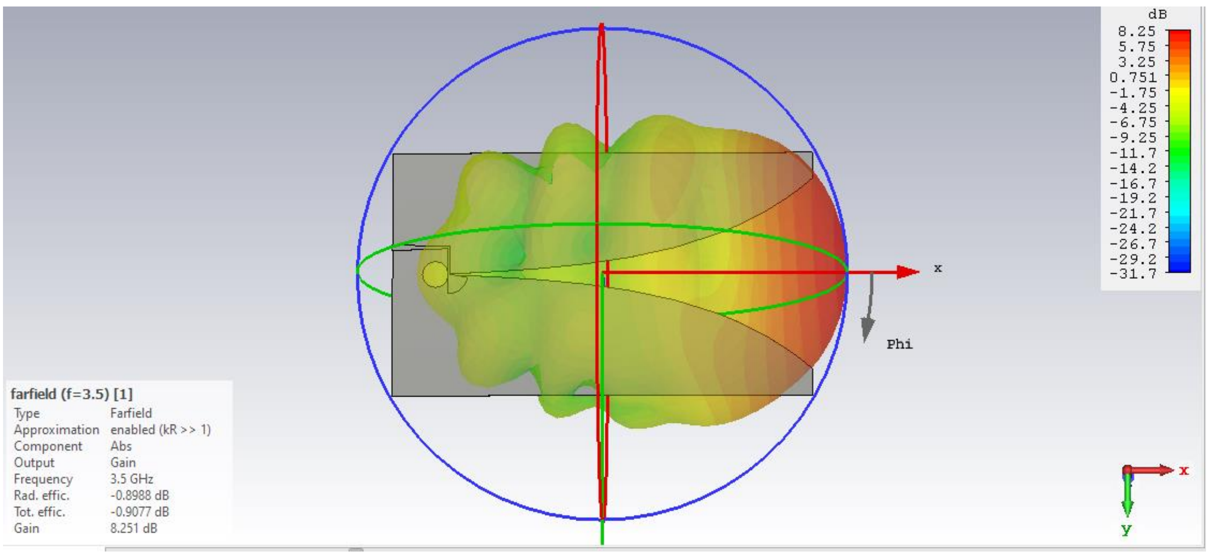


Figure 10: 3-D Gain at 3.5 GHz

Vivaldi Antenna for Wi – MAX application simulations have given expected results in terms of VSWR, return loss and gain. Figure 10 shows 3 dimensional gain plot of antenna. The maximum gain of antenna is 8.3101 dB is achieved at 3.6 GHz as shown in figure 9. The antenna presented in this paper can be used in limited range of broadband applications. Wi – MAX antenna can be used to connect 802.11 hotspots to the internet, provide campus connectivity, and provide a wireless alternative to cable and DSL for broadband access.

In future, this antenna can be converted to 5X1 H-plane array to find out the effect of array environment on the characteristics of Vivaldi Antenna [5]. The parametric study of Vivaldi Antenna and arrays might be extended observing their effects on antenna and array performance in a broader bandwidth. The microstrip to slot line, antipodal, and balanced antipodal transitions as well as the stripline to slotline transitions with no-uniform stubs might be considered in order to observe the effects of parameters on the designs with different antenna feeding techniques [6].

A Vivaldi antenna has been designed for Wi Max applications in the frequency range of 3.2 to 3.8 GHz. The proposed design is simulated on CST Microwave Studio Suite 2018, fabricated on ProtoMat S64 circuit Board Plotter and measurements have been done on Fox RF Network Analyzer N9914A from Keysight Technologies Field. Simulated and fabricated results shows good agreement with each other.

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AUTHORS

Dr.Priyanka Jain
Ph.D., M.Tech. B.E
Associate Professor
Department of Electronics and Communication Engineering
Delhi Technological University

Sony
Pursuing M.Tech
Microwave and Optical Communication Engineering
Department of Electronics and Communication Engineering
Delhi Technological University