


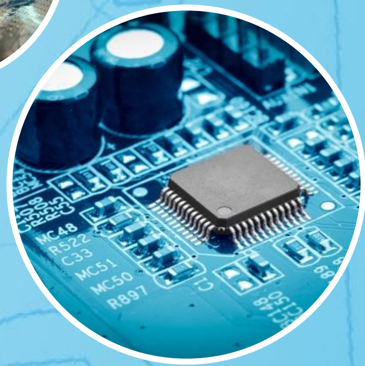


IEEE Summer Research Internship Report

On

# VIRTUAL PROTOTYPING OF ANTENNAS USING HFSS


Submitted by:

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# Declaration

*This is to certify that the internship report comprises of original work (except where indicated) carried out by me and due acknowledgments have been made in the text to all other material used. The report does not contain any classified information which will be detrimental to national security and is not submitted in any form for another degree or diploma at any other institute/university.*

**Shirshendu Chatterjee**

Shirshendu Chatterjee

# Abstract

*With the proliferation of RF communication in present era, the antenna design with scientific approach is very important criteria to meet the demand of various frequency bands. The exercise of choosing different construction in line with the Dipole, Monopole with Co-Ax feed and Horn Antenna is a scientific approach as per frequency selection and to comply its characteristics on Directivity, Gain and different parameters as per the requirements of relevant standards. The design of such antennas using HFSS has been done to extrapolate the exact characteristics of different shape of the antenna. This report is having such exercise to carry out the test and establish relevant data and evaluation of the relevant parameters through mathematical approach and software application. This design concept has been done based on application in Domestic as well as Industrial Development.*

# Acknowledgment

*I would like to express my gratitude to my Mentor as well as the IEEE AP-MTTS branch IIT Kharagpur who gave me the golden opportunity to do this wonderful project on the Design and Simulation of Antennas, which also helped me in doing a lot of research and I came to know about so many new things.*

*I am really thankful to them.*

*Secondly I would really like to thank my parents and my friends who helped me finishing this project within the limited time. I am making this project not only for marks but to gather and increase my knowledge.*

*THANKS AGAIN TO ALL WHO HELPED ME.*

# 1.INTRODUCTION

An antenna that transmits sends and receives signal such as microwave, radio or satellite signals. A high gain antenna increases signal strength and a low gain antenna decreases signal strength. An antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver.

It is a specialized transducer that converts radio-frequency (RF) fields into alternating current and vise versa or a device which is required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. There are two types of basic antennas: the Receiving antenna which intercepts the RF energy and delivers AC to electronic equipment and the transparent antenna, which is fed with AC from electronics equipment and generates an RF field.

## 1.1 BASIC TYPES OF ANTENNA:

There are two basic types of antenna-1) Transmitting Antenna 2) Receiving Antenna
Transmitting Antenna-
This is the type of antenna which fed by AC from electronic equipment and generates an RF field. The transmitter is represented by its input impedance( which is frequency dependent and is affected b the object nearby) as seen from the generator.
Receiving Antenna-
This is what intercepts RF energy and delivers AC to the electronic equipment. The receiver is represented by input impedance as seen from the antenna terminals (i.e. transformed by the transmission lines).
Except these basic two antennas there are many antennas in our communication system. Such as: Horn Antenna, Monopole Antenna, band Antenna, long wire antenna, corner antenna, reflector, cubical quad antenna, rhombic antenna, plasma antenna, GPS antenna, ground plane antenna, liquid metal antenna, yagi-uda antenna etc.

Here we are going to report three different types of antenna- the Dipole Antenna, the Monopole Antenna with Co-Ax feed both operating at 1 GHz and Horn Antenna operating at X band. Different parameters of antenna such as: Z parameter, Current distribution, S parameter and Directivity gain etc.

# 2.THEORY

The equations governing the premetioned antenna is a bit different from each other and thus needs a good introduction. The dipole or the monopole antennas fall in the group of Linear wire antennas, thus they may show a similarity governing the basic theory. Wire antennas, linear or curved, are some of the oldest, simplest, cheapest, and in many cases the most versatile for many applications.

## 2.1 DIPOLE ANTENNA

A dipole antenna commonly consists of two identical conductive elements, such as metal wires or rods. The driving current from the transmitter is applied, or for receiving antennas the output signal to the receiver is taken, between the two halves of the antenna. Each side of the feedline to the transmitter or receiver is connected to one of the conductors. This contrasts with a monopole antenna, which consists of a single rod or conductor with one side of the feedline connected to it, and the other side connected to some type of ground.

Dipoles are of three types depending upon the length of the conductor- Infinitesimal Dipole, Small dipole and Finite length dipole. Here we are interested in Finite length dipole whose length is comparable to that of the wavelength.

The fundamental resonance of a thin linear conductor occurs at a frequency whose free-space wavelength is twice the wire's length, i.e. where the conductor is 1/2 wavelength long. Dipole antennas are frequently used at around that frequency and thus termed half-wavelength dipole antennas.

Thin linear conductors of length are in fact resonant at any integer multiple of a half-wavelength, For a center-fed dipole, however, there is a great dissimilarity between *n* being odd or being even. Dipoles which are an odd number of half-wavelengths in length have reasonably low driving point impedances (which are purely resistive at that resonant frequency). However ones which are an even number of half-wavelengths in length, that is, an integer number of wavelengths in length, have huge driving point impedance (albeit purely resistive at that resonant frequency).

$l=n\lambda/2$**,** where l is the length of the conductor, n is an integer and $\lambda$ is the wavelength.

**OPERATION OF DIPOLE ANTENNA-**

The edge of the dipole has maximum voltage. This voltage is alternating (AC) in nature. At the positive peak of the voltage, the electrons tend to move in one direction and at the negative peak, the electrons move in the other direction. The cumulative effect of this produces a varying field effect which gets radiated in the same pattern produced on it. Hence, the output would be an effective radiation following the cycles of the output voltage pattern.

## 2.1.1 FINITE LENGTH DIPOLE

The dipole antenna with a very thin radius is considered. The dipole antenna is similar to that of the short antenna except it is not required to be small compared to the wavelength (at the frequency antenna is operating at).

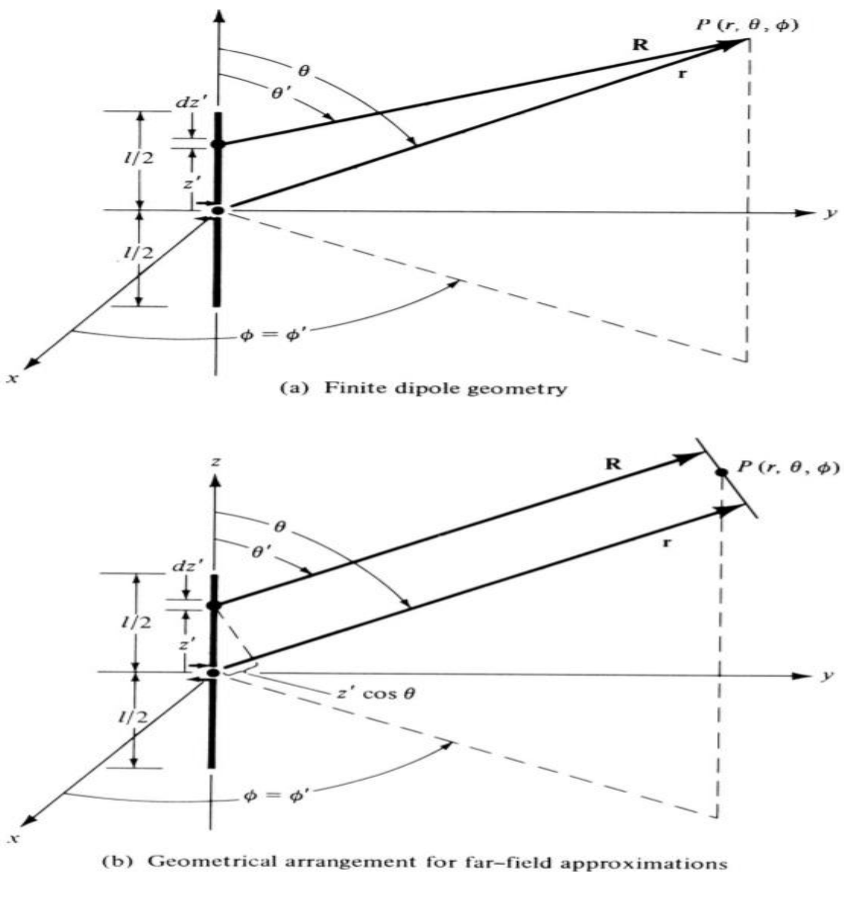



Fig 1- Finite Dipole Geometry and Far Field approximation

The Current distribution of the finite length dipole is given by-

$$\mathbf{I}_e(x'=0, y'=0, z') = \begin{cases} \hat{\mathbf{a}}_z I_0 \sin\left[k\left(\frac{l}{2} - z'\right)\right], & 0 \le z' \le l/2 \\ \hat{\mathbf{a}}_z I_0 \sin\left[k\left(\frac{l}{2} + z'\right)\right], & -l/2 \le z' \le 0 \end{cases}$$

……Eq.1)

For each of the three types of dipoles the very basic and important parameter which varies the field characteristics is the current distribution. This distribution assumes that the antenna is center-fed and the current vanishes at the end points ($z' = \pm l/2$). Experimentally it has been verified that the current in a center-fed wire antenna has sinusoidal form with nulls at the end points.

The radiating fields are calculated by introducing the current distribution of the dipole into picture. For the current distribution it is seen that closed form expressions for the E- and H-fields can be obtained which are valid in all regions (any observation point except on the source itself).

Thus the E and H fields are given by-

$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]$$

…Eq.2)

$$H_\phi \simeq \frac{E_\theta}{\eta} \simeq j\frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]$$

…Eq.3)

Usually we are limited to the far-field region, because of the mathematical complications provided in the integration of the vector potential A. Since closed form solutions, which are valid everywhere, cannot be obtained for many antennas, the observations will be restricted to the far-field region.

Some of the important parameter which are very important to discuss are the-

**Impedance of various lengths**- The impedance of feed point of a dipole antenna is sensitive to both of its electrical length and feed point position. Hence, a dipole will perform over rather narrow bandwidth . When it exceeds beyond this bandwidth the impedance will match poorly to the transmitter or receiver. The smaller dipole with small wavelength of the signal is called as short dipole. These diploes are having low level of radiation resistance which insists them to be as ineffective antennas. The Transmitter current is mostly dissipated owing to the resistance of the conductor which is greater than the Heat - radiation resistance.

**Directivity** – Directivity is a fundamental antenna parameter. It is a measure of how ‘directional’ an antenna’s radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1(or 0dB).
If the antennas normalized radiation parameter can be written as a function in spherical co-ordinates,
$F(\theta,\phi)$ , then the directivity can be written as –

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}|F(\theta,\phi)|^2 \sin\theta d\theta d\phi}$$

…Eq.4)

**APPLICATIONS-**

The dipole antennas have many applications which include-

- Dipole Arrays- Many types of array antennas are constructed using multiple dipoles, usually half-wave dipoles. The purpose of using multiple dipoles is to increase the directional gain of the antenna over the gain of a single dipole; the radiation of the separate dipoles interferes to enhance power radiated in desired directions.
- Shortwave Antenna- Horizontal wire dipole antennas are popular for use on the HF shortwave bands, both for transmitting and shortwave listening.
- “Rabbit Ears” TV Antenna- One of the most common applications of the dipole antenna is the rabbit ears or bunny ears television antenna, found atop broadcast television receivers. It is used to receive the VHF terrestrial television bands, consisting in the US of 54 to 88 MHz and 174 to 216 MHz ,with wavelengths of 5.5 to 1.4 m.

# 2.2 MONOPOLE ANTENNA

A **monopole antenna** is a class of radio antenna consisting of a straight rod-shaped conductor, often mounted perpendicularly over some type of conductive surface, called a ground plane. The driving signal from the transmitter is applied, or for receiving antennas the output signal to the receiver is taken, between the lower end of the monopole and the ground plane. One side of the antenna feedline is attached to the lower end of the monopole, and the other side is attached to the ground plane, which is often the Earth. This contrasts with a dipole antenna which consists of two identical rod conductors, with the signal from the transmitter applied between the two halves of the antenna.

Using image theory, the fields above the ground plane can be found by using equivalent source( antenna ) in free space. This is simply a dipole antenna of twice the length.

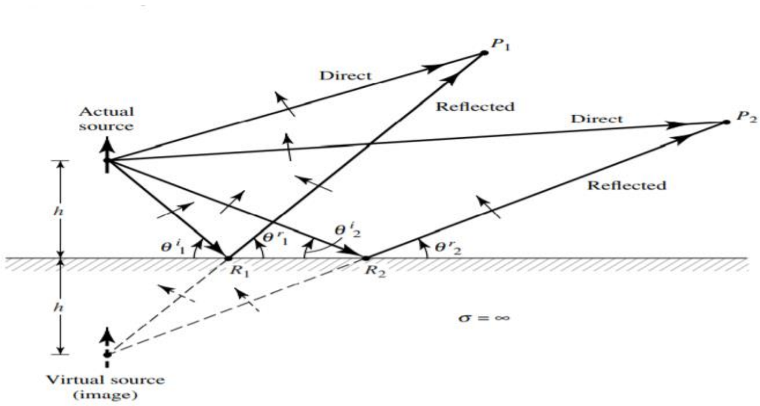



Fig 2- Vertical electric dipole above an infinite, flat, perfect electric conductor.

The monopole is often used as a resonant antenna; the rod functions as an open resonator for radio waves, oscillating with standing waves of voltage and current along its length. Therefore the length of the antenna is determined by the wavelength of the radio waves it is used with. The most common form is the quarter-wave monopole, in which the antenna is approximately one quarter of the wavelength of the radio waves.

Based on the image theory, the mathematical expression for the fields of vertical linear element near a perfect electric conductor is developed and for simplicity far field observations are considered.

After calculations, field has been observed as,

$$\left.\begin{array}{ll} E_\theta \simeq j\eta \dfrac{kI_0 l e^{-jkr}}{4\pi r} \sin\theta[2\cos(kh\cos\theta)] & z \geq 0 \\ E_\theta = 0 & z < 0 \end{array}\right\}$$

…Eq.5)

It is evident that the total electric field is equal to the product of the field of a single source positioned symmetrically about the origin and a factor which is a function of the antenna height (h) and the observation angle ($\theta$). This is referred to as pattern multiplication and the factor is known as the array factor.

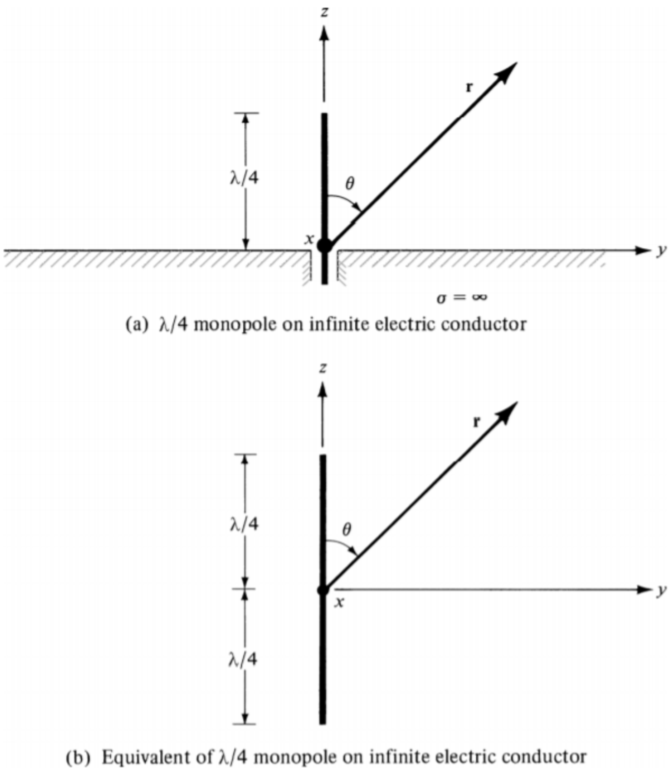



Fig 3- Quarter-wavelength monopole on an infinite perfect electric conductor.

The directivity of the monopole is given by-

$$D_0 = \frac{4\pi U_{\max}}{P_{\text{rad}}} = \frac{2}{\left[\frac{1}{3} - \frac{\cos(2kh)}{(2kh)^2} + \frac{\sin(2kh)}{(2kh)^3}\right]}$$

...Eq.6)

**APPLICATIONS-**

Monopole Antennas are widely used and are used in our daily applications which includes-

- Cordless telephones
- Walkie- Talkies
- WLAN
- The Antennas on Car, Aeroplane etc.

## 2.3 HORN ANTENNA

A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz. They are used as feed antennas (called feed horns) for larger antenna structures such as parabolic antennas, as standard calibration antennas to measure the gain of other antennas, and as directive antennas for such devices as radar guns, automatic door openers, and microwave radiometers. Their advantages are moderate directivity, low standing wave ratio (SWR), broad bandwidth, and simple construction and adjustment.

There can be different types of horn antenna-

**Pyramidal horn** – a horn antenna with the horn in the shape of a four-sided pyramid, with a rectangular cross section. They are a common type, used with rectangular waveguides, and radiate linearly polarized radio waves.

**Sectoral horn** – A pyramidal horn with only one pair of sides flared and the other pair parallel. It produces a fan-shaped beam, which is narrow in the plane of the flared sides, but wide in the plane of the narrow sides. These types are often used as feed horns for wide search radar antennas.

**E-plane horn** – A sectoral horn flared in the direction of the electric or E-field in the waveguide.

**H-plane horn** – A sectoral horn flared in the direction of the magnetic or H-field in the waveguide.

**Conical horn** – A horn in the shape of a cone, with a circular cross section. They are used with cylindrical waveguides.

**Exponential horn** – A horn with curved sides, in which the separation of the sides increases as an exponential function of length. Also called a scalar horn, they can have pyramidal or conical cross sections. Exponential horns have minimum internal reflections, and almost constant impedance and other characteristics over a wide frequency range. They are used in applications requiring high performance, such as feed horns for communication satellite antennas and radio telescopes.

**Corrugated horn** – A horn with parallel slots or grooves, small compared with a wavelength, covering the inside surface of the horn, transverse to the axis. Corrugated horns have wider bandwidth and smaller sidelobes and cross-polarization, and are widely used as feed horns for satellite dishes and radio telescopes.

**Dual-mode conical horn** – This horn can be used to replace the corrugated horn for use at sub-mm wavelengths where the corrugated horn is lossy and difficult to fabricate.

**Diagonal horn** – This simple dual-mode horn superficially looks like a pyramidal horn with a square output aperture. On closer inspection, however, the square output aperture is seen to be rotated 45° relative to the waveguide. These horns are typically machined into split blocks and used at sub-mm wavelengths.

**Ridged horn** – A pyramidal horn with ridges or fins attached to the inside of the horn, extending down the center of the sides. The fins lower the cutoff frequency, increasing the antenna's bandwidth.

**Septum horn** – A horn which is divided into several subhorns by metal partitions (septums) inside, attached to opposite walls.

**Aperture-limited horn** – a long narrow horn, long enough so the phase error is a negligible fraction of a wavelength, so it essentially radiates a plane wave. It has an aperture efficiency of 1.0 so it gives the maximum gain and minimum beamwidth for a given aperture size. The gain is not affected by the length but only limited by diffraction at the aperture. Used as feed horns in radio telescopes and other high-resolution antennas.

Here we are only interested in Pyramidal Horn Antenna.

**OPERATION OF HORN ANTENNA-**

A horn antenna serves a similar function for electromagnetic waves that an acoustical horn does for sound waves in a musical instrument such as a trumpet.

When radio waves travelling via the waveguide hit the opening this impedance step reflects a very important fraction of the wave power remise the guide unto the source, so that not all of the energy will be radiated. This can be the same as the reflection at an open ended cable between optical mediums with a low and high index of refraction, like a glass surface.

When a waveguide is suitably excited at one end and opened at the other end a small portion of the energy will be radiated. The reason is a mismatch at the end of the waveguide is opened out, the drawback of mismatch can be avoided. The opening of the waveguide results in an electromagnetic horn.

When the waveguide is terminated by a horn, the abrupt discontinuity is replaced by a gradual transformation and impedance matching is correct. Hence all the energy travels forward and will be radiated. The shape of the radiated field depends on the flare angle of the horn.

The pyramidal horn and the conical horn give pencil like beams that have pronounced directivity in both vertical and horizontal planes. Fan shaped beams result in sectoral horns.

**WHAT IS FLARING?**

To improve the radiation efficiency and directivity of the beam, the waveguide should be provided with an extended aperture so as to make the abrupt discontinuity of the wave into a gradual transformation, so that all the energy in the forward direction gets radiated. This can be termed as **Flaring**.

## 2.3.1 PYRAMIDAL HORN ANTENNA

The most widely used horn is the one which is flared in both directions. It is widely referred to as a pyramidal horn, and its radiation characteristics are essentially a combination of the E- and H-plane sectoral horns.

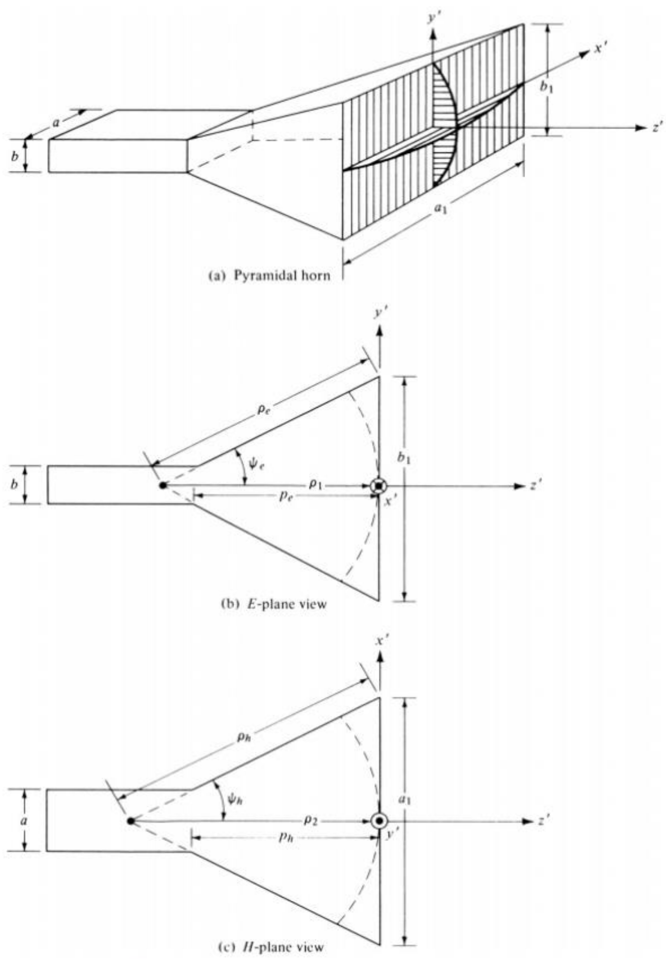



Fig 4- Pyramidal Horn Antenna

To simplify the analysis and to maintain a modeling that leads to computations that have been shown to correlate well with experimental data, the tangential components of the E- and H-fields over the aperture of the horn are approximated by-

$$E_y'(x', y') = E_0 \cos\left(\frac{\pi}{a_1}x'\right) e^{-j[k(x'^2/\rho_2 + y'^2/\rho_1)/2]}$$

$$H_x'(x', y') = -\frac{E_0}{\eta} \cos\left(\frac{\pi}{a_1}x'\right) e^{-j[k(x'^2/\rho_2 + y'^2/\rho_1)/2]}$$

…Eq.7)

And the current densities are given by,

$$J_y(x', y') = -\frac{E_0}{\eta} \cos\left(\frac{\pi}{a_1}x'\right) e^{-j[k(x'^2/\rho_2 + y'^2/\rho_1)/2]}$$

$$M_x(x', y') = E_0 \cos\left(\frac{\pi}{a_1}x'\right) e^{-j[k(x'^2/\rho_2 + y'^2/\rho_1/2]}$$

...Eq.8)

After calculating, he far zone E and H fields are given by-

$$E_r = 0$$

$$E_\theta = -j\frac{ke^{jkr}}{4\pi r}[L_\phi + \eta N_\theta]$$

$$= j\frac{kE_0 e^{-jkr}}{4\pi r}[\sin\phi(1 + \cos\theta)I_1 I_2]$$

$$E_\phi = +j\frac{ke^{-jkr}}{4\pi r}[L_\theta - \eta N_\phi]$$

$$= j\frac{kE_0 e^{-jkr}}{4\pi r}[\cos\phi(\cos\theta + 1)I_1 I_2]$$

…Eq.9)

Where, I1 and I2 and N is defined as-

$$I_1 = \frac{1}{2}\sqrt{\frac{\pi\rho_2}{k}}(e^{j(k_x'^2\rho_2/2k)}\{[C(t_2') - C(t_1')] - j[S(t_2') - S(t_1')]\}$$
$$+ e^{j(k_x''^2\rho_2/2k)}\{[C(t_2'') - C(t_1'')] - j[S(t_2'') - S(t_1'')]\})$$

...Eq.10)

$$I_2 = \sqrt{\frac{\pi\rho_1}{k}} e^{j(k_y^2\rho_1/2k)}\{[C(t_2) - C(t_1)] - j[S(t_2) - S(t_1)]\}$$

and,

$$N_\theta = -\frac{E_0}{\eta} \cos\theta \sin\phi I_1 I_2$$

$$N_\phi = -\frac{E_0}{\eta} \cos\phi I_1 I_2$$

$$L_\theta = E_0 \cos\theta \cos\phi I_1 I_2$$

$$L_\phi = -E_0 \sin\phi I_1 I_2$$

…Eq.11)

Again going into the basic important parameters of the horn antenna, the Directivity of the pyramidal antenna is given by-

$$D_p = \frac{\pi\lambda^2}{32ab} D_E D_H$$

…Eq.12)

where $D_E$ and $D_H$ is the directivity of the E and H plane sectoral horns.

**APPLICATIONS-**

- They are commonly used for higher antenna formation as parabolic antennas for like devices as radar guns, automatic door openers, microwave radiometer etc.
- The common element of the phased array.
- Satellite and microwave communications.
- Used in calibration and high gain antenna.

# 3. SIMULATION SOFTWARE

For designing and simulation of the prementioned antennas, the software ANSYS HFSS (student version) has been used.
HFSS is a high performance full wave electromagnetic (EM ) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical interface. It integrates simulation, visualization, solid modeling, and automation in an easy to learn environment where solutions to the 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method(FEM) adaptive meshing, and brilliant graphics to give you unparallel performance and insight to all of 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S parameters, resonant frequency, directivity and fields.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows to shape any arbitrary geometry especially those in complex curves and shapes, in a shape, in a fraction of the time it would take other techniques.
The name HFSS stands for HIGH FREQUENCY STRUCTURE SIMULATOR.

# 4. RESULTS

Using HFSS results are obtained and compared with the predetermined results in previous research papers. The antennas have been designed and simulated using appropiate design methodology.

## 4.1 DIPOLE ANTENNA

The dipole antenna has been designed using HFSS operating at a frequency of 1GHz in the band of 800MHz-1200MHz.
The design properties of the dipole were given and the length of the dipole was varied from quarter wavelength of the dipole to the full wavelength of the applied frequency.

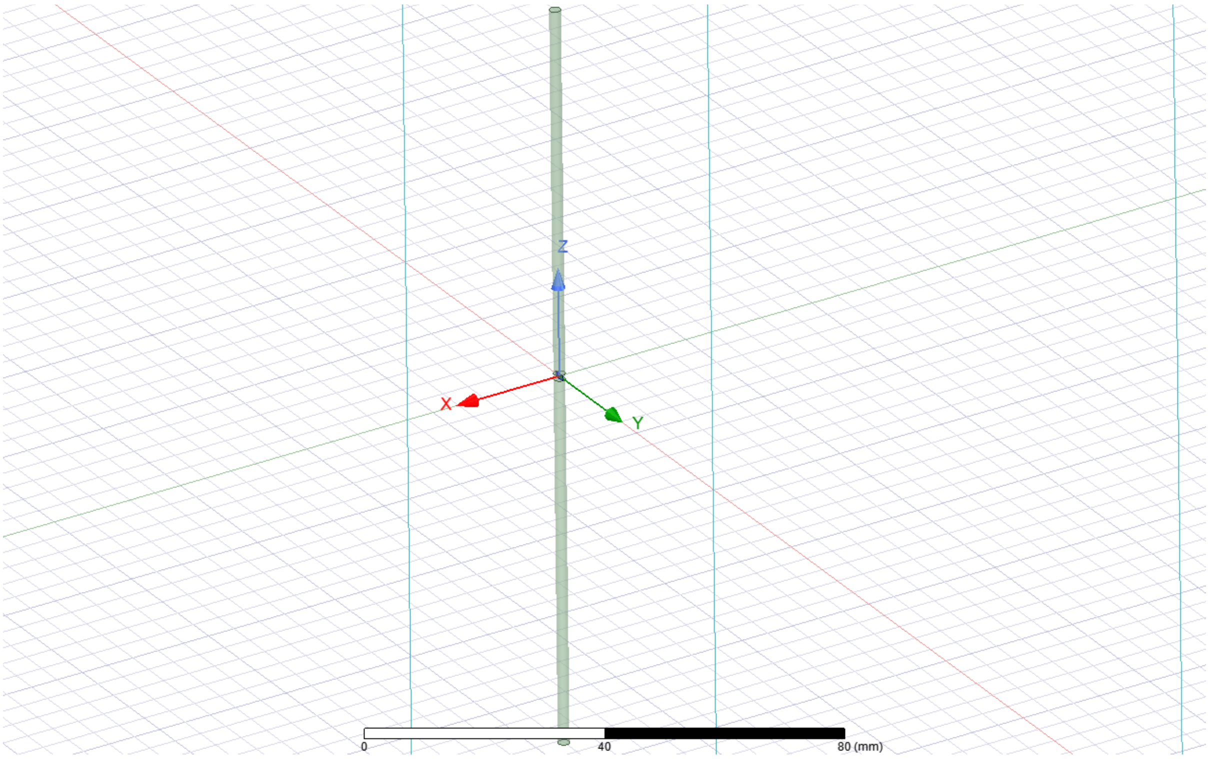



Fig 5- Design of the Dipole Antenna operating at 1GHz

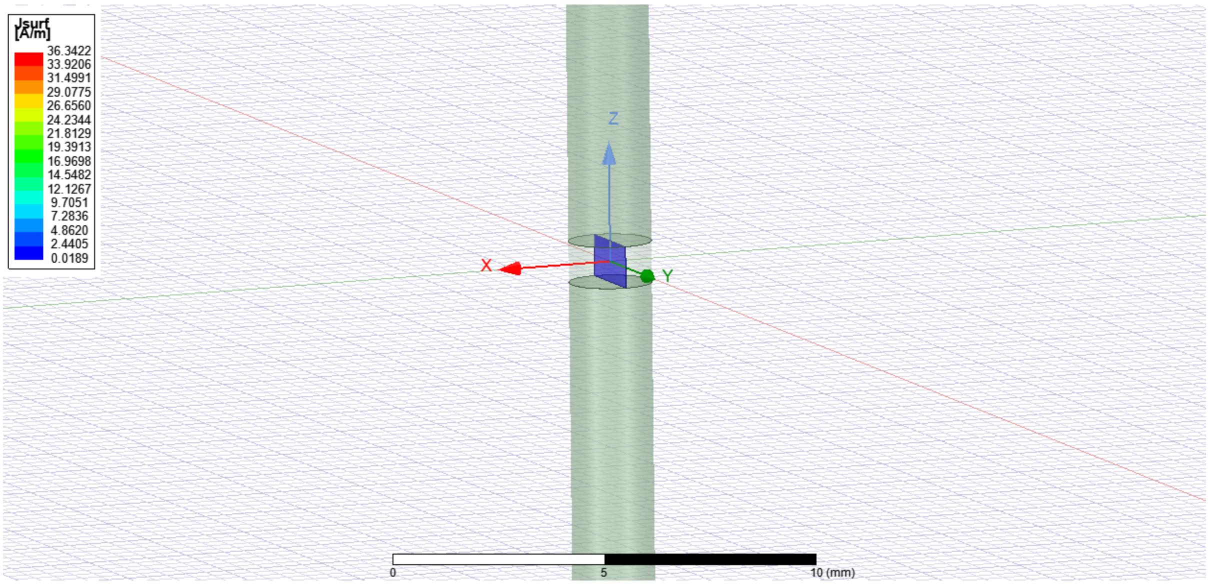
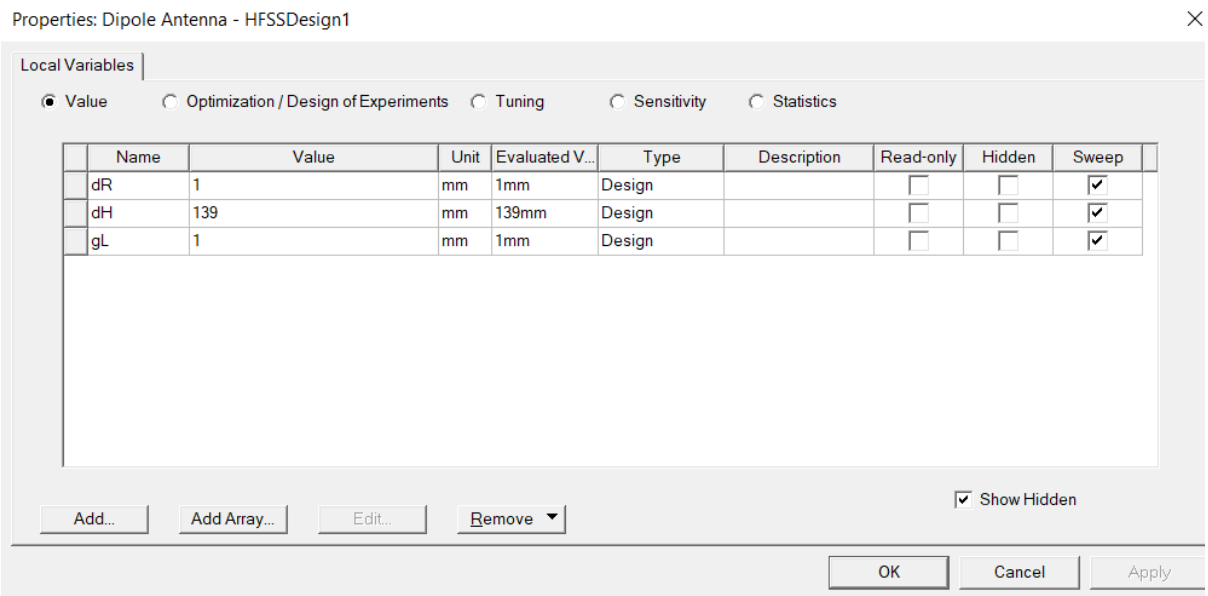



Fig 6- Rectangular Lumped Port separating the two parts of the dipole

The above figure is the design of the dipole. The design parameters is given- the radius of the dipole is 1 mm and the length of the dipole is parameterized and sweeped over four values of the lengths, λ/4,λ/2,3λ/4,λ, where λ=c/f, c is the velocity of light, f is the frequency or the applied frequency.

The design properties and the dimensions used play a critical role in the designing of the antenna. The properties which are used are shown as-




Here the unit is in mm. dR corresponds to the radius of the dipole, dH corresponds to the length of the dipole and gL corresponds to the length of the rectangle.

The conductor used is a pec, with each half of the dipole having length of $\lambda/2$. The feed is given in the middle by a lumped port which has been constructed by creating a rectangle and thus giving excitations to it. A vacuum radiation boundary was created so as to measure the fields.

For excitations a lumped port was used which was given through a square of length 1mm. Some important basic parameters of this dipole were obtained and were re-checked with previously determined results thus proving the design to be accurate. These parameters include- the Z parameter, S parameter, Directivity and the distribution of current along the surface.

First the results are obtained for HALF WAVELENGTH DIPOLE, and after that using optimetrics in HFSS results were obtained for different lengths of the dipole.

HALF WAVELENGTH DIPOLE-

For an applied frequency of 1GHz, the corresponding $\lambda$ is equal to 300 mm. thus for a half wavelength dipole the length of the dipole comes out to be 150 mm. The corresponding dipole parameters are shown below.

**Z-Parameter-**

The z-parameter of the dipole has been plotted and is rechecked with results obtained earlier. In the plot, the real and imaginary impedances are plotted with both their axis defined differently.

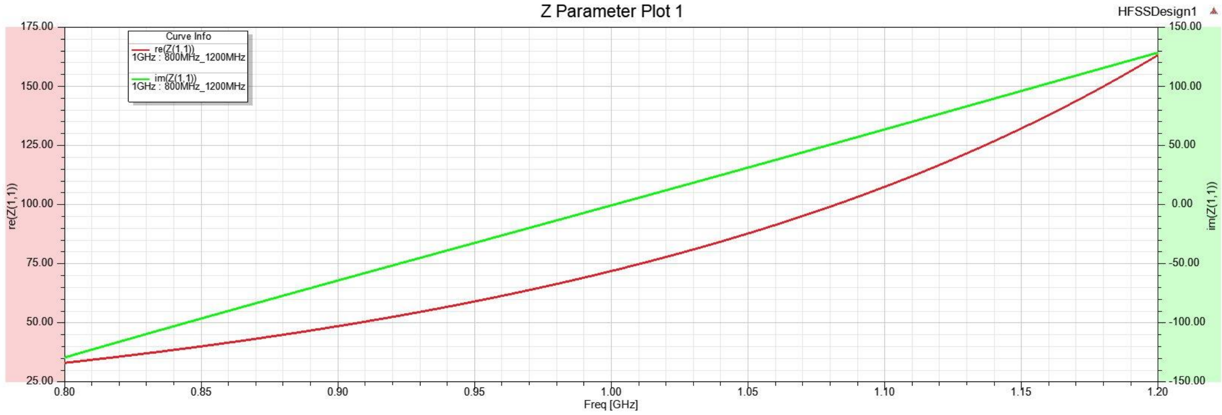



Fig 7- The Z parameter plot of the half wavelength Dipole

It can be seen from the plot the real part of the impedance have been given by the red curve and the imaginary part is given by the green part, and it has been plotted in a frequency sweep of 800MHz-1200MHz. At the frequency of 1GHz it is seen that the real part of the impedance is 98.1 ohms and the imaginary part is -58.22 ohms which approximately matches with the result.

**S-Parameter**

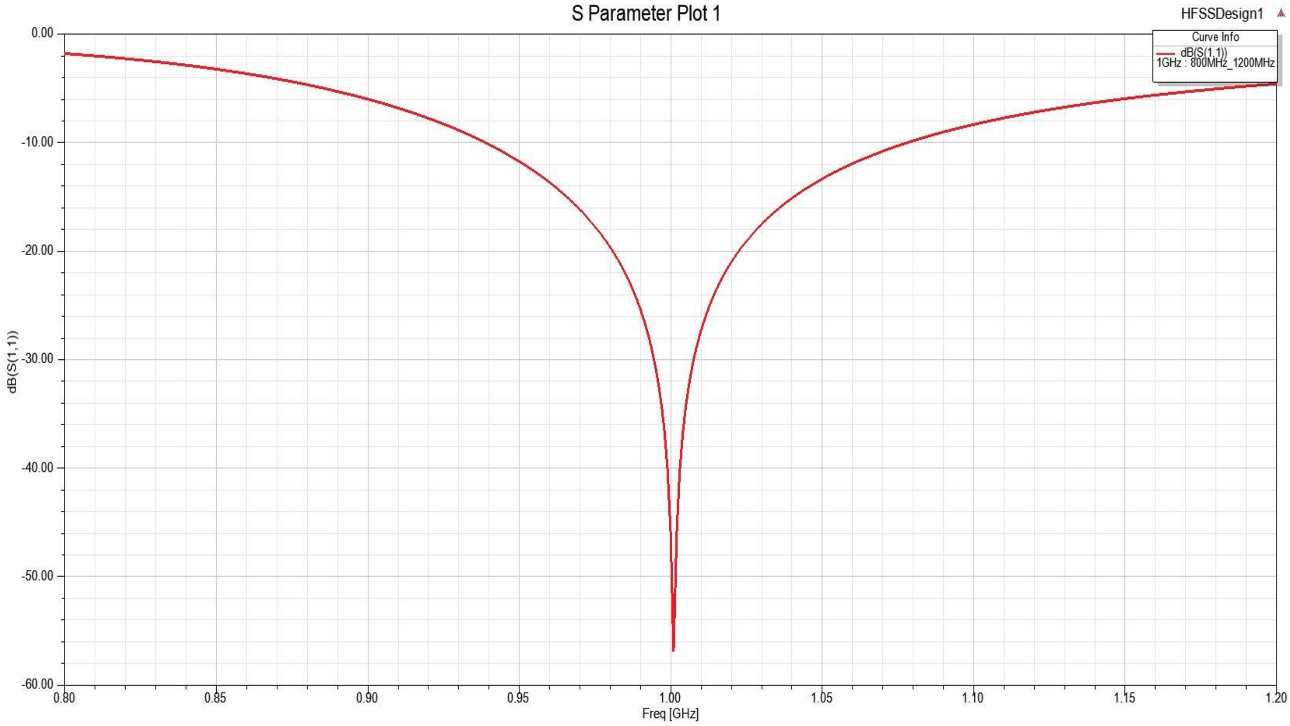



Fig 8- S Parameter plot of the half Wavelength Dipole

The S-parameter of the dipole was first obtained by for the length L=150mm but the it was seen the dipole was not perfectly tuned to the frequency of 1 GHz thus tuning of the dipole was very much required so that it operates perfectly at the given frequency. This is because there is an additional capacitance associated with the finite size of dipole and it also has a finite radius so it pulls the resonant frequency down. Thus the dipole was tuned to a length of 139mm thus having the resonant frequency perfectly at 1 GHz.

**DIRECTIVITY-**

The directivity of the dipole has been plotted for the dipole. For directivity both 2D and 3D plots have been seen. It is known as the length of the dipole gets larger, the more directive it gets.

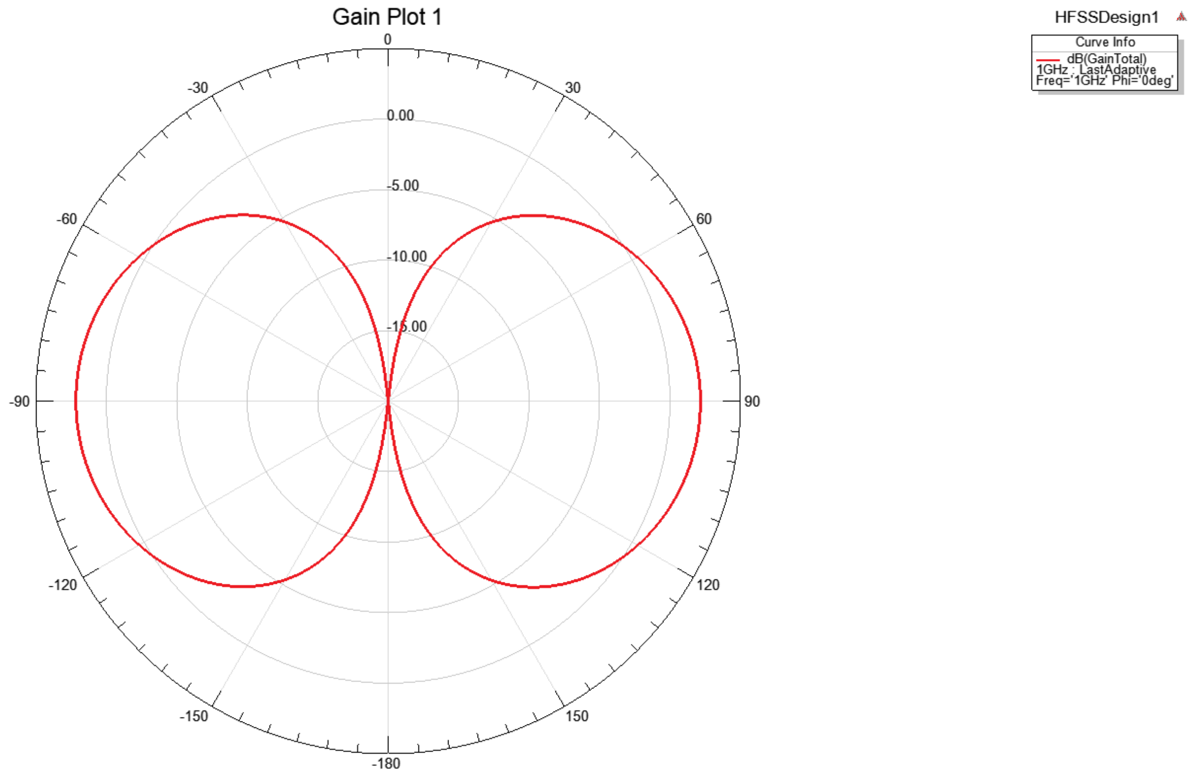



Fig 9 – Directivity of the Half Wavelength Dipole Antenna

This plot is compared and checked with graph obtained from Balanis for the gain plot.

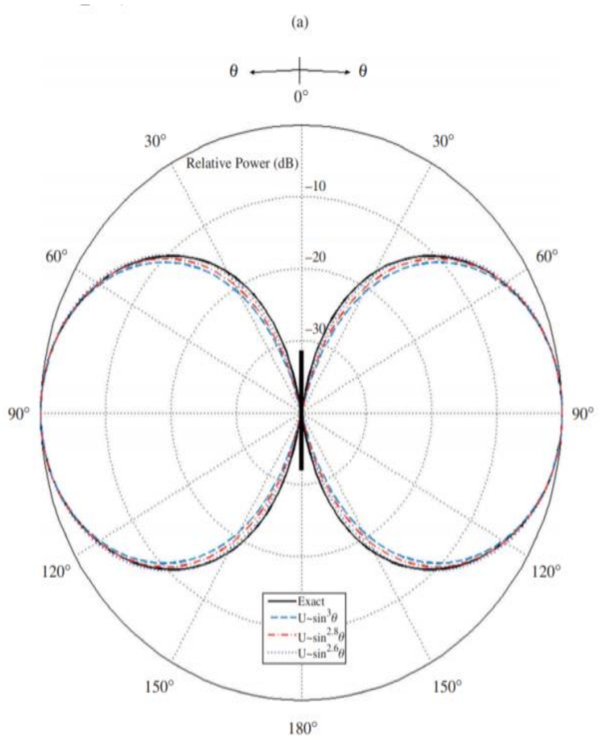



Fig 10- Directivity of the Half Wavelength Dipole Antenna obtained from Balanis

### 3D Directivity Plot-

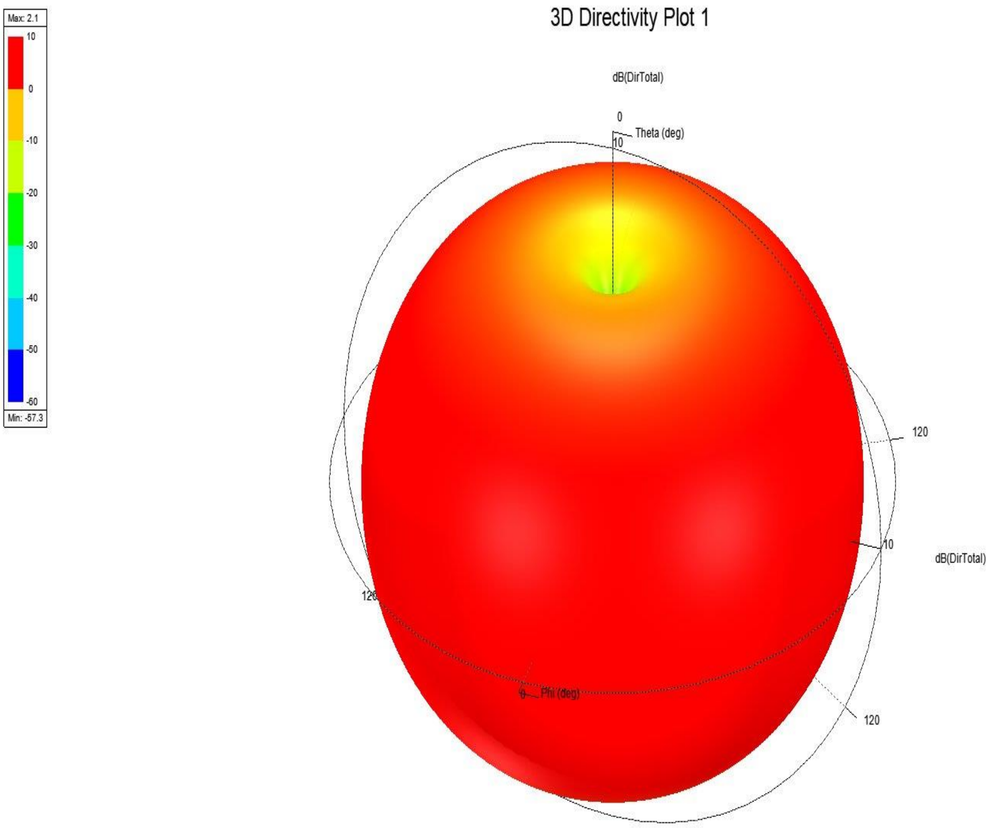



Fig 11- 3D Directivity plot of the Half Wavelength Dipole Antenna

Again, the validity of this plot has been rechecked with graph in Balanis.

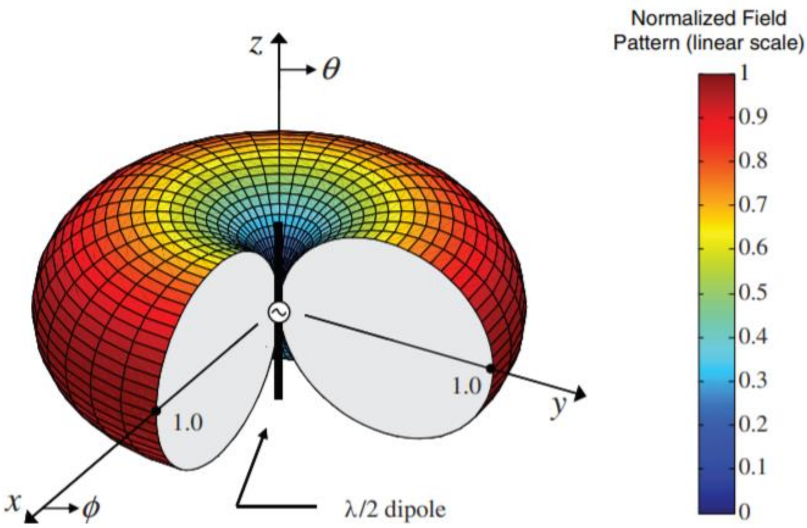



Fig 12- 3D Directivity Plot of the Dipole obtained from Balanis.

**CURRENT DISTRIBUTION-**

The current density has also been plotted which shown on the surface of the conductor and a contour has been created showing the maximum and the minimum of the current for the half wavelength dipole.

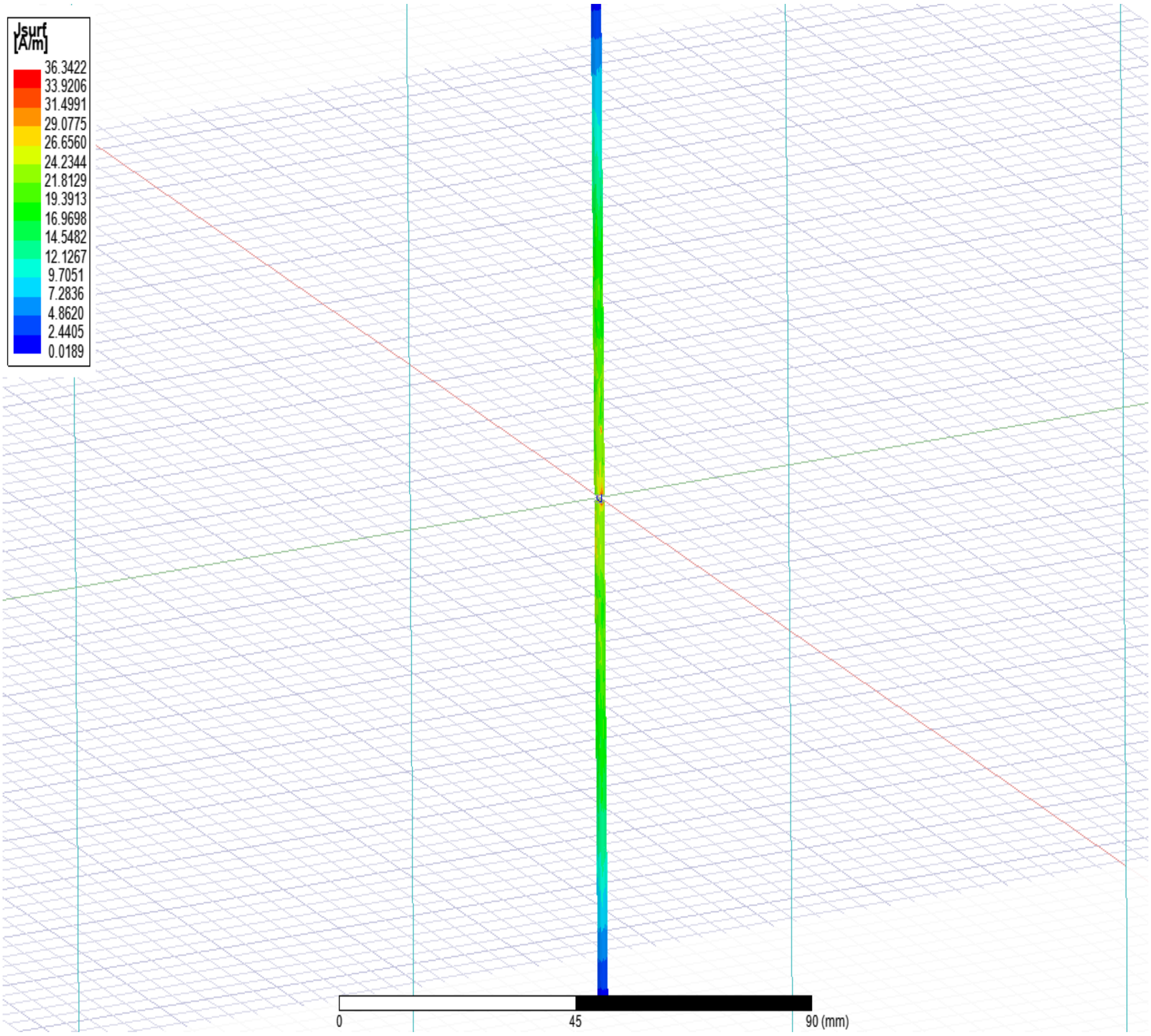



Fig 13- Current Distribution plot overlayed on the Dipole

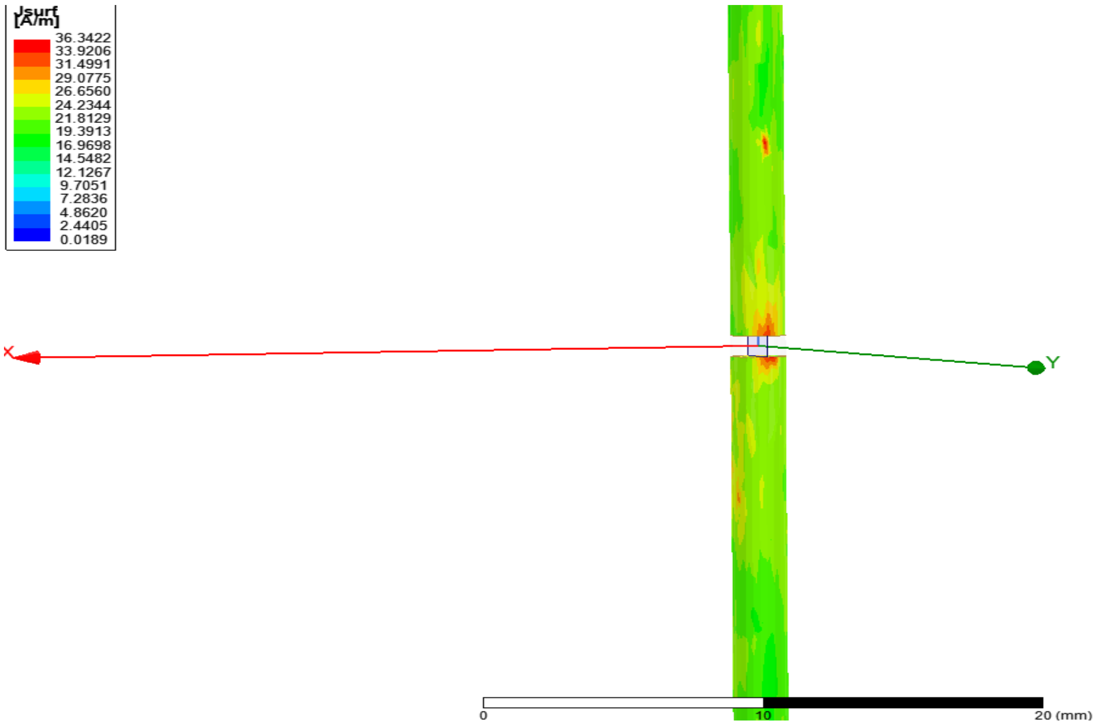



Fig 14- Maximum Current at the centre of the Dipole

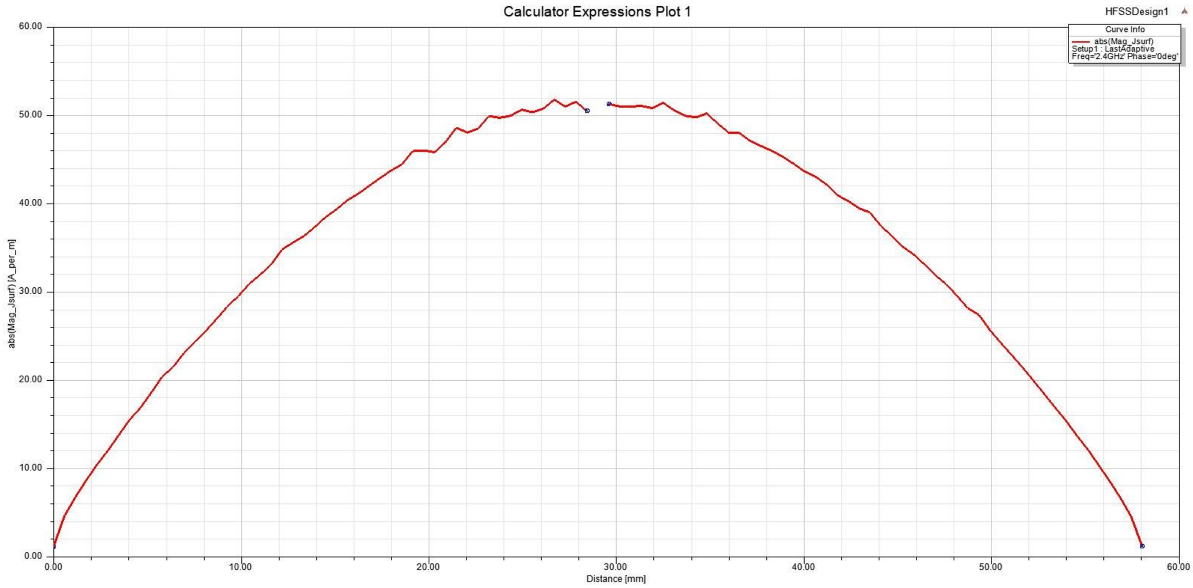



Fig 15- Current Distribution of the half wavelength dipole for freq 2.4GHz.

It is seen from the plot that the current maximizes at the centre and eventually vanishes at the ends. This is in accordance with the figure below which shows the half wave dipole indeed has the same variation as in the plot.

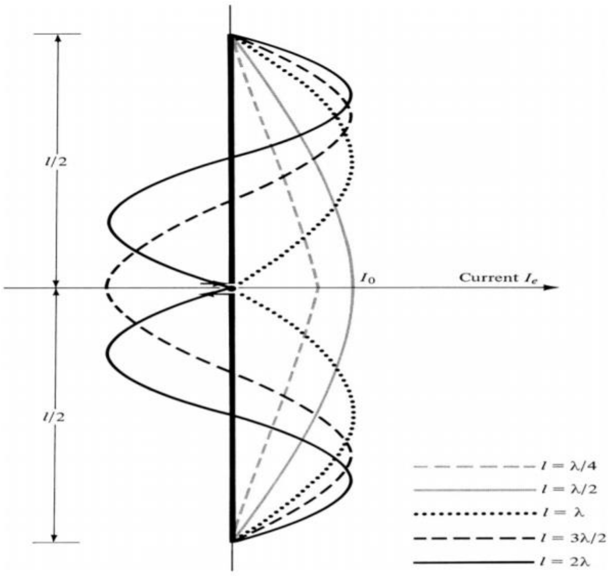



Fig 16- Current distributions along the length of a linear wire antenna

Now, not only for the half wavelength dipole, but we will consider all different lengths and the directivity and the impedances will be matched.

**Z-Parameter** for different lengths- λ/4, λ/2, 3λ/4, λ.

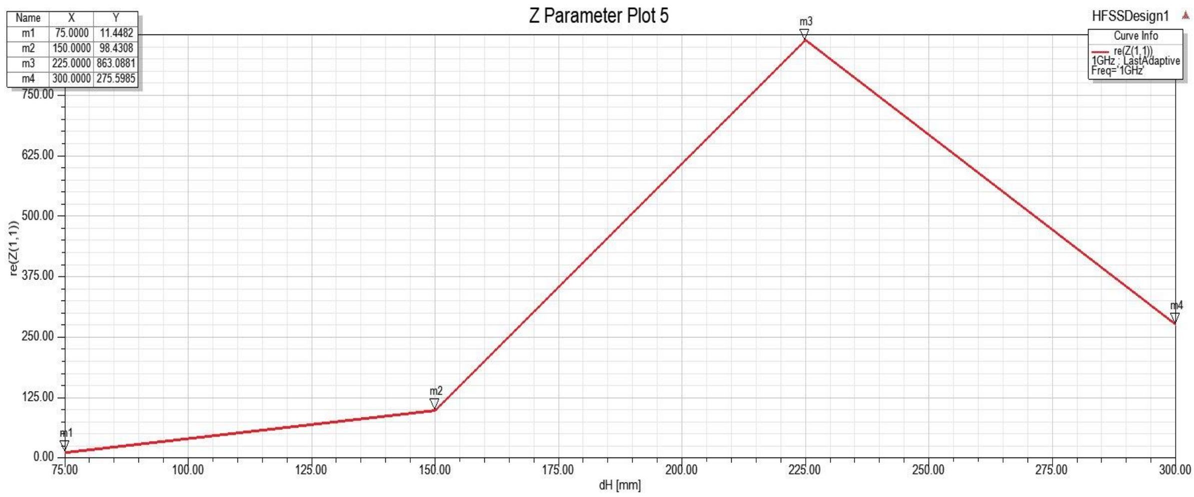



Fig 17- Z-Parameter for different lengths-75mm,150mm,225mm,300mm

The real part of the Z is plotted and is marked for different values of length of the dipole. This is in accordance with the result given in Balanis. The graph of it I given by-

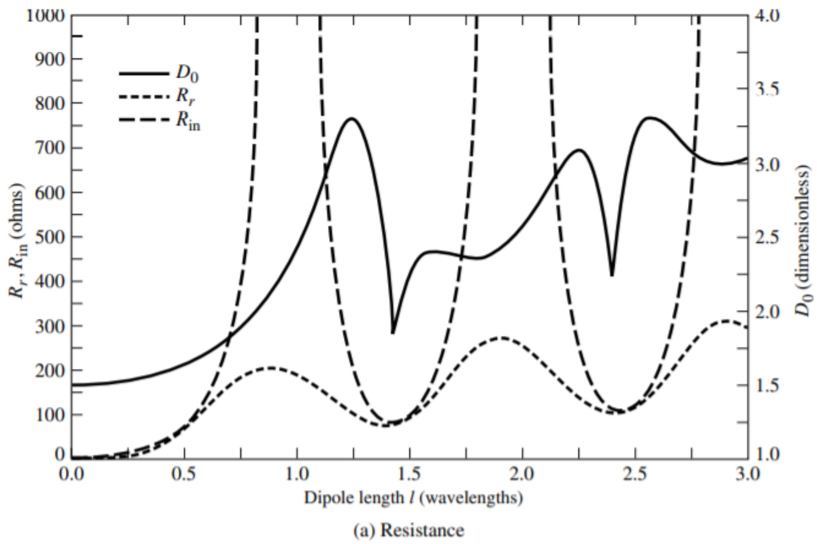



Fig 18- Input resistance and directivity of a thin dipole with sinusoidal current distribution.

It is seen from the given graph and matched that resistance for given lengths match the plot obtained, thus confirming its device properties.

**DIRECTIVITY-**

We know the directivity measures how well directive the antenna actually is. It will be seen from the graph that the directivity of the antenna depends on length of the dipole and varies with inverse proportionality.

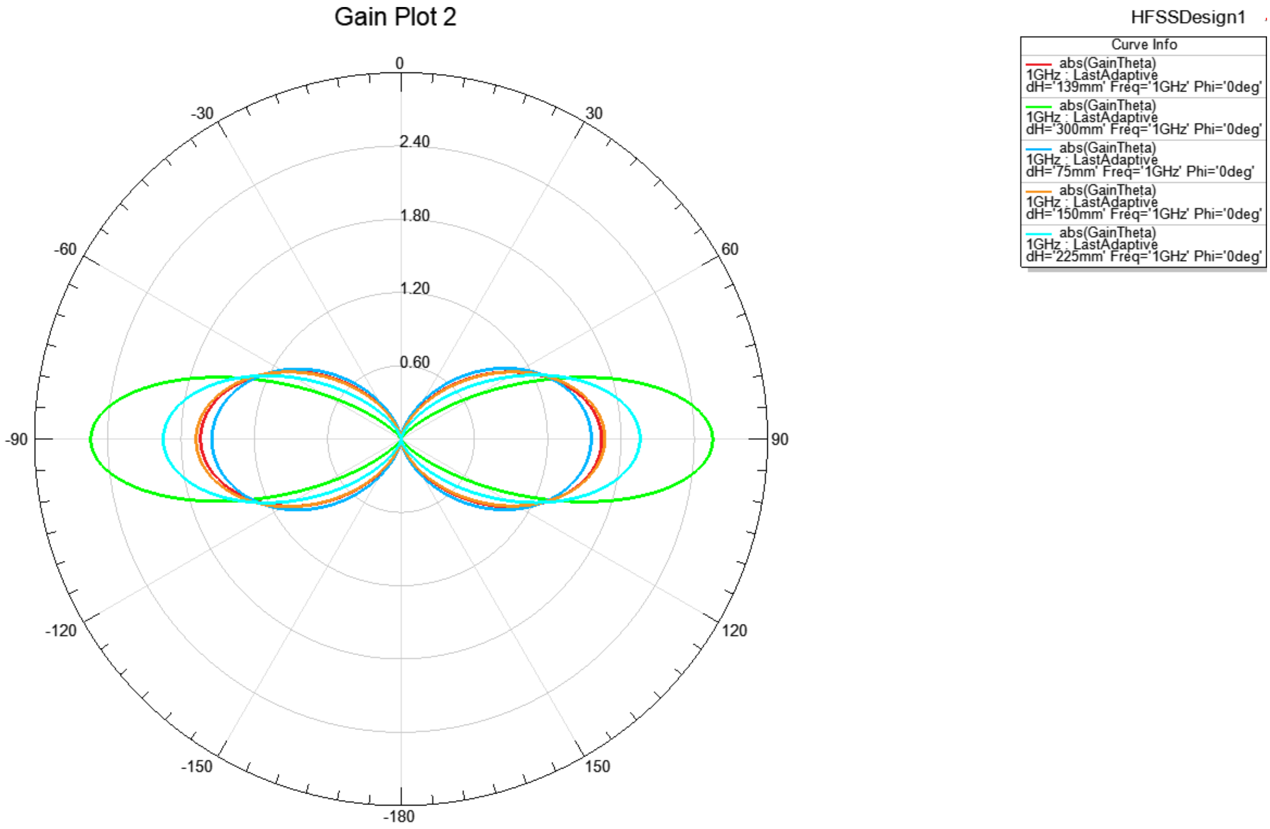



Fig 19- Directivity plot of antenna with different lengths- 75mm,150mm, 225mm, 300mm

It is seen from the graph as the length of the dipole increases the more directive it gets which again is in accordance with given graph in Balanis, where a directivity plot for 3dB bandwidth is given.

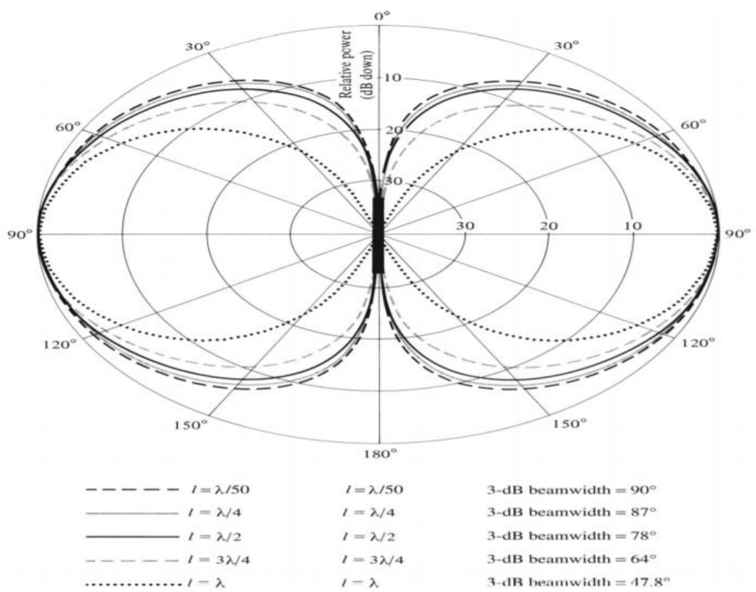



Fig 20- Elevation plane amplitude patterns for a thin dipole with sinusoidal current distribution

# 4.2 MONOPOLE ANTENNA

The horn antenna is designed to work at a frequency of 2.4GHz and in the frequency band of 2GHz-3GHz. The material used for the monopole is copper and to feed the monopole co-axial cable is used. A ground plane was also drawn with a size of 250mm with a thickness of 0.1 mm. The monopole thus designed is shown below.

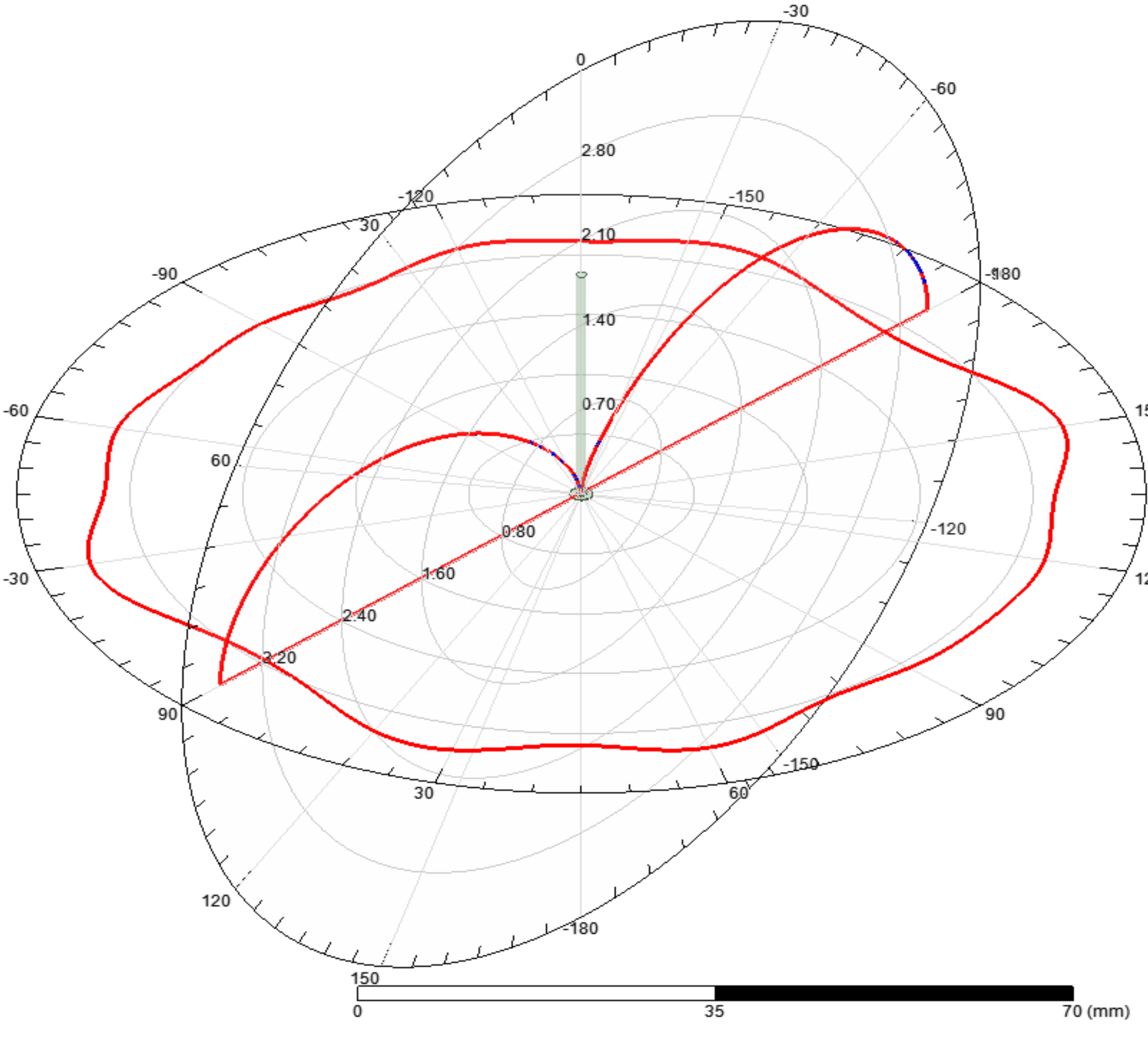
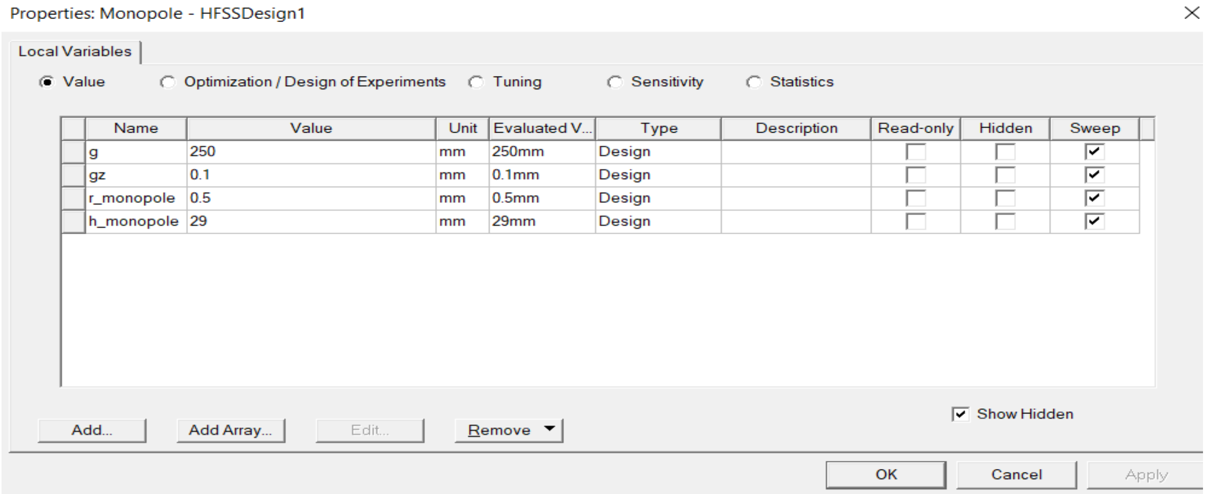



Fig 21 – Deisgn of the monopole Antenna operating at 2.4GHz using HFSS.

The design properties of the monopole is given as follows-



Properties: Monopole - HFSSDesign1

Local Variables

Value | Optimization / Design of Experiments | Tuning | Sensitivity | Statistics

| Name | Value | Unit | Evaluated V... | Type | Description | Read-only | Hidden | Sweep |
|---|---|---|---|---|---|---|---|---|
| g | 250 | mm | 250mm | Design | | ☐ | ☐ | ☑ |
| gz | 0.1 | mm | 0.1mm | Design | | ☐ | ☐ | ☑ |
| r_monopole | 0.5 | mm | 0.5mm | Design | | ☐ | ☐ | ☑ |
| h_monopole | 29 | mm | 29mm | Design | | ☐ | ☐ | ☑ |

☑ Show Hidden

Add... | Add Array... | Edit... | Remove

OK | Cancel | Apply

Here g is the size of the ground plane, gz is the thickness of the ground plane, r_monopole is the radius of the monopole and h_monopole is the height of the monopole.
Some basic yet important parameters of the monopole is obtained – S parameter, Z parameter and directivity and the current distribution.

**Z-PARAMETER-**

The Z-parameter of the monopole is obtained for a frequency band from 2GHz-3GHz.

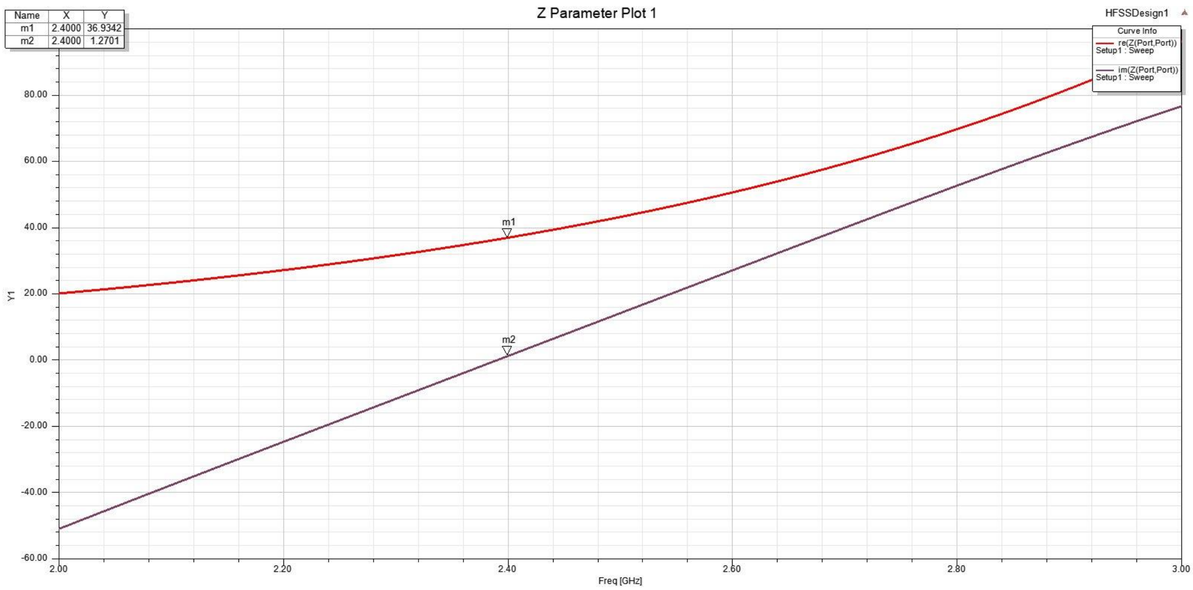



Fig 22- Z-parameter plot obtained

It is seen that at the frequency of 2.4GHz, the real part of the impedance is 36.9342 ohms and the imaginary part of the impedance is 1.2701 ohms.

**S-PARAMETER-**

The S parameter of the monopole antenna is obtained and tuned approximately close to the frequency of 2.4GHz. Tuning of the antenna is very much important so that the resonant frequency becomes equal to the applied frequency.

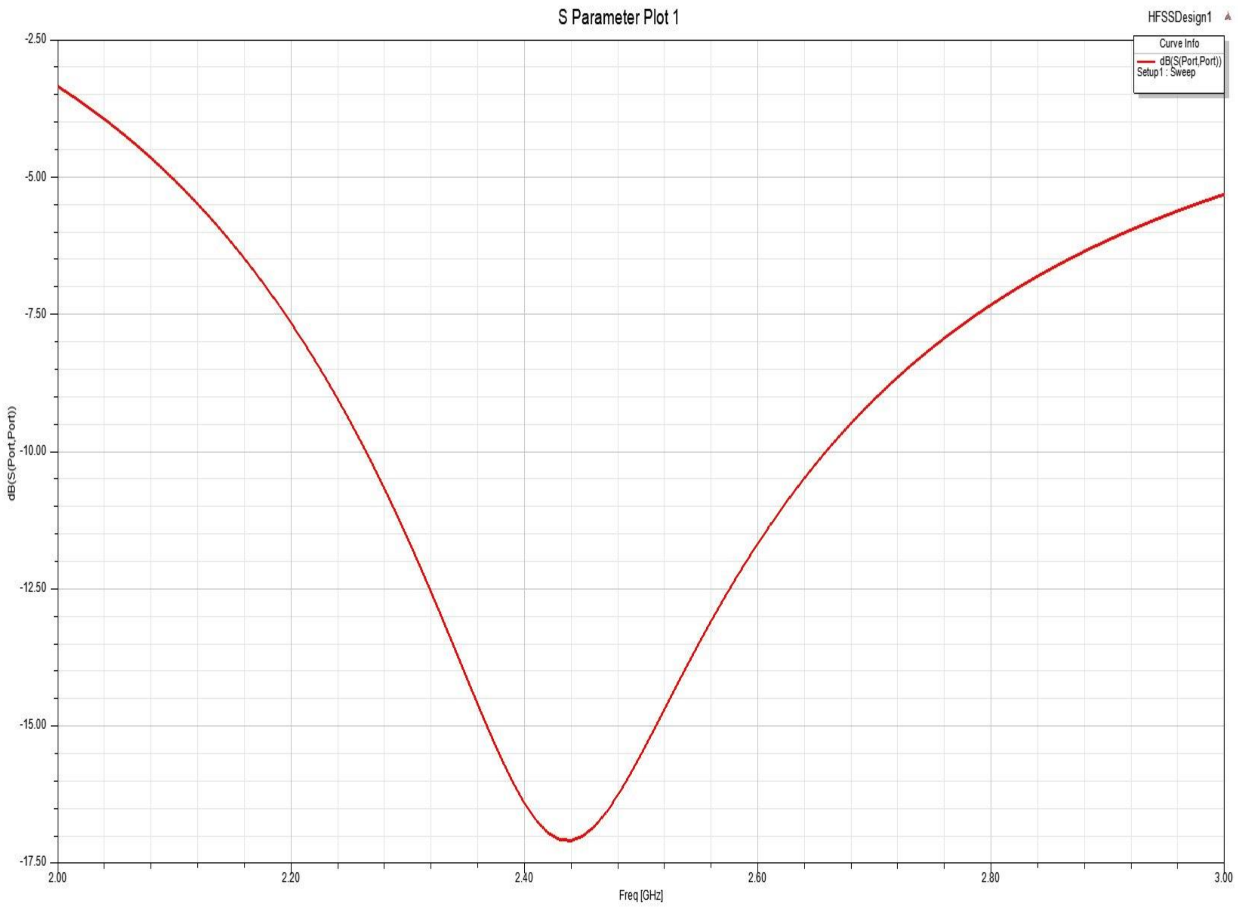



Fig 23- S-Parameter plot of the Monopole

**RADIATION PATTERN-**

The Radiation pattern of the quarter wave monopole is obtained and re-checked with the previously obtained plot from Balanis. The pattern thus obtained is-

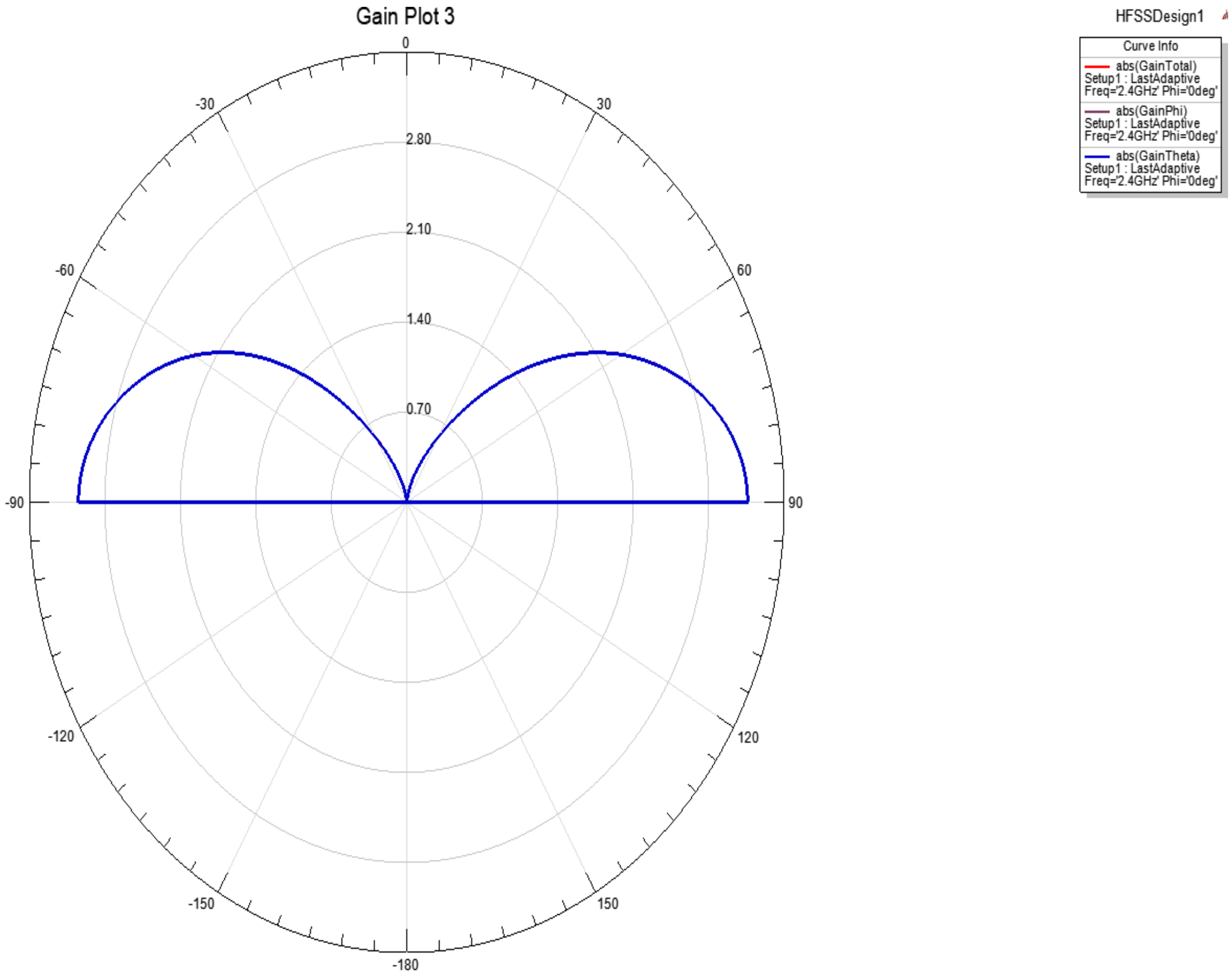



Fig 24- Radiation Pattern of the Monopole

# 4.3 HORN ANTENNA

The Horn Antenna is designed and operating at a frequency of 10GHz with a frequency sweep of 8.4GHz-12.4GHz. Different design parameters- S-Parameter, Z-Parameter, Directivity of the horn antenna are plotted and verified with previously determined results.

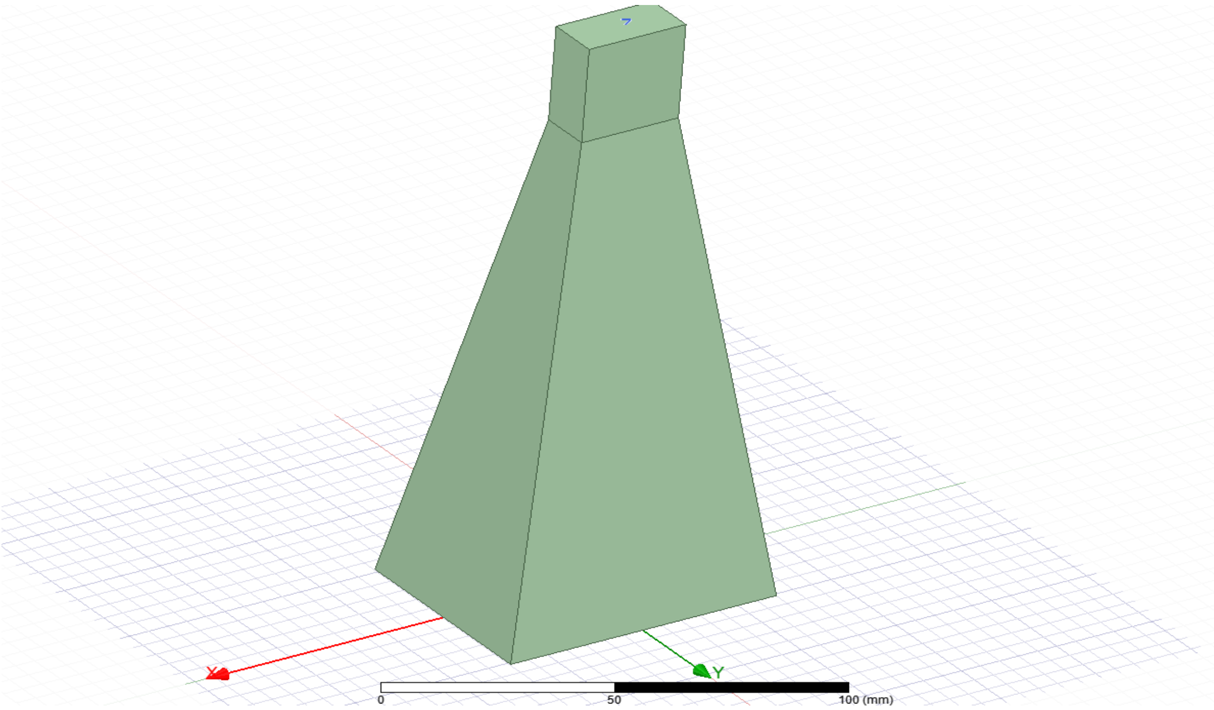
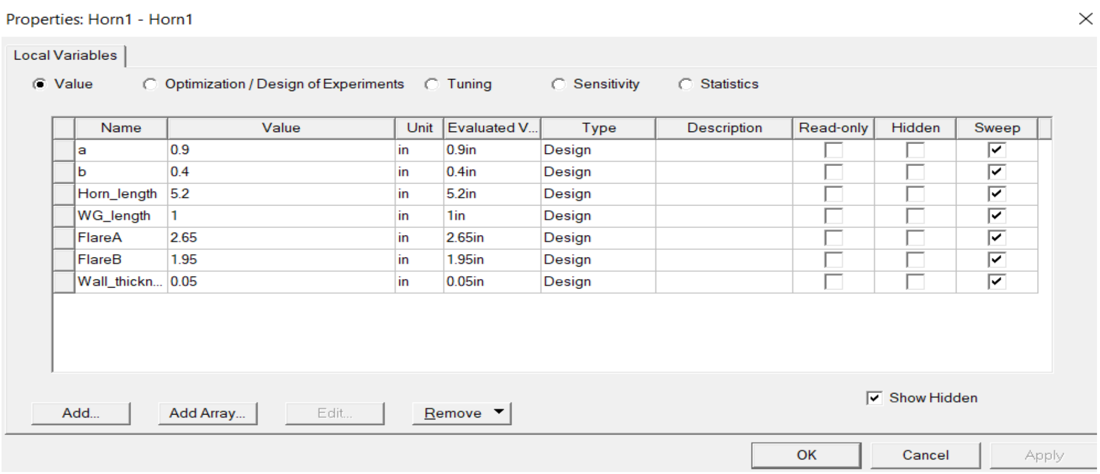



Fig 25- Design of the Horn Antenna operating at 10 GHz.

The design properties of the antenna are always critical. The dimensions which are used for designing are shown as follows-



Properties: Horn1 - Horn1

Local Variables

Value | Optimization / Design of Experiments | Tuning | Sensitivity | Statistics

| Name | Value | Unit | Evaluated V... | Type | Description | Read-only | Hidden | Sweep |
|---|---|---|---|---|---|---|---|---|
| a | 0.9 | in | 0.9in | Design | | ☐ | ☐ | ☑ |
| b | 0.4 | in | 0.4in | Design | | ☐ | ☐ | ☑ |
| Horn_length | 5.2 | in | 5.2in | Design | | ☐ | ☐ | ☑ |
| WG_length | 1 | in | 1in | Design | | ☐ | ☐ | ☑ |
| FlareA | 2.65 | in | 2.65in | Design | | ☐ | ☐ | ☑ |
| FlareB | 1.95 | in | 1.95in | Design | | ☐ | ☐ | ☑ |
| Wall_thickn... | 0.05 | in | 0.05in | Design | | ☐ | ☐ | ☑ |

☑ Show Hidden

Add... | Add Array... | Edit... | Remove

OK | Cancel | Apply

Here unit is set in inches. Horn_length is the length of the horn; WG_length is the length of the waveguide.

**Z –PARAMETER-**

The Z parameter of the horn antenna is obtained having both their real and imaginary axis shown for a frequency ranging from 8.4GHz-12.4GHz.

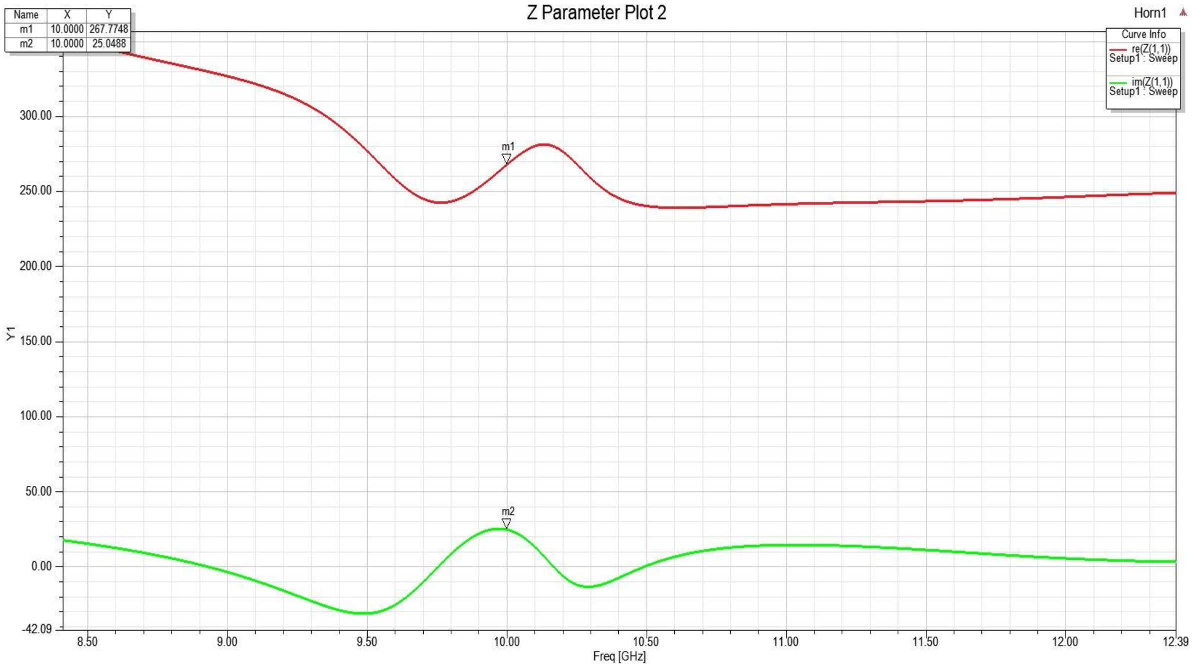



Fig 26- Z-Parameter of the Horn Antenna

The real part is shown by the red line and the imaginary part is shown by green line. It is seen at 10GHz the real part is approx. 267.7748 ohms and the imaginary part is 25.0488 ohms.

**S-PARAMETER-**

The S parameter is obtained for the frequency range of 8.4GHz-12.4GHz.

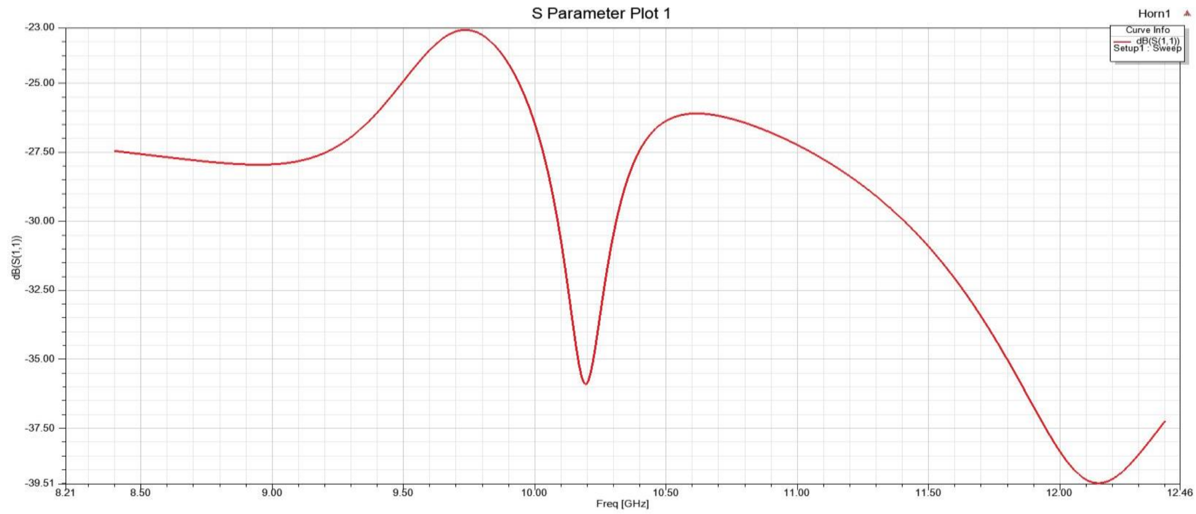



Fig 27- S-Parameter of the Horn Antenna

**DIRECTIVITY-**

Just as stated before, directivity of an antenna determines how directive an antenna is, both 2D and 3D plots are obtained for the given horn antenna.

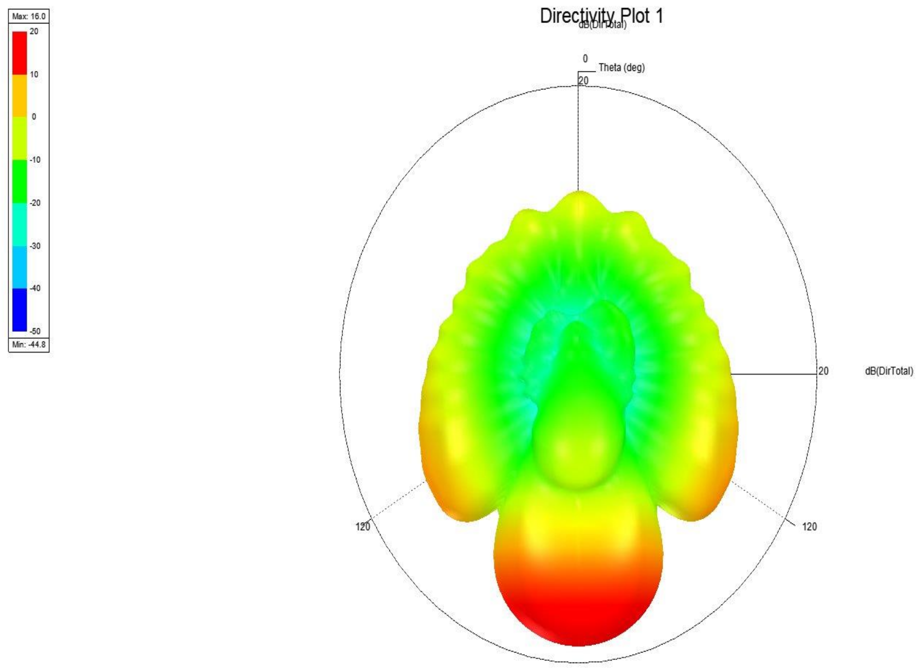



Fig 28.1- 3D Directivity of the Horn Antenna

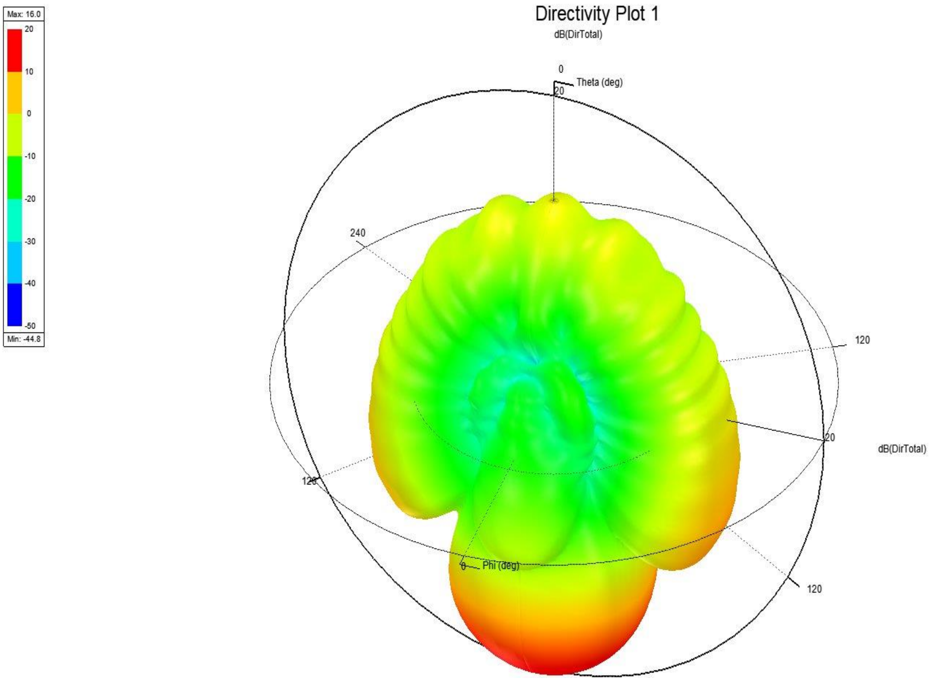



Fig 28.2- 3D Directivity of the Horn Antenna

**CURRENT DISTRIBUTION-**

The current distribution is obtained which shows the maximum current is where the feed is given and then sinusoidal variation of current is obtained which gradually lessens towards the end of the antenna.

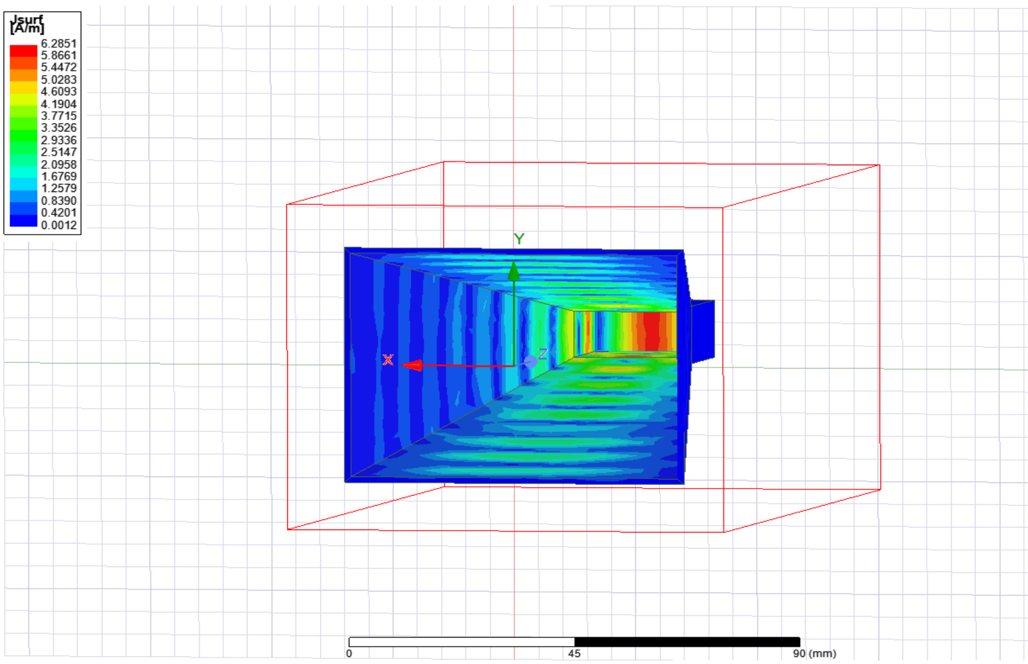



Fig 29- Current Distribution of the Horn Antenna

# 5. CONCLUSION

The construction of Dipole Antenna, Horn Antenna and the Monopole Antenna was simple in terms of paper and pencil. However the fabrication was far more difficult than anticipated before starting of the project, but we have managed to construct both the antennas and reached our goal. The resulted measured data supports our expected radiation pattern and calculation of correct dimensions.

# 6. REFERENCES


1) Antenna Theory Analysis and Design- Constantine A. Balanis
2) Antennas for all application- John D. Krauss
3) R. Kiran Chand, Dr. M V Raghavendra, K.Sathyavathi, IJERT,2013, ISSN: 2278-0181.
4) P.Revath , T.Ananth Kumar & R.S. Rajesh, AJAST, August 2018.