ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL AND COMPUTERENGINEERING

PARAMETRIC STUDY AND PERFORMANCE ANALYSIS OF PIFA ARRAY ANTENNA AT Ka-BAND

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Declaration

I, the undersigned, declare that the thesis comprises my own work in compliance with internationally accepted practices; I have fully acknowledged and referred all materials used in this thesis work.

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This thesis has been submitted for examination with my approval as a university advisor.

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Abstract

Planar inverted F-antenna are playing an important role in wireless communication systems because of their many advantages like light weight, low profile, low cost, easy integration with planar structure and easy fabrication. The main objective of this thesis is to discuss the characteristics of PIFA antenna using different change of design parameters such as shortening plate width, ground plane width ground plane length, patch width, and patch length and height. The design issues include PIFA antenna dimensions, feeding techniques and various polarization mechanisms whereas the performance issues include voltage standing wave ratio, radiation pattern, directivity and specific absorption rate. In this thesis, both single element and four by four elements of PIFA antenna at Ka-band are designed using the CAD-FEKO simulation software. To design it, standard formulas are used to calculate different parameters of the antenna. The proposed antenna is designed to work at 28GHz frequency band and simulation results shows that 4.66 dB and 7.63dB of directivity for single element and four by four elements of PIFA antenna were attained respectively and also SAR values of 2.26w/kg for single element and 0.613w/kg for four by four elements design were attained. To achieve all the above results both single element and planar array of PIFA antenna were designed with micro-strip line feeding based on quarter wave impedance matching technique using CAD-FEKO simulation software.

Keywords*: PIFA, Planar Array antennas, Ka-Band, Specific absorption rate.*

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List of Symbols

Ɛr	Dielectric constant of substrate
Fr	Operating frequency
Ɛe	Effective dielectric constant
c	Free space velocity of light, which is 3x108 m/s
h	Height of dielectric substrate
hs	Shortening plate height
Wp	Width of the patch
Wg	Width of the ground plan
Ws	Width of the shortening plate
L p	Length of the patch
Lg	Ground plan length
λ	Lambda
d	Position of the feed from the edge along the direction of the patch length
ωr	Angular resonant frequency
Pr	Power radiated from the patch
λ0	Free-space wavelength
|г|	Reflection coefficient
ZL	Load impedance
Z0	Characteristic impedance
Le f f	Effective length of the patch
η	Radiation efficiency
AF	Array factor
N	Number of elements
f H	Frequency high
f L	Frequency low
f C	Center frequency
|E|	Electric field
P	Mass density
σ	Conductivity

List of Abbreviations

AAiT	Addis Ababa Institute of Technology
AF	Array factor
CM	Cavity model
CS	Circuit-Switched
CW	Continues Wave
ETC	Ethio Telecom Communication
FEM	Finite element method
FDTD	Finite difference time domain
GSM	Global System for Mobile Communication
HFSS	High frequency simulation software
HSPA	High Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IFA	Inverted f- antenna
IMS	IP Multimedia Subsystem
IP	International Mobile Telecommunications
IMT	Inter-Symbol Interface
ISI	International Telecommunication Union
ITU	Multiple Input Multiple Output
MIMO	Millimeter wave
MNM	Multiport network model
MoM	Method of moments
PIFA	Planar inverted f- antenna
PL	Path Loss
QoS	Quality of Services
RAN	Radio Access Network
RF	Radio Frequency
SAR	Specific absorption rate
SNR	Signal to Noise Ratio
TL	Transmission line model
VSWR	Voltage standing wave ratio
WRC	World Radio communication

CHAPTER - ONE

INTRODUCTION

1.1 Background

Since the dawn of civilization, communication has been of foremost importance to mankind. In first place, communication was accomplished by sound trough voice. However, as the distance of communication increased, numerous devices were introduced, such as horns, drums, and so forth. The radio antenna is a primary component in all radio systems. It may be defined as the structure associated with the region of transition between a guided wave and a free space wave, or vice versa. In other words, radio antennas couple electromagnetic energy from one medium (space) to another (e.g. wire, coaxial cable, or wave guide). Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. It must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired. The receiving antenna as a part in the system is responsible of turning the electromagnetic waves in to its original form (electrical signal in wire).The properties of the transmitting and receiving antennas are fully represented by Maxwell's equations [1].

A good design of the antenna can reduce the system requirements and improve the overall system performance. Antenna serves as one of the critical component in any wireless communication system. In general, the antenna behaves as a transducer between guided wave and a free space [2].

1.2 Types of Antennas

There are various types of antennas and they include wire antennas, aperture antennas, reflector antennas, lens antennas, micro strip antennas and array antennas.

Wire antennas: characterized by a presumed known current distribution, these are the oldest and still the most prevalent of all antenna configurations and they can be seen virtually anywhere. There are different shapes of wire antennas such as a straight wire (dipole), loop and helix.

Aperture antennas: characterized by a presumed known E-field distribution, they are most utilized for higher frequencies and antenna of this class are very useful for aircraft and space craft applications because they can easily be flush mounted onto the surface of the aircraft or space craft.

Reflector antennas: are sophisticated forms of antennas used for communications over long distances. They are large in dimensions as to achieve high gain required to transmit or receive Signals after millions of miles travel.

Lenses: are mainly employed to collimate incident divergent energy to prevent it from spreading in undesired directions. Proper modeling of the geometrical configuration and using the correct materiel for the lenses can transform various forms of divergent energy into plane waves and these lens antennas are used in most of the applications of higher frequencies.

1.3 Basic Antenna Parameters

Definitions of various parameters are necessary to describe the performance of an antenna. Although the parameters may be interrelated, it is however, not a requirement to specify all the parameters for complete description of the antenna performance. An antenna is chosen for operation in a particular application according to its physical and electrical characteristics. Furthermore, the antenna must perform in a required mode for the particular measurement system. An antenna can be characterized by the following parameters, not all of which apply to all antenna types [1]:

- Radiation pattern
- Radiation resistance
- Beam width and gain of main lobe.
- Position and magnitude of side lobes.
- Magnitude of back lobe.
- Bandwidth
- Aperture
- Antenna correction factor
- Polarization of the electric field that it transmits or receives
- Power that the antenna can handle
- Efficiency.

Typically, antenna characteristics are measured in two principal planes and they are known as azimuth and elevation planes, which can also be considered as the horizontal and vertical planes. Conventionally, the angle in the azimuth plane is denoted by the Greek letter phi (ϕ) while the Greek letter theta (θ) represents the angle in the elevation plane.

The desire for compact antenna has increased these days due to rapid decrease in dimensions of mobile devices [1]. Therefore conventional antennas are replaced by compact planar Inverted F-antennas. Due to multiband properties and compact dimensions, planar Inverted F-Antenna is relatively good alternative to be used in mobile devices. The planar inverted F-antenna has been devised from inverted F-antenna (IFA). The inverted F-antenna suffered from a narrow bandwidth, due to which the wire radiator was replaced by a shorting plane in Planar Inverted F-Antenna. PIFA shows improved performance with a compact size [2] [3].

With rapid growing of the telecommunication industry and an increasing demand of more advanced network communication properties such as higher network speed and lower network latency, the current generation of telecommunication system will not be able to fulfill the consumer's requirements anymore. In this paper a novel design of PIFA antenna for fifth Generation wireless standard were recommended since Planar Inverted F-Antenna has lower specific absorption rate (SAR) value.

1.4 Thesis Motivation

The recent revolution in electronic circuits pressured the antenna designers to come up with small, lightweight and low cost radiating structures. This requirement led to the invention of several antenna structures, of which, printed PIFA antenna received a lot attention in recent years. Due to their low profile and conformable geometry, they are widely used as embedded antennas in handheld wireless devices [2] and military equipment's [3]. However, intensive research is required to improve the inherent disadvantages of this antenna, such as; narrow bandwidth, low efficiency, spurious feed radiation and limited power capacity [3] Narrow bandwidth is one of the major disadvantages of PIFA antenna; therefore most of the research work has been focused on this point. One possible means to widen the impedance bandwidth of PIFA antenna is to simply increase the thickness of the substrate. This, however, increases the antenna dimension [4] and introduces unwanted surface waves. Therefore, a more acceptable approach to improve the bandwidth without deteriorating the antenna response is required.

To achieve dual frequency response, one of the most common methods used in the literature involves stacking multiple radiating patches on top of each other. This configuration exhibits dual frequency response without substantially increasing the antenna dimension.

Other problems, such as lower gain can be overcome by arranging multiple antenna elements in linear or phased array configuration [2]. It is of note that, designing an array configuration of stacked patch antennas requires optimizing dozens of antenna parameters.

In this study single element and four by four elements of planar inverted F-antenna are designed using micro strip line feeding methods due to the various advantages explained in next paragraph. The design process in both cases is analyzed using calculations and CAD-FEKO simulation software.

During the design process, the motivations involved in selecting different antenna components among the four most popular feed techniques, micro strip line feeding method has low spurious feed radiation and is easy to match. However, it is also easy to model and to implement, particularly for array antennas.

In this research, a comprehensive study of different parameters that affect antenna performance, (such as shortening plate width, ground plane width ground plane length, patch width, patch length and height), was carried out. Though several initial designs of linear antennas have been previously proposed, most of them are limited to operation only on a particular non-planar surface with a fixed and known curvature. Therefore if an antenna system can be developed to be operated under such conditions where the change of the curvature of the surface of the antenna array is acceptable during its operation, then the system will offer more flexibility in terms of using it on a non- planar surface with different and unknown curvatures. Thus, implementation of the conformal array concepts of PIFA antennas on a flexible substrate can be a solution to applications that require the antenna to be used on curved surfaces that change with time. The outcome of this study serves as a design guide and is very useful for Ka-band antenna designers. The usefulness of the study is illustrated through the design of a planar antenna.

1.5 Statements of the Problem

Many progress has been made in the study of PIFA antenna for different applications, it is still great challenge to select the appropriate design parameters which enhance the performance of PIFA antenna. To do so, it is necessary to identify the particular design parameters to get suitable and better PIFA performance, effective performance comparisons is needed to understand the effect of change in dimensions of each design parameters such as shortening plate width, ground plane width ground plane length, patch width, patch length and height.

1.6. Thesis Objectives

1.6.1. General Objective

General objective of the study is to Design, Demonstrate and to analyze the performance of single element and 4x4planar arrays of PIFA antenna at 28 Ghz.

1.6.2. Specific Objectives

This study is carried out specifically to accomplish the followings:

- To design single element PIFA antenna at 28 Ghz.
- To design 4x4 planar array of PIFA antenna at 28 Ghz.
- To obtain VSWR, Radiation Patterns, radiation efficiency, directivity and Gain of 4x4 planar array PIFA antenna by using CAD-FEKO simulation software.
- To compare performance of single element and 4x4 planar arrays by using change of parameters, Parameters such as shortening plate width, ground plane width ground plane length, patch width, patch length and height.
- To compare characteristics of both single element and four by four elements planar inverted F-antenna.
- To compare specific absorption rate for both single element and four by four elements.
- To validate the results of the simulations with related research work.

1.7. Literature Review

In [4] antenna is feed using micro strip feeding technique and simulated using HFSS commercial software. The antenna shows single band bandwidth of 5GHz with reduced height. The proposed antenna is useful for DCS, PCS, UMTS, Bluetooth standards.

In [5] the antenna is proposed for GSM and WLAN frequency and the proposed antenna operates in two different frequencies which are 1.8 and 5.5 GHz and simulated by using HFSS simulation software. By introducing E-shape slot in the radiating patch the proposed antenna is used for the GSM Application.

In [6] antenna Simulated at frequency range of 2-2.4GHz and simulated using design Framework EMS CAD tool The proposed antenna is useful for WLAN, Wi-Fi applications.

In [7] very compact PIFA antenna was designed, the proposed antenna is applicable for: Wi-Fi (2.45GHz), Bluetooth (2.4 GHz) and the two Long Term Evolution bands (LTE 2.3GHz, LTE 2.5GHz). The antenna is feed using coaxial feeding technique; FR-4 substrate material is used and simulated using CST software.

In [8] PIFA antenna for 4G Mobile Telecommunications Networks was proposed. Antenna is feed using probe-feeding technique. The proposed antenna is applicable for: 710 MHz, 1900 MHz (PCS), 2.3 GHz (WCS band), 3.65 GHz (rural 4G) and 5.8 GHz (FCC unlicensed band) and also The GPS signal can be received in GPS L2 band around the frequency 1575 MHz.

In [9] dual band planar inverted F-antenna (PIFA) is proposed for cellular phone applications. The antenna consists of E-shaped patch, 1.6 mm thicken FR-4 substrate and the finite integration technique (FIT) based computer simulation technology (CST) is used. The proposed antenna is applicable for: GSM 900 MHz and DCS 1800 MHz. Moreover, the specific absorption rate (SAR) values of the proposed antenna exhibit considerably lower SAR compared to helical antenna.

In [10] three-elements Single-Band PIFA MIMO antenna for Future 5G wireless communication applications was proposed and simulated using CST software. The proposed antenna operates at 28GHz. The proposed antenna array shows good isolation characteristics between closely spaced antenna elements. The proposed antenna has a bandwidth of 807 MHz (27.73 GHz - 28.54 GHz).

In [11] study of planar inverted F-antenna (PIFA) for wireless applications was proposed.

In [12] comprehensive numerical and experimental study of Planar Inverted F-Antenna (PIFA) was proposed and parameters which may affect the characteristics of PIFA was studied. The proposed antenna operates at 2.75GHz. Furthermore, new empirical formula was introduced for the estimation of the central operational frequency of PIFA.

In [13] feeding Characteristic Modes in multi antenna handsets MIMO terminal antennas operating at Long Term Evolution (LTE) bands below 1 GHz was proposed.

In [14] analysis and characterization of a single band planar inverted F-antenna (PIFA) operating at 28 GHz frequency was proposed. The proposed PIFA design is extended to dual element Multiple Input Multiple Output (MIMO) antenna. Computer Simulation Technology (CST) software is used to design proposed antenna.

This research work is different from the above mentioned research works in the way that this research work is performed on CAD-FEKO simulation software at frequency band of 28Ghz, With change of different parameters, such as shortening plate width, ground plane width ground plane length, patch width, patch length and height. Characteristics of both single element and four by four elements of planar inverted F-antenna were studied and specific absorption rate for both single and four by four elements also compared by change of above mentioned design parameters.

1.8. Thesis Contributions

In all the literatures seen so far in Section 1.7, different PIFA antenna design and modeling has been investigated at different design parameters. However, the contributions of this thesis work are underlined in the following points.

- In this thesis, 4X4 PIFA Antenna were designed, modeled and also recommended for future wireless communication technology at 28GHz. The proposed design has provided better directivity and specific absorption rate (SAR) value. It is believed that such consideration is missing from previous work and this thesis gives solution to such issues for future mobile communication technology.
- With a change of different parameters each design has also recommended for different wireless communication application. This is also another major contribution of this thesis work. Simulation results has also discussed in form of table in the following result and discussion section.
- Different studies have been made in the area of planar inverted F- antenna technologies. Hence, special attention has to be given by Ethiopian telecommunication cooperation, local practicing engineers and antenna manufacturing companies for planar inverted F- antenna technologies at mm-Wave band.

1.9. Methodology

The methods employed to achieve the objective of this thesis work are:

- **Literature review**: this includes the survey and reading of books, articles, journals, and simulation tools and all forms of other resources which are related to PIFA antenna.
- **Modeling**: this involves modeling of the substrate material and patch antenna.
- **Simulation**: this is the approximation of the modeled PIFA antenna in FEKO software, to investigate performance of the proposed antenna. This involves the VSWR, Radiation Patterns, directivity and Gain Simulation.
- **Performance comparison**: this involves the VSWR, Radiation efficiency, and radiation pattern using FEKO software.
- **Analysis and interpretation of the results**: this is the performance analysis and interpretation which is based on the results and findings obtained from the simulated results.

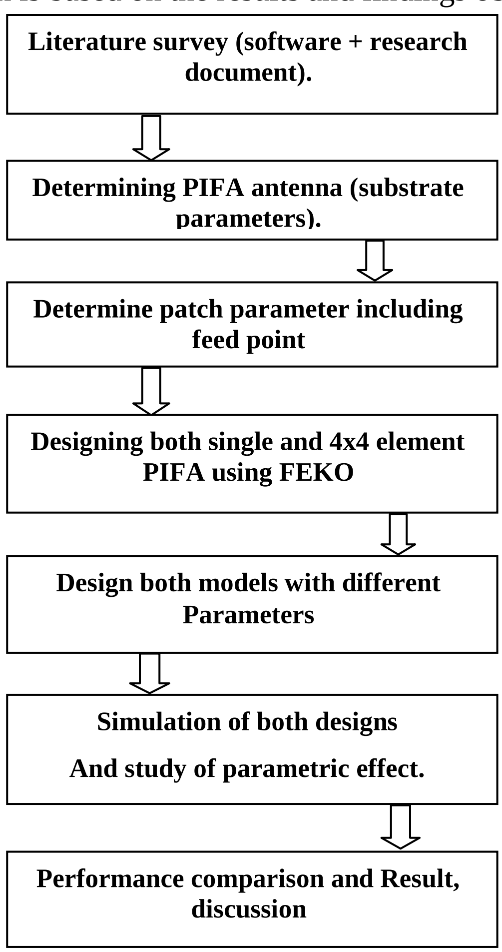

Figure 1.2: flow chart of methodology

1.10. Thesis Outline

This thesis work is composed of five chapters. The thesis begins with an introduction on antennas, describing the fundamental antenna parameters. **Chapter two** is totally be devoted to the Review of PIFA antenna, its working principle and design techniques. **Chapter three** discusses the design of both single and four by four elements of PIFA antenna, which operates at Ka-band. **Chapter four** summaries simulation results of both single element and four by four elements of planar inverted F-Antenna. Finally, **chapter five** draws conclusion and recommendation.

CHAPTER –TWO

REVIEW OF PLANAR INVERTED F- ANTENNA

2.1 Introduction

Electrical components in wireless communication systems are designed to be small and light for portability and productivity while maintaining decent performance and efficiency. Antennas are essential components in mobile devices and are required to fit in the limited space allowed by industrial specifications. To fulfill this requirement, a planar inverted-F antenna (PIFA) is common and a popular choice for miniaturized antennas in cellular phones. The PIFA design can be tuned and extended to cover multiple frequency bands from cellular phones, Wi-Fi and Bluetooth. This antenna is tuned for the Advanced Wireless Services (AWS) band downlink frequency range. The impedance matching properties of the antenna are calculated in terms of S-parameters and the far field radiation pattern is simulated [8].

2.2. Planar Inverted F-Antenna

Planar inverted F-antenna is used in a wide range of applications because it is easy to design and fabricate. The antenna is attractive due to its low-profile conformal design, relatively low cost, and very narrow bandwidth. For applications where size, weight, cost, performance, ease of installation and aerodynamics are constraints, low profile antennas are needed. Aircraft, spacecraft, satellite and missile applications and recently mobile radio and wireless communications demands [1].

To meet these requirements planar inverted F-antenna can be used because of it has numerous advantages such as small structure, multiband behavior, low cost, mechanically robust and reduced absorption rate as compared to other conventional antennas [5]. Planar Inverted F Antenna has reduced Specific Absorption Rate (SAR) value; hence fewer radiations are illuminated towards user’s head and body [6].

Planer inverted F- antenna in its simplest configuration consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side. The patch conductors usually made of copper or gold can be virtually assumed to be of any shape. However, conventional shapes are normally used to simplify analysis and performance prediction. The radiating elements and the feed lines are usually hinged on the dielectric substrate.

2.3. Advantages and Disadvantages

2.3.1. Advantages of PIFA Antennas

- small size
- light weight
- low-profile
- simple fabrication
- relatively low specific absorption rate (SAR) and
- provides good efficiency
- It can be realized in a very compact form, desirable for personal and mobile communication hand held devices.
- It allow for dual and triple band operations

2.3.2. Disadvantages of PIFA Antennas

- Narrow bandwidth
- Lower power gain
- Lower power handling capability
- Polarization impurity
- Surface wave

2.4. Antenna Array and Feed Techniques

An antenna array (often called a ’phased array’) is a set of two or more antennas. The signals from the antennas are combined or processed in order to achieve improved performance over that of a single antenna.

The antenna array can be used to:

- increase the overall gain
- provide diversity reception
- cancel out interference from a particular set of directions
- "steer" the array so that it is most sensitive in a particular direction
- determine the direction of arrival of the incoming signal
- To maximize the Signal to Interference plus Noise Ratio (SINR).

Array means a collection of similar entities or set of individual antenna elements connected together to behave as a single unit. Advantages

- Higher Gain
- Beam Steering Capability
- Reliable
- Higher SNR

2.5. Array Design

Array design Features:

- Single feed point
- Insertion of phase shifters into corporate feed network.
- Introduce the sensor circuit as the feedback network with autonomous controller circuitry for radiation pattern recovery

2.5.1. Array Factor (AF)

The array factor due to isotropic point sources is the weighted sum of the signals received by the elements. Mathematically [22],

$$AF = \sum_{n=1}^{N} W_n \exp^{j\varphi_n} \tag{2.1}$$

Where:

N= number of element

$$W_n = \exp^{j\delta_n} \tag{2.2}$$

Array factor depends on:

- Number of element.
- Relative magnitude and phase of current on each element
- Relative inter element spacing
- Geometrical orientation of the element.

Usually the radiation pattern of a single element is relatively wide, and each element provides low values of directivity (gain). In many applications, it is necessary to design antennas with very high directive characteristics (very high gain) to meet the demands of long distance communication. This can only be accomplished by increasing the electrical size of the antenna.

Enlarging the dimensions of single elements often leads to more directive characteristics. Another way to enlarge the dimensions of the antenna, without increasing the size of individual element, is to form an assembly of radiating elements in an electrical and geometrical configuration. The antenna arrays are of vast importance and are widely used nowadays for various purposes like military, missiles and satellite communication. There are different forms of antenna arrays linear, circular, planar etc. The radiation pattern of an array antenna is mostly considered in the far field, where the field depends on two parameters. One is the distance of the receiver and the other deals with the spherical coordinate's μ and $\acute{A}$. The radiation pattern of an antenna can be calculated by:

$$Array\ pattern = array\ element\ pattern * array\ factor\ (AF)$$

The array factor determines the overall radiation pattern of the array while the element pattern describes radiation pattern of the individual element The array factor can also be defined as" The function of the total number of elements, their spacing and the phase difference between each element" [22]. Arrays are very versatile and are used, among other things, to synthesize a required pattern that cannot be achieved with a single element. In addition, they are used to scan the beam of an antenna system, increase directivity, and perform various other functions which would be difficult with any one single element .The elements can be fed by a single line called the series-feed network or by multiple lines called corporate-feed network. A series feed network is easy to fabricate and implement as compared to corporate feed network. The disadvantage of using series feed is that it gives phase delay and hence it is not preferred for the phase scanning arrays. These phase shifts are frequency dependent due to which beam scanning is dependent on the frequency. Corporate feed networks provide flexible phase control of each array element. It is suitable for phase scanning as it is less affected by the frequency scan.

There are four different feeding techniques.

1. Micro strip line Feed
2. Coaxial feed
3. Aperture coupling
4. Proximity Coupled

Table 2.1: summarizes the advantages and disadvantages of the four feeding methods [21]

Advantage of micro strip line	**Disadvantages of micro strip line**
Monolithic Easy to fabricate Easy to match by controlling insert position Easy to match	Spurious radiation from feed line especially for thick substrate when line is significant
Advantages of aperture coupled	**Disadvantages of coaxial feed**
Use of substrates avoids deleterious effect No direct contact between feed and patch No radiation from the feed and active devices	Soldering requirement substrate Large inductance for thick substrate
Advantages of proximity coupled	**Disadvantages of aperture coupled**
No direct contact between feed and patch Large effective thickness for patch	Multilayer fabrication required Higher back lobe radiation
Advantages of Proximity-coupled Feed	**Disadvantages of Proximity-coupled Feed**
No direct contact between feed and patch. large effective thickness for patch substrate	Multilayer fabrication required

2.5.2. Radiation Pattern

The antenna radiation pattern, or antenna pattern, is defined as "a mathematical function or a graphical representation of the radiation properties of antenna as a function of space coordinates". Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. A trace of received electric or magnetic field at a constant radius is called amplitude pattern. A graph of the spatial variation of the power density along a constant radius is called an amplitude power pattern. The radiation pattern can be presented in two forms:

- Azimuth Pattern
- Elevation Pattern

The top view of the energy radiated by an antenna is known as Azimuth Pattern while the graphical side view is called an Elevation. It is determined in the far field region and is represented as a function of the directional coordinates. Using the "electric current model" or a "magnetic current model", we can resolve the radiation field of the micro strip antenna. Usually, the current is used directly to find the far-field radiation pattern. If the substrate is neglected (replaced by air) for the calculation of the radiation pattern, the pattern may be found directly from image theory. If the substrate is accounted for, and is assumed infinite, the reciprocity method may be used to determine the far-field pattern [9].

2.5.3. 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 0 dB). Again, increased directivity implies a more 'focused' or 'directional' antenna. In words, Antenna 2 receives 2.707 times more power in its peak direction than an isotropic antenna would receive. Antenna 1 would receive 1.273 times the power of an isotropic antenna. The isotropic antenna is used as a common reference, even though no isotropic antennas exist.

Antennas for cell phones should have a low directivity because the signal can come from any direction, and the antenna should pick it up. In contrast, satellite dish antennas have a very high directivity, because they are to receive signals from a fixed direction. As an example, if you get a direct TV dish, they will tell you where to point it such that the antenna will receive the signal.

2.5.4. Antenna Impedance

Antenna **impedance** relates the voltage to the current at the input to the antenna. This is extremely important as we will see. Let's say an antenna has an impedance of 50 ohms. This means that if a sinusoidal voltage is applied at the antenna terminals with an amplitude of 1 Volt, then the current will have an amplitude of 1/50 = 0.02 Amps. Since the impedance is a real number, the voltage is in-phase with the current. Alternatively, suppose the impedance is given by a complex number, say Z=50 + j*50 ohms. Since the impedance is complex the voltage is out of phase.

2.5.5. Antenna Gain

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur. A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power. Note that a lossless antenna would be an antenna with an antenna efficiency of 0 dB (or 100%). Similarly, a receive antenna with a gain of 3 dB in a particular direction would receive 3 dB more power than a lossless isotropic antenna.

2.5.6. Mutual Coupling in Antenna Array

One of the basic characteristics of an antenna array appears when two or more elements are Located near to each other and affect each other. The amount of coupling depends on the following:

- Radiation characteristics.
- Actual separation between elements.
- Relative orientation of elements.

The mutual coupling between two radiating elements depends upon the distance between them. If they are close to each other the mutual coupling will be greater. Thus energy is transferred between elements and this is called mutual coupling.

In these theses the geometry of the proposed antenna is shown in Fig. 3.3 the 16 antenna elements are separated by a distance D which is used to reduce inter element effect on each other:

$$D = \lambda/4 \qquad (2.3)$$

$$D = (3x10^8/28x10^9)/4$$

$$=\underline{2.5\ mm}$$

2.5.7 Voltage Standing Wave Ratio (VSWR)

We see that an antenna's impedance is important for minimizing impedance-mismatch loss. A poorly matched antenna will not radiate power. This can be somewhat alleviated via impedance matching, although this doesn't always work over a sufficient bandwidth (bandwidth is the next topic). A common measure of how well matched the antenna is to the transmission line or receiver is known as the Voltage Standing Wave Ratio (VSWR). VSWR is a real number that is always greater than or equal to 1. A VSWR of 1 indicates no mismatch loss (the antenna is perfectly matched to the tx line). Higher values of VSWR indicate more mismatch loss. As an example of common VSWR values, a VSWR of 3.0 indicates about 75% of the power is delivered to the antenna (1.25 dB of mismatch loss); a VSWR of 7.0 indicates 44% of the power is delivered to the antenna (3.6 dB of mismatch loss). A VSWR of 6 or more is pretty high and will generally need to be improved [11].

2.6. Antenna Design Challenges

Challenges that typically influence the design of antenna for mobile communication technology are:

- ❖ Minimal antenna size and tight integration with other device components.
- ❖ Mutual coupling between different antennas have to be minimized.
- ❖ Compliance with radiation hazard restrictions has to be maintained.
- ❖ Antenna Size.
- ❖ Mutual Coupling.
- ❖ In-Suite Performance.
- ❖ Compliance with SAR Regulation.
- ❖ Channel Capacity Improvements.

2.7 Substrate material

The first step in the design process is the selection of a dielectric substrate material. The dominant features of a PIFA array are controlled by substrate parameters such as thickness and permittivity more than by the particular element type. Because weight is a primary consideration in cellular system, a substrate must be chosen which not only has satisfactory dielectric properties, but which also has low density [22].

Table 2.2 Criteria for substrate selection [2]

S.N	Material	Dielectric constant	Loss tangent	Dimension stability	Chemical resistance	Temperature range	Moisture absorption (%)	Relative cost
1	RT/Duroid 5870	2.33± 0.02	0.0012	Fair to Good	Good	-27 to +110	0.02	Medium to high
2	RT/Duroid 5880	2.2	0.0009	Good	Excellent	-27 to +110	0.02	Medium
3	RT/Duroid 6002	2.94	0.0012	Good	Excellent	-27 to +110	0.02	Medium
4	RT/Duroid 6006	6.0± 0.152	0.0019	Excellent	Excellent	-27 to + 205	0.05	Medium to high
5	RT/Duroid 6010.5	10.5± 0.25	0.0024	Good	Excellent	-27 to +260	0.01	Medium
6	FR-4/ reinforced epoxy	4.4	0.0019	Excellent	Excellent	-27 to +140	< 0.10	Low

As for the substrate selection, the major consideration will be the dielectric constant and loss tangent. A high dielectric constant will result in a smaller patch size but this will generally reduce bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna. A high loss tangent will reduce the antenna efficiency. FR-4 is better because it has moderate dielectric constant, loss tangent and it has relatively low cost so it was chosen for this thesis work.

2.8 Different Analyzing Methods

For the analysis purposes, the MSA are categorized as two-dimensional planar structure. Some of the analytical methods are based on equivalent distribution of the magnetic current around the patch edges and some are based on the equivalent distribution of the electric current on the patch and the ground plane based on magnetic current distribution the analytical methods are given as:

2.8.1 Transmission Line Model

For understanding the basic performance of the micro strip antenna a very simple model was used called Transmission line model. In this model, the antenna structure is viewed as transmission line resonator with the field only varies along the length of the resonator and the fringing field at the open circuited ends is responsible for the radiation occurs. This model represents the patch by two radiating apertures (slots) which are spaced by the length of the resonator. This model is first prepared by Robert E. Munson for the rectangular patch antenna. Many other variations of transmission line model have been used to analyze the MSA.

Due to the variation of field in the orthogonal direction to the direction of the propagation this model cannot be used for all types of configurations.

2.8.2 Cavity Model

Cavity model gives the more accurate results than the transmission line model. The region between the patch and the ground plane is act as cavity. This region is surrounded by magnetic walls around the parameter of the patch and by electric walls from top and bottom sides. Since the substrate height is very small, the field variations along the height will be uniform [24].

2.8.3 Multiport Network Model (MNM)

In the cavity model, the solution for the far field is difficult to evaluate [24]. To overcome this problem MNM is used for analyzing the MSA. In this model, the multiple numbers of ports are used around the periphery of the patch to analyze MSA. The EM fields are modeled separately for both under and outside the patch. As the patch is supposed as two dimensional planar networks, the Green's Function is used to obtain the multiport impedance matrix of the patch. Then the segmentation method is used to find the overall impedance matrix. From voltage distribution around the periphery we can obtain the radiated fields from the patch. The above three analytical methods are very simple but these methods are accurate only for the regular patch geometries instead of arbitrary patch geometries. The numerical methods are used for the complex geometries on the basis of electric current distribution.

2.8.4 Method of Moments (MoM)

The MoM is the technique to solve volume integral equations in the frequency domain. In this method the surface current and the volume polarization current are used to model the fields in micro strip patch and dielectric slab respectively. The fringing fields outside the physical boundary of the two dimensional patch takes into account for obtaining more exact solution [24].

2.8.5 Finite element method (FEM)

FEM is a method in which we use variation form to solve the frequency domain boundary valued electromagnetic problems. For a highly accurate discretization of the solution domain FEM can be used with two or three dimensional conical elements of different shapes. Unlike the MoM, this method is suitable for the volumetric configurations. On the basis of the structures to be analyzed, the region is first divided into number of finite volume elements. These finite elements can be well defined geometrical shapes like triangular, rectangular elements for planar configuration and tetrahedral and curved geometry for three dimensional configurations[24].

2.8.6 Spectral domain technique (SDT)

In this technique, along the two orthogonal directions of the patch the two dimensional Fourier transform is used along with boundary conditions. By using this technique the various parameters of the antenna can be evaluated. The electric current distribution on the patch and the magnetic current distribution surrounding the substrate surface are evaluated by solving the matrix equation

2.8.7 Finite difference time domain (FDTD)

The FDTD technique is well suited for MSAs; it offers many advantages as an electromagnetic simulations, modeling and analysis tools. It can capable for arbitrary three dimensional model geometry and predict the response of MSA over broad range of frequency. For practical consideration of the FDTD4 the initial choice is the cell size. At highest frequency the cell size must be small for the accurate results. FDTD is most suitable technique at the analysis of inhomogeneous and nonlinear media. However due to the discretization of entire solution domain its demand for system memory are high. The spatial discretization along Cartesian coordinates is same [24].

Simulation of the proposed antenna structure is performed using the simulation tool called CAD FEKO and among all those analyzing methods for this thesis work it was chosen to use both Finite difference time domain (FDTD) and Method of Moments (MoM).

CHAPTER – THREE

DESIGN OF SINGLE ELEMENT AND 4X4 PLANAR PIFA ARRAY ANTENNA IN MILLIMETER WAVE BAND

3.1. Introduction

It was discussed about PIFA antenna application in the above section, applications in recent wireless communication such as radar, microwave and space communication. In this chapter, the procedure for designing of both single and 4x4 element elements of PIFA antenna Where discussed.

3.2. Design Specifications

Specifications for the normal design of single element PIFA is:

- Type of antenna: **planar inverted F-antenna**
- Resonance frequency: **28 GHz**.
- Input impedance: **50-ohm.**
- Feeding method: **Micro strip Line Feed**
- Material for the radiating element: **copper**
- Dimension of radiating patch is **Lp**and **Wp**
- Dimension of Ground plane is **Lg** and **Wg**
- Substrate Dielectric constant:ε_r **= 4.4(FR-4)**

PIFA mainly consists of ground plane, radiating patch and the shortening plate where the shortening plate is used to connect the antenna patch and ground plane. it has a simple structure fed by 50 Ω micro strip lines is used between the ground plane and radiating patch where the ground Plane is folded at one edge of a patch and length as shown in Fig 3.1 below.

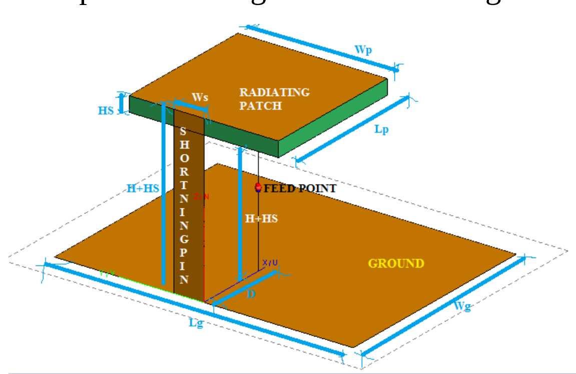

Figure .3.1. Single element PIFA antennas

3.3. PIFA Design Calculation

The three essential parameters for the design of a PIFA antenna are:

- **Frequency of Operation (fr)**: the resonant frequency of the antenna must be selected appropriately.
- **Dielectric Constant of the Substrate($\mathcal{E}r$)**: the dielectric material applied for this design has a dielectric constant of 4.4
- **Height of dielectric substrate (h)**: for the antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate selected here is 1.6 mm.

Table 3.2: Design Specifications.

Parameters	**Frequency**	**Substrate**	**Dielectric constant ($\mathcal{E}r$)**	**Loss tangent**	**Substrate height**
Specification	28 Ghz	FR-4	4.4	0.0019	1.6 mm

$$Lp+Wp-W = \lambda/4 \quad (3.1)$$

$$Fr^* \lambda = \frac{c}{\sqrt{\mathcal{E}r}} \quad (3.2)$$

$$Fr = 4(L1+L2-W)\sqrt{\mathcal{E}r} \quad (3.3)$$

$$F = \frac{c}{4(Wp+Lp)} \quad (3.4)$$

$$Wp = 1/4\,\frac{c}{f\sqrt{\mathcal{E}r}} \quad (3.5)$$

$$Lp = c/4f = \frac{2}{\sqrt{\mathcal{E}r+1}} \quad (3.6)$$

$$\lambda = \frac{c}{f} \quad (3.7)$$

$$w = \frac{c}{2f}\sqrt{2/\mathcal{E}\mathrm{r}+1} \quad (3.8)$$

$$L = Leff - 2\Delta \quad (3.9)$$

$$Leff = c\,\frac{1}{2f\sqrt{\mathcal{E}\mathrm{reff}}} \quad (3.10)$$

$$\Delta L = 0.412h\frac{(\mathcal{E}\mathrm{reff}+0.3)(\frac{w}{h}+0.264)}{(\mathcal{E}\mathrm{reff}-0.258)(\frac{w}{h}+0.8)} \quad (3.11)$$

$$\mathcal{E}\text{reff} = \frac{\mathcal{E}\text{r}+1}{2} + \frac{\mathcal{E}\text{r}-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{3.12}$$

$$\text{Lg} = \text{L} + 6\text{h} \tag{3.13}$$

$$\text{Wg} = \text{W}+6\text{h} \tag{3.14}$$

$$\text{h} = \frac{0.0606\lambda}{\sqrt{\mathcal{E}\text{r}}} \tag{3.15}$$

Step 1, Calculation of the wave length (λ): from equation (3.7):

$\lambda = \frac{c}{f}$ = <u>1.07mm</u>

Step 2, Calculation of the width (W): the width is given by equation (3.8) as

$w = \frac{c}{2f}\sqrt{2/\mathcal{E}\text{r} + 1}$ =<u>3.26mm</u>

Step 3, Calculation of effective dielectric constant: Where Ɛreff =effective dielectric constant and the equation for it is given in (3.12)

$\mathcal{E}\text{reff} = \frac{\mathcal{E}\text{r}+1}{2} + \frac{\mathcal{E}\text{r}-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}$ = <u>3.5959mm</u>

Step 4, Calculation of the effective length (Leff): from equation (3.10)

Leff = $c\,\frac{1}{2f\sqrt{\mathcal{E}\text{reff}}}$ = <u>2.8mm</u>

Step 4, Calculation of the length extension (ΔL): equation (3.11) gives the length extension as

ΔL = $0.412\text{h}\frac{(\mathcal{E}\text{reff}+0.3)(\frac{w}{h}+0.264)}{(\mathcal{E}\text{reff}-0.258)(\frac{w}{h}+0.8)}$ = <u>2.458x10^ -4mm</u>

Step 5, Calculation of the actual length of the patch (L): the actual length is obtained by subtracting the length extension from the effective length from equation (3.9).

L = Leff -2ΔL = <u>2.799mm</u>

Step 6, Calculation of the ground plane dimensions (Lg and Wg): The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. Hence, for this design, the ground plane dimensions would be given as:

Lg = L + 6h = <u>2.24mm</u>

Wg = W+6h =<u>3.2mm</u>

Where Lg and Wg are length and width of substrate and 'h' is given by equation (3.15).

$\text{h} = \frac{0.0606\lambda}{\sqrt{\mathcal{E}\text{r}}}$=0.6mm

Step 6, Calculation for radiating Patch dimension: from equation (3.5) and (3.6)

Wp = $1/4 \frac{c}{f\sqrt{\mathcal{E}r}}$ ¼(3*10^8)/28*10^9($\sqrt{4.4}$) = 1.277mm

Lp = $\frac{c}{4f}$ = 3*10^8/4*28*10^9 = 2.677mm

where Lp = length of the patch,

λ = wavelength.

$\mathcal{E}r$ = dielectric constant

c = free space velocity of light 3× 108 m/s

Wp = width of the patch

f = frequency of operation

3.4. Single Element PIFA Antenna Design Parameters

The geometry of the single element PIFA is shown in Fig. 3.1above. The antenna was designed on FR-4 substrate of thickness generated by FEKO The total area of the antenna is Wp x Lp. On the bottom side is the ground plane of width Wg and length Lg. The feeding probe is located at a distance of 'd' from the antenna edge. The shorting strip of width is added form the inverted F- Antenna. The antenna design parameters are summarized in Table 3.2.

Table .3.1: Design Parameters of the single-Element pifa antenna

Parameters	Wg	Lg	Wp	Lp	d	Ws	Wf	h	hs
Value in (mm)	3.2	2.24	1.2	2.67	0.45	0.47	0.35	0.65	0.1

3.5. Array Design Specifications

Specifications for the design purpose of the 4x4 elements planar arrays PIFA Antenna are as follows:

- Type of antenna: **planar inverted F-antenna**
- Resonance frequency: **28 GHz.**
- Feeding method: **Single feed Micro strip Line point**
- Material for the radiating element: **copper**
- Dimension of radiating patch is **Lp** and **Wp**
- Dimension of ground plane is **Lg** and **Wg**
- Substrate used and dielectric constant: $\mathcal{E}r$ = **4.4(FR-4)**

3.6. 4x4 Planar Array of PIFA Antenna Design

Single element PIFA design is extended to be 4x4 as shown in figure 3.2 and table 3.2 shows dimensions of 4x4 array antennas Referring to the calculation of the distance between the elements, which is half wavelength (λ/4).

3.7. 4x4 Element planar array of PIFA Antenna Design Parameters

Before designing the antenna, the first step is to consider the specification of the antenna based on its application. The various parameters that are used for this thesis are listed in Table 3.2. At resonating frequency 28GHz the length of the antenna decreases as the relative dielectric constant of the substrate increases. The geometry of the proposed antenna is shown in Fig. 3.3. The width and the length of the array antenna are denoted by Wg and Lg in mm.

Table .3.2: Design Parameters of four by four elements pifa antenna

Parameters	**Wg**	**Lg**	**Wp**	**Lp**	**d**	**Ws**	**Wf**	**h**	**hs**
Value in (mm)	11	18	3.5	1.5	2.5	0.7	0.35	1.1	0.2

Simulation of the proposed antenna structure is performed using the simulation tool called CAD FEKO and among all the analyzing methods for this thesis work both Finite difference time domain (FDTD) and Method of Moments (MoM) Where chosen.

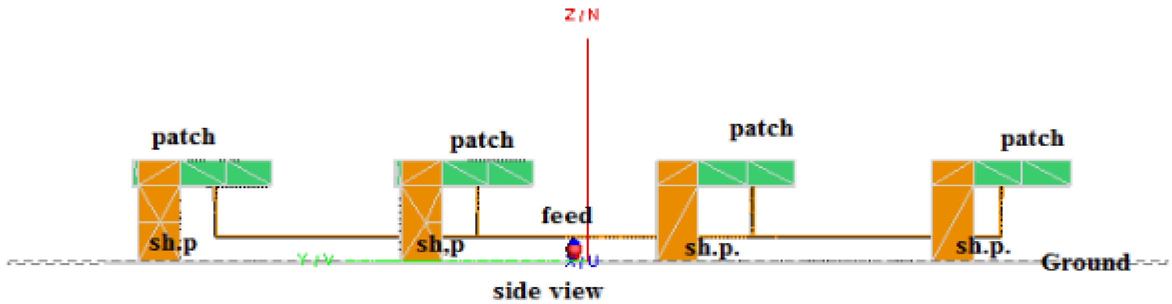

Figure 3.2: (A) Side view

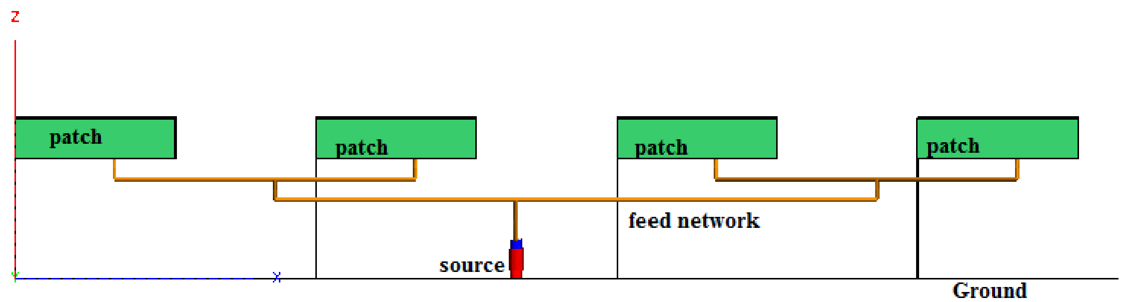

Figure 3.2: (B) Side View

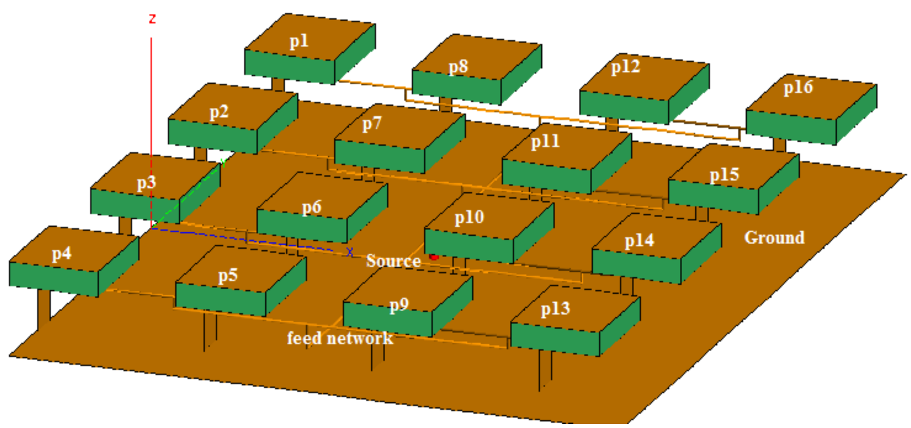

Figure 3.3: 3D views of 4x4 designs.

3.8. Feed Network

A feed network distributes energy to the elements of the array sometimes by means of phase shifters according to a desired amplitude function. Corporate binary feed, as shown in below is common in arrays of dipoles, open-end guides and patches. Such feed circuits are commonly binary but can be modified to design 3-way or 5-way dividers, depending upon the number of array elements. The critical component in the corporate feed is the power divider that can be realized by bifurcated T waveguide or coaxial T junctions [22]. One challenge in design of this type of feed network is that each of the elements is required to be impedance matched and isolated or the reflected signal from each element results in a parasitic radiation pattern that will be superimposed on the required pattern. This condition plays an important role in the design of feed networks, where it is often necessary to use a directional couplers or a matched transmission line.

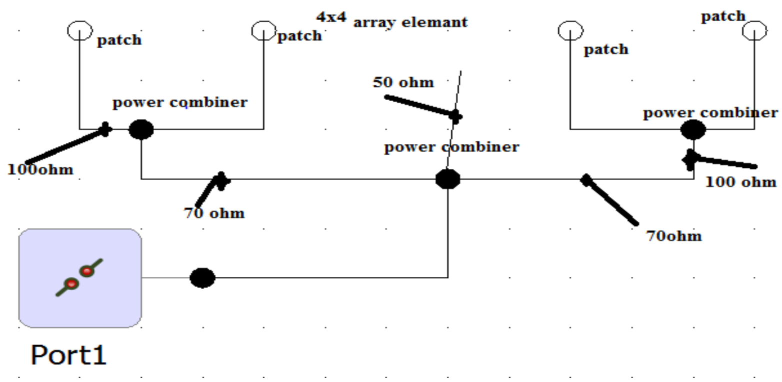

Figure 3.4 Corporate feed structures for an array system with impedance.

The impedance of the quarter-wave transformer is given by the equation

$$Z1 = \sqrt{RinZo} \tag{3.8}$$

Where: $Z1$ is the transformer characteristic impedance and $Z0$ is the characteristic impedance (real) of the input transmission line. Rin is the edge resistance at resonance.

$$Rin = \frac{1}{2Ge} \tag{3.9}$$

Where $$Ge = 0.00836\,\frac{W1}{\lambda o} \tag{3.10}$$

In this paper, a planer inverted f- antenna is proposed for at mm-wave band the proposed antenna has a low profile structure with dimensions 11 mm × 18 mm and covers frequency band from 28 GHz. The size of the antenna is very compact and hence is well suited for mobile devices or the devices where the space is a major issue.

For the substrate selection, the major consideration will be the dielectric constant and loss tangent. High dielectric constant will result in a smaller patch size but this will generally reduce bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna. A high loss tangent will reduce the antenna efficiency. FR-4 is better because it has moderate dielectric constant, loss tangent and it has relatively low cost so it was chosen for this thesis work.

CHAPTER - FOUR

SIMULATION RESULTS AND DISCUSSION

4.1. Introduction

In this section of the thesis, the numerical dimensions of both single element and four by four elements design parameters such as shortening plate width, ground plane width ground plane length, patch width, patch length and height were varied and after the formation of sets of the initial conditions, the results of the performed computer simulations are presented in the form of tables and figures and finally, the results were discussed in terms of the selected parameters for comparison. All simulation result snipping shat is taken from FEKO.

4.2. Simulation Result and Discussion of Single element PIFA Antenna

The simulation result of single-band PIFA antenna such as VSWR, Directivity, Gain, and radiation pattern are shown in Fig. 4.1, 4.2, 4.3, 4.4, 4.5 and Fig. 4.6, for both single element and 4x4 elements using change of dimensions in shortening plate width, ground plane width ground plane length, patch width, patch length and height respectively.

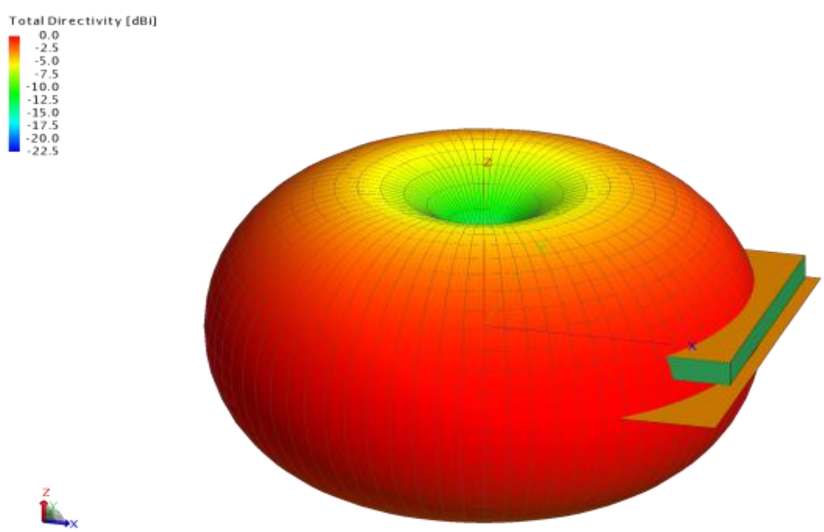

Figure4.1 (a) 3D Single element Radiation pattern for change of dimensions in Ws

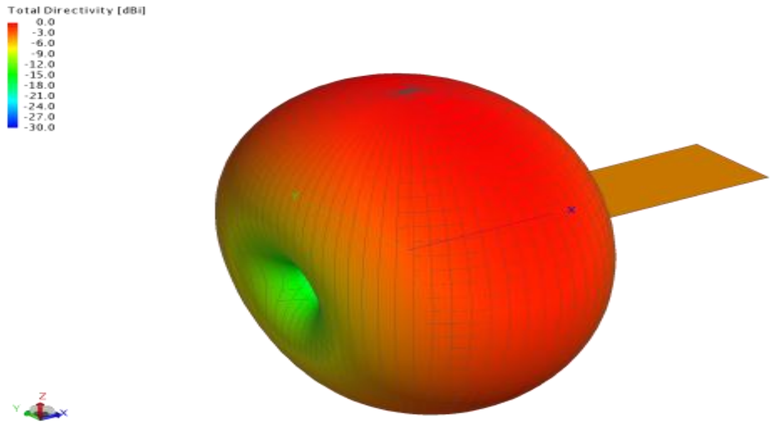

Figure4.1 (b) 3D Single element Radiation pattern for change of dimension in feed point

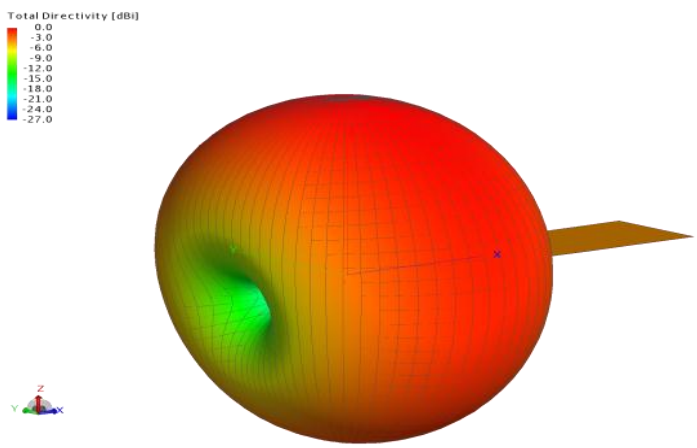

Figure4.1 (c) 3D Single element Radiation pattern for change of dimension in ground plane

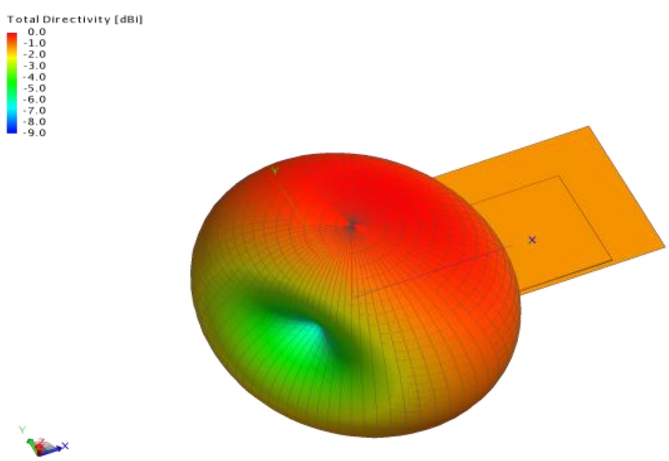

Figure4.1 (d) 3D Single element Radiation pattern for change of dimension of patch

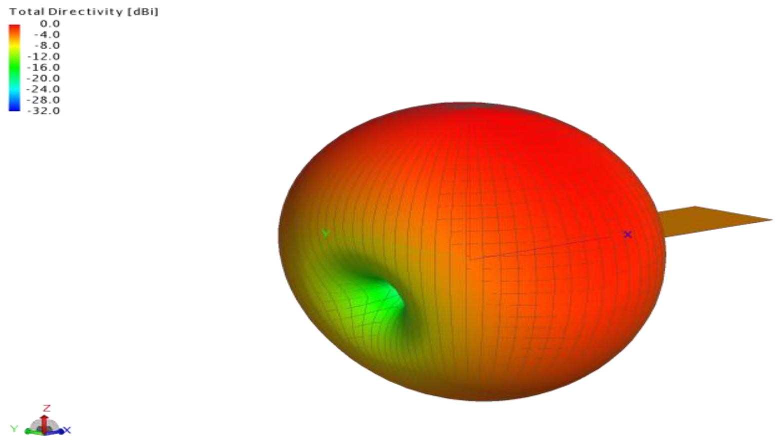

Figure4.1 (e) 3D Single element Radiation pattern for change in dimension of height

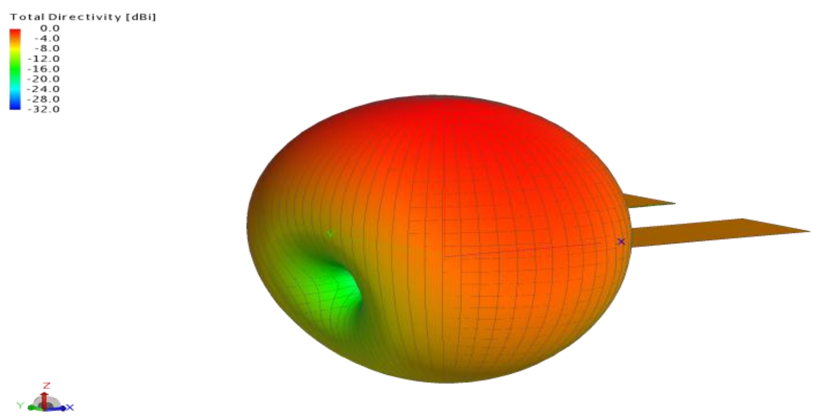

Figure4.1 (f) 3D Single element Radiation pattern for final design

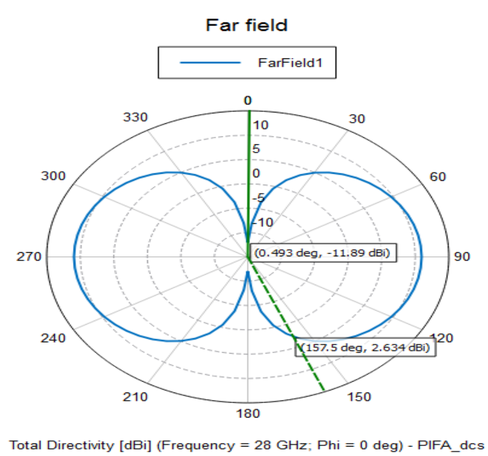

Figure4.2 (a) Single element Radiation pattern for change of dimensions in Ws

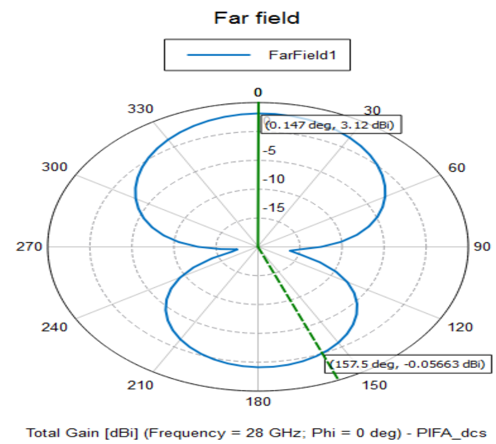

Figure4.2 (b) Single element Radiation pattern for change of dimension in feed point

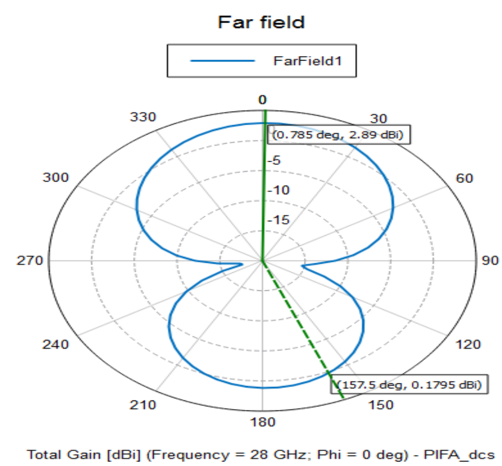

Figure4.2 (c) Single element Radiation pattern for change of dimension in ground plane

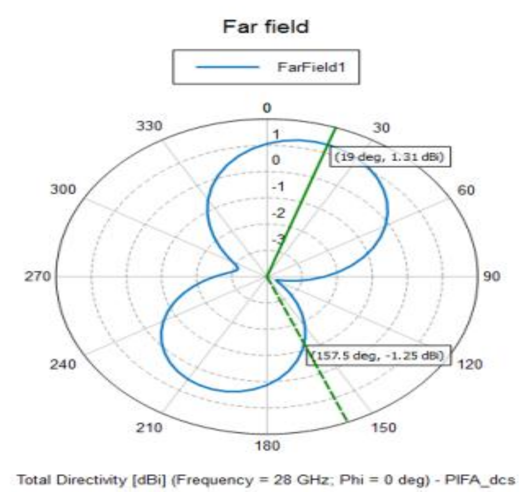

Figure4.2 (d) Single element Radiation pattern for change of dimension of patch

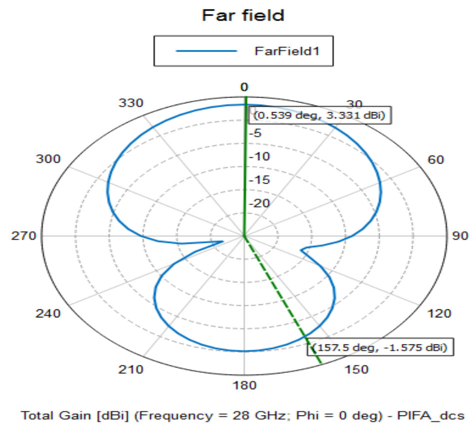

Figure4.2 (e) Single element Radiation pattern for change in dimension of height

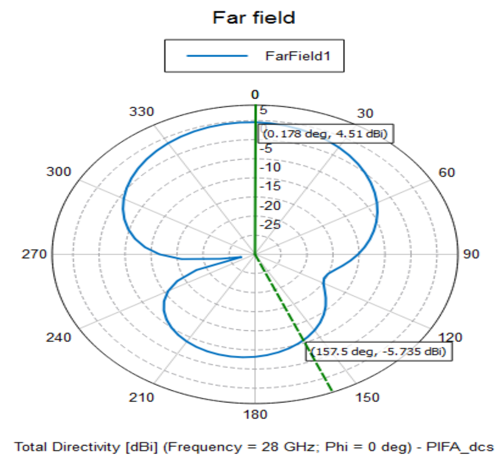

Figure4.2 (f) Single element Radiation pattern for final design

Width of shorting plate, from the side edge of the top plate is changed and its effects on the characteristics of PIFA is shown in **figure 4.1(a) and figure 4.2(a)** the increase in *Ws* changes on radiation pattern and becomes in the azimuth plane which is parallel to the plane of ground plane these kind of radiation is not recommended for mobile phone and the position of the feeding configuration is investigated by altering the values of horizontal distance ‘’d ‘’ from 0.45 mm to 1 mm its effects on the characteristics of PIFA is shown in **figure 4.1(b) and figure 4.2(b)** the increase in *(d)* increases Directivity and gain. The value of *Wg* is changed from 1.5 mm to 2.5 mm and the value of *Lg* is changed from 2.24 mm to 5 mm as we can see from **figure 4.1(c) and figure 4.2(c)** the variations in *Wg* and *Lg* changes the directivity and VSWR.

Similarly changes are made in the length and the width of the rectangular top plate and The width of the top plate is varied from 1.2 mm to 2.4 mm and length of the top plate is changed from 2.67 mm to 3 mm as we can see from **figure 4.1(d) and figure 4.2(d)** the increase in the length or width of the top plate increases the Directivity and affects the radiation pattern. The radiation pattern is basically dependent on size and shape of top plate. It can also be concluded that the greater the size of the top plate of the PIFA, the more directive the radiation pattern. As we can see from **figure 4.1(d) and figure 4.2(d)** the height of the top plate *h* is now varied from 0.75 mm to 1.5 mm and the simulation results shows that the increase in height will slightly affect Directivity, but does not have any significant effect on the radiation pattern. The height of PIFA can be increased to enhance the radiation efficiency but a small height of the top plate is preferred in practice as the antenna has to be small enough to fit in the chassis of small terminal devices.

Finally with the consideration of height the top plate *h*, dimension of patch and ground plane the final design of single element were carried out. To observe their effects while all other parameters are unchanged results are shown in **figure 4.1(e) and figure 4.2(e)** that the final proposed antenna design shows a good Directivity at 28 GHz. It confirms that the proposed single element PIFA is a good candidate for the future wireless communication systems.

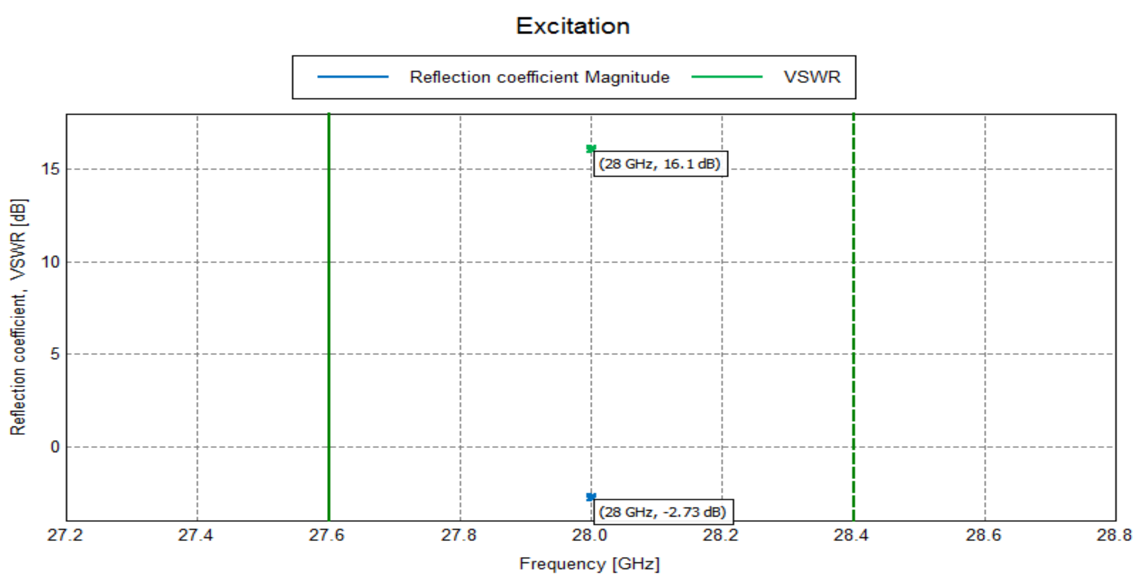

Figure4.3 (a) S11 and VSWR plot for Single element with change of dimension in feed point

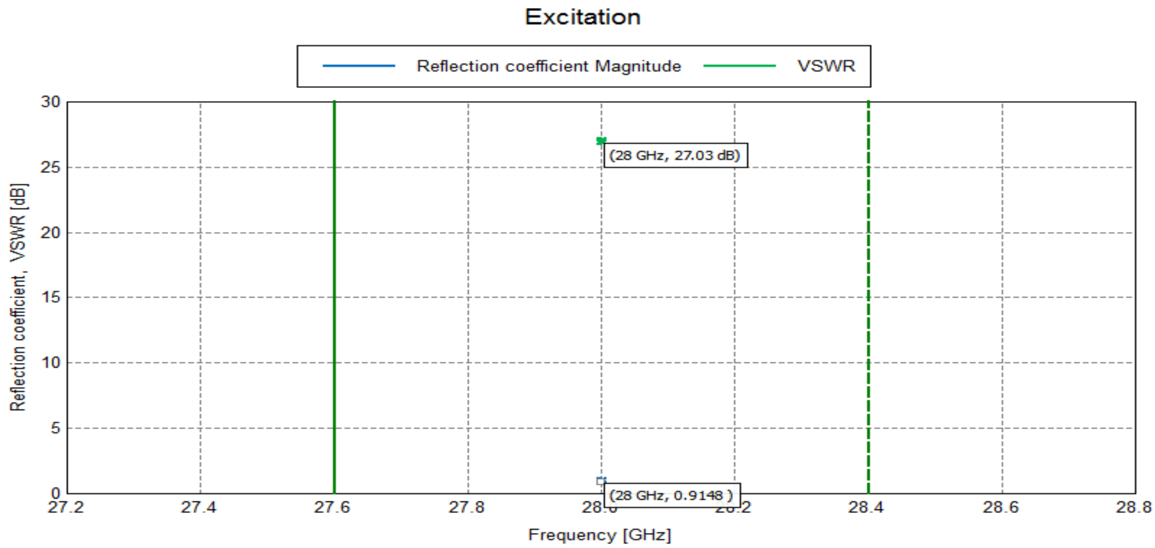

Figure4.3 (b) S11 and VSWR plot for Single element with change in dimension of patch

During the development of designing single element PIFA antenna there is a response taken from the magnitude of magnitude (dB) versus frequency. This is known as the return loss. To have a perfect matching between the antenna and the transmitter, $\Gamma = 0$ and $RL = \infty$, this indicates that there is no power that is returned or reflected but when $\Gamma = 0$ and $RL = 0$dB, this indicates that the power that is sent is all reflected back. It is said that for the practical applications VSWR = 2 is acceptable as the return loss would be -9.54dB. In this thesis the final reflection coefficient for the final single element design is $\Gamma = 0.2$and VSWR =1.5.

4.3. Summary of Simulation Result

A parametric analysis was performed on the design of both single element and 4x4 element PIFA antennas. The parameters which have been studied in this parametric analysis are the length 'L', Width 'W' of ground plane, radiating patch and height of shortening plate, positions of shortening plate and feed point the planar inverted F-antenna The effect of altering these dimensions impose a change in the Directivity, radiation pattern, VSWR, reflection coefficient and Gain. Summary result of the above mentioned performance parameter for the above simulation result where discussed in below table.

Table 4.1 Summary of Numerical values of simulation result for single element design

PIFA Parameters In (mm)	Action	Gain At 0^0 (dB)	Directivity (dBi) at 0^0	VSWR	Reflection coefficient	Radiation Efficiency (in %)
shortening plat	Increase Ws	11.4	12.1	1.72	0.2647	70.6
'D' of feed point	Increase d	2.84	2.9	1.61	0.2337	97.9
Dimension of ground	Increase Wg&Lg	1.06	1.26	1.91	0.3127	79.3
patch dimension	Increase Wp and Lp	2.43	2.57	1.48	0.1935	94.5
PIFA height	Increase h	3.26	3.33	1.8	0.2857	97.8
Final Design		4.36	4.51	1.5	0.2	99.3

Table 4.2 summary of result observed from simulation

PIFA Parameters	Action	Directivity	Radiation efficiency	Radiation Pattern
Dimensions of the ground plane	Increase the length and width of ground plane	Increases	Decreases (not very sensitive)	Affects
Position of feed on the ground Plane and patch	Increase the distance from edges	Increases	Decreases	Significant effects
Dimensions of patch	Increase thelength/width of the top plateLp and Wp	Increases	Small increase	slightly Small effects only
Height of PIFA	Increase the height	Slightly small effect	Increases	No significant effects
Width of shorting plate	Increase the width of the shorting plate	Increases	Increases	significantly affected
Final design		Increases	Increases	Affect

Due to the unique advantages of PIFA, it has become a popular material choice for individual antenna or antenna array implementations. The ease of fabrication, compatibility and low cost, especially after the development of various enhancement techniques, which are focusing in neutralizing the shortcomings of the PIFA technology the purpose of this paper is to design, studying characteristics of PIFA antenna and recommending the final design to mobile communication. Therefore, an antenna design based on frequency of 28 GHz is adoptable for the next generation of wireless communication.

4.4. Simulation Results and Discussion of 4x4 elements PIFA Antenna

The simulation result for 4x4PIFA antenna is discussed shown in **figure 4.4 (a–f)** and **figure 4.5 (a-f)** in terms of reflection coefficient, VSWR, Directivity and Gain using change in dimension of parameters such as shortening plate width, ground plane width ground plane length, patch width, patch length and PIFA height were varied.

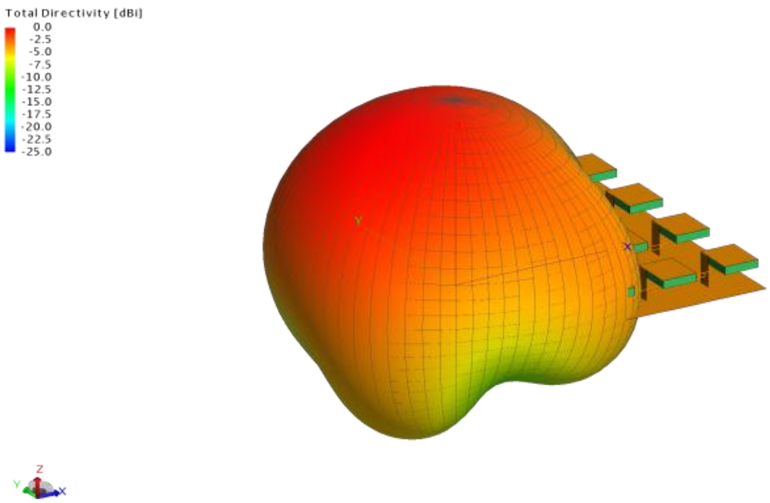

Figure4.4 (a) 3D 4x4 elements Radiation pattern change of dimension in Ws

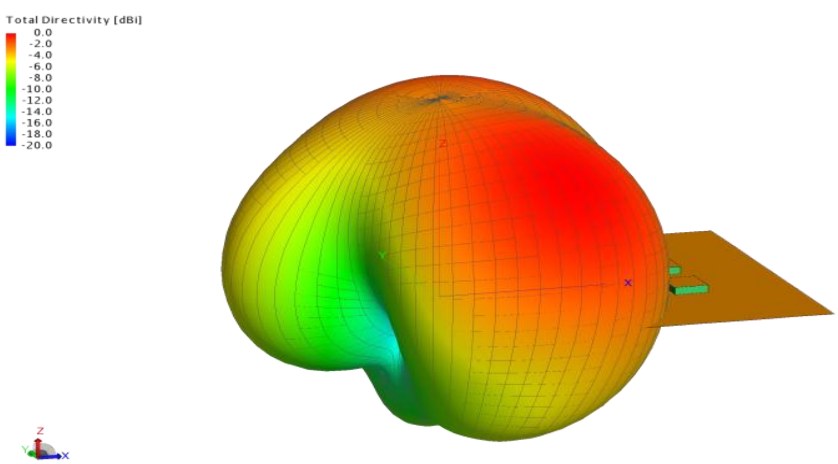

Figure4.4 (b)3D 4x4 elements Radiation pattern with change of dimension in feed point

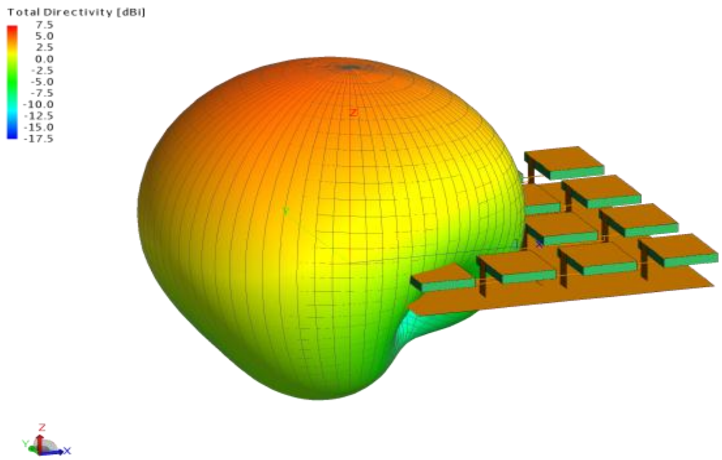

Figure4.4 (c) 3D 4x4 elements Radiation pattern with change of dimension in ground plane

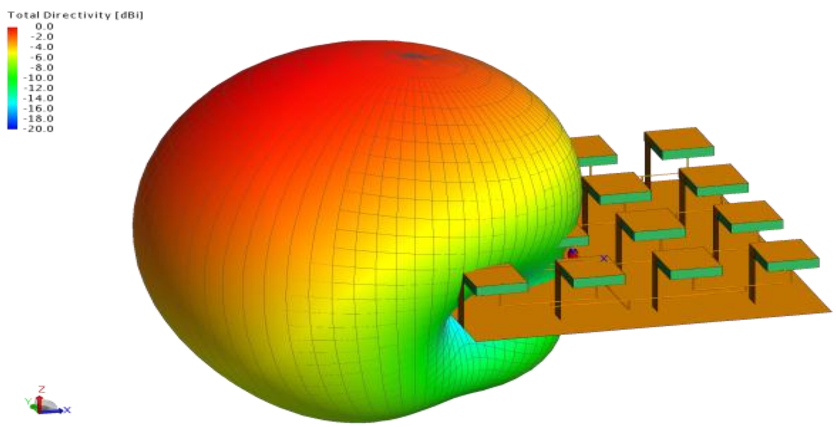

Figure4.4 (d) 3D 4x4 elements Radiation pattern with change of dimension of patch

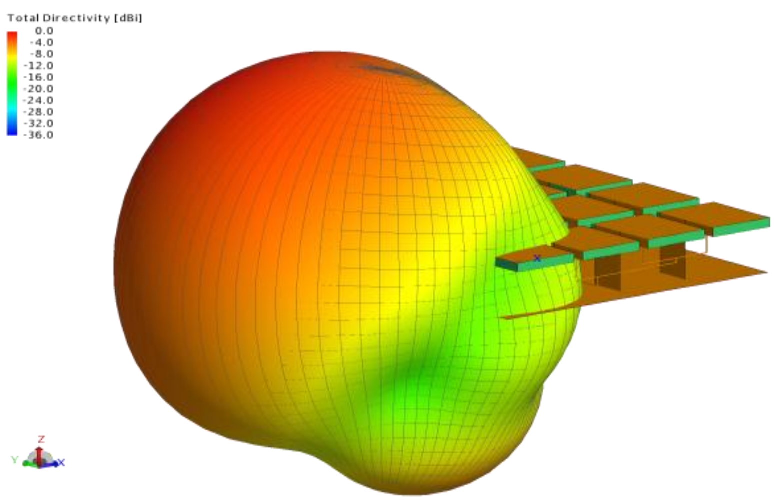

Figure4.4 (e) 3D 4x4 elements Radiation pattern with change of dimension in height

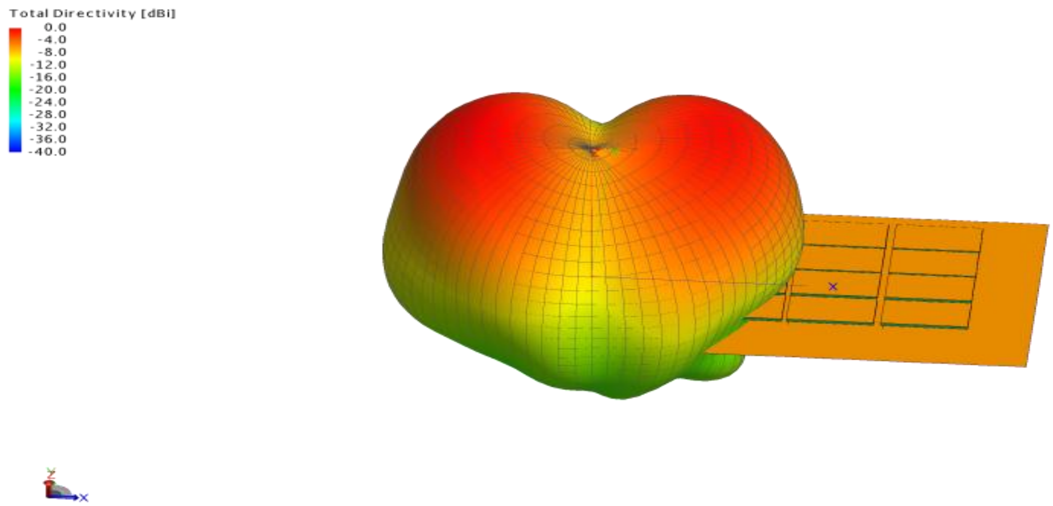

Figure4.4 (f) 3D 4x4 elements radiation pattern for final design

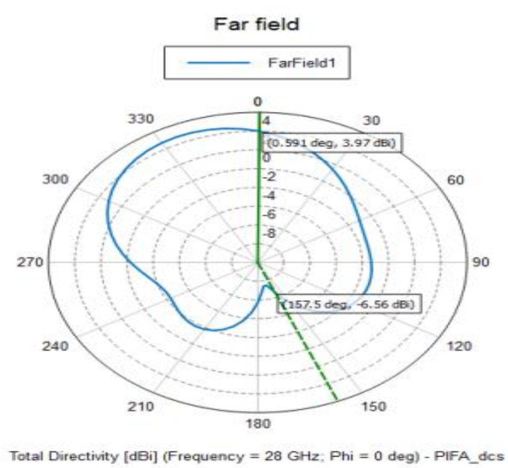

Figure4.5 (a) 4x4 elements Radiation pattern with change of dimensions in Ws

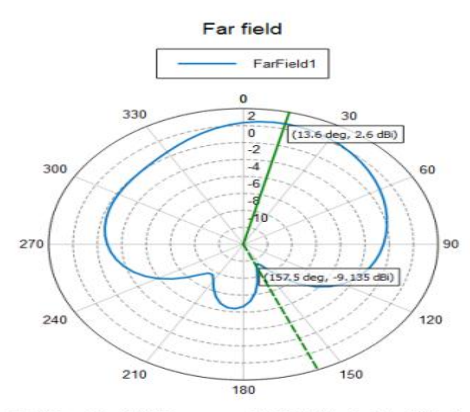

Figure4.5 (b) 4x4 elements Radiation pattern with change of dimensions in feed point

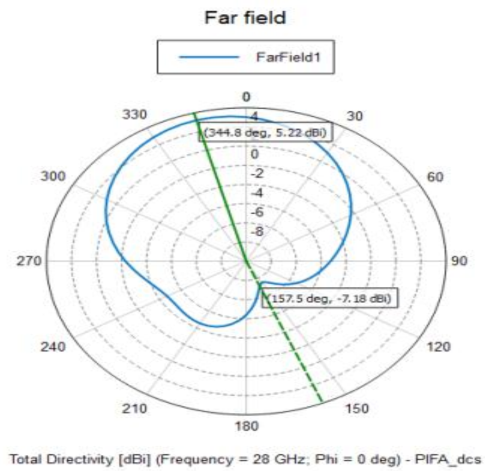

Figure4.5 (c) 4x4 elements Radiation pattern with change of dimensions in ground plane

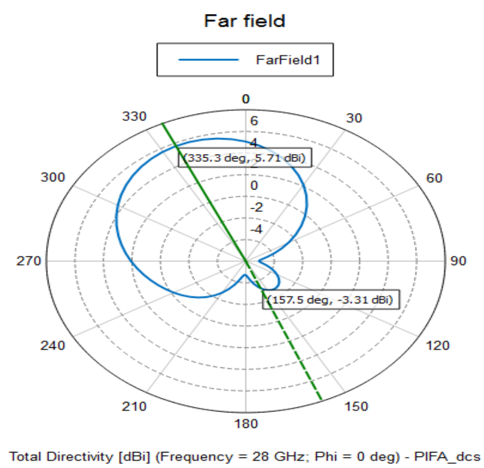

Figure4.5 (d) 4x4 elements Radiation pattern with change of dimensions of patch

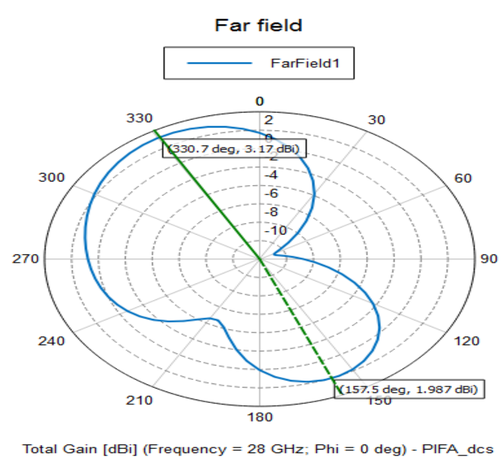

Figure4.5 (e) 4x4 elements Radiation pattern with change of dimensions in height

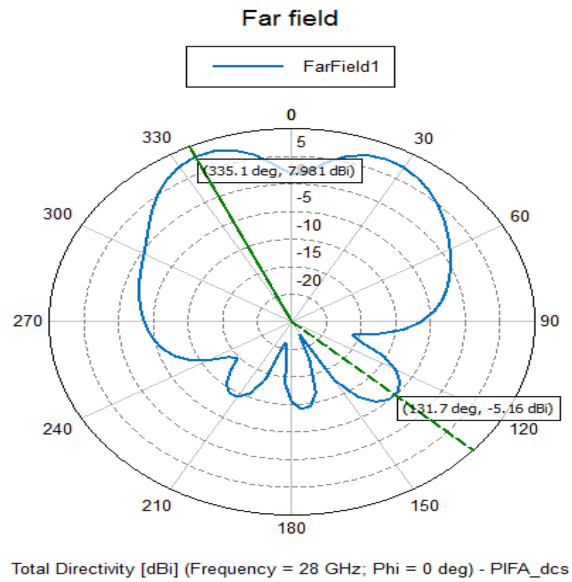

Figure4.5 (f) 4x4 elements radiation pattern for final design

As it is shown in **figure 4.4 (a-f) and figure 4.5 (a-f)**, the 3D far field plots of the antenna radiates in broadside at 0.00 degree direction with maximum directivity of 7.43dB and some side lobe occur because of improper element spacing. To improve the return loss and reduce the side lobes inter-element spacing is used. The element spacing has a large influence on the array factor as well. If element spacing is greater than 0.25λ, the side lobe is big and grating lobes occur. A grating lobe is another unwanted peak value in the radiation pattern of the array. If element spacing is less than 0.25λ, mutual coupling effects occur. To avoid grating lobes and mutual coupling effects, the patch spacing for this design was chosen as 0.25λ. In this thesis, 4x4PIFA antenna array is designed with an equal spacing of 0.25λ. The corporate feed method is used to excite the array elements. If the side lobe level is less than -10dB or 15dB, the antenna performance is good as it is shown in **Figure 4.5 (f)** it was found that the side lobe level is -5.16dB. So the antenna performance is good.

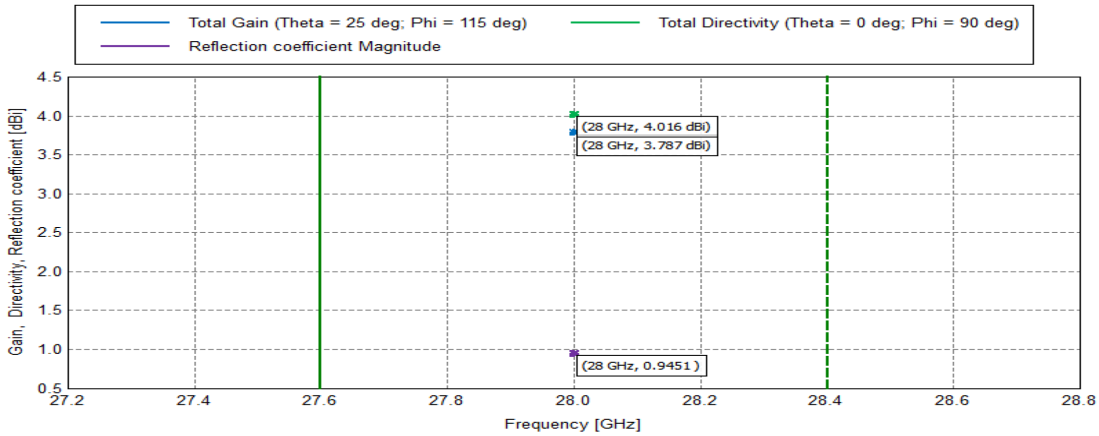

Figure4.6 (a) S11 and VSWR plot for 4x4 elements with change in dimension of Ws

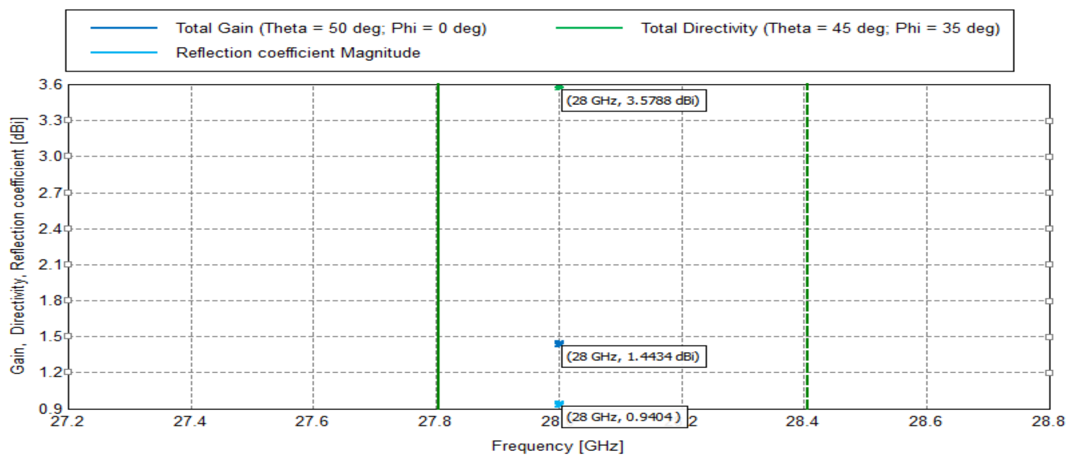

Figure4.6 (b) S11 and VSWR plot for 4x4 elements with change in dimension of feed point

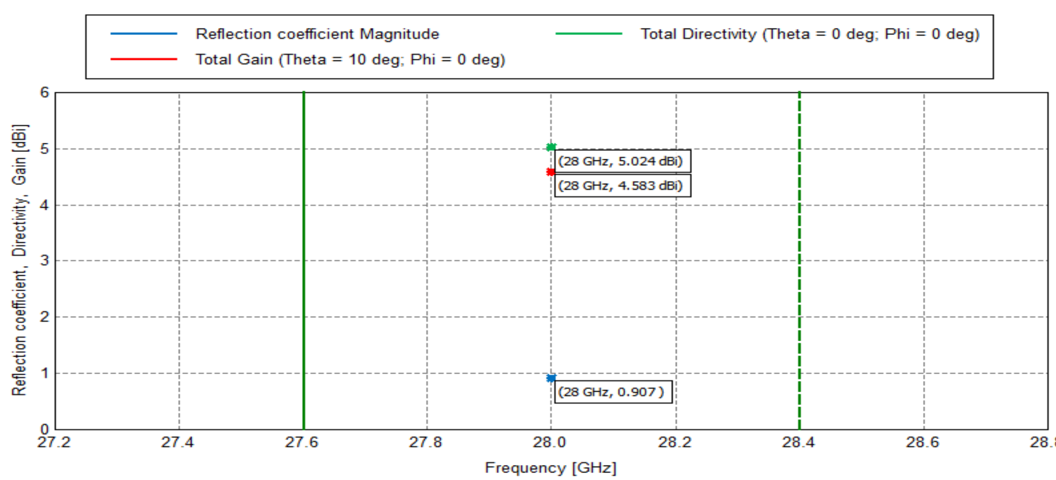

Figure4.6 (c) S11 and VSWR plot for 4x4 elements with change in dimension of ground plane

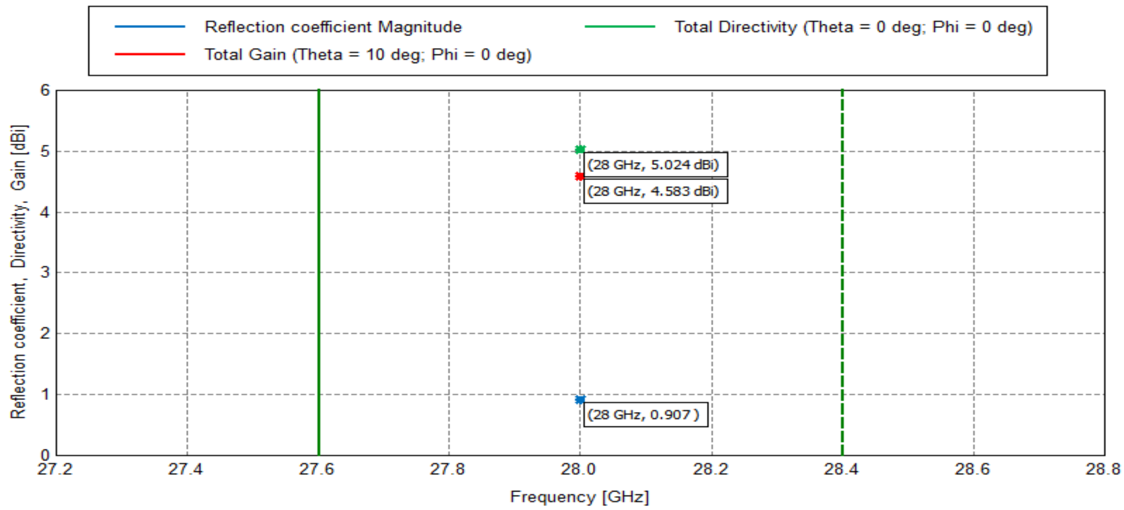

Figure4.6 (d) S11 and VSWR plot for 4x4 elements with change in dimension of patch

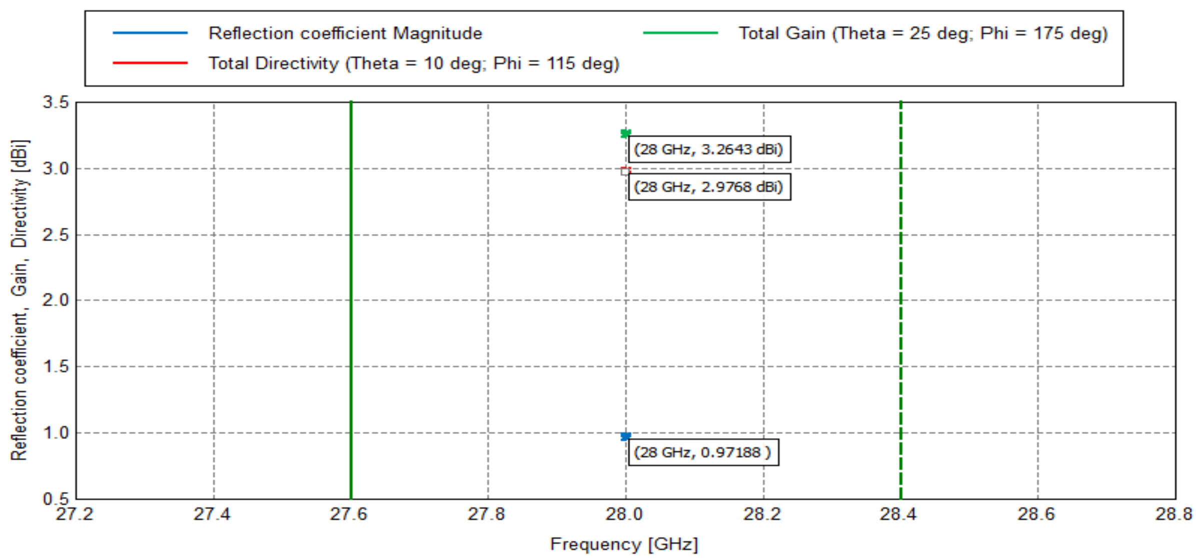

Figure4.6 (e) S11 and VSWR plot for 4x4 elements with change in dimension of height

During the development of designing the rectangular patch array antenna there is a response taken from the magnitude of magnitude (dB) versus frequency. This is known as the return loss. To have a perfect matching between the antenna and the transmitter, $\Gamma = 0$ and $RL = \infty$, this indicates that there is no power that is returned or reflected but when $\Gamma = 0$and $RL = 0$dB, this indicated that the power that is sent is all reflected back. It is said that for the practical applications VSWR = 2 is acceptable as the return loss would be -9.54dB. The reflection coefficient of the patch to confirm a good impedance match in our design is VSWR =1.7.

4.5. Summary of Simulation Results

A parametric analysis was performed on the design of both single element and 4x4 elements of PIFA antennas. The parameters which have been studied in this parametric analysis are the length 'L', Width 'W' of ground plane, radiating patch and height of shortening plate, width of shortening plate and feed point of the planar inverted F-antenna. The effect of altering these dimensions imposes a change in the Directivity, radiation pattern, VSWR, reflection coefficient and Gain. Numerical values of the simulation results were discussed in table below.

Table 4.3 Summary of Numerical values of simulation result for 4x4 elements design

PIFA Parameters	Action	Directivity(dB)	Gain(dB)	VSWR	S11	Efficiency (%)
Normal design		4	3.7	1.31	0.134	92.5
Ground plane dimension	Increase Wg&Lg	2.3	2.0	1.30	0.130	86.9
Radiating patch dimension	Increase Wp and Lp	5	4.92	1.262	0.1158	98.4
Dimension of patch height	Increase h	5.04	4.97	1.27	0.1189	98.6
Shortening plate width	Increase Ws	3.16	3.07	1.28	0.1228	97.1
Final design		7.43	7.40	1.168	0.0775	99.5

Table 4.4 summary of result observed from simulation

PIFA Parameters	Action	Directivity	Radiation efficiency	Radiation Pattern
Dimensions of the ground plane	Increase the length and width of ground plane	Decreases (very sensitive)	Decreases	Affects
Dimensions of top Radiating patch	Increase the length/width of the top plate	Slightly Small change(increase)	Increases	slightly Small effects only
Height of PIFA	Increase the height	slightly Small increase	Increases	No significant effects
Width of shorting plate	Increase the width of the shorting plate	Decrease	Increases	No significant effects
Final design		Increases	Increases	significant effects

4.6 Comparisons of both single and 4x4 elements of PIFA antenna

After selecting the substrate parameter, calculating some model parameter and designing patch array antenna, the computer simulations are carried out for both single 4x4 elements using FEKO. After performing the relevant computer simulations for each of these situations separately, the corresponding directivity, gain, return loss and VSWR of both designs were compared as given in **table 4.5** below from this table we can see that the PIFA planar array antennas are more advantages than single element antenna.

Table 4.5: Comparison of results of both single and 4x4 element

Quantity	Single element	4x4 element
Patch Dimensions	3.2 x 2.24	11 x 18
Directivity	4.51dB	7.43dB
VSWR	1.5	1.168
Return loss (dB)	0.2	0.775

4.7 Comparison of Specific Absorption Rate (SAR) for Both Antenna design

Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the body when exposed to a radio frequency (RF) electromagnetic field. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). The SAR (W/kg) at any point in the model can be determined from the calculated electric field E (V/m) and it is given by the following equation:

$$\text{SAR} = \frac{\sigma|E|2}{\rho} \quad [\text{W/kg}] \qquad (4.1)$$

$$\text{Incident power density} = E^2/377 \quad \text{Kg/m\^{}3(4.2)}$$

Where E is the internal electric field (V/m), SAR is the Specific Absorption Rate (W/kg), σ is the conductivity (S/m) of the tissue and ρ is the mass density (kg/m3)

The FEKO simulation model consists of homogeneous human head and Dual band slotted planar inverted-F antenna mounted on a mobile handset. By considering the problem size and complexity, the FEKO program is simulated using the Method of Moments (MoM) based platform.

Table 4.6 SAR Comparison along with standards set by FCC for single element

One element			
Changed parameters	**Action taken**	**SAR [w/kg] at 3cm near field**	**Incident power [kg/m^3]**
Dimensions of the ground plane	Increase the length and width of ground plane	4.749	24.818
Position of feed on the ground Plane	Increase the distance from edges	13.061	68.252
Dimensions of top patch	plate Increase the length/width of the top plate	1.235	6.457
Height of PIFA	Increase the height	6.129	32.031
Width of shorting plate	Increase the width of the shorting plate	2.365	12.350
Final design		2.26	1.1835
FCC standards		1.6	

Table 4.7 SAR Comparison along with standards set by FCC for the 4x4 element

4x4 element			
Changed parameters	**Action taken**	**SAR [w/kg] at 3cm near field**	**Incident power [kg/m^3]**
Dimensions of the ground plane	Increase the length and width of ground plane	0.2914	1.523
Position of feed on the ground Plane	Increase the distance from edges	0.4044	2.112
Dimensions of top patch	plate Increase the length/width of the top plate	0.1507	0.7872
Height of PIFA	Increase the height	0.1550	0.810
Dimension of shorting plate	Increase the width and length of the shorting plate	0.1946	1.017
Final design		0.613	0.320
FCC standards		1.6	

The SAR analysis of proposed both antenna design is presented. In this study, the CADFEKO simulation tool is used the specific absorption rate (SAR) values of PIFA conforms that the proposed antenna exhibit considerably lower SAR compared to a reviewed related research work**.**

4.8. Comparison and Validation of Result with related research (thesis) work

In this paper, it was attempted to do an intensive survey of the works done by various researchers on PIFA technology. In this thesis work some of the important aspects of PIFA technology and PIFA design are considered.

Table 4.8 Comparison and validation of proposed with related research work.

No	**No of element**	**Resonant frequency**	**Directivity dBi**	**Gain dB**	**VSWR**	**S_{11}**	**Remark**
Research done on PIFA On 2009 on 4G/		2.4 Ghz	-	8.89	1.0583	-	Loaded IFA
Research done on PIFA 2014 on 4G/		2.4Ghz	3.89	1.67	-	-	Using HFSS
Research done on PIFA b/n 2015 on 4G/		2.4Ghz	2.9	1.07	4.6	0.389	On HFSS
Research done on PIFA b/n 2016 on 4G/		9.77-11.58 GHz	-	4.27	2.31	0.676	On CST
				4.02	1.30	0.492	
Research done on PIFA b/n 2016 on 5G/							
1	**Single element**	28 GHz	3.31	3.20	-	0.676	On CST
2	**Three element**	28 GHz	4.93	4.85	-	0.759	On CST
Single element final design		28 GHz	4.51	4.48	1.7	0.2	On FEKO
4x4 element final design		28 GHz	7.43	7.40	1.68	0.0775	On FEKO

In the above table results found by related research work where compared and discussed. It was observed that the proposed PIFA offers better scope in comparison with other low profile antennas while considering the SAR values, as an array element and for use in handheld devices from the above table, it can be concluded that the proposed PIFA antenna resulted a better result than the results found by related research work.

CHAPTER - FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this thesis work, it was attempted to do an intensive survey of the works done by various researchers on PIFA technology. Some of the important aspects of PIFA technology and design are considered. Various design considerations and applications are evolving in this area and it was observed that the proposed PIFA offers better scope in comparison with other low profile antennas while considering the SAR values, as an array element and for use in handheld devices. In this thesis work Planar Inverted F-Antenna is designed and simulated. And objectives of this thesis work have been achieved. Only a few adjustments have to be done to the radiating patch dimension, ground plane dimension, substrate material thickness sand height when employing design to get better performance. A Micro strip Line fed and a dielectric constant of FR-4 at an operating frequency of 28 GHz with different parametric change where employed in these thesis work and it have shown that the PIFA characteristics are affected by a number of parameters. The conclusions are summarized as follows:

- The radiation pattern of PIFA is basically dependent on the size and shape of the top plate and is affected by the dimensions of the ground plane and the position of PIFA on the ground plane.
- By increasing the height of the top plate, the slightly no effect on the radiation pattern but as PIFA needs to be of low profile so the height has to be limited in the design.
- The greater the size of the top plate, the more directive will be the radiation pattern which means that it will have higher gain and directivity as well. If we decrease the size (length or width) of the top plate, the directivity of antenna decreases and the intensity of radiation pattern behind the ground plane increases.
- By increasing the widths of shorting plate the radiation pattern will be parallel to the ground plane.
- The increasing distance between shorting plate and feeding position the radiation pattern, radiation efficiency and directivity will not be affected.
- The Directivity is also affected by the ground plane dimensions and height.

In these thesis work results found by related research work where compared and discussed. It was observed that the proposed design offers better scope in comparison with other low profile antennas while considering the SAR values, as an array element and for use in handheld devices. It can be concluded that the proposed PIFA antenna resulted a better result than the related research work.

5.2. Recommendation

Although this thesis had provided a significant study on the mm-wave band PIFA antenna system for mobile communications in the era of 5thG wireless communications, there are still other equally important areas that require attention. Another area of interest is examining the effect of the ground plane dimensions on the performance of the antenna element in order to increase system performance it can be designed using different substrate materials.

It is very important to take the feed technique the impedance and the substrate materials into consideration. In addition, different orientation of the radiating patch can be employed and analyzed to justify the best position and different type of feed technique affects the performance of the antenna Micro strip feed line is shown in this thesis and the results implies the performance of the antenna is good. In future other different type of feed techniques can be used to evaluate the overall performance of the antenna without missing the standard parameters in the action extensively and exclusively focusing on the area of different design methods especially in minimizing the mutual coupling between the elements. Finally it was recommended that this researcher can be carry out by increasing the array element in order to enhance the performance.

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APPENDIX - A

Introduction to CADFEKO

CADFEKO is the FEKO component that facilitates the creation of CAD geometry using canonical structures and performs Boolean operations. It also supports the import and modification of CAD models and meshed geometries [24].

Typical CADFEKO workflow when constructing geometry

The first step in constructing a general CADFEKO model is to create or modify the geometry, see Figure below. The model creation is accomplished by using the available primitives such as solids, surfaces, curves and arcs. Boolean operations as well as transforms may be applied to obtain the desired geometry [24].

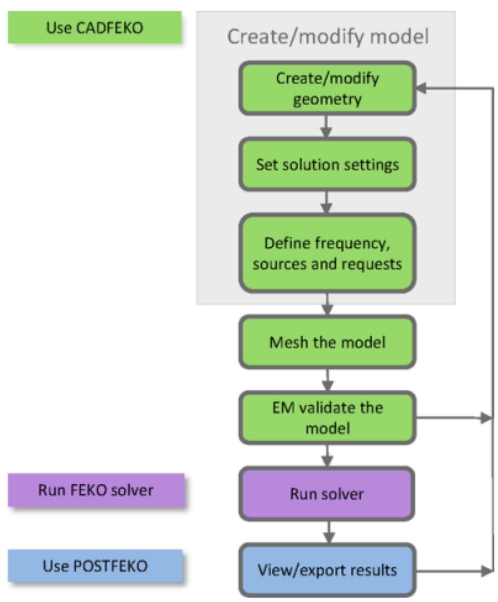


Illustration of the CADFEKO workflow.

FEKO start pages

When starting a blank instance of CADFEKO, EDITFEKO or POSTFEKO (no models are loaded), the start page will be displayed, giving quick access to create a new model, Open an existing model or recent projects and a list of recently opened models. Links to the documentation (in PDF format) for FEKO are also available [24].

CADFRKO and POSTFEKO start pages.

The window

The various main elements and terminology of the CADFEKO window will be briefly described. This terminology will be used extensively in the chapters to follow.

1. Quick access toolbar

These items give the user quick access to controls such as *New model*, *Open model*, *Save model*, *Undo* and *Redo* actions (grouped at the left side of the toolbar) as well as launching the FEKO solver, POSTFEKO (for the display of the results obtained by the FEKO solver), EDITFEKO and PREFEKO (grouped at the right side of the toolbar, next to the help button [24] and called *Application Launcher*).

2. Ribbon

The ribbon contains the application menu, default tabs, contextual tabs and contextual commands.

3. Configurations list

The configurations list contains the defined standard-, S-parameter and characteristic mode.

4. Model tree

The *Model tree* consists of the *Construction*- and *Configuration* tabs. On the *Construction* tab the geometry representation of the current model is given. On the *Configuration* tab the global and specific model settings and requests are defined.

5. Details tree

The details tree contains the geometry object details (edges, faces and regions). Custom solution and mesh settings may be set here.

6. Active status bar

Theactive status bar gives the user quick access to general display settings, tools, selection method and type.

7. Message window

The message window displays messages regarding user interaction such as geometry creation, meshing, source configuration, etc. It also provides details regarding warnings and error messages. Errors and warnings in the message window will provide links to the corresponding geometry objects in the details tree which resulted in the error or warning.

8. Notes view

The notes view can be used to document a model. Additional comments, explanations or descriptions can be added.

9. 3D view

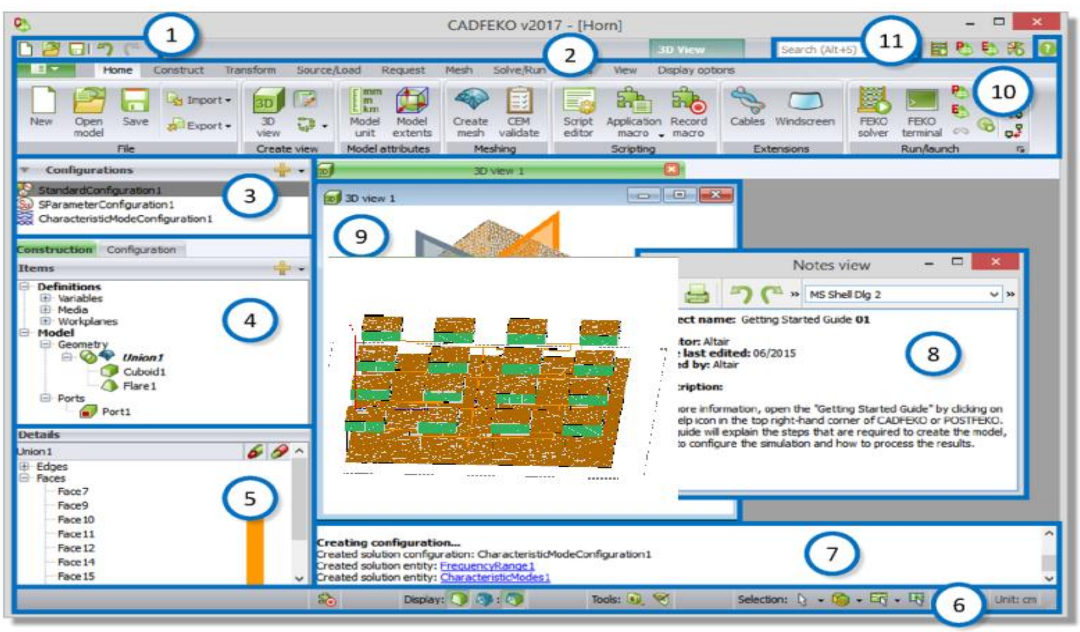
The 3D view enables the user to visualize the geometry and solution settings (such as far afield requests). Additional visualizations such as cut planes and symmetry can also be displayed.

10. Help

The *Help* button gives the user quick access to the FEKO manuals. Context sensitive help is available in all FEKO GUI components by pressing <F1> at any time.

11. Search bar

The search bar enables the search for a specific action/keyword in CADFEKO. Entering a keyword in the search bar will populate a dropdown list of actions as well as the location of the respective action on the ribbon or context menu. Clicking on any one of the items in the list will execute the respective action.



APPENDIX - B

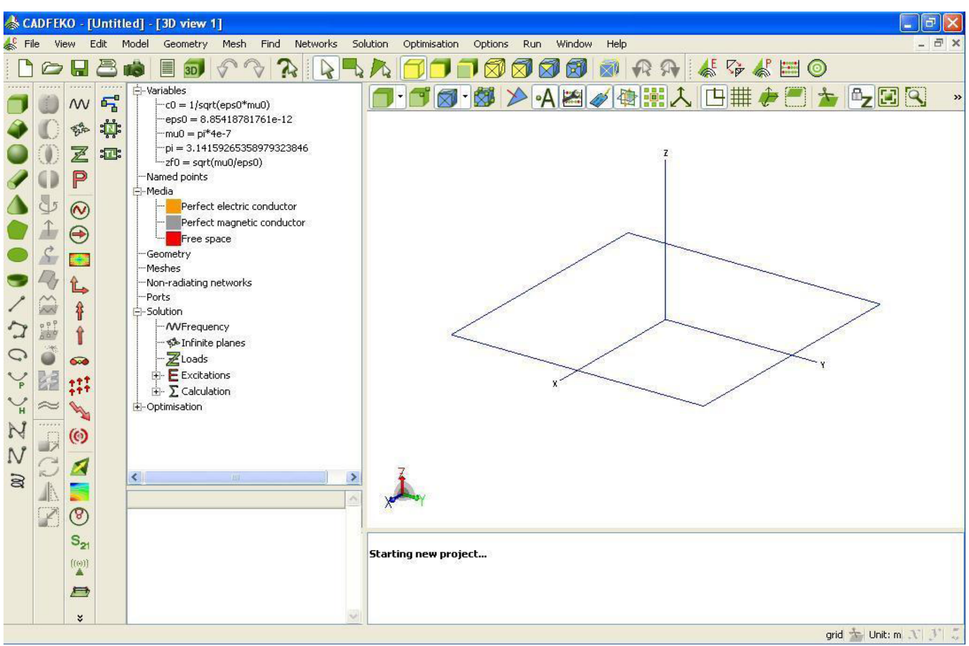
SAMPLE DESIGN PROCEDURE

FEKO is a Method of Moments (MoM) tool that can be used to calculate the radiation pattern, impedance and gain of an antenna while mounted on some defined geometry. In addition, it can calculate the isolation or mutual coupling between pairs of antennas.

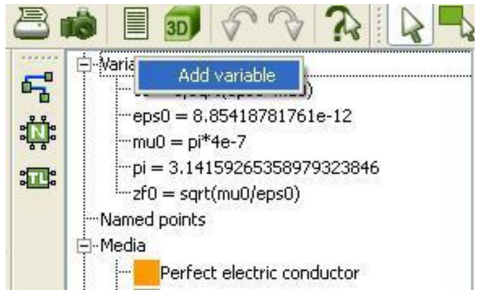
The basic flow of performing a FEKO analysis consists of:

- Building geometry, for the antenna in CADFEKO or EDITFEKO.
- Building a geometry to represent surrounding geometry in CADFEKO, EDITFEKO or an external tool.
- Meshing the Created Antenna and Surrounding Geometries (CADFEKO or EDITFEKO)
- Requesting Solution Types and Setting Solution Parameters (CADFEKO or EDITFEKO)
- Running the FEKO solver (FEKO).
- Read in and interpret results using Post FEKO.

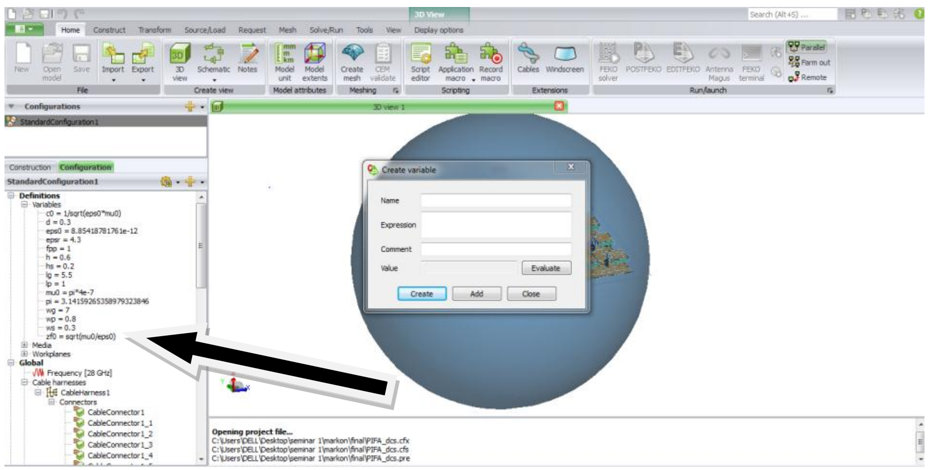
First, let's click the CADFEKO button wherever we have FEKO installed. If you have everything set up properly, you'll see a screen similar to that shown below. This is where we can build geometry using a fairly simple graphical user interface.



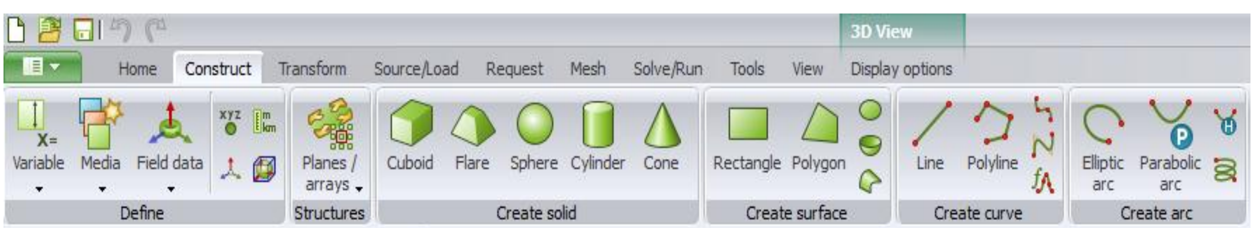
The first step is to make our antenna. Note that the default settings for all geometry lengths are meters. This can be altered by clicking **Model ⟹Model Unit** and selected a different unit, if say, you prefer inches. Let's say we want a PIFA antenna to operate at 28GHz. The wavelength at this frequency is 1millimeter, so a quarter-wavelength would be 0.25 millimeter. We'll first declare a variable called "**Length**" to represent this. **Right-click on the "Variables"** label in the **Model** Tree as shown below and select "**add variable**":



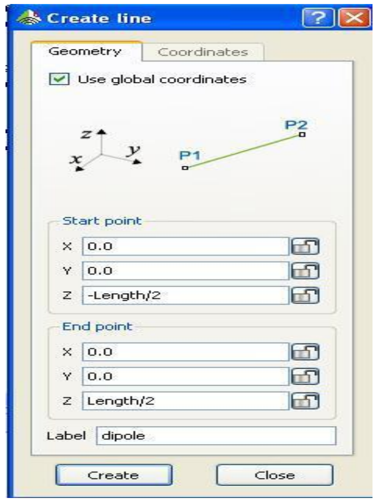
The following window pops up, and we enter the length as 0.25 (the unit is millimeter unless we specified otherwise). Then click **create**, and the variable is saved in the Variables Tree.



For now, that is all the variables we'll make. You can add as many expressions for variables as you want, and even define variables in terms of other variables if you feel like it. Now, we'll create the geometry of our antenna. Click the "**create rectangle**" button on the far left side of the CADFEKO screen:

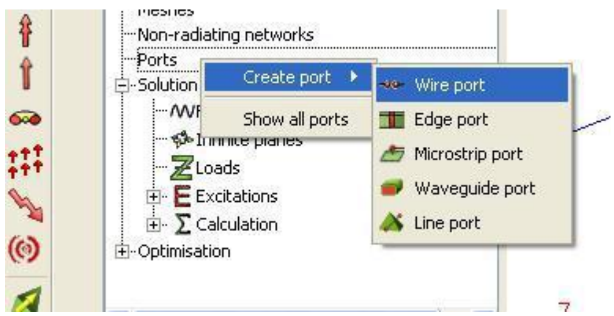


A create line window pops up. We will place this rectangle centered at the origin (x,y,z)=(0,0,0), with the length given by our declared variable "Length". We will name it "**patch**" in the label panel. **Click create** to create the patch, **then close** to close the create line window (see window below).

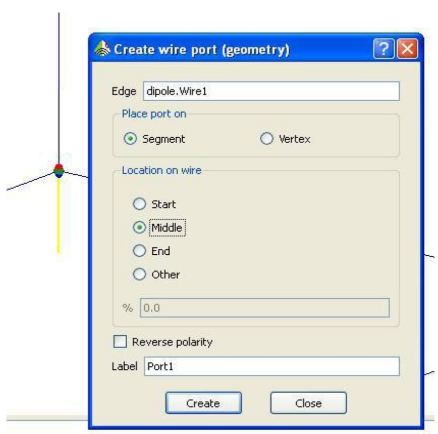


Sources and meshing in FEKO

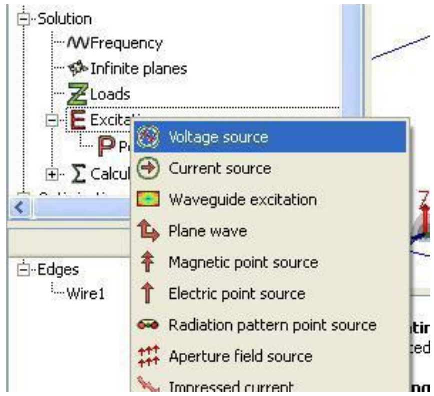
To make it an antenna, we need to **add a voltage source** to the center of the wire. This is simple. In the CADFEKO tree, **right click Ports** and then select **Create Port⇨ire Port**.



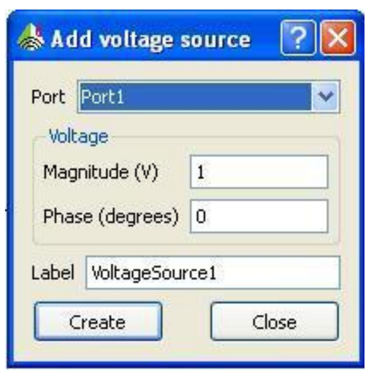
Once you select Wire Port, another window pops up. The **Edge box** is initially highlighted – this is the place where the wire port should be applied. We simply select the object we want the port applied to. In this case, just **click anywhere on the wire** we just created. Then select the location as "**middle**" to have the port at the center of the wire. Then **click Create**, and then **Close** as shown in the window below:



We now have a port, but to calculate the radiation pattern we will need to **apply a source**. This can be done by **right clicking on Excitations** in the Solution list of the CADFEKO model tree, and **then selecting Voltage Source**.

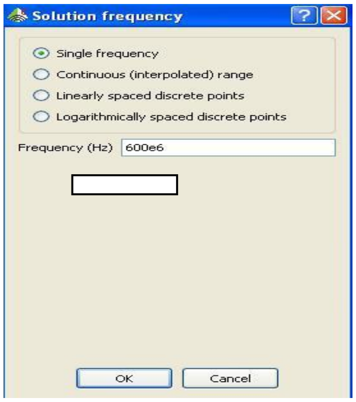


The **add voltage source** dialogue pops up. We want to apply the source **to Port1**, and we'll leave the magnitude and phase at the default values of 1 and 0, respectively. You can assign a **name** here if you want, but VoltageSource1 (**the default**) is fine. Click **Create**, and then **Close**.

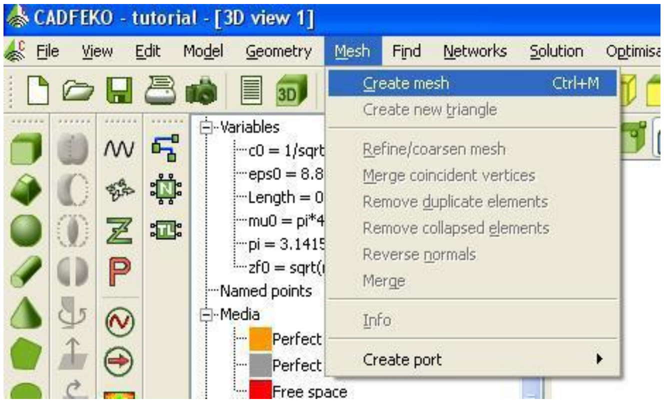


We need to specify the **solution frequency** now. We would like to see results at 28GHz, so **right click on Frequency** under the Solution bar and **select "Set Frequency"**:

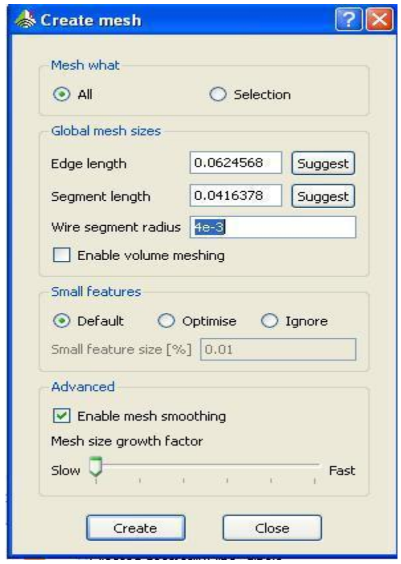
The frequency window pops up, and **Enter 28e9**for 28GHz, then click ok:



Now we **need to mesh our geometry** (our geometry is just the wire). At the top of the screen, there is a **Mesh menu**, **click** that and **then click Create Mesh**. See window below.

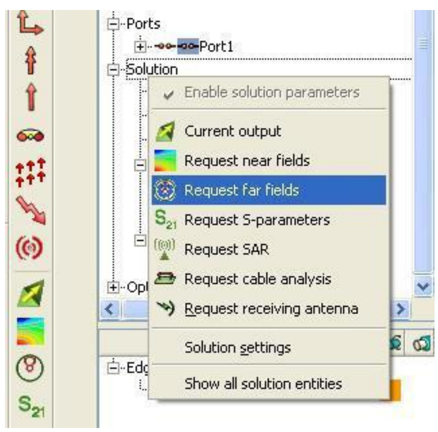


The mesh needs lengths specified which will determine how finely to grid the geometry. The mesh should have triangles that are no longer than an eighth of a wavelength, or wire segments not longer than one twelfth of a wavelength. When the create mesh window pops up, click the "**suggest** "buttonnext to the edge length and segment length fields. This will determine the required lengths for you based on the frequency we specified.

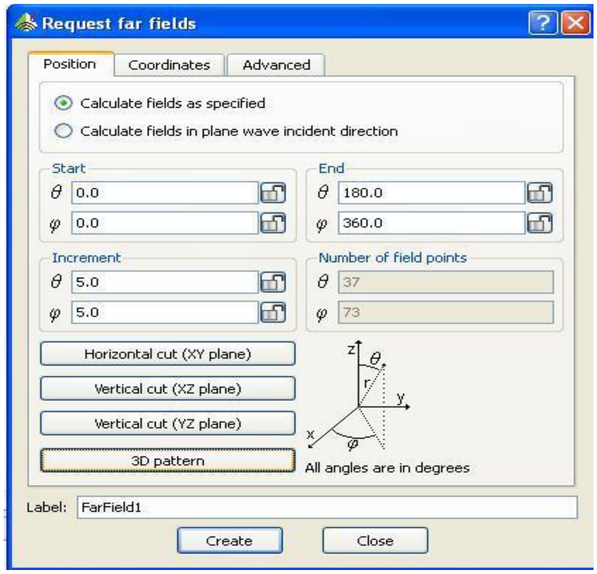


Requesting outputs, running FEKO and using POSTFEKO

At this point, we have our antenna **geometry, port, source and mesh**. We've set the **solution frequency** to be 28GHz. Now, we need to request outputs. **Right click on Solution** in the CADFEKO tree, and **click "Request Far Fields"**.



The Request Far Fields window pops up, and if you click the **3D Pattern** at the bottom (see window below), you will be requesting the far field pattern. The default setting will be the entire sphere, with a grid sampling in 5 degree increments. You can change these parameters if you would like. Then **click create** and then **close**, and you have told FEKO that you want to see the far field patterns (including gain) once the analysis is complete.



We've now set up our model in CADFEKO, run the FEKO solution kernel, and we're ready to process our results using **PostFEKO**. Go to **Run⇨PostFEKO** (or **ALT+3**) and PostFEKO (FEKO's utility to view the output or solutions) will come up. Let's look at the **3D** Radiation patterns first. On the Far Left Column of buttons, **click the "view radiation patterns"**: