VHF/UHF (30 - 512 MHz) Antenna for Man-Pack Radio

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CERTIFICATE OF CORRECTIONS & APPROVAL

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ABSTRACT

A VHF/UHF (30 - 512 MHz) ANTENNA FOR MAN-PACK RADIO

Like any other field, effective communication is critical in warfare. The earliest military communications were delivered by runners. Later, communications progressed to visual and audible signals, and then advanced into the electronic age. Present day military forces conduct intense and complicated communicating activities on a daily basis, using modern telecommunications and computing methods. One of the radio sets that is used by Pakistan Army for this purpose is the Software Designed Radio (SDR) set. Most of the communication in armed forces is carried out in VHF and UHF bands. SDR based radio sets used in Pakistan Army has limited performance due to lack of antenna that is optimized for all frequencies in range of 30 to 512 MHz. There are separate antennas optimized for different sub-bands in 30 – 512 MHz band which are needed for specific sub band. There is a need for an all range (30 to 512 MHz) Omni-directional whip antenna that can be integrated with man pack so that the user does not need different antennas every time frequency is changed to different sub bands. Therefore, a broadband monopole antenna with a very low-cost mechanical structure is proposed. This monopole with inductor/resistor (LR) loading circuits is designed to operate in the frequency range of 30-512 MHz. By choosing optimized locations of LR loads, the radiation pattern is controlled. Meanwhile, the VSWR is adjusted by an input matching circuit, tuning a number of LR loads, and using a transmission line transformer. The impedance matching is improved in whole frequency bandwidth and antenna gain is also increased than in the existing antennas. The antenna is considered to be used in portable applications.

Key Words: *Monopole antenna, broadband antenna, inductor/resistor loading circuits*

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CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

The research work presented in the ensuing dissertation outlines the importance of Broadband Antennae in practical life with the prime focus on its significance in military communication. It discusses complete project design and development of the antenna in detail along with some basic antennae theory concepts. In the end, a thorough analysis is provided for better comprehension of the results with recommendations for the future.

1.2 BACKGROUND

Like any other field, effective communication is critical in warfare. The employment of messengers and runners was the earliest means of communication in war since ancient times. Later, communications advanced to visual and audible signals making use of the immobile Telegraph System. But of course, one could not rely on such a system in a changing battle-field. Over time, these elementary methods of communication progressed into the electronic age.

With the revolution of wireless technology, new means of communication have emerged that provided more comprehensive, reliable and efficient communication and electronic equipment to be used in tactical communication. The present-day military forces have evolved greatly with the advent of this technology, and are performing activities daily, using these modern telecommunications methods. In this era of wireless technology, an antenna is one of the major components and plays a vital role in communication because, without it, transmission and reception of signals are not possible. Now a day, in order to establish any reliable and efficient communication, wireless technology is essentially required.

Ever since the first demonstration of an antenna in 1888 by a German physicist, Heinrich Hertz, antenna technology has undergone a huge advancement. With the establishment of modern wireless communication technologies, antenna research is entering another phase of development. It is no more an isolated element unlike the earlier antennae, rather they are integrated with other circuit components.

One notable characteristic of an antenna is that, it itself is not smart, instead, the system on which it is mounted for its operation is smart hence rendering it as a smart antenna. Smart Antennae can be considered as a new technology that was first introduced in the 1960s to be used in military applications. But the up-gradation of man-made portable communications system has always been on the wish list of Armies that have been relying on traditional radio sets in the field. For more than 25 years, numerous efforts and researches have been carried out by the Army to revolutionize its tactical military communication infrastructure since there has always been a need for more reliable and efficient broadband antennae for wireless communication systems for use in the military.

Over the last decade, there has been a significant increase in the demand of these antennae in modern communication systems. This project *“VHF/UHF (30 – 512 MHz) Antenna for Man-pack Radio”* also features this technology that involves integrating the antenna with a Software Defined Radio (SDR) set hence making it a smart antenna. The central idea that led to the invention of such man-pack radio sets was to field a family of radios that could be modified by downloading new software instead of replacing the whole hardware which can be a very expensive solution. This software re-configurability greatly assisted the production of smaller, light-weight and economical antennae with enhanced characteristics.

1.3 PROBLEM STATEMENT

Most of the communication in armed forces is carried out in VHF and UHF bands. SDR based radio sets used in Pakistan Army has limited performance due to lack of antenna that is optimized for all frequencies in range of 30 to 512 MHz. There are separate antennas optimized for different sub-bands in 30 – 512 MHz band which are needed for specific sub band. There is a need for an all range (30 to 512 MHz) Omni-directional whip antenna that can be integrated with man pack so that the user does not need different antennas every time frequency is changed to different sub bands. Pakistan Army has imported 9,000 such sets from Turkey and 45,000 are yet to be imported. Therefore, there must be an all range antenna working efficiently in the desired range to obtain maximum benefit from the imported sets.

1.4 PROJECT OBJECTIVES

Given below are the objectives of this project: -

- To design a high gain UHF/VHF antenna that can be integrated with man-pack radio.
- To simulate and optimize the design using CST Studio Software.
- Study the previous works done on man-pack antennae.
- To implement new techniques e.g. use of passive loads, to achieve high gain and improved radiation pattern in the desired frequency range.
- To design an antenna with minimum possible weight and height.
- To optimize the antenna for all frequencies in the range 30 to 512 MHz.
- To prevent the jamming of a particular frequency/ sub- band by the adversary.

1.5 ANTENNA PARAMETERS

To demonstrate the efficiency and performance of an antenna, there are some important characteristics and performance metrics which are associated with it. The parameters on which antenna performance depends are described as follows: -

a. Bandwidth

Bandwidth is the the most important parameter of an antenna. It specifies the range of frequencies over which an antenna is operating [1]. It is the band of frequencies within which the antenna can radiate or receive the electromagnetic signals properly. Bandwidth is calculated in Hertz (Hz) and it is usually the number of Hertz for which an antenna maintains a specified performance and has an SWR of 2:1. Bandwidth is calculated as: -

Bandwidth= Highest Frequency – Lowest Frequency

Another way to specify bandwidth is in terms of Fractional Bandwidth (FBW) that is given as: -

$$FBW = \frac{fh - fl}{fc} \times 100\%$$

Where '*fh'* is the highest frequency component and '*fl'* is the lowest frequency component in the band. The higher percentage of FBW shows a wider bandwidth.

b. Radiation Pattern

Radiation Pattern is the mathematical function or a graphical representation of power radiated by an antenna as a function of the directional co-ordinates in the antenna's far field [1]. It can be either a 3-D representation in spherical co-ordinates (r, Θ,∅) as shown in Fig. 1 (a) or a 2-D representation which is basically a horizontal or vertical slice of 3-D radiation pattern as shown in Fig. 1 (b).

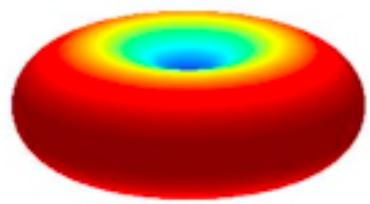

Figure 1.1 (a) – 3D Radiation Pattern

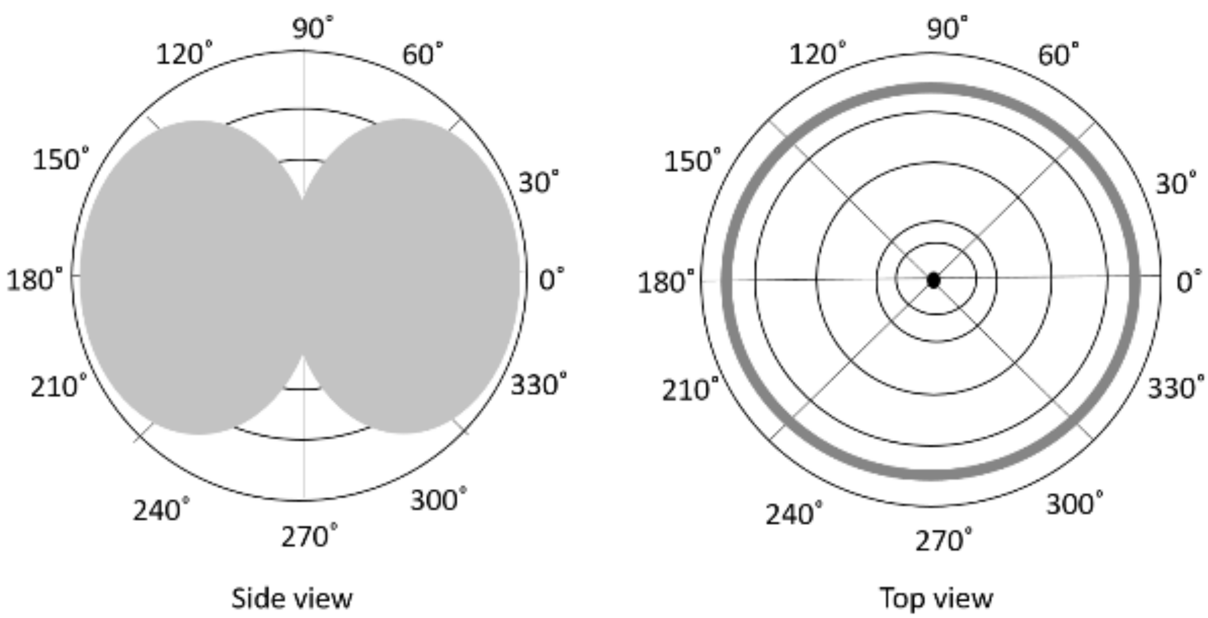

Figure 1.1 (b) – 2D Radiation Pattern

The radiation pattern demonstrates the strength of the fields radiated from antenna in various directions at a constant distance. The pattern obtained in the Near-Field region is not identical to the one in the Far-Field region. As it is the radiated power that is of interest, therefore, radiation patterns are usually measured in the Far-Field regions. In addition, this pattern describes transmitting as well as the receiving characteristics of an antenna. These measurements are presented either in *rectangular* or *polar* form.

Types of Radiation Patterns

Depending upon the type of antenna, there are some common types of radiation patterns [2]. For example,

1. Isotropic Antenna Pattern

A pattern is said to be isotropic if the radiation is same in all the directions. This characteristic is unique to isotropic antennae which practically do not exist. These patterns are considered as referential point for all other types of radiation patterns [2].

2. Omni-directional Antenna Pattern

Another type of radiation pattern is that of an omni-directional antenna. These are the patterns which are isotropic in one direction or plane [2]. Dipole antennae and slot antennae have omni-directional radiation patterns.

3. Directional Antenna Pattern

Directional Antennae is another category of antennae whose radiation pattern does not have a symmetry. In the radiation pattern, they usually have a single peak which shows the direction in which the radiated power travels [2]. The directional antennas can have any one the following radiation patterns.

- **Pencil-beam Pattern** – Sharp directional pencil shaped beam
- **Fan-beam Pattern** – Beam shaped like a fan
- **Shaped-Beam Pattern** – non-uniform and pattern-less beam

Examples of directional antennae include dish antennae and slotted waveguide antennae.

c. Radiation Resistance

Radiation Resistance is the circuit quantity of an antenna. In Fig. 2, the resistance Rr is the radiation resistance which represents the amount of radiation of electromagnetic waves from an antenna [1].

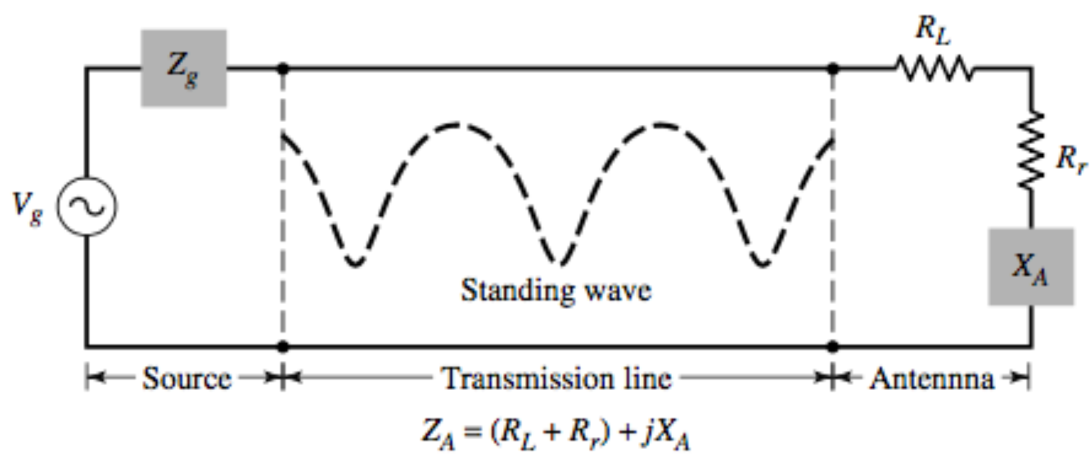

Figure 2 – Thevenin Equivalent of antenna

In contrast, the resistance RL is the loss resistance which dissipates the RF energy as heat. The geometry of an antenna plays an important role in determining the radiation resistance and it primarily depends on the current distribution in an antenna [1]. It is simply a measure of effective radiation of energy into the space. It can be calculated as: -

$$\text{R}r = \frac{P}{|I|^2}$$

Where P is the power of radiated electromagnetic wave and I is the current that flows into the feed-point of antenna. The greater the radiation resistance, the more effective is the electromagnetic energy radiation.

d. Beam Width

The radiationapattern can also be characterized by beam width and side lobe levels. Beam Width is very important figure of merit. It gives the angular separation between two identical points on the opposite sides of the main beam which is the region around the direction in which the radiation is maximum [1]. For example, it can be seen in Fig. 3, the main beam is centered at 90°. This is the angle from which maximum antenna power is radiated.

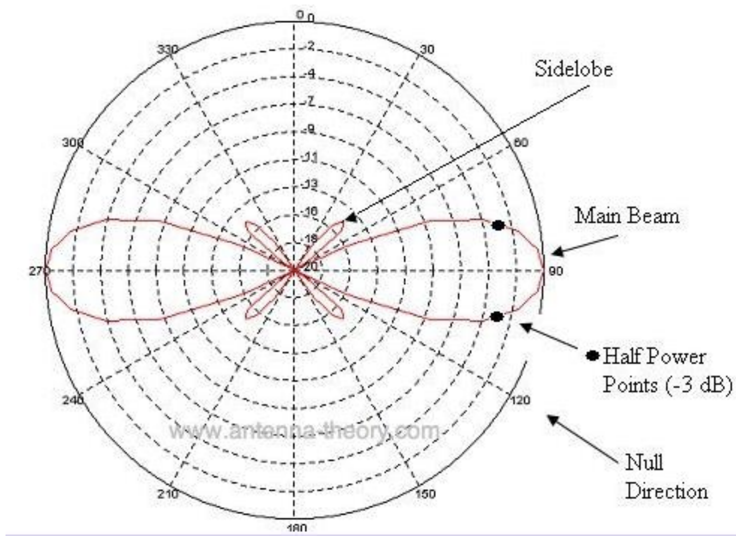

Figure 1.3 – Main Beam centered at 90°

Side lobes are another parameter which are often used as a traade-off between it and the beam width. The lobes formed due to energy radiation in undesired directions, away from the main beam are termed as side lobes. Beam width varies inversely proportional with the side lobe level. Greater the beam width, smaller is the side lobe level and vice versa [2]. The side lobe level indicates the maximum value of the side lobes.

Beam width has two main key parameters which are given below: -

1. **Half Power Beam Width (HPBW)**

   In plane containing the direction of maximum of the beam, the angle between two opposite sides of main beam where the distance between them is less than half of the maximum is known as Half Power Beam Width or HPBW [1]. These points on the opposite sides of the main beam are the indication where magnitude of radiation pattern is decreased by 50% or -3 dB from the main beam peak. Fig 3 (a) illustrates the HPBW.

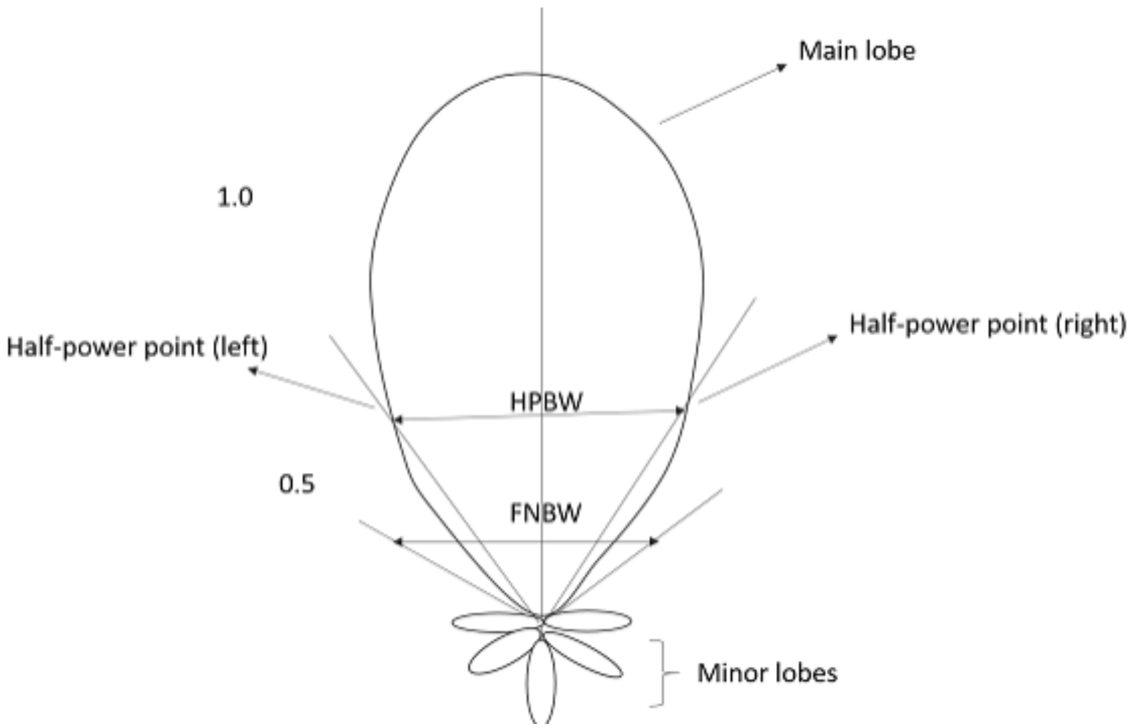

Figure 1.3 (a) – Illustration of Half Power Beam Width

2. **First Null Beam Width (FNBW)**

   First Null Beam Width, as shown in Figure 3 (B), is the degree of angular separation between the first nulls of the radiation pattern away from the main beam [1]. Mathematically, FNBW is given as: -

$$FNBW = 2 * HPBW$$

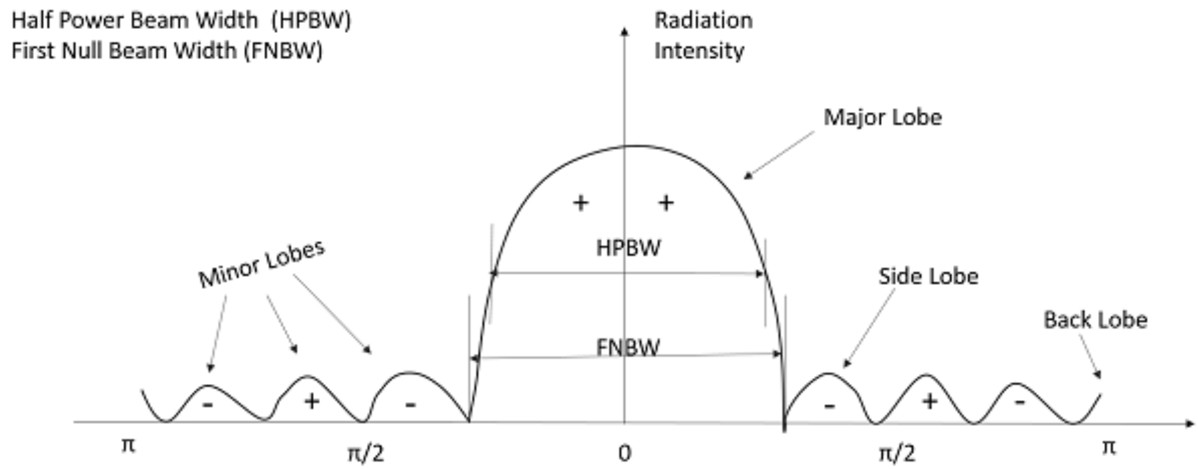

Figure 1.3 (b) – Illustration of First Null Beam Width

e. Resolution

Resolution is the ability of an antenna to distinguish between two sources that are separated by angular distances equal to or greater than half the First Null Beamwidth (FNBW/2) that is approximately equal to the Half Power Beamwidth [1]. A separation smaller than this would tend to smooth out that distance.

f. Directivity

During transmission or reception, directivity is the ability of an antenna to focus energy in a particular direction. It gives an idea that how directional an antenna is. The directivity for an isotropic antenna would effectively be zero and its directivity is 1or 0 dB as it radiates equally in all directions and not in a particular direction [1]. The more the directivity, the more focused or directional the antenna will be.

Mathematically, an antenna's directivity is ratio of radiation intensity in a particular direction to radiation intensity averaged over all directions or to the radiation intensity of an isotropic source. It is given as: -

$$D = \frac{U}{Uo} = \frac{4\Pi U}{Prad}$$

g. Antenna Efficiency

Antenna efficiency is often used to mean the radiation efficiency which describes how efficiently an antenna transmits and receives signals. It is defined as the ratio of power radiated (P_{rod}) by the antenna to the power supplied (P_T) to the antenna. An ideal antenna would have an efficiency of 100% i.e. all power fed to the antenna will be radiated by it [2]. Usually it is measured in an anechoic chamber where some power is fed to the antenna and strength of radiated EM fields is measured in the surroundings. It is calculated as: -

$$Antenna\ efficiency = \frac{Prad}{Pt}\%$$

The total antenna efficiency, e_o, is used to take into account losses at the input terminals and within the structure of the antenna. e_o is due to the combination of number of efficiencies: -

$$e_o = e_r e_c e_d$$

Where e_r =reflection (mismatch) efficiency = $(1-|\Gamma|^2)$,

e_c = conduction efficiency

e_d = dielectric efficiency

Usually e_c and e_d are very difficult to compute, but they can be deter-mined experimentally. It is usually more convenient to write e_o as $e_o = e_r e_{cd} = e_{cd}(1-|\Gamma|^2)$, where $e_{cd} = e_c e_d$ = antenna radiation efficiency, which relates the gain and directivity.

h. Antenna Gain

Gain is a dimensionless ratio that is given in reference to a standard antenna such as an isotropic antenna. Isotropic antennas are hypothetical antennas but they provide useful theoretical antenna patterns with which real antennae can be compared. Gain is a measure of energy radiated in a particular direction compared to the energy an isotropic antenna would radiate in the same direction when given the same input power. An antenna of 3 dB gain compared to an isotropic antenna would be written as 3 dBi [1]. Mathematically, the following equation gives the gain of any antenna: -

$$G = \eta D$$

Where G = Gain

η = efficiency factor

D = Directivity

i. Antenna Impedance

The impedance of antenna is a key parameter that is associated with its performance. It relates the voltage to current that are being fed to an antenna at its input terminals [2]. For and efficient energy transmission, the impedance of antenna and that of the transmission cable connecting them must be same. Antenna and their transmission lines are typically designed for 50 Ω impedance. If there is a mismatch between the impedances, then a matching circuit is required.

j. Polarization

Polarization is the orientation of the electric field of an electromagnetic wave that is radiated by an antenna [1]. It is usually evaluated in Far Field. On the basis of this phenomenon, antennae are often classified as: -

- **Linearly Polarized**

In this case, the electric and magnetic fields are orthogonal to each other and to the direction of propagation. It further can be classified as horizontally and vertically polarized antennae. Antenna is said to be vertically polarized when its electric field is perpendicular to the Earth's surface and it is said to be horizontally polarized if its electric field is parallel to the Earth's surface [2].

- **Circular Polarized**

  An antenna is said to be circular polarized if at each point, the electric field has two orthogonal that have equal magnitude. If the field is rotating in a counter-clockwise direction, it is said to be Right Hand Circularly Polarized (RHCP) [2]. If the fields are rotating in clockwise direction, it would be Left Hand Circularly Polarized (LHCP).

- **Elliptically Polarized**

  If the electric field has two out of phase orthogonal components that are not equal in magnitude, then field is said to be elliptically polarized [2].

For the maximum transmission of energy between a transmitter and a receiver, it is essential for both the antennas to have same spatial orientation. Otherwise it will cause considerable signal loss hence reducing the overall performance and efficiency.

k. Voltage Standing Wave Ratio (VSWR)

VSWR is a parameter that numerically describes how efficiently the antenna's impedance is matched to the transmission line it is connected to. It indirectly describes the amount of power reflected from the antenna [1]. It is the ratio of maximum to minimum voltage of the antenna. It is given as: -

$$VSWR = \frac{|\Gamma|+1}{|\Gamma|-1}$$

A VSWR of 1:1 means that there is no power being reflected back to the source hence an ideal situation that is rarely seen. Practically, a VSWR of 1.2:1 or simple 1.2 is considered excellent in most cases. This value denotes a maximum standing wave amplitude that is 1.2 times greater than the minimumastanding wave value [2].

l. Return Loss

Return loss is another way to express the power reflected back to source due to mismatch. It is a logarithmic ratio measured in dB which compares the power fed into the antenna via transmission line and the reflected power [1]. The relationship between SWR and return loss is given by the following equation: -

$$\text{Return Loss (in dB)} = 20\log_{10} \frac{SWR}{SWR - 1}$$

A return loss of -10 dB is considered sufficient for many applications. This means that 90% of the input power is transmitted and less than 10% of the total power is reflected. A return loss greater than this shows that antenna is a poor radiator of energy [2].

m. Effective Aperture

Effective aperture is a useful parameter for calculating the receiving power of an antenna. It describes how much power an antenna is capable of capturing from a plane wave [1]. In terms of peak antenna gain (G), affective antenna can be given as: -

$$A_e = \frac{\lambda^2}{4\pi} G$$

CHAPTER 2

LITERATURE REVIEW

Taking into account the necessary measures to acquire quality coverage as well as quality communication, the type of antenna chosen is a monopole and comes under the category of broadband technology. It will be the mode of signals Tx and Rx in the VHF/UHF spectrum i.e. (30 MHz- 512 MHz).

2.1 MONOPOLE ANTENNA

2.1.1 Introduction to a Monopole

Formulated by G. Marconi in the late 1800's, it is also popularly known as the Marconi Antenna. A monopole antenna belongs to a radio antenna class that is constructed from a straight rod of conducting material [14]. It comprises a single element and is perpendicularly mounted on top of a ground surface which happens to be an SDR in our scenario. The monopole antenna comes in several different shapes and types which happen to be as follows [2]: -

1. Whip Antenna.
2. Slip- Sleeve.
3. Flanged Pipe.

The monopole antenna is fed with respect to the ground with an A.C supply. It undergoes the principle of perfect reflection. When an A.C source is supplied to the antenna at its feed point, a virtual ground is established. Under the virtual ground, a virtual single element antenna is formed [1]. As a result of it, a replica of the current and voltage distribution is produced under the virtual ground. In figure 2.1, it is illustrated below.

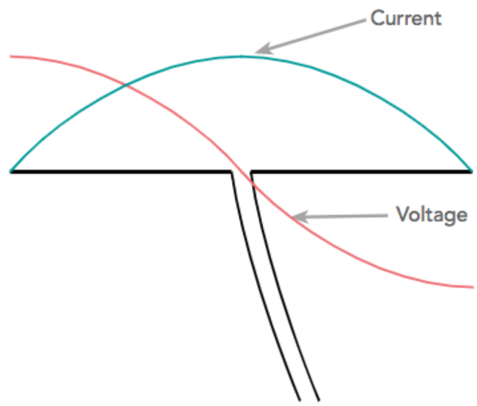

Figure 2.1 – Voltage and Current Distribution in a Monopole

2.1.2 Image Theory

Monopole antennas are based on the Image Theory. This uses the concept of a virtual image or source that represents the reflection. As shown in Figure – 2.2, these sources are initially not real but form an equivalent system when they are combined with real sources [2]. The virtual source is considered as ground and it does not represent correct fields. Only the actual system above the ground gives the exact and correct radiated fields. This is the principle of monopole antennas where the ground plane represents the other arm of the dipole [1].

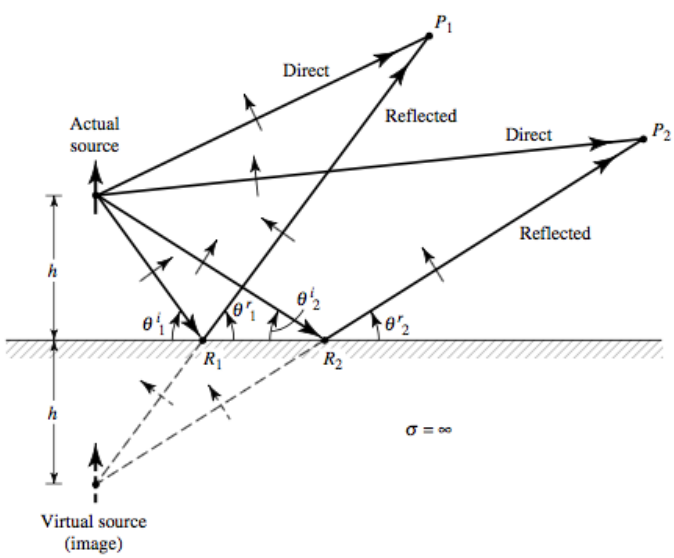

Figure 2.2 – Principle of Image Theory

2.1.3 Advantages of Monopole Antenna

- With monopole antennas, efficiency can be increased up to 80%.
- Monopoles are very easy to assemble and are suitable for small sites.
- Using monopole antennas can greatly reduce the height of an antenna [12].
- Monopole antennas have high reactive impedance.
- Installation cost is very low.

2.1.4 Disadvantages of Monopole Antenna

- Monopole antennas have a narrow bandwidth [1].
- The gain for monopole is low.
- The feed and other junctions in the antenna cause extra radiations.
- Being an Omni-directional antenna, there is a poor radiation equally in all directions.
- There is no radiation on the apex of antenna .
- The ground of the antenna causes signal reflections.

2.2 MONOPOLE ANTENNA PARAMETERS

2.2.1 Radiation Pattern

The monopole antenna has an omnidirectional radiation pattern. Therefore, it happens to be the perfect choice. Being omnidirectional means that the antenna is capable of radiating the RF energy equally in all the directions providing a 360-degree pattern of radiation. This results in connectivity in all directions. As the antenna is vertically polarized thus, the radiation will be maximum in the horizontal direction. The radiation pattern for a vertically polarized monopole antenna is shown in the figure below [1]: -

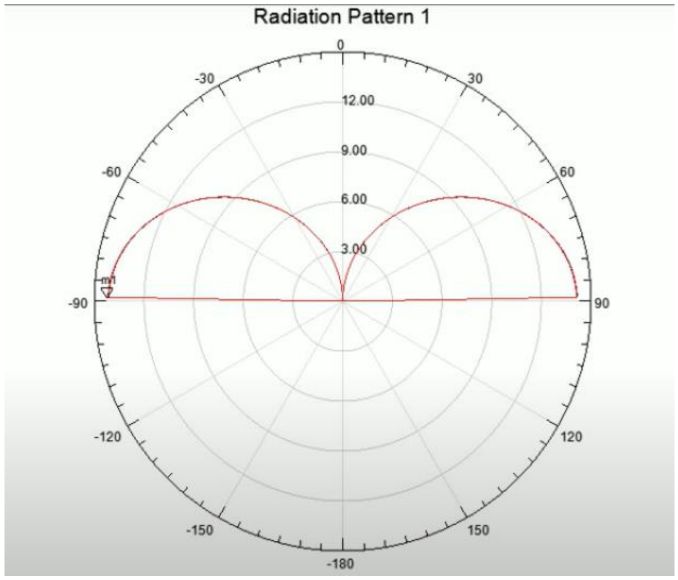

Figure 2.3 – Radiation Pattern of a Monopole Antenna

It can be seen from figure 2.3 that the radiation is only in the upper hemisphere region of the ground plane [2].

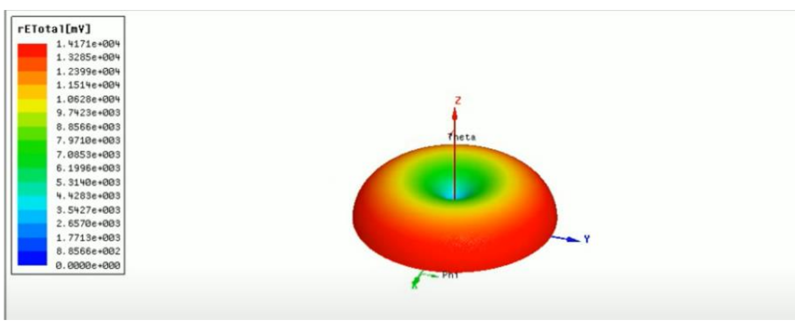

Figure 2.3 (a) – 3D Polar Plot of Monopole Antenna

In figure 2.3 (a) the 3-D polar plot simulation of the monopole antenna is displayed. Furthermore, the radiated energy greatly depends upon the angle of elevation. A slight change in the angle can affect the pattern. From figure 2.3 (a), it can be noticed that the pattern drops off to zero at the zenith position of the antenna axis.

2.2.2 Directivity & Gain

A monopole is a far more directive antenna as compared to a dipole antenna. It's the directivity near the radio horizon which makes it efficient for communication purposes [2]. The directivity can be calculated as follows:

$$\text{Directivity} = \frac{32}{3\pi} = \mathbf{3.39} \cong 5.31 \text{ dB}$$

The directivity happens to be approximately 5.31 dB

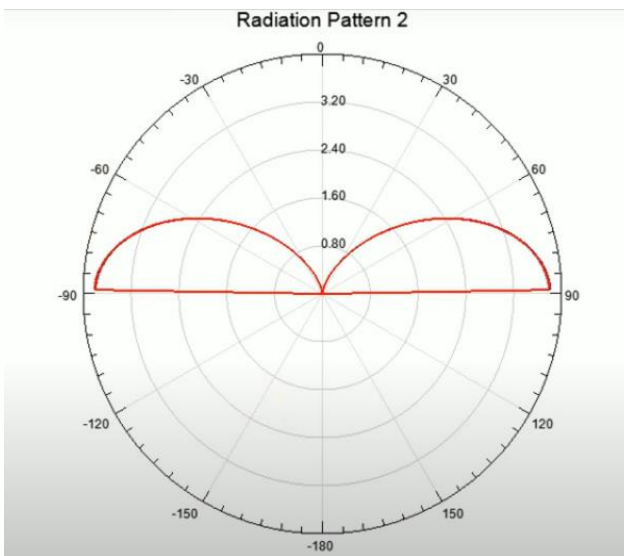

Figure 2.4 – Gain of Monopole Antenna

Figure 2.4 shows the gain of a monopole which is twice the gain of a dipole antenna.

2.3 BROADBAND (BB) ANTENNA

2.3.1 Principles of BB Antenna

a. Broadband is a radio communication technology in which an antenna maintains all its parameters and characteristics effectively over a wide range of frequencies.

b. An antenna is said to be a broadband antenna if its pattern and impedance do not change over an octave i.e. $\frac{fU}{fL} = 2$.
c. Broadband means that a broader or wider bandwidth is being covered. The wider the bandwidth is covered, the greater is its data-carrying capacity.
d. Broadband antennas are frequency independent antennas with bandwidth in the range 40:1 [10].
e. Types of broadband antennas include cylindrical dipole, Biconical dipole, Yagi-Uda/Long periodic dipole, array antennas, spiral antennas etc.
f. Broadband technology allows for a wider bandwidth which in turns promises faster communication.
g. If a particular frequency range or a discrete frequency component is jammed by the adversary, communication can be done on some other frequency component or range.

2.3.2 Role of Broadband Technology in Communication

The term "band" is used to refer set of frequencies and channels. There are many types involved in the band they may be baseband passband and wideband. Broadband communication is possible only by using wideband signals. As more the band will be wide more data it can transmit over a signal. Thus, Broadband technology allows us to transmit more data at a faster speed as compared to the landline telephone with which we can transmit only 56Kbps. With the help of this broadband technology, we can transmit at the data rate of thousands of Kilobytes per second and a few Megabytes per second (Mbps). Broadband technology is not only limited to the cellular networks but nowadays broadband technology can be accessed by using various other ways e.g TV, satellite, and Digital Subscriber Line (DSL), WIFI [14].

DSL also uses broadband technology to transmit data at a higher speed. DSL is the most important tool used in our homes and offices based networks. DSL used to transmit the voice video data at the rate of about 2Mbps. DSL provides the user access to the downstream data as well as upstream data. It uses signal processing techniques to reduce the noise in the signal.

Satellite communication also uses broadband to access the data rate. It broadcast the signals of broadcast internet which are used by direct internet users. It also broadcast television signals. Satellite broadcast signals at the upstream as well as downstream data rates. This technique is used because it provides data at a low price and high speed [8].

Broadband Technology causes direct connectivity to the internet. We can easily get access to the internet simply when we on the connection. We don't have to wait for access to an internet connection. Broadband technology not only provides us the high speed of the internet but also provides us high quality of voice, video, and data by using packet switching techniques. Also internet-based phone calls, video conferences are possible only due to broadband technology [8].

Broadband Technology has digitalized and accessed by the users using IP (standard protocol) in the form of a continuous stream of data called streaming data. Broadband Technology provides the information demanded by the costumers. Broadband Technology not only helps us to transmit data at high speed but also has brought revolutionary changes in the field of communication. It has switched the circuit switch network to a data-oriented network. Also copper base network to optical-based network. This technology enables users to change their network. Broadband technology has made possible encoding and decoding of video signals thus conditional access of video signals will be removed because video signals are multiplexed signals from tape as well as satellite.

Set-Top Boxes used in our home as well as offices also used for a broadband network. It is used as an interface between our TV and wireless network to provide multimedia services. Set-Top Box is only a modem that we use for broadband connectivity in our homes. It does not provide the whole connection. There is a whole setup of a broadband network is installed at the backend which we can't see and don't have access to it.

Nowadays the internet is playing a vital role in the service of mankind. It has revolutionized the way how people live and this is only possible due to broadband technology. It plays a vital role in the world’s economy. Video and conference calls and online meetings have changed the way of business by globalizing the world. Now the business is independent of the location of people. This technology is used to save the time of people. This technology has provided a greater benefit to business enterprises. With the help of broadband technology, many businesses would be able to achieve their specific goals. According to research, it has proved that broadband technology has improved the market share rate.

Broadband Technology helps in bringing people closer in the sense of their interests people having same interests can collaborate chat and discuss their ideas. Different software is created to bring people of the same interest on the same scale. For example, peoples who are planning to spend their holidays the software created for them which will use broadband technology and connect them to the places of their interest and in this way dream would come into reality. They can easily go to their dream places and would not regret going to the place and spending money. In this way, broadband technology revolutionized the tourism industry.

Over the years, online education systems have come into a place where a student can take classes from any part of the world. Many programs based on this type of education system has introduced. Broadband Technology, in this case, helps to connect students to teachers by using the remote access system and desktop conferencing. Broadband Technology also helps students with internet-based classes and programs of the online education system. In this way, better communication is achieved.

2.4 UHF AND VHF COMMUNICATION

2.4.1 UHF Communication

UHF (Ultra-High Frequency) are the radio waves with the range starting at 300 MHz all the way up to 3 GHz. Radio signals in the UHF band work on **Line of Sight** propagation and **Ground Reflection.** Line of Sight propagation is a characteristic of electromagnetic radiation in which waves travels in a directly from source to receiver as displayed in Figure – 2.5 [9].

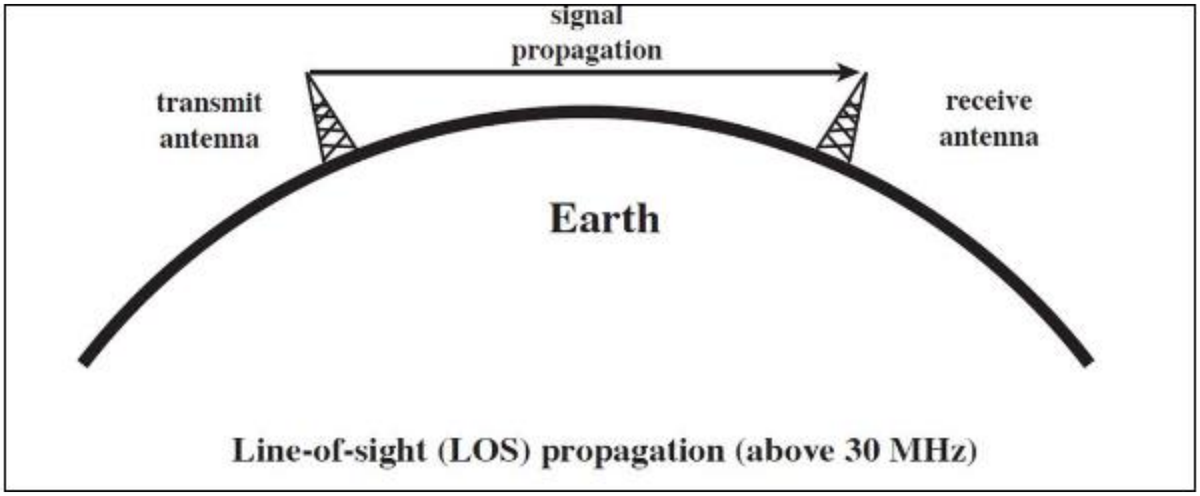

Figure 2.5 – Line-of-Sight (LOS) Propagation

Ground propagation is the radio propagation model predicting the path loss when the signal received consists of line of sight component and multiple path components formed by predominantly a single ground reflected wave. There is a minute to no reflection from the ionosphere layer unlike in HF communication [9]. UHF waves are shorter length waves and hence it is hard for them to penetrate through walls and objects more effectively than their VHF counterparts. UHF communication is preferred in most two-way radios where there is urban environment and buildings because UHF radios are capable of receiving very short length radio waves.

2.4.2 Advantages of UHF Communication

- UHF radio waves are suitable for indoor uses as they are short waves.
- Due to their short wavelength, they can easily penetrate through concrete and other solid obstacles.
- They allow for a smaller antenna length.

2.4.3 Disadvantages of UHF Communication

- Attenuation increases with increase in the distance while propagation.
- UHF propagation has limited broadcast and reception range.
- They suffer interference from nearby channels that are relying on UHF.

2.4.4 VHF Communication

VHF (Very High Frequency) are the radio frequencies ranging from 30 to 300 MHz. Radio waves in the VHF band also propagate by line of sight(LOS) propagation and little ground reflection [9]. For VHF communication, the distance between the transmitter and receiver must not be more than 100 miles of the radio horizon. VHF radio waves are less prone to interference by atmospheric noise, buildings, and other obstacles as compared to UHF so they are preferred for communication in places like farms and rural environment with a vast amount of space and low amount of physical obstructions.

2.4.5 Advantages of VHF Communication

- Suitable for places which have clear LOS or an open terrain.
- VHF radio waves allow for a shorter antenna
- They provide a larger bandwidth.
- VHF waves are less interfered by the background radiation

2.4.6 Disadvantages of VHF Communication

- VHF radio waves have a shorter range
- These waves can not pass through walls and windows
- They are affected by weather conditions like rain, snowfall etc.
- When indoors, these signals attenuate more than UHF radio waves.

CHAPTER 3

DESIGN AND DEVELOPMENT

The software used to design and model this antenna is **CST Studio Suite 2015**. Initially, an inspection of the existing design is made to analyze how we can reach our goal. The advantages and the disadvantages of the structure are minutely observed. On the basis of current design, a new modification is introduced to provide a better efficiency as well as coverage.

3.1 PREVIOUS WORK DONE

In the first step, a recently published research paper proposes a 173 cm long and 2.5 cm diameter Dipole Antenna which covers the frequencies in 30 MHz – 512 MHz band [3].

a) **Enhancement of BW using a Dipole Antenna:**
   A dipole antenna is well known for it's Narrowband results. However, a narrowband is not sufficient for communication and improvisations are needed to achieve the targeted Bandwidth. Since, the communication is meant for a Broadband channel thus research and its implementation is done to improve the results.

b) **Loading Elements for Broadband Communication:**
   After an extensive research, it was proposed that with the aid of reactive loads at appropriate locations, the input impedance and the bandwidth patterns were expanded. The loading concept was opted to observe the patterns [4] – [7].
   Firstly, a simple dipole was made and its results were observed. Upon success more reactive loads were added and the bandwidth got better and better. This led to a 173 cm antenna broken down into 5 sub-antennas of various heights in the spacing of which reactive loads were placed [3].

The table below displays the values of Resistances & Inductances used [3].

Serial Number	Inductance Value	Resistance Value
L4	0.2772μH	270
L3	0.3045 μH	27
L2	0.4760 μH	560
L1	0.4152 μH	0
Lf	1.9932 μH	1000

Table 1 – Existing Design Lumped elements values

c) Effects of Reactive Loads:

Figure 3.1 shows the peak power showed by each resistance at a particular range of frequency.

The statistics reveal that

1. Large amount of power was handled by Resistance in the mid-range frequencies.
2. In the higher frequency ranges, large amount of power was handled by Resistance 2.
3. Resistance 3 handled minimum power in the entire range.
4. In the lower frequency ranges, Resistance 4 handled a large amount of power.

So, each range is maintained at a maximum level with a certain resistance. This aids us to remain consistent in communication over the entire range [3].

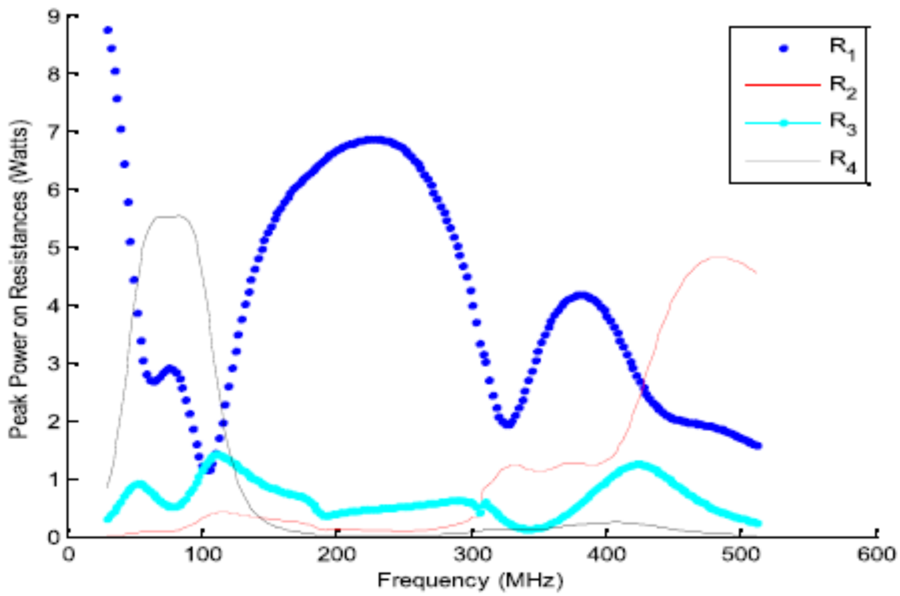

Figure 3.1 – Peak Power Showed by each Resistance

d) Comparison of Unloaded & Loaded Dipole Antenna:

Figure 3.2 is a graph comparing the two antennas i.e. loaded and unloaded. The variations easily observable.

In figure 3.2 the comparison is made on the basis of VSWR. It is evident from the figure that in the unloaded dipole antenna the VSWR falls below 2 only in the range of 355 MHz – 370 MHz (Encircled dip). All the ranges other than this face a maximum reflection loss. More the reflection loss, Less the power transmitted which means poor communication. So it is not a wise choice. Where as a there are dips going below 2 so we are getting relatively better communication. The ranges that are not below 2 are just minimally above 2 which seems to be a bit acceptable [5]-[7].

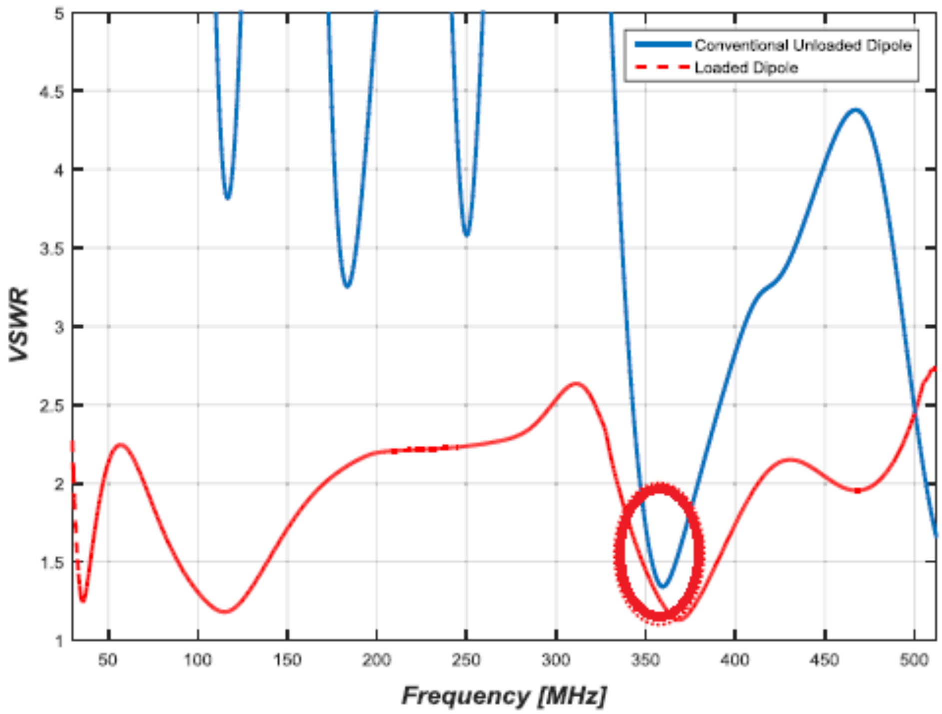

Figure 3.2 – Loaded vs. Unloaded Antenna

The second comparison in figure 3.3 is made on the basis of Gain. The graph shows an almost uniform gain pattern in the desired range (30 MHz to 512 MHz) for the loaded dipole but non uniform gain peaks for the unloaded antenna. So it proves that the results of the loaded antenna are better than that of the unloaded antenna in all the perspectives [3]. Thus, the ultimate choice for further research should be the loaded dipole antenna.

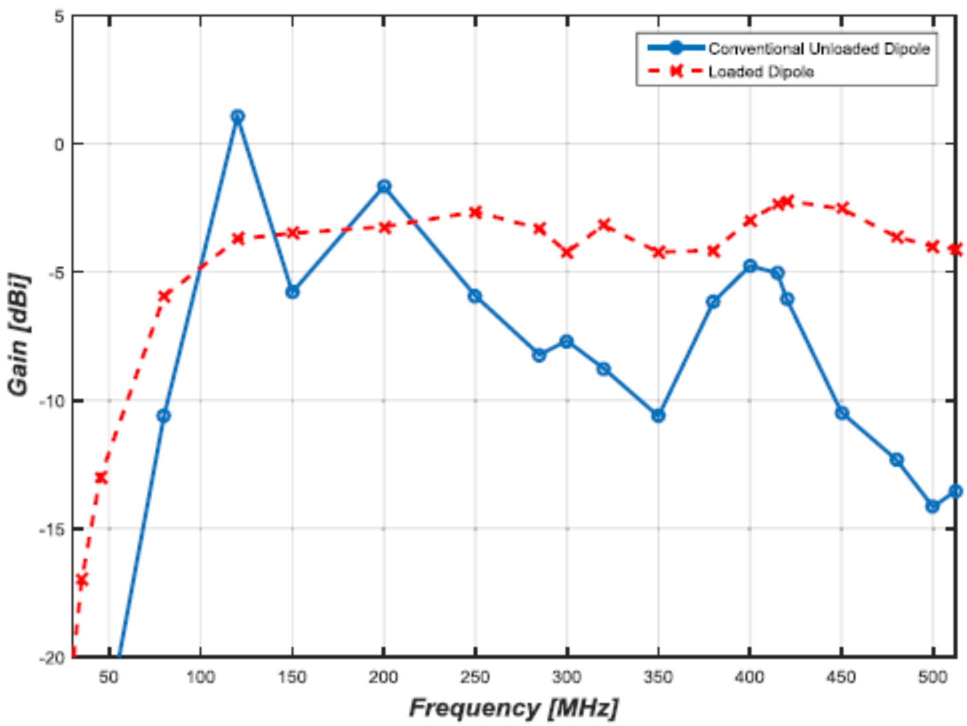

Figure 3.3 – Gain of Loaded and Unloaded Antenna

3.2 TECHNIQUES EMPLOYED IN THE MODIFICATION OF EXISTING DESIGN

Monopole antennas are narrow band antennas. To achieve a wider bandwidth, certain techniques can be employed. The bandwidth enhancing technique used in this project are Reactive Loading of the antenna using passive LR circuits [3] –[7].

3.2.1 LR Loading Circuits

Concept of Loading:

Monopole antennas are the resonators of electromagnetic waves. Standing waves of voltages and currents in the antenna are excited by the power that is applied by the transmitter [1]. In order to make an antenna resonate at a particular desired frequency, the antennas reactance must be zero. At resonance, the antenna absorbs all the power that is being transmitted to it via transmitter and acts as pure resistance. Most of the times, the antenna offers a capacitive reactance which means a fraction of power is reflected back and travels towards the transmitter through the transmission line. This creates standing wave ratio (SWR) in the antenna and impedes the process of transmission. In such a case to make the antenna resonant, loading coils can be inserted in the antenna. If the offered reactance is capacitive only then an equal and opposite inductive reactance is required to cancel out the capacitive effect, so that the combination of reactance cancel each other out and antenna is purely resistive. The calculations for the inductive reactance and resistors were made on the basis of this concept [3]-[7].

LR circuits are circuits that are composed of Inductors (L) and Resistors (R) in series or parallel. According to a study, reactive loading of an antenna can be used for making the impedance behavior of an antenna adapt to the desired operating frequency band. This concept is illustrated in Figure – 3.4 below. In Figure – 3.4 (a), a monopole was designed with an operating frequency at 340 MHz. It can be seen that initially without any reactive loading, a bandwidth of only 39 MHz is covered by the monopole.

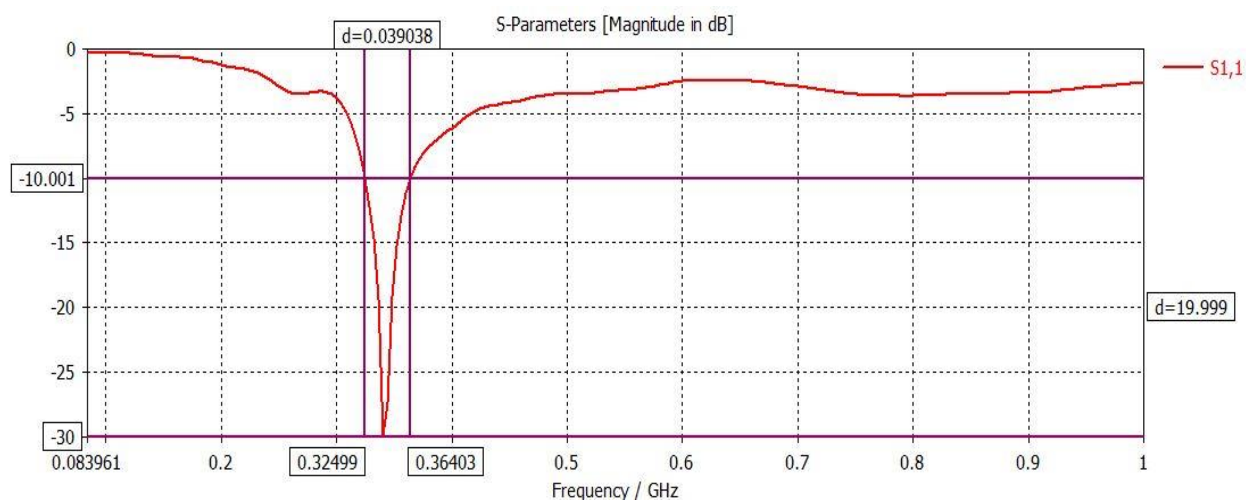

Figure 3.4 (a) – Bandwidth without loading

An LR circuit was inserted in the port of the same antenna. The LR circuit comprised of a **1000-ohm resistor** and an **18 H inductor** attached in parallel. After the insertion of this LR circuit, it can be seen in Figure – 3.4 (b) that the covered bandwidth coverage has improved. Now the monopole covers the frequency band of almost 53.67 MHz.

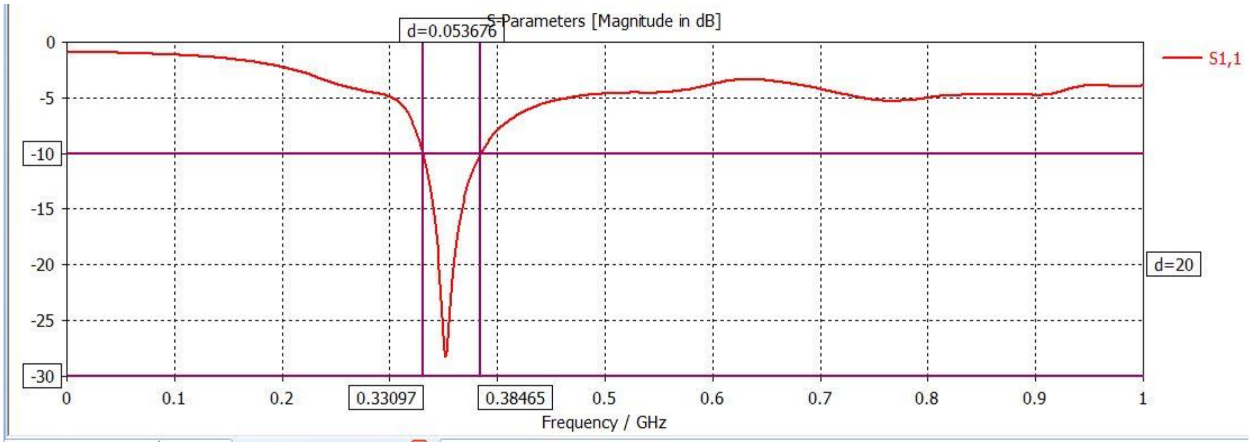

Figure 3.4 (b) – Bandwidth after loading

3.3 FINAL DESIGN

In the final design of the length is 170 cm which is reduced up to 5 cm. The radius of antenna is 4.5 cm and it is covering frequency range of 198 to 496 MHz. The design is shown in Figure – 3.5 (a,b)

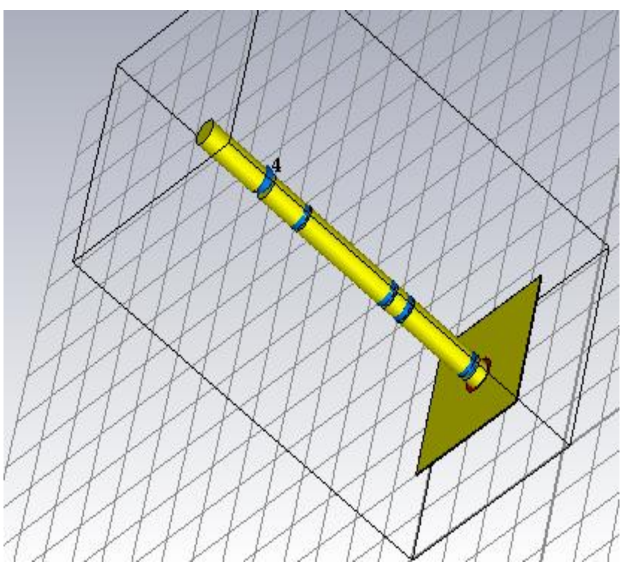

Figure – 3.5 (a)

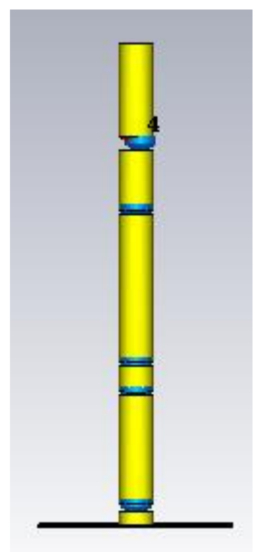

Figure – 3.5 (b)

Lumped elements:

The capacitive or inductive nature of antenna cause to reduce its bandwidth. The nature of our antenna is capacitive [13]. It is necessary to cancel the effect of capacitor by inductors in series and parallel [4] – [7]. The cancellation if the capacitive effect of on this antenna will cause to increase the bandwidth of antenna. In this antenna we have used 5 lumped elements. The detail of every element is given below.

- Element 1: It has an RLC series circuit with a resistor of 270 ohms and an inductor of 6 H.
- Element 2: It consists of RLC series circuit with a resistor of 27-ohm and an inductor of 4 H.
- Element 3: It consists of RLC parallel circuit with a resistor of 580-ohm and an inductor of 4 H.
- Element 4: It consists of RLC series circuit with an inductor of 7 H.
- Element 5: It consists of RLC series circuit with a resistor of 1 ohm and an inductor of 18 H.

3.4 COMPARISON BETWEEN EXISITNG AND NEW DESIGN

A comparison between the existing and the new design is made in this section to depict the differences in the two models.

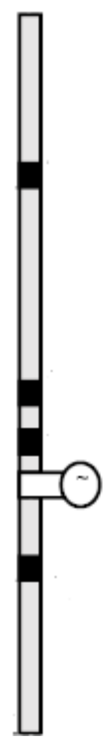

Figure 3.6 – Design of existing dipole

Figure – 3.6 is the design of the previously implemented research. The height of antenna is 173 cm and the radius is 2.5 cm. The type of this antenna is a dipole. It covers a range of 300 MHz – 512 MHz. There is one port and a series of reactive loads whose values have been tabulated earlier. The gain starts at -20 dBi and changes to -2 dBi [3].

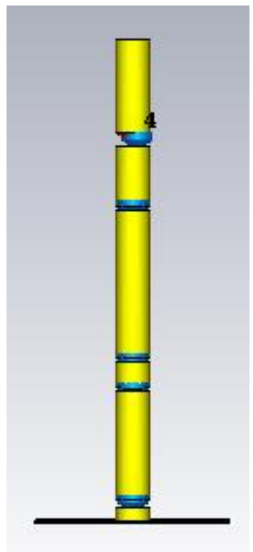

Figure 3.7 – Design of new Monopole

Figure 3.7 shows our project design. It is better than previous design in terms of

i. Gain
ii. Radiation Pattern
iii. Size
iv. Directivity

The design shown above is a Monopole Antenna with a height of 130 cm and radius 4.5 cm. It has a total of 6 ports out of which 4 are for output. No such technology has been used in the previous research which makes it less efficient as compared to the current design. The gain of antenna changes from 3.7 dBi to 5.738 dBi.

CHAPTER 4

ANALYSIS AND EVALUATION

This project was designed using CST Studio Suite 2015 software and comprises of a VHF/UHF antenna for Man Pack Radio. The antenna is designed to operate in the frequency range **198 to 496 MHz** with a gain of **5.738 dBi** and directivity as **5.854 dB.** This **130 cm** long antenna has a radius of **4.5 cm.** The VSWR for the antenna in the attained bandwidth is **1.7** which shows that the antenna is a good radiator of electromagnetic energy. The following sections contain analysis of the different parameters of the antenna.

4.1 PROJECT ANALYSIS AND EVALUATION

(a) S plot:

For the better communication of the s plot of the design should have curve of graph below -10 dB at the particular frequency. For a broadband communication of antenna, it is required to have the curve of graph below -10 dB in the whole frequency range of antenna [1]. In this antenna we have used 2 inputs for the broadband communication as a result of which there will be four curves obtained. In which the port with the 50-ohm impedance will provide us required results. For this port of antenna, we obtain a curve below -10dB for the whole bandwidth of antenna. At this curve we have lowest magnitude -**29.15 dB** at the frequency of 435 MHz. The second lowest magnitude **-21. 99 dBi** at the frequency of 294 MHz. It means that at these frequencies our design will give the best results. This result is shown in Figure – 4.1.

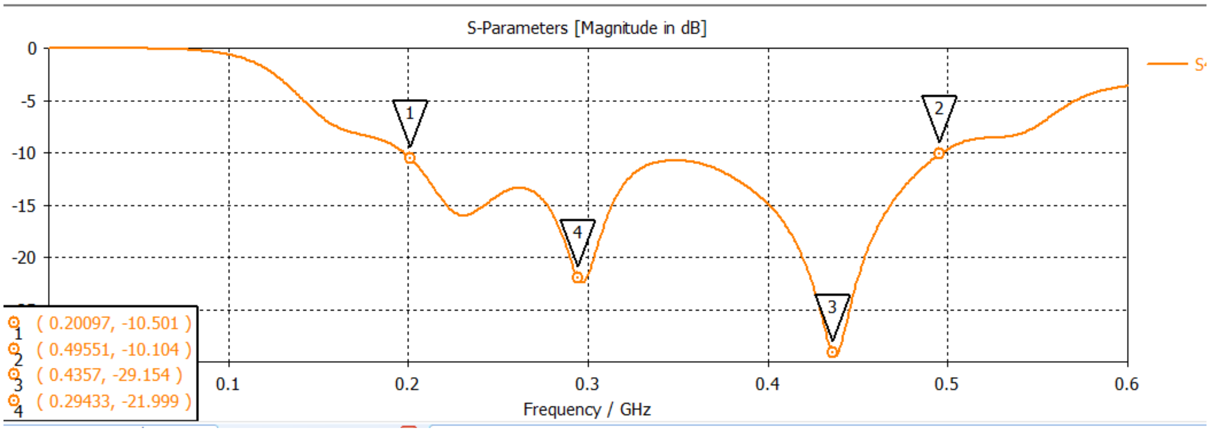

Figure 4.1 – S-Parameter of the antenna

(b) Gain:

The gain of antenna should be uniform for the better communication of antenna. It is required that the gain should vary its value [2]. The value of gain should remain almost same. It is required for the better communication the gain should not extend its value too much. In this design we can see that the gain of antenna is almost uniform in the required bandwidth i.e. in the given range of frequencies. The gain of antenna with respect to the frequency is shown in fig below which is **5.738 dBi**.

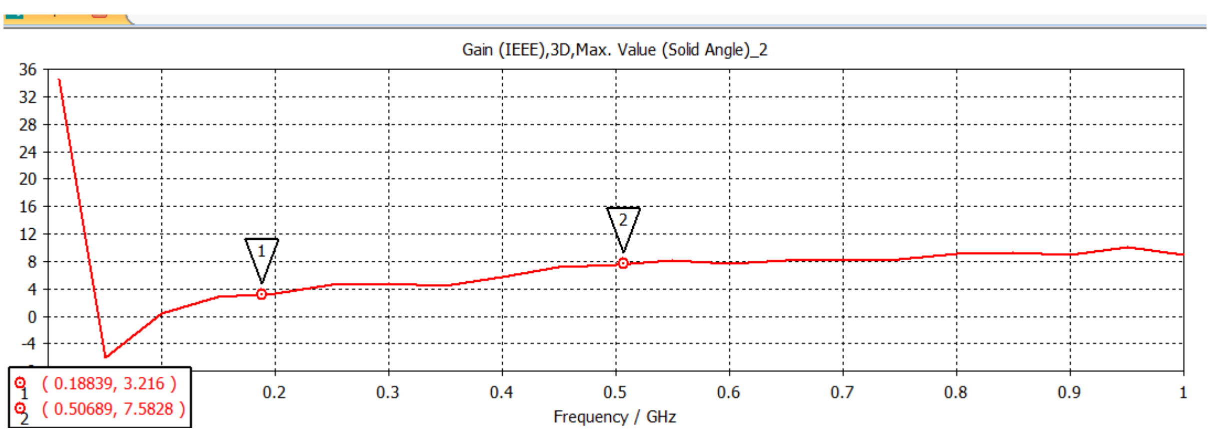

Figure 4.2 – Gain of the antenna

Gain of antenna is uniform pattern at the frequency of 400 MHz. This is shown in Figure – 4.3.

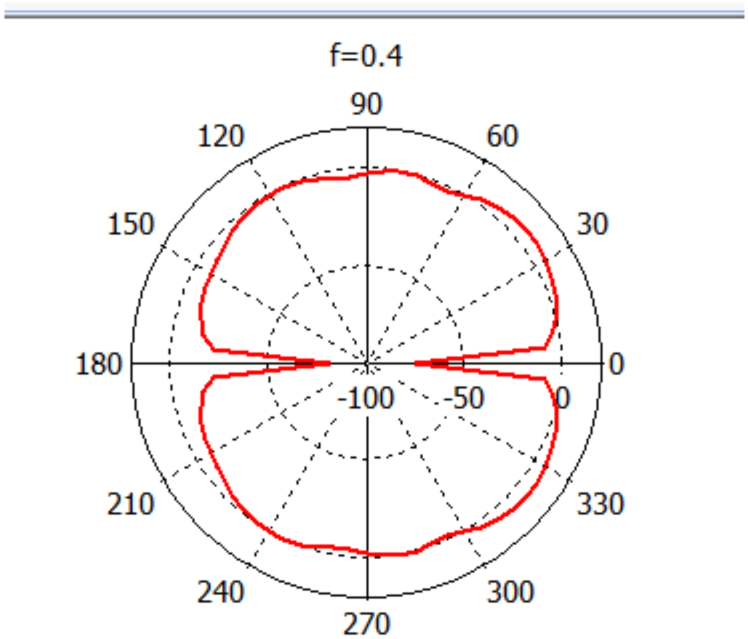

Figure 4.3 – Gain of antenna at 400 MHz

The gain of antenna in the far field is shown in figure – 4.4

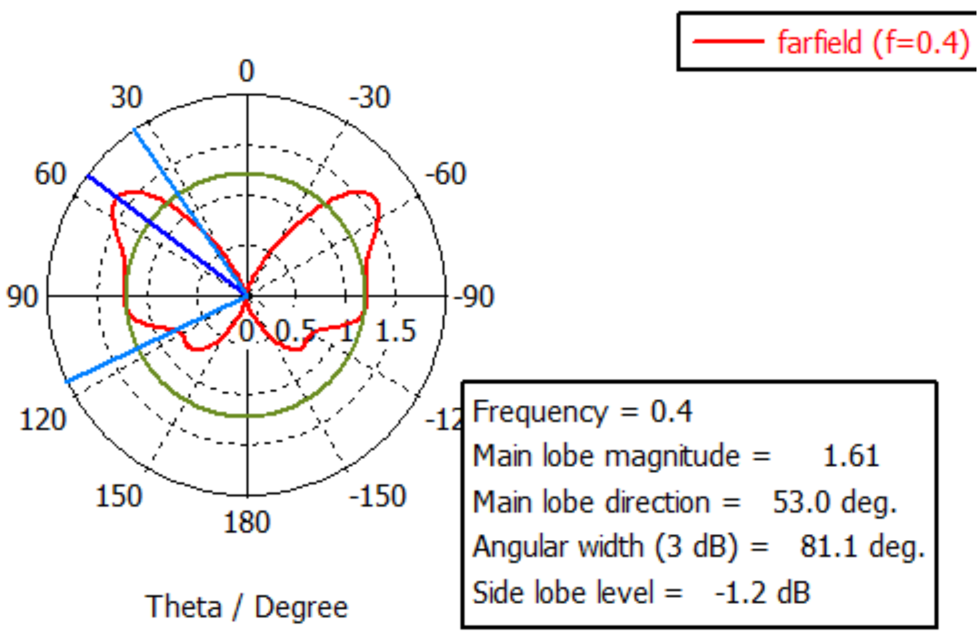

Figure 4.4 – Gain of Antenna in Far field

Figure – 4.5 shows the 3D polar plot of the gain.

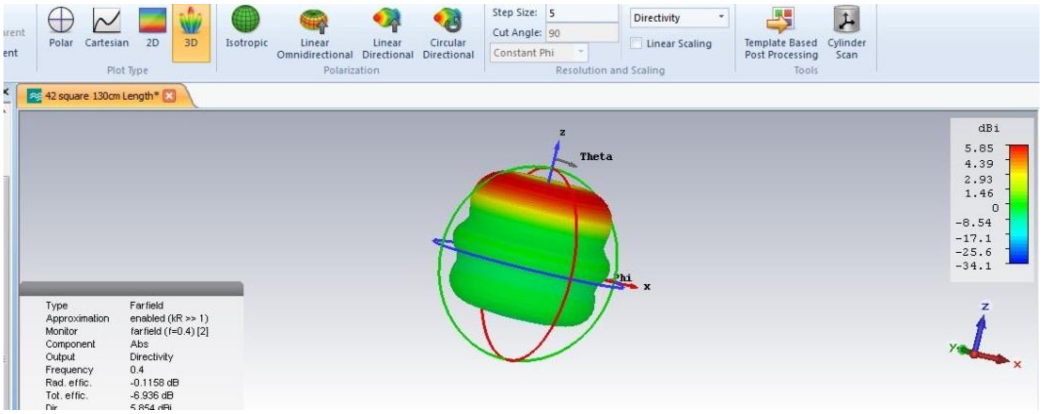

Figure 4.5 – 3DPolar Plot of the Gain

(c) Bandwidth of antenna:

For the measurement of the performance of antenna it is required to measure VSWR (voltage standing wave ratio) for the different values of frequencies [1]. Bandwidth of an antenna related with the frequencies at which VSWR (voltage standing wave ratio) of antenna is less than 2. Figure – 4.6 shows the bandwidth of our antenna design. This design covers a wider bandwidth of antenna. In the frequency range of 193.55-500 MHz.

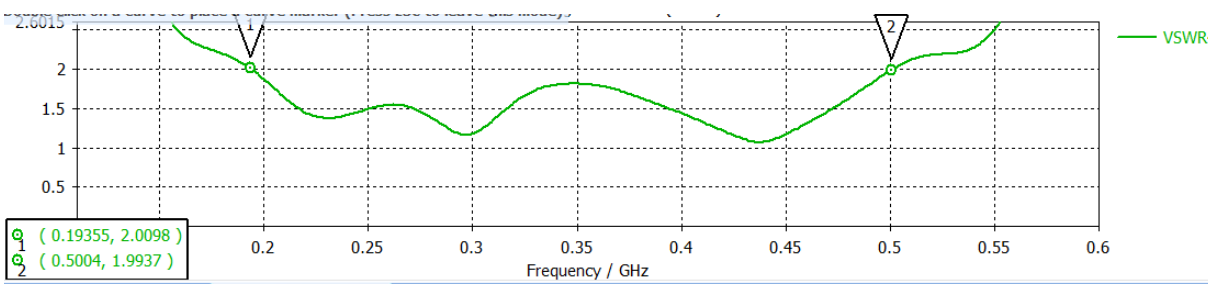

Figure 4.6 – Bandwidth of the Antenna

(d) Radiation efficiency:

It relates the power radiated from the antenna with the power given to antenna for an efficient antenna design the efficiency must be between 0 and 1 [2]. The radiation efficiency of antenna is shown in Figure – 4.7.

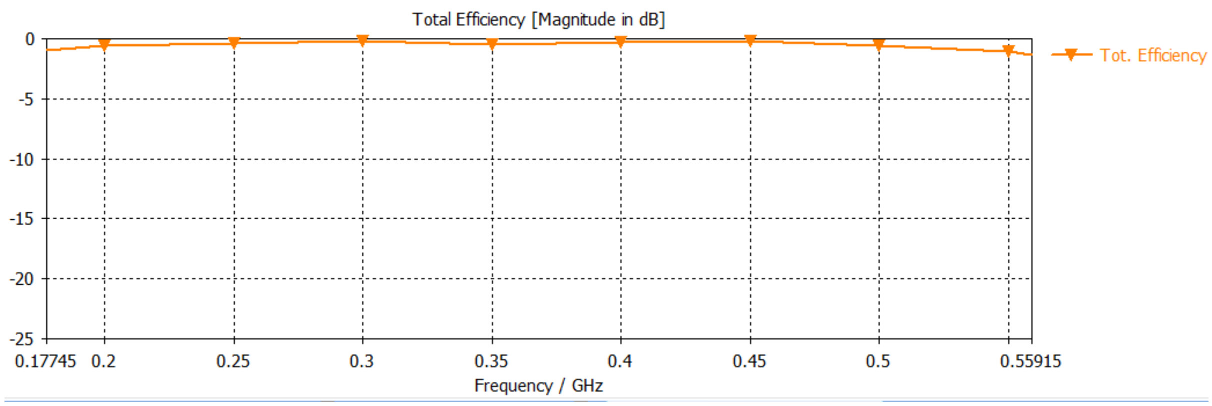

Figure 4.7 – Radiation Efficiency of the Anenna

(e) Port:

The port of antenna is the Radio frequency connection system of antenna [2]. In this design we have used a single port of 50 Ω impedance. The port is along z-axis in co-ordinate system. In the design of this project, two input ports are modelled which yield four outputs as shown below:

- **S22 Plot:** Figure – 4.8 shows the S22 plot. From this it can be seen that the antenna is not radiating. The return loss is quite greater than -10 dB i.e. -1.5 dB which shows there is no radiation.

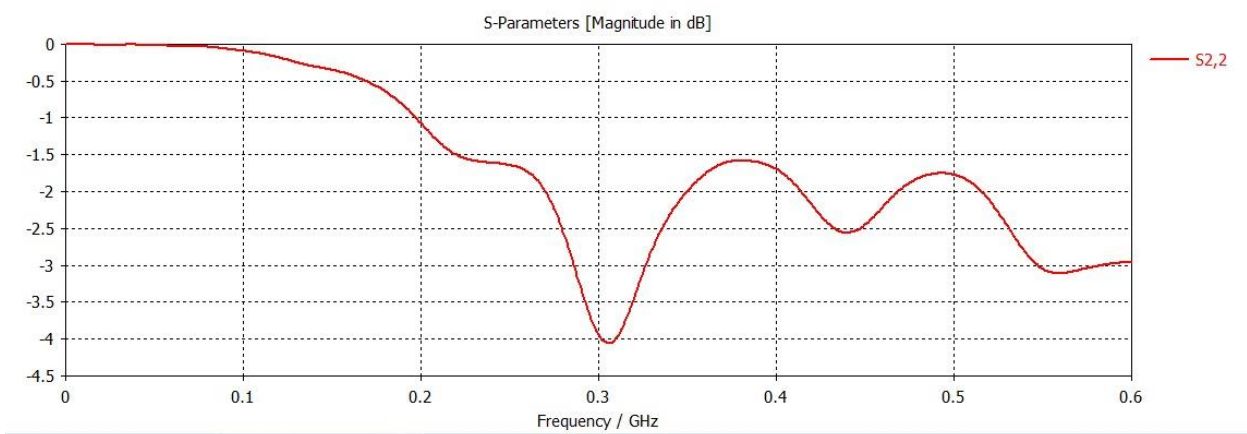

Figure 4.8 – S2,2 Plot

- **S24 Plot:** From figure – 4.9 it can be seen that the antenna is radiating well in the frequency band from 11 MHz to 600 MHz with a return loss less than -10 dB in the whole frequency range.

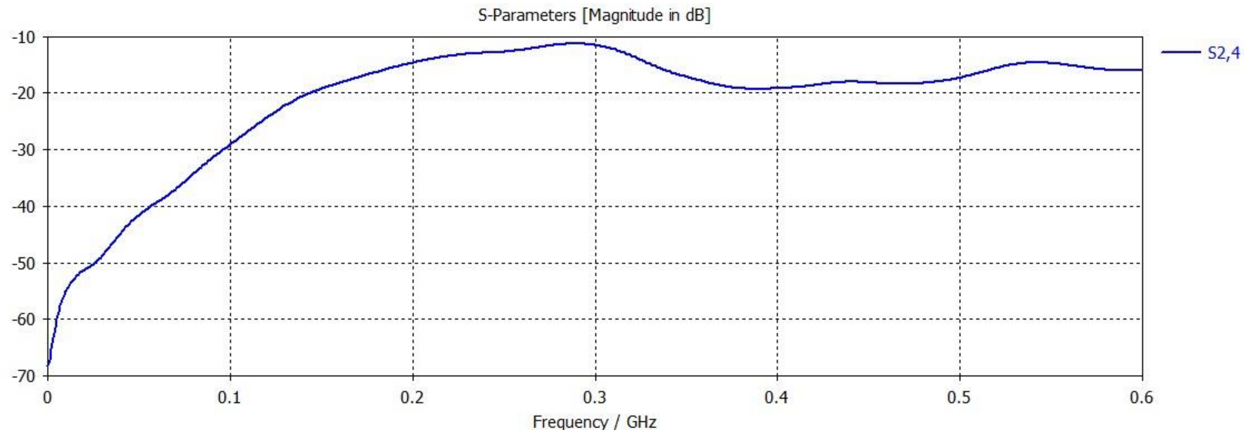

Figure 4.9 – S2,4 Plot

- **S42 Plot:** From Figure – 4.10, again it can be seen that the antenna is acting as a good radiator of electromagnetic waves. In the whole frequency band, the return loss is less than -10 dB.

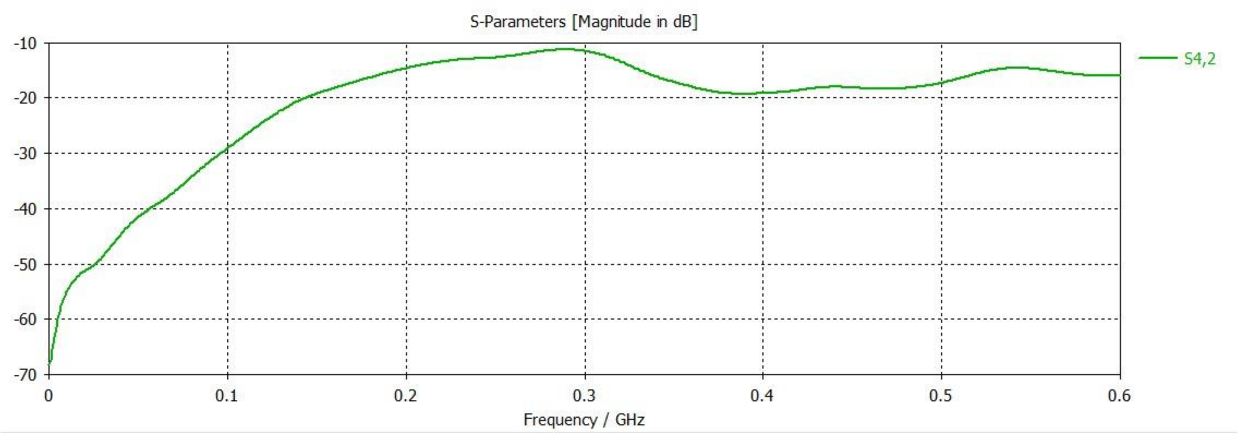

Figure 4.10 – S4,2 Plot

- **S44 Plot:** From 200 MHz to 500 MHz, the return loss is better than -10 dB. This is shown in Figure 4.11.

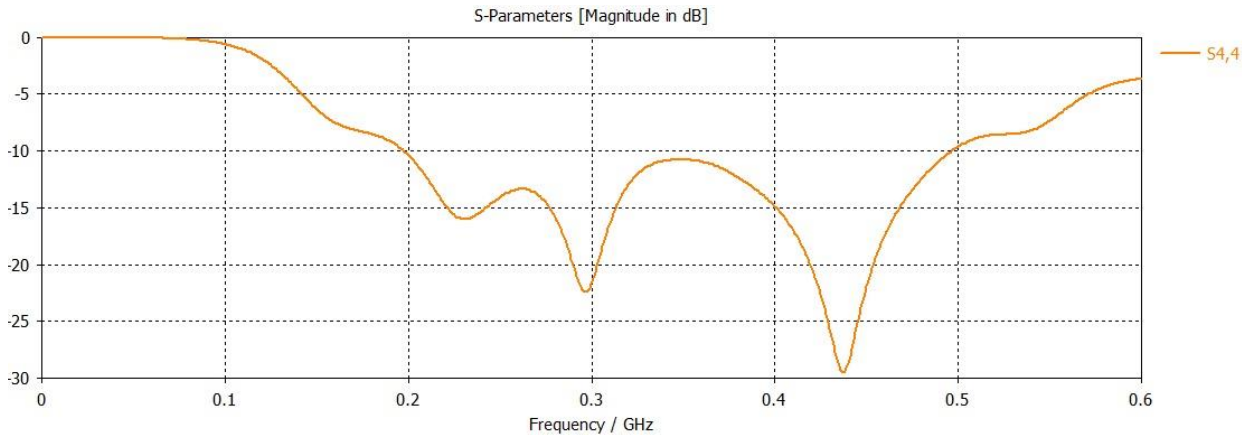

Figure 4.11 – S4,4 Plot

(f) VSWR:

The VSWR for this antenna is shown below in figure – 4.12. The VSWR for an antenna should be greater than 1 and less than 2 [1]. For this antenna, the VSWR is **1.7** in the achieved frequency band. This shows that the antenna is well-matched and there very little reflections. The antenna is a good radiator of electromagnetic energy and most of the power is being transmitted from the source towards the receiver via the transmission line.

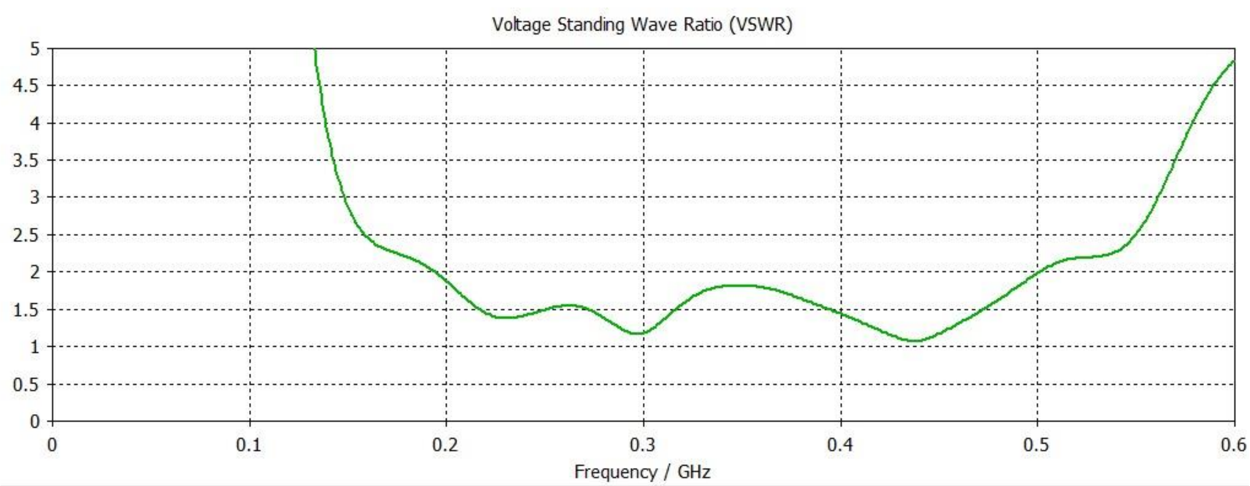

Figure 4.12 – VSWR of the Antenna

4.1.1 Dimensions of the Antenna

This section discusses the dimensions of the VHF/UHF antenna for Man Pack Radio. Figure – 4.13 represents a general picture of how the antenna is divided. The gap portion shows where the reactive loads and ports are connected.

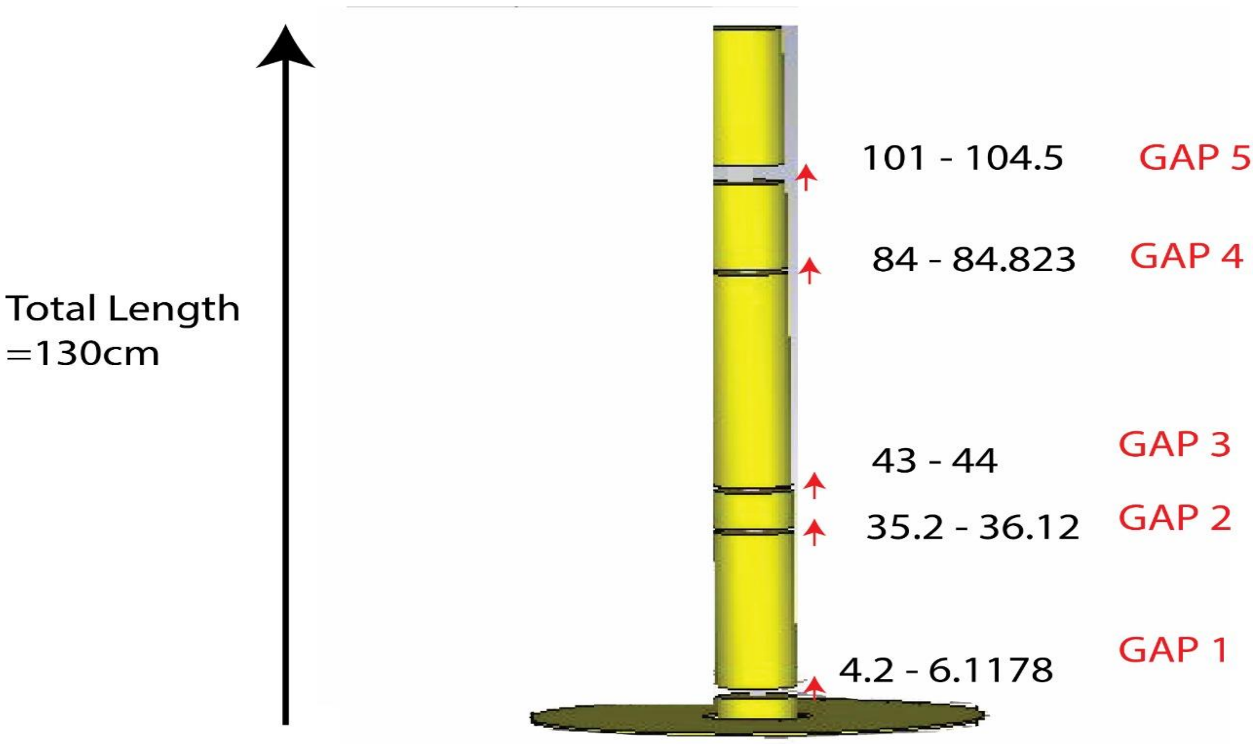

Figure 4.13 – Dimensions of theaAntenna

The following table enlist the dimensions of all the major elements that form part of this antenna.

Reactive Load 01	
Inductance	6 H
Resistance	270 ohms
Length of LR circuit	0.823 cm
Radius of LR circuit	1.02 cm

Reactive Load 02	
Inductance	4 H
Resistance	27 ohms
Length of LR circuit	1 cm
Radius of LR circuit	0.8892 cm
Reactive Load 03	
Inductance	4 H
Resistance	580 ohms
Length of LR circuit	0.92 cm
Radius of LR circuit	0.8892
Reactive Load 04	
Inductance	5 H
Length of Inductor	1.9178 cm
Radius of Inductor	0.8892 cm
Reactive Load 05	
Inductance	18 H
Resistance	1 ohm
Length of LR circuit	3.5 cm
Radius of LR circuit	0.65 cm
Port 01	
Port Impedance	50 ohms
Port Length	3.5 cm
Port 02 (Waveguide Port)	
Port Length	6 cm
Port Width	6 cm

Ground Plane	
Length	52 cm
Width	52 cm

Table 2 – Antenna Dimensions

4.2 SUMMARY TABLE

Table – 3 shows the summarized information of the antennas that have been designed using lumped elements with varying values and different port numbers before finalizing the actual product. Reactive loading has been used in all these antennas [3] – [7]. The table gives the frequency ranges covered by the antennas and the gain of these antennas in that particular frequency band(s). The data provided in this table can further help in the future work that can be done on this antenna to improve the achieved results and make it able to cover the entire bandwidth from 30 to 512 MHz.

		Antenna #1	**Antenna #2**	**Antenna #3**	**Antenna #4**	**Antenna #8**	**Antenna #9**	**Antenna #10**	**Antenna #10**
LUMPED ELEMENT 1	**R1(Ω)** **L1 (H)** **C1 (F)**	270 (Ω) 6 (H) 0 (F)	270 (Ω) 60 (H) 0 (F)	270 (Ω) 0.000006(H) 0 (F)	270 (Ω) 60 (H) 0 (F)	270 (Ω) 0 (H) 0 (F)	0 (Ω) 1 (H) 0 (F)	0 (Ω) 50 (H) 0 (F)	0 (Ω) 0 (H) 500(F)
LUMPED ELEMENT 2	**R2 (Ω)** **L2 (H)** **C2 (F)**	27 (Ω) 4 (H) 0 (F)	27 (Ω) .0000004 (H) 0 (F)	27 (Ω) .0000004(H) 0 (F)	27 (Ω) 40 (H) 0 (F)	27 (Ω) 0 (H) 0 (F)	0 (Ω) 1 (H) 0 (F)	0 (Ω) 50 (H) 0 (F)	0 (Ω) 0 (H) 500 (F)
LUMPED ELEMENT 3	**R3 (Ω)** **L3 (H)** **C3 (F)**	580 (Ω) 4 (H) 0 (F)	580 (Ω) 4 (H) 0 (F)	580 (Ω) 0.000004 (H) 0 (F)	580 (Ω) 40 (H) 0 (F)	580 (Ω) 0 (H) 0 (F)	0 (Ω) 1 (H) 0 (F)	0 (Ω) 50 (H) 0 (F)	0 (Ω) 0 (H) 500 (F)
LUMPED ELEMENT 4	**R4 (Ω)** **L4 (H)** **C4 (F)**	0 (Ω) 5 (H) 0 (F)	0 (Ω) 5 (H) 0 (F)	0 (Ω) 0.000005 (H) 0 (F)	0 (Ω) 50 (H) 0 (F)	10 (Ω) 0 (H) 0 (F)	0 (Ω) 1 (H) 0 (F)	0 (Ω) 50 (H) 0 (F)	0 (Ω) 0(H) 500 (F)

LUMPED ELEMENT 5	**R5 (Ω) L5 (H) C5 (F)**	1000 (Ω) 18 (H) 0 (F)	1000 (Ω) 18 (H) 0 (F)	1000 (Ω) 0.000018 (H) 0 (F)	1000(Ω) 18 (H) 0 (F)	1000(Ω) 0 (H) 0 (F)	0(Ω) 1 (H) 0 (F)	0(Ω) 50 (H) 0 (F)	0 (Ω) 0 (H) 500(F)
LUMPED ELEMENT 6	**R6 (Ω) L6 (H) C6 (F)**	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)	0 (Ω) 0 (H) 0 (F)
Bandwidth Achieved		**200MHz To 521MHz**	**201MHz To 521MHz**	**201MHz To 522MHz**	**200MHz To 521MHz**	**239MHz To 491MHz**	**198MHz To 518MHz**	**198MHz To 518MHz**	**70- 78, 287-456MHz**
Gain Achieved		3.144 dBi	1.702 dBi	1.748 dBi	1.737 dBi	1.231 dBi	2.243 dBi	2.243 dBi	3.375 dBi
Directivity		3.201 dBi	2.269 dBi	2.288 dBi	2.307 dBi	3.708 dBi	2.252 dBi	2.252 dBi	3.379 dBi

Table 3 *– Summary of Antennas*

CHAPTER 5
FUTURE WORK

5.1 RECOMMENDATIONS FOR FUTURE WORK

The antenna design achieved in this project is a combination of best possible results which are achieved through integrating various antenna design techniques and detailed analysis. Still some recommendations can be taken into consideration for enhanced and improved results. This antenna can undergo some modifications for meeting the requirement of communication. Since communication demands changes over time, this antenna can serve as a basis for the designing of more efficient antennas comprising of following properties which are derived from this antenna results.

a. The antenna size can be reduced as to keep the volume minimum so that when integrated with SDR, it is manageable and easy to carry by the soldier.

b. The gain that has been achieved up till now can be improved.

c. A new technique can be employed in the antenna design to achieve the broadband frequency range.

d. Efforts can be made to reduce the height of the antenna, the smaller the antenna, the more manageable it is.

e. Varying the values of LR circuits or introducing more loading circuits into the antenna design can further improve the bandwidth and efficiency of the antenna.

f. For complete coverage of UHF and VHF, different matching circuits can be used.

g. The antenna design can be modified in such a way that an additional antenna can be integrated with the existing one to cover the desired frequency band.

5.2 CONCLUSION

In this project a monopole omnidirectional antenna is proposed having length of 130cm and radius 4.5 cm. In this project we have used reactive loading technology through which we have achieved a combination of VHF and UHF bands i.e. from 198 to 496 MHz. In this antenna impedance matching is less than -10 dB which indicates that antenna can radiate efficiently and VSWR is below 2. This antenna is linear polarized along y axis which indicates that it would radiate horizontally. This antenna has omni-directional radiation pattern which clearly shows that it would radiate equally in all directions. This antenna is designed for communication which is integrated with SDR based radio sets. Results are much better and improved.

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