ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Design of 6 and 28 GHz Omnidirectional Circular Polarized Antenna for 5G Communication

Submitted by: Haftamu Mekonen

Thesis Submitted to Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical and Computer Engineering (Communication Engineering)

Advisor: Dr. Merhawit Berhane

Addis Ababa, Ethiopia

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Approval by Board of Examiners

Chairman Department of Graduate Committee	Signature	Date
Dr. Merhawit Berhane		09/01/2020
Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

DECLARATION

I the undersigned, declared that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other University and all sources and materials used for the thesis are duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree in Communication Engineering at Addis Ababa University.

Haftamu Mekonen ____________________

Name Signature

Addis Ababa 09/01/2020

Place Date of Submission

This thesis work has been submitted for examination with my approval as a University Advisor.

Dr. Merhawit Berhane ____________________ 09/01/2020

Advisor Signature Date

Acknowledgment

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Abstract

The upcoming fifth generation (5G) of mobile communication that can enhance the capacity and data rates attracts many attentions in recent years. One drawback of 5G technology is that it is more prone to interference comparing to the other technologies. To overcome this problem 5G infrastructure uses much smaller base stations instead of using the large cellular antenna that we use today. To cover large area multiple number of small cells can be used. This makes the antenna costy. So, nowadays omnidirectional circularly polarized antennas are commonly designed in 5G technology to reduce sector antenna and the interference. Hence. Due to the various advantages of omnidirectional circularly polarized antennas different methodology was used to design. However, getting a good performed antennas based on their gain, radiation efficiency, low reflection coefficient and small electrical size of antenna are the major challenges.

Therefore, in this paper a circularly polarization omnidirectional antenna which is applied to 5G communication is designed to improve the gain. The essence of this research is combining two different kinds of antenna in High Frequency Structure Simulator (HFSS) to achieve the characteristic of omnidirectional radiation pattern and circular polarization. The two kinds of antenna are dipole and negative magnetic permeability zeroth-order resonator respectively. Because both of them are linear polarization and omnidirectional radiation pattern, the characteristic of omnidirectional radiation pattern and circular polarization can be achieved as long as they are combined in physical space with 90 degrees. The radiation pattern of antennas is simulated to generate the gain. For the antenna designed at 6 GHz the gain is 1.9 dBi and for the antenna at 28 GHz the gain is 2.0 dBi. Both antennas achieve circular polarization performance and Omni-directional radiation within the operational band. This research output can be especially applied to 5G small base stations in the future.

Keywords: Dipole, MNG-TL, Zeroth-order transmission line, Omnidirectional circularly polarized antenna,

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List of Abbreviation

CRLH	Composite Right/Left-Handed
CP	Circular Polarized
dB	Decibel
DNG	Double Negative
DPS	Double Positive
EM	Electromagnetic
EMW	Electromagnetic wave
ENG	Epsilon Negative
GHz	Giga Hertz
GNSS	Global Navigation Satellite Systems
HFSS	High Frequency Structure Simulator
ISWR	Current Standing-Wave Ratio
LHC	Left-Hand-Circular
LOS	Line-of-Sight
LP	Linear Polarized
MNG	Mu Negative
MNG-TL	Mu Negative Transmission Line
MZR-EZR	Epsilon-Zero Resonance and Mu-Zero Resonance
NR	New Radio
NRI	Negative Refractive Index
OCP	Omnidirectional Circular Polarized
RF	Radio Frequency
RFID	Radio Frequency Identification

RHC	Right-Hand-Circular
RHCP	Right Handed Circularly Polarization
SNG	Single Negative
SWR	Standing Wave Ratio
VSWR	Voltage Standing Wave Ratio
VP	Vertical polarization
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless local Area Networks
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation

Chapter One

1.1 Introduction

In recent years, 5G technology has been extensively studied in the academic world. 5G NR (5G New Radio) standard for 5G networks are set of frequency bands at sub-6 GHz range and millimeter waves of the RF spectrum. As today's mobile phones have become an indispensable part of human life, the rise of wearable devices and the use of the Internet of Things, the use of smart devices will only increase in the future and can be greatly improved through 5G technology. At present, 3GPP and the major communication companies in the world have completed preliminary measurement of several major 5G communication frequency bands and announced the technical report on the millimeter wave channel model in early 2016. Durga Malladi, vice president of engineering at Qualcomm Technology, pointed out that high speed is the main feature of 5G networks, and the data rate is likely to reach 5-10Gbit/s [1].

Although the frequency band of 5G can provide a considerable available bandwidth, there are also inevitable problems, such as the problem of high path loss and high transmission loss in outdoor communication [2]. Communications in 5G networks are expected to operate over shorter distances and in crowded urban environments [3]. Since the height of the 5G base station transmitter could be much lower than that of traditional base stations (BS), humans surrounding the receiver can act as blockers to signal propagation. Rapidly fading channels caused by pedestrians in dense urban environments will have a significant impact on 5G communications systems [5]. Furthermore, human presence between the transmitter and the receiver severely attenuates the received signal. The human body can reduce the signal strength by the order of 20 dB [1], [6].

With the rise of fifth-generation (5G) omnidirectional circular polarized(OCP) antenna have received much attention in wireless communications. Circularly polarized omnidirectional antennas have been studied for communication applications for many years. Omnidirectional linearly polarized (LP) antennas have been widely used in base stations of mobile communications because they can reduce the number of cell sectors and the effects of small sector variations. Circularly polarized (CP) antennas have an advantage over traditional LP antennas in that CP antennas can enhance the stability of signal reception by receiving arbitrarily LP signals [9]. The use of circular polarization can also suppress the effect of polarization mismatch losses and multi-path reflection of waves caused by building walls and the ground surface [8], [10]. Data transmissions with CP antennas are independent of the orientation of the transmitter and the receiver [11]. The study in [24], is well known that a circularly polarized (CP) signal can be received by both circularly and linearly polarized antennas with some degradation (3dB loss), that leads to CP antennas becoming more and more popular in communication systems.

At present, the development of 5G systems by various companies has continued to evolve below 6 GHz in addition to the development of high frequency bands of 28 GHz and 38 GHz. In addition, although the millimeter wave provides a considerable available bandwidth, due to the small coverage, NTT DOCOMO (Japan Telecom) proposes a high-frequency, low-frequency parallel system to overcome the coverage problem.

This thesis focuses on the study of omnidirectional circular polarization applied to small base stations. In this thesis, it has considered the implementation of an omnidirectional circularly polarized antenna with two simple antenna structures in sub-6 GHz band of the fifth-generation communication, and then designed the same structure in the 28 GHz millimeter wave band. Finally, compare the simulation results of the two antennas with other papers.

1.2 Statement of the Problem

An important feature of the higher frequencies used by 5G technologies is that they do not travel as far from the source (they become weaker much more rapidly) than the lower frequencies currently used. One drawback of 5G technology is that it is more prone to interference comparing to 4G signals as they pass through physical objects. To overcome this problem 5G infrastructure uses much smaller base stations instead of using the large cellular antenna that we use in 4G.

Multiple small cells can be used to give large coverage in the same area. Small cells have a coverage range of 50–200 meters and it can be installed inside residential and office buildings, and their antennas are never longer than 1.2 meters. They are smaller than macrocell base stations and have a lower power output. Small cells are a key feature of 5G [10]. Because of their limited propagation, these high bands will mainly be used to build out dense small cell networks in outdoors or indoors.

At present, the Omnidirectional circularly polarized (OCP) antenna is very attractive in small cell antennas since the Omni directionality and the CP property of an antenna highly increased the signal coverage area, reduce the sector antenna and also improve immunity to multi-path distortion and polarization mismatch losses. Due to these advantages various methodology was used by researchers to design omnidirectional circularly polarized (CP) antenna for 5G communications. But getting a good omnidirectional axial ratio, gain, radiation efficiency, small electrical size of the antenna and low reflection coefficient are still the major challenges.

So in this thesis, an omnidirectional circularly polarized antenna for small cells is designed by combining dipole antenna and MNG-TL orthogonally to improve gain and finally, it will be compared and discussed the simulation of this thesis design with other studies.

1.3 Objective of the Thesis

This thesis is focused to achieve the following general and specific objectives

1.3.1 General Objective

The general objective of this thesis is to design an improved performance of omnidirectional circular polarized antenna for future 5G antenna communication.

1.3.2 Specific Objective

- ✓ Design omnidirectional circular polarized antenna operating at 6 GHz and 28 GHz for 5G coverage.
- ✓ Analyze the performance parameters of the improved antenna design simulations.
- ✓ Compare and contrast the improved simulation results with existing omnidirectional circular polarized antenna.
- ✓ Validate the results of the simulations of the improved antenna design.

1.4 Scope and Limitation of the Study

1.4.1 Scope of the Study

The thesis starts with designing the omnidirectional circular polarized antenna. Then, the omnidirectional circular polarized antenna is simulated using HFSS. After that the gain of the simulation value of the omnidirectional circular polarized antenna is compared with the simulated value of other related papers.

1.4.2 Limitation of the Study

In this thesis comparing the simulated value of gain of the new designed omnidirectional circular polarized antenna are the scope. The designed antenna is not fabricated because it is not possible here in Ethiopia and it is too costy to send to other countries for fabrication. As a result, this work did not compare the measured value of gain, only compared its simulated value.

1.5 Literature Review

So far many researches have been conducted on different aspects on 5G antenna design. A short literature survey of some of selected papers are presented here.

Sun, Kai, Lin Peng, and Xing Jiang. [2017], in this paper three novel compact omnidirectional circularly polarized antennas operating from 24.25 GHz to 27.5 GHz which is good candidature for 5G was designed [4]. In order to fulfill 5G wireless communication system, antenna miniaturization is required. So this paper works on three zero order resonant antenna which can realize miniaturization and performance of the circular polarization. The three antennas are designed using MZR-EZR resonators. The performance in terms of reflection coefficient, gain and radiation pattern are compared and discussed. The three antennas are well satisfied with properties of circular polarization and omnidirectional radiation. However, gain is low, it needs more to improve, though it is still good potential for wireless communication.

J. M. Fernández, J. L. Masa-Campos, and M. Sierra-Pérez [2007], this paper aim is to design Broadband Omni-directional Circularly Polarized Antenna based on Vertically and Horizontally Polarized Elements [12]. It shows good omnidirectional property in azimuth direction. But it has low radiation efficiency 72%.

Yu, Ang, Fan Yang, and Atef Z. Elsherbeni. [2008], in this paper Composite Right/Left-Handed(CRLH) Transmission Line Based Compact Resonant Antennas which is composed of dual feed and 90° phase shifter have been published [13]. A circularly polarized antenna based on the concept of CRLH transmission line has been realized. However, these metamaterial antennas have directional radiation patterns and also have low gain 0.3dB.

W.-W. Li and K.-W. Leung, [2013], the design in this paper has inclined slots etched on a circular waveguide to realize the OCP radiation [14]. However, its size is very large; and its fabrication is not cost effective. This design is also not suitable for embedding into small portable devices such as smart phones, watches, and glasses.

Lin, Wei, Richard W. Ziolkowski, and Thomas C. Baum. [2017], in this paper 28 GHz Compact Omnidirectional Circularly Polarized Antenna for Device-to-Device Communications in the Future 5G Systems is designed [15]. An omnidirectional circularly polarized (OCP) antenna operating at 28 GHz is designed. But dimensions of the antenna become very small (the wavelength being small), which results in complexity of fabrication.

Verma, P. K., Singh, M., & Kumar, R. (2014), the design in this paper consists of an LP omnidirectional monopole radiator and a surrounding sleeve polarizer which transforms the radiated LP wave into a CP wave [16]. The developed antenna has excellent omnidirectional coverage over the desired frequency band. However, its size is very large both electrically and physically. In addition, these designs are not suitable for embedding into small portable devices such as smart phones, watches, and glasses.

Y. Fan, X.-L. Quan, Y. Pan, Y.-H. Cui and R.-L. Li, [2015], in this paper Wideband Omnidirectional Circularly Polarized Antenna Based on Tilted Dipoles is designed [17]. But it adopts the three-dimensional structure design, which hinders the difficulty of the implementation.

Sakaguchi, K. [1995], in this paper, a circularly polarized omnidirectional small helical antenna consisting of n-pairs of tilted half wavelength dipole antennas wound helically in the same direction was proposed [18]. The antenna has a simple structure and it has no feeding network such as a 90 degrees’ phase shifters or a split-sheath balun and a quarter wavelength transformer. The antenna proposed here is available for fixed and mobile stations, such as base, ground, satellite, airplane, ship and car stations. However, these antennas must be placed vertically and they are not suitable for low-profile applications and also it has narrow bandwidth.

Y. Yu, Z. Shen and S. He [2012], in [19], four bended monopoles with a power dividing feeding network structure is designed. The vertical part and the horizontal part together would produce a vertical polarized and a horizontal polarized with a 90 phase difference at the azimuth plane. A good CP characteristic could be satisfied by adjusting the length of the vertical dipole and the horizontal dipole. An identical bandwidth of 3.56% ($|S11|$<-10dB and AR<3dB) was realized in this structure. However, the bandwidth of this structure was still narrow in the application of wireless communication system which makes to reduce its radiation efficiency.

Ma, Y., Li, J., & Xu, R. (2017), in this paper, a novel omnidirectional CP antenna is developed at the operating frequency 1.7GHz, 1.95GHz and 2.2GHz [20]. This omnidirectional CP antenna consists of a top loaded monopole with four shorting pins and four arc dipoles which printed on a substrate. Each arc dipole is coupled with a power divided feeding network. This antenna has a wide bandwidth. However, it has low gain which is 0.35dB, -0.63dB, -1.45dB respectively for each operating frequency.

Rajmohan, I. J., Nasimuddin, & Alphones, A. (2013), in this paper, a low-profile, Omni-directional, circularly polarized, micro strip antenna is proposed and studied using dual-patch radiators [21]. Omni directional right handed circularly polarization (RHCP) is obtained using back to back patches antenna configuration. The design has the advantages of low-profile and simple structure. But the CP performance in the plane parallel to the patches is poor and have a narrow bandwidth which limits their practical applications.

Li, B., & Xue, Q. (2013), in this paper, omnidirectional circular polarized antenna is developed by combining a dipole and loop radiators [22]. The far fields of a short dipole and a small loop excited by the same current are orthogonal to each other and 90 different in phase, the omnidirectional circularly polarized (CP) radiation can be achieved. However, the RHCP and LHCP gains are 0.05 and 0.15 dB, respectively, in the azimuthal plane which is low that reduces the antenna performance.

Xue-Xia Yang, Bing-Cheng Shao, Fan Yang, Elsherbeni, A. Z., & Bo Gong. (2012), in this paper, a novel reconfigurable patch antenna with polarization agility is designed [23]. However, these antennas are not omnidirectional.

1.6 Contribution of the Study

The focuses of this thesis is designing of an omnidirectional circularly polarized antenna applied for fifth-generation communication. So, the main contributions of this thesis is combining the widely used dipole antenna with the completely different structure of the negative magnetic permeability zero-order transmission line antenna at 90 degree phase difference to have omnidirectional circularly polarized antenna . Since, the two antennas have the same radiation field an omnidirectional circularly polarized antenna that can be applied to future 5G small base stations is generated.

1.7 Methodology

The formal methodologies used to achieve the objectives of this thesis work are:

Literature review: includes reading books, articles, simulation tools and other resources related Antenna types, omnidirectional circularly polarized antenna and other related papers in detail.

System design: includes design of dipole antenna, negative magnetic permeability antenna, feeding techniques and finally omnidirectional circular polarized antenna for 5G to enable reliable communication.

Simulation: Simulating the modeled system with the assumed parameters using HFSS

Performance Evaluation: Comparing the system performance of this thesis with other researches

Analysis and Interpretation of the results: Analyzing the performance improvements attained by the omnidirectional circular polarized antenna for 5G.

Result and conclusion: the results obtained from the implemented system is studied.

Recommendation: at the end a recommendation for the feature research work is given.

1.8 Thesis Organization

This thesis is divided into different topics and presented in six chapters, they are stated as follows.

Chapter one contains, brief introduction, statement of the problem, the scope with special emphasis on the objectives of proposed study and methodology. Chapter two contains, literature review on the theoretical background of the antenna. The chapter looks at the basic antenna parameters, antenna types, metamaterials as antenna evolution of mobile wireless technology and omnidirectional circular polarized antennas. Chapter Three describes the design part. In the fourth Chapter the result and discussion part is presented. Finally, Chapter Five Conclusion and recommendation for future work are presented.

Chapter Two

Theoretical Background of Antenna

2.1 Introduction

An antenna is a device that is used to convert guided electromagnetic waves into electrical signals and vice versa. Antennas are frequency dependent devices. Each antenna is designed for a certain frequency band and outside of this band, antenna rejects the signal [25], [26] ,[30].

Electromagnetic waves are regularly referred to as radio waves. Most antennas are resonant devices, which work proficiently over a relatively narrow frequency band. An antenna must be tuned (matched) to the same frequency band as the radio system to which it is connected, otherwise reception and/or transmission will be impaired [26].

Components of wave

- ✓ Amplitude: Amplitude is the distance from the reference line to the highest point (crest) or lowest point (trough) on the wave. Amplitude is directly related to the amount of energy in the wave.
- ✓ Power: The amount of power in the wave is the amount of energy contained under each pulse.
- ✓ Wavelength: Wavelength is the distance between from crest to crest or trough to trough.

$$\lambda = c/f \quad (2.1)$$

  where λ denotes wavelength, f is the frequency and c represents for speed of light.
- ✓ Frequency: The frequency of the wave is the number of complete cycles that pass a set point in 1 second.

Impedance matching

For efficient transfer of energy, the impedance of the receiver/transmitter system, the antenna and the transmission line connecting the radio to the antenna must be the same [26].

Decibel

Decibels (dB) are the accepted method of describing a gain or loss relationship in a communication system. A decibel relationship for power is calculated using the following formula [26].

$$dB = 10log\frac{Power\ A}{Power\ B} \qquad (2.2)$$

2.2 Basic Antenna Parameters

In order to describe the performance of an antenna, definitions of various parameters are necessary. Some of the parameters are defined as below.

2.2.1 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as a graphical representation of radiation properties of an antenna. In most cases, the radiation pattern is determined in the far field region. Radiation properties includes power flux density, radiation intensity, field strength, directivity, phase or polarization. It can be field patterns (magnitude of the electric or magnetic field) or power patterns (square of the magnitude of the electric or magnetic field) [30].

A. Isotropic Antenna

An isotropic antenna is a hypothetical lossless antenna Radiates power equally in all directions in space co-ordinate system. True isotropic radiation does not exist in practice.

B. Directional Antenna

Directional antenna is an antenna which receives or radiates electromagnetic waves more effectively in specific directions than in other directions allowing increased performance and reduced interference from unwanted sources.

C. **Omnidirectional Antenna**

This type of antenna radiates or receives electromagnetic waves equally across the azimuthal angle but varies with respect to elevation angle and goes to minimum at 90 degrees from the azimuth angle. This type of antenna is non-directional in horizontal plane and directional in the vertical plane. Omnidirectional antenna is a special kind of directional antenna capable of radiating uniformly in azimuthal pane and having non uniform direction in elevation plane**.** Dipole antenna is a common examples of omnidirectional antenna [5].

2.2.2 Radiation Power Density

Electromagnetic waves are used to transport information from one place to another place through a wireless medium or guided structures. Power and Energy are associated with electromagnetic field. Instantaneous Poyning vector(W) is a vector representing the density and the direction of the EM power flow [30].

$$W=ExH \tag{2.3}$$

Where W = instantaneous poynting vector

E = instantaneous electric field intensity

H = instantaneous magnetic field intensity

Then, the total power crossing a closed surface can be obtained by integrating the normal component of poynting vector over the entire surface.

$$\mathrm{Prad} = \oiint \mathrm{Wrad} \cdot \mathrm{ds} \tag{2.4}$$

2.2.3 Radiation Intensity

Radiation intensity (U) is the power radiated from an antenna per unit solid angle.

It is far field parameter [29].

$$U=r^2 Prad \tag{2.5}$$

Where U= radiation intensity

Prad= Average power radiated by an antenna(watts/m^2)

$$U= \frac{r^2|E^2|}{2\mu}$$

Where μ =Permeability

Radiation intensity indicates the energy of an antenna.

2.2.4 Standing Wave Ratio

It is a measure of how well the antenna terminal impedance is matched to the characteristic impedance of the transmission line. Specifically, the SWR is the ratio of the maximum amplitude of radio-frequency (RF) to the minimum amplitude of RF along the transmission line. This is also known as the voltage standing-wave ratio (VSWR). The SWR can also be defined as the ratio of the maximum RF current to the minimum RF current on the line (current standing-wave ratio or ISWR). For most practical purposes, ISWR is the same as VSWR.

If the antenna terminal impedance exhibits no reactive (imaginary) part and the resistive(real) part is equal to the characteristic impedance of the transmission line, then the antenna and transmission line are said to be matched. It indicates that none of the RF signal sent to the antenna will be reflected at its terminals. There is no standing wave on the transmission line and the VSWR has a value of one. However, if the antenna and transmission line are not matched, then some fraction of the RF signal sent to the antenna is reflected back along the transmission line. This causes a standing wave to exist on the line. In this case, the VSWR has a value greater than one. The VSWR is easily measured with a device and VSWR of 1.5 is considered excellent, while values of 1.5 to 2.0 is considered good, and values higher than 2.0 may be unacceptable.

SWR is determined as follows [29]

$$\mathrm{SWR} = \frac{(\text{maximum voltage or current})}{\text{minimum voltage or current}} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.6}$$

Where SWR=Standing Wave Ratio

Γ=Reflection coefficient

$$\text{And } \Gamma = \frac{z_L - z_0}{z_L + z_0} \tag{2.7}$$

Where z_L=Load impedance

z_0= Characteristic impedance

2.2.5 Bandwidth

Bandwidth of an antenna is defined as the range of frequency within which the performance of the antenna with respect to some characteristic conforms to a specified standard. In other words, characteristics of antenna (gain, radiation pattern, terminal impedance) have acceptable values within the band width limits. For most antennas, gain and radiation pattern do not change as rapidly with frequency as the terminal impedance does. Since the transmission line characteristic impedance hardly changes with frequency, VSWR is a useful, practical way to describe the effects of terminal impedance and to specify an antenna's bandwidth. For broadband antennas, bandwidth is usually expressed as the ratio of the upper to lower frequencies of acceptable operation. However, for narrow band antennas, the bandwidth is expressed as a percentage of the bandwidth.

2.2.6 Return Loss

In telecommunications, return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. The return loss is related to both standing wave ratio(VSWR) and reflection coefficient(Γ). The increase of return loss corresponds to lower VSWR. In another word, return loss is the measurement of how well devices or lines are matched and a match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Using return loss, we can provide the best and most convenient method to calculate the input and output of the signal sources. The Return Loss in dB is determined as follows [30]:

$$RL(dB) = -20\log|\Gamma \tag{2.8}$$

Or $RL(dB) = -20\log|S11|$

$$\text{Where } \Gamma = \frac{v_0^-}{v_0^+} = \frac{z_L - z_0}{z_L + z_0}$$

Here, S11 S-parameters, Γ reflection coefficient, v_0^- reflected wave, v_0^+ incident wave, Z_L and Z_0 are the load and characteristic impedance.

2.2.7 S-Parameters

The S-parameters are very important in microwave design for describing the behavior of electrical devices. Most of the electrical properties i.e. gain, return loss, power, VSWR etc. relates to the S parameters. The S-parameters can be observed by sending a signal through an input port and observing the response on an output port. The term impedance is of great importance while calculating the S-parameters because the system should be matched properly, otherwise reflection which will give rise to standing waves and the system will not produce the desired output. The S-parameters S_{11} and S_{22} represent input and output reflection while S_{21} is the forward transmission coefficient (gain)and S_{12} are the reverse transmission coefficient(isolation) [31].

2.2.8 Directivity

Directivity in a given direction is the ratio of the radiation intensity (U) in this direction and the radiation intensity averaged over all directions. The radiation intensity averaged over all directions is equal to the total power radiated by the antenna divided by 4π. If a direction is not specified, then the direction of maximum radiation is implied.

It can be also defined as the ratio of the radiation intensity of the antenna in a given direction and the radiation intensity of an isotropic radiator fed by the same amount of power. It is determined as [30].

$$D(\theta,\varphi)=\frac{U(\theta,\varphi)}{\mathrm{Uavg}}=\frac{4\pi U(\theta,\varphi)}{Prad} \tag{2.9}$$

Where $U(\theta,\varphi)$= radiation intensity of the antenna in a given direction

Uavg= radiation intensity of an isotropic

Prad= radiated power

The directivity is a dimensionless quantity. The maximum directivity is always ≥1.

2.2.9 Gain

Gain of an antenna is the ratio of the radiation intensity U in a given direction and the radiation intensity that would be obtained, if the power fed to the antenna were radiated isotropically. It is determined as [30].

$$G(\theta, \varphi) = 4л \frac{U(\theta,\varphi)}{Pin} \tag{2.10}$$

Where $G(\theta, \varphi)$=Gain of an antenna

Pin= input power

The gain is a dimensionless quantity, which is very similar to the directivity D. When the antenna has no loss Pin=Prad then $G(\theta, \varphi) = D(\theta, \varphi)$. Thus, the gain of the antenna takes into account the losses in the antenna system. It is calculated via the input power Pin, which is a measurable quantity, unlike the directivity, which is calculated via the radiated power Prad.

There are many factors which can reduce the transfer of energy from the transmitter to the antenna or from the antenna to the receiver:

- ✓ Mismatch losses
- ✓ Losses in the transmission line
- ✓ Losses in the antenna: dielectric losses, conduction losses, polarization losses

The power radiated by the antenna is always less than the power fed to the antenna system that is Prad<Pin and that is the reason why G<D.

According to IEEE Standards, the gain does not include losses arising from impedance mismatch and from polarization mismatch [30].

The radiated power is related to the input power through a coefficient called the radiation efficiency [30].

$$\mathrm{p_{rad}} = e.\mathrm{p_{in}}, \quad e \leq 1 \tag{2.11}$$

$$G(\theta, \varphi) = e.D(\theta, \varphi) \tag{2.12}$$

2.2.10 Antenna Radiation Efficiency

The total efficiency of the antenna e_t is used to estimate the total loss of energy at the input terminals of the antenna and within the antenna structure. It includes all mismatch losses, polarization mismatch and the dielectric/conduction losses (radiation efficiency, e). Whereas radiation efficiency only considered the dielectric and conductor losses. Radiation efficiency is determined as [32].

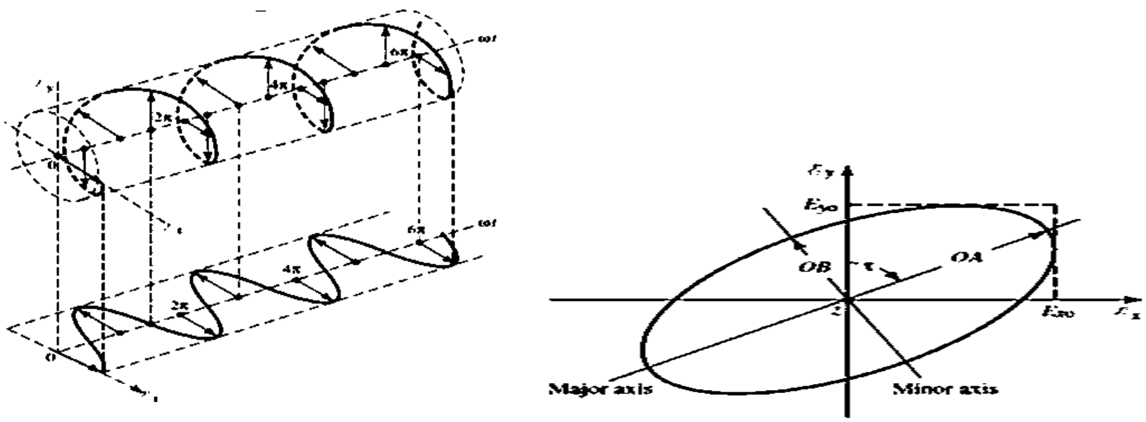
$$\mathrm{e} = \mathrm{Prad}/\mathrm{Prec} \tag{2.13}$$

where: Prad=Power radiated by the antenna and Prec=Power accepted by the antenna.

2.2.11 Polarization of Antenna

Polarization is defined as the orientation of the electric field of an electromagnetic wave with respect to earth. And the electric field is perpendicular to the direction of magnetic field and propagating wave. Polarization is a function of time, direction and magnitude. Antenna Polarization is a very important parameter when choosing and installing an antenna. Most communications systems use either vertical, horizontal or circular polarization. Knowing the difference between polarizations and how to maximize their benefit is very important to the antenna user.

Figure 2-1 shows trace of EMW as the function of time. At any point in radiation sphere of a far field the wave is to be characterized by plane wave whose strength of electric field is same like radiated wave and propagation direction is radial out ward from antenna.



(a) (b)

Figure 2-1: (a) Rotation of wave (b) polarization ellipse [30] [32]

As the distance from antenna increases up to infinity, radius of radiation sphere also increases to infinity and strength decreases. Polarization is the combination of two orthogonal polarizations which are co-polarization and cross polarization. Co-polarization characterizes the polarization of wave the antenna wants to radiate, whereas cross- polarization is the polarization orthogonal to radiated polarization and it is an unwanted component.

Polarization of radiated wave can be classified as Linear, Circular and Elliptical Polarization.

A. Linear polarization

A plane wave is linearly polarized if there is no phase difference between Ex and Ey and linear polarization can be vertically polarized or horizontally polarized but not both. Orientation of a linearly polarized electromagnetic wave is defined by the direction of electric field vector.

Figure 2-2 shows linearly polarized curve, a linear polarized antenna radiates wholly in one plane containing the direction of propagation. An antenna is said to be vertically polarized when its electric field is perpendicular to the Earth’s surface and also the radiation is said to be horizontally polarized when its electric field is parallel to the Earth’s surface.

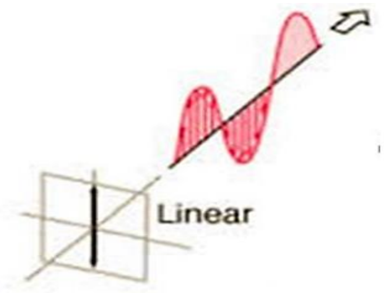


Figure 2-2: linearly polarized curve [32]

In linear polarized wave, two planar components of electric field component of equal or unequal amplitude are in phase.

$$\Delta\phi = \phi y - \phi_x = n\pi,\ n=0,1,2\ldots\ldots \quad (2.14)$$

Where ϕy and ϕ_x are phase angle of electric field in y and x direction and $\Delta\phi$ is the phase difference between x and y component.

In case of linear polarization, if the electric field of radiated wave have only vertical component and there is no any horizontal component i.e. E_{x_o}=0 then polarization is called vertical linear polarization. In this case polarization curve is along y-axis only. Similarly, if there is only horizontal component and there is no any vertical component i.e. $E_{y_o} = 0$, then polarization is called horizontal polarization. In this case polarization curve is along x-axis only.

B. Circular polarization

Circularly polarized wave radiates energy in the horizontal and vertical plane, as well as every plane in between. There are two directions of propagation that come with circular polarization: Right-Hand-Circular (RHC) which follows a clockwise pattern, and Left Hand-Circular (LHC) which follows a counter clock wise pattern. The difference between the maximum and the minimum peaks as the antenna is rotated through all angles is called the axial ratio and is usually specified in decibels (dB). If the axial ratio is near 0 dB, the antenna is said to be circular polarized. If the axial ratio is greater than 1.2 dB, the polarization is often referred to as elliptical.

Circular polarization antennas have several advantages compared to antennas using linear polarizations, and are becoming a key technology for various wireless systems including satellite communications, mobile communications, global navigation satellite systems (GNSS), wireless sensors, radio frequency identification (RFID), wireless power transmission, wireless local area networks (WLAN), wireless personal area networks (WPAN),Worldwide Interoperability for Microwave Access (WiMAX) and Direct Broadcasting Service (DBS) television reception systems [34].

Nowadays circular polarization is very important in the antenna design industry, it gives much more flexibility to the angle between transmitting / receiving antennas, also it enhances weather penetration and mobility [32, 33]. On antenna, for circular polarization to be generated, two modes equal in magnitude and 90 out of phase are required. In circular polarized wave, two planar components of electric field component of equal amplitude are in odd multiple of 90 phase difference, that is E_{x_o}=E_{yO} and

$$\Delta\phi = \phi y - \phi_x = \begin{cases} \left\{+\left(\frac{1}{2}\right)+n\right\}, n = 0,2,3 \dots\dots.. CW \\ \left\{-\left(\frac{1}{2}\right)+n\right\}, n = 0,2,3 \dots\dots CCW \end{cases} \tag{2.15}$$

where, CW is clockwise and CCW is counterclockwise. Figure 2-3 is circular polarization

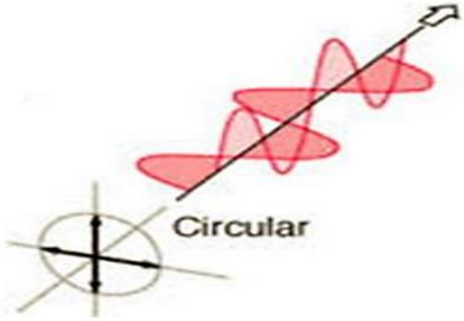


Figure 2-3: circularly polarized curve [32]

A circularly polarized antenna can be classified based on their feeding system into two categories, i.e. single or dual-fed types.

I. Circular polarization Feeding techniques

1. Dual Feed circularly polarized antenna

A 90-degree phase shift between the fields in the antenna is a perquisite for having circular polarization, then dual feed is an easy way to generate circular polarization. With the help of external polarizer, the antenna is fed by equal in magnitude and orthogonal feed. Dual feed can be carried out using ring hybrid, Wilkinson power divider, quadrature hybrid, T-junction power splitter or Two coaxial feeds with physical phase shift 90 degrees [33]. Out of the listed dual fed types Wilkinson power divider is more importantly used for circular polarized antenna that designed using antennas having different structure like in this paper which is designed using dipole antenna and the negative-conductivity zero-order transmission line. The reason why Wilkinson power divider is used more is, the other types of dual feeding techniques have high loss in which at the end can't be matched.

2. Single Feed circularly polarized antenna

Single fed antennas are simple, easy to manufacture, low cost and compact in structure. The major advantage of single-feed circularly polarized antennas is their simple structure which does not require an external polarizer. Therefore, they can be realized more compactly by using less board space than do dual-feed, circularly polarized antennas. Single fed circularly polarized micro strip antennas are considered to be one of the simplest antennas that can produce circular polarization [35]. In order to achieve circular polarization using only single feed two degenerate modes should be exited with equal amplitude and 90-degree difference. Since basic shapes antenna produce linear polarization there must be some changes in the design to produce circular polarization. However, single feed has narrow band than that of dual feed which is its main disadvantage.

C. Elliptical Polarization

In any given point of radiation sphere, if the electric field component of radiated wave traces an ellipse with advancing of time then the wave is said to be elliptical polarized. Figure 2-5 shows elliptical polarization curve, in elliptical polarized wave, two planar components of electric field component have unequal amplitude and in odd multiple of 90-degree phase difference or when phase difference is not equal to integer multiple of 90 degrees.

$E_{x_0} \neq E_{yO}$ And,

$$\Delta\phi = \phi y - \phi_x = \begin{cases} \left\{+\left(\frac{1}{2}\right)+n\right\}, n = 0,2,3 \ldots \ldots . . CW \\ \left\{-\left(\frac{1}{2}\right)+n\right\}, n = 0,2,3 \ldots \ldots CCW \end{cases} \tag{2.16}$$

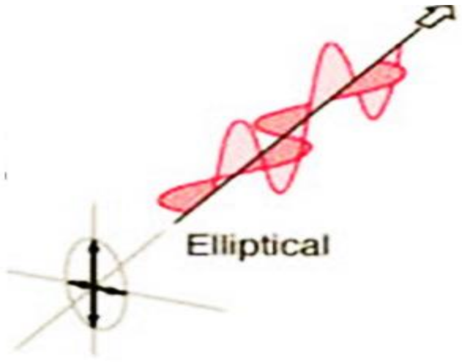


Figure 2-4: Elliptical polarization curve [32]

D. General concept of polarization

Polarization is an important design consideration. The polarization of each antenna in a system should be properly aligned. Maximum signal strength between stations occurs when both stations are using identical polarization. On line-of-sight (LOS) paths, it is most important that the polarization of the antennas at both ends of the path use the same polarization. In a linearly polarized system, a misalignment of polarization of 45 degrees will reduce the signal up to 3dB and if misaligned 90 degrees the attenuation can be 20 dB or more. Likewise, in a circular polarized system, both antennas must have the same sense. If not, an additional loss of 20dB or more will be suffered.

Linearly polarized antennas will work with circularly polarized antennas and vice versa. However, there will be up to a 3 dB loss in signal strength. In weak signal situations, this loss of signal may impair communications. Cross polarization is another consideration. It happens when unwanted radiation is present from a polarization which is different from the polarization in which the antenna was intended to radiate. For example, a vertical antenna may radiate some horizontal polarization and vice versa.

Another point to note is when radio waves strike a smooth reflective surface, they may have 180-degree phase shift, a phenomenon known as mirror image reflection. The reflected signal may then destructively or constructively affect the direct LOS signal. Circular polarization has been used to an advantage in these situations since the reflected wave would have a different sense than the direct wave and block the fading from these reflections.

2.3 Antenna Types

The most common antenna types are the wire antennas, aperture antennas, fractal antenna, microstrip antennas, reflector and array antenna. Some of the common types of antennas will discussed here.

2.3.1 Wire Antenna

Wire antennas are antennas that are constructed with wires. Some of the common wire antennas are dipole antenna, loop antenna, helical antenna, and monopole. The half wave dipole antenna part is the simplest in structure and more efficient than the other types of wire antenna. It is an omnidirectional antenna types [36].

2.3.2 Aperture Antenna

An Antenna with an aperture at the end is called as an aperture antenna. Same examples of aperture antennas are: Wave guide antenna, Horn antenna and slot antenna. Aperture antennas have omnidirectional radiation but they are poor in radiation and have increased VSWR than wire antennas.

2.3.3 Fractal Antenna

According to Webster's Dictionary a fractal is defined as being "derived from the Latin fractus meaning broken, uneven: any of various extremely irregular curves or shape that repeat themselves at any scale on which they are examined." A fractal antenna is an antenna that utilizes a fractal design which is approximately or exactly similar to a component of itself, with an aim to increase the efficacious boundary length or perimeter of the material that can accept as well as channelize electromagnetic radiation within a provided area or volume.

2.3.4 Microstrip Antenna

Microstrip Antenna is also called patch antenna. Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming widely used within the mobile phone. Patch antennas are low cost, have a low profile and are easily fabricated.

2.3.5 Reflector Antenna

High-gain antennas are required for long-distance radio communications. Reflector systems are probably the most widely used high-gain antennas. They can easily achieve gains of above 30 dB for microwave and higher frequencies.

2.3.6 Array Antenna

Radiation patterns of single-element antennas are relatively wide, i.e. they have relatively low directivity (gain). In long distance communications, antennas with high directivity are required. Such antennas are possible to construct by enlarging the dimensions of the radiating aperture. However, this approach may lead to the appearance of multiple side lobes. In addition, the antenna usually large and difficult to fabricate. Multiple number of antennas which is called array antenna is used instead of single antenna.

2.4 Material Classification

Materials can be classified based on their ε and μ in four quadrants. The 1st quadrant is a double positive(DPS) media which is find in conventional materials. Electromagnetic response of conventional materials (naturally occurring materials) are based on their chemical reaction (composition). We have forward wave. In this material both permittivity and permeability are positive. Electric permittivity and magnetic permeability determines the electric and magnetic properties of materials. Both parameter determines material response to electromagnetic radiation. The double positive(DPS) media are also called right handed materials. In such medium, the direction of the Poynting vector (Group velocity) of the wave is the same as phase velocity (wave vector). The group velocity is a velocity at which information can propagate or energy is transported, whereas phase velocity is a velocity at which the direction of wave propagation is determined. It is well known that the response of any material to applied electromagnetic radiation can be characterized by two electromagnetic parameters, magnetic permeability and electric permittivity. These two physical characteristics are combined in a product to define the square of a refractive index, which measures how fast the material transmits light and how light is bent on entering the material, the higher the refractive index, the slower the propagation and the stronger the deflection.

The 2nd quadrant is single negative(SNG) media. They are called Epsilon negative media (ENG) Those materials have negative permittivity (ε) and positive permeability (μ). The 3rd quadrant is double negative materials (DNG). They have negative permittivity (ε) and permeability (μ). They are called left handed materials. In such medium, the direction of the Poynting vector (Group velocity) of the wave is in opposite direction to the phase velocity (wave vector). The 4th quadrant is single negative (SNG) media. They are called Mu negative (MNG) media. They have permeability (μ) and positive permittivity (ε). All the three materials find in quadrant 2nd, 3rd and 4th are called metamaterials.

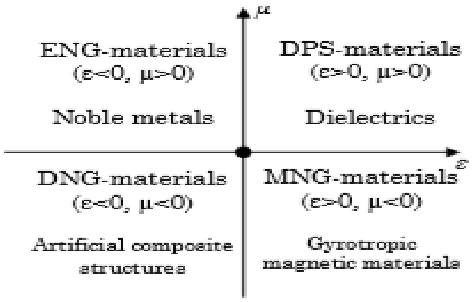


Figure 2-5: General classification of physical materials depending on values of permittivity and permeability [37]

2.4.1 Metamaterials as Antenna

Metamaterials Antennas are the type of antennas which are used to increases the performance of the antenna system and to enhance the radiated power. Metamaterials having negative permeability are mostly used in radiate power enhancement. Metamaterials increases bandwidth by using superstrate of metamaterials over conventional patch antenna.

Metamaterials are artificial materials engineered to provide properties not readily available in nature. These materials usually gain their properties from structures rather than composition. Metamaterials are created because the electromagnetic response of naturally occurring materials is limited. Metamaterials must be dispersive, i.e., their permittivity and permeability must be frequency dependent to achieve negative values of ε and μ [38]. Metamaterial are usually implemented in a periodic structure. Natural materials usually affect electric component refraction in optics, whereas metamaterials can affect the magnetic component. Metamaterials are used to propagate electromagnetic wave to a desired direction. They have negative refractive index(NRI).

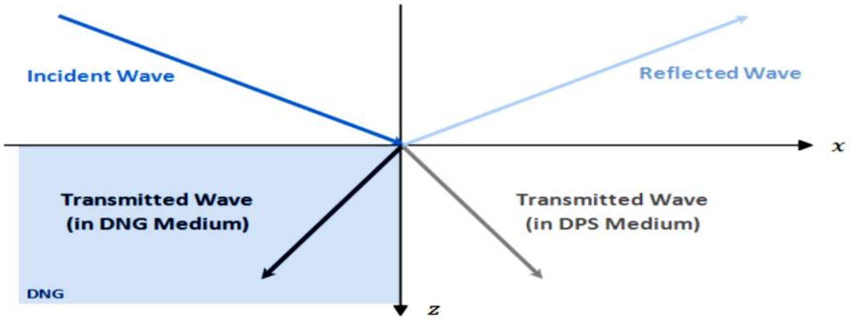


Figure 2-6: refractive index of DPS and DNG materials [39]

Metamaterials affect the electromagnetic waves by having small wavelength than the wavelength of electromagnetic radiation. Double negative (DNG), Epsilon negative media (ENG) and Mu negative (MNG) are types of metamaterials.

A. Double Negative(DNG)

Double negative metamaterials are those metamaterials which have both the negative permittivity and permeability with the negative index of refraction and also known as backward wave media. They are called left handed materials. Left handed materials was first introduced by V. G. Veselago in 1967 for media with a negative refractive index.

B. Epsilon Negative Media (ENG)

The first and the most-known ENG-material for microwave applications are thin metal wires arranged periodically. Propagation of electromagnetic waves in such a structure is similar to propagation in plasma. It has negative permittivity.

C. Mu Negative(MNG)

The first and the most widely-used MNG-structure is split-ring resonator (SRR). The SRRs are characterized as high-conductive resonant structure, in which the capacitance between the two rings balances the inductance. An array of split-ring resonators (SRRs) are arranged periodically. A split ring resonator is constructed by having two concentric metallic rings, with a gap in each ring, and the gaps are 180 degrees apart. The gap between inner and outer ring acts as a capacitor while the rings themselves act as an inductor, which results in an LC resonant circuit.

By loading the host TL with series inductances and shunt capacitances, the propagation constant (β) can be made positive, zero, or even negative. At the ZOR mode propagation constant, is zero, the effective wavelength is infinite and its resonant frequency is independent with the physical dimension.

2.4.2 Advantages and challenges of metamaterials in antenna design

The main advantage of metamaterials in antenna design is to enhance radiation pattern and matching properties of antennas, reduce mutual coupling between antenna elements in array and reduce the antenna size [40 - 41].

The significant challenges researchers have faced in metamaterial antenna designs are high-loss, bandwidth broadening and efficiency improvement. These high losses seriously limit the practicality of metamaterials for many novel applications, which is also a major obstacle in the design of efficient devices. Thus, new materials with relatively low loss are desirable. Therefore, for more efficient antenna design using Mu negative (MNG) types of metamaterials is preferable.

2.5 Evolution of Mobile Wireless Technology from 1G to 5G

Mobile wireless communication has become more popular in last few years due to fast reform from 1G to 5G in mobile technology. Mobile wireless Communication networks have experienced a remarkable change. The mobile wireless Generation (G) generally refers to a change in the nature of the system, frequency, data capacity, speed, technology, latency etc. Each generation have some standards, different capacities, new frequency bands, new techniques and new features which differentiate it from the previous one. In 1980 the mobile cellular era had started, and since then mobile communications have undergone considerable changes and experienced massive growth.

2.5.1 First Generation(1G)

It was analog transmission technology designed to provide basic voice service and was based on technology called as Advanced Mobile Phone System (AMPS). The AMPS system was frequency modulated and used frequency division multiple access (FDMA) with a channel capacity of 30 KHz and frequency band of 824-894MHz. It has poor spectral efficiency and major security issues.

2.5.2 Second Generation (2G)

The second generation (2G) brought a digital technology to a cellular system and also it supports text messaging. It was providing a significantly improved voice quality in the evolution of the cellular networks. It uses more efficient bandwidth/spectrum allocation by way of multiple access schemes such as frequency division multiple access (FDMA), time division multiple access (TDMA) or code division multiple access (CDMA). It also provides secure short message service (SMS) and multimedia messaging service (MMS) services to overcome some of the limitations of 1G. It was based on a technology called Global System for Mobile communications (GSM) to foster connectivity all over the world, a feat that was not achieved by 1G. Practically, the 2G global system for mobile communications (GSM) specification supports cell sizes of up to 35km using macro, micro, pico or femto cells.

2.5.3 Third Generation (3G)

Third generation mobile communication started with the introduction of Universal Mobile Terrestrial / Telecommunication Systems (UMTS) technology. UMTS supports video calling for the first time on mobile devices. After the introduction of 3G smart phones became popular across the globe. Specific applications were developed with smartphones to handle multimedia chat, email, video calling, games, social media and healthcare. The third generation (3G) mobile technology provided increased capacity, higher data rate and provide multimedia support. The challenges of 3G are expensive spectrum licenses, infrastructure cost, higher bandwidth requirement to support higher date rate and compatibility with older generation 2G system and frequency bands.

2.5.4 Fourth Generation (4G)

4G systems are enhanced version of 3G networks which offers higher data rate and capable to handle more advanced multimedia services. LTE and LTE advanced wireless technology are used in 4th generation. The fourth generation (4G) integrates 3G with fixed internet to support wireless mobile internet and it overcome the limitations of 3G. It also increases the bandwidth and reduces the cost of resources. Simultaneous transmission of voice and data is possible with LTE system which improve data rate. All services including voice services can be transmitted over IP packets. Wireless transmission technologies like WiMax are added in 4G system to enhance data rate and network performance.

2.5.5 Fifth Generation (5G)

Fifth Generation (5G) will be using advanced technologies to deliver ultra-fast internet and multimedia. Complex modulation technique has been developed to support high data rate for Internet of Things. The main features of 5G are high throughput, reduced latency, improved spectrum efficiency, better mobility support, and high connection density. It supports interactive multimedia, voice, Internet, video, and other broadband services. The frequency spectrum used in 5G are never used before. If this new range of spectrum will be used the bandwidth will be wide and more number of users will hold. However, there is one main drawback using this spectrum. That is these waves cannot travel through walls or any other obstacles and also these waves are easily observe by weather [42]. So small cell networks solve this problem. Small cell is the way of using thousands of mini base station. Small cell mini base station is closer to each other than traditional tower. So small cell can able to transmit signal around the obstacles. As user moves around the obstacles this device gets automatically switched from one nearest small cell to another nearest small cell [43]. Hence, for these types of technology using omnidirectional circular polarized antenna is preferable to minimize the noise, cost and obstacles.

2.6 Omnidirectional circular polarized antenna

In modern wireless communication circular polarized antennas are widely used because of their strong immunity to polarization mismatch losses and multipath distortion. Omnidirectional antennas are also essential for modern wireless communication systems, in particular for base-station applications for providing a wide coverage and for stability of the signal transmission. As a result of this, various circularly polarized antennas with omnidirectional radiation patterns have been proposed and investigated over the past few years. For a circularly polarized omnidirectional antenna the electric field lies in both the vertical and horizontal planes. Circularly polarized omnidirectional antennas have been widely used in television broadcasts, mobile satellites, space vehicles such as airplanes, missiles, rockets, spacecraft; mobile communication; and WLANs [44]. A circularly polarized radiation can be obtained by generating two orthogonal field components with 90-degree phase difference. Designing a circularly polarized omnidirectional antenna is more complicated than that of the linearly polarized.

Compared to linearly polarized antenna, a circularly polarized antenna have the following advantage [44]:

- ✓ Their ability to establish a reliable signal link regardless of the orientation of the antennas
- ✓ More effective to suppress multipath interferences.
- ✓ More resistant to signal degradation due to weather conditions.
- ✓ The circularly polarized wave is more effective to be propagated through wall and can achieve to better reach throughout the building.

Chapter three

Design of Omnidirectional Circular polarized Antenna

3.1 Introduction

Circularly polarized omnidirectional antennas are used in the modern wireless communication system because they make devices to decrease signal loss. The circularly polarized omnidirectional antennas can receive all wireless signal in equipment with high speed.

Hence, in this thesis an omnidirectional circularly polarized antenna at 6 GHz frequency band of the fifth-generation communication is designed and the design repeated for the 28 GHz millimeter wave band. This omnidirectional circular polarized antenna is designed by combining two antenna structures, dipole antenna and negative magnetic permeability zero-order transmission line (MNG) antenna at 90-degree phase difference and connecting feed system. The feeding techniques used is the dual feed because using this technique will help to have wide bandwidth. Out of the many dual feed techniques Wilkinson power divider is used in this antenna system design because this types of feeding system have low loss at high frequency in which at end can be easily matched. In this thesis first omnidirectional circularly polarized antenna at 6 GHz is designed. Dipole antenna, negative magnetic permeability zero-order transmission line (MNG) antenna and dual feed Wilkinson power divider are designed separately to verify their reflection coefficient and at the end the two antenna are combined orthogonally to be circularly polarized and connect with Wilkinson power divider. Using the same procedures omnidirectional circularly polarized antenna at 28 GHz is designed.

3.2 Design of Omnidirectional Circularly Polarized Antennas in the 6 GHz Band

In this design, the two antennas and feeders are designed separately.

3.2.1 Dipole Antenna Design

The half wave dipole antenna is the simplest in structure, easiest to understand and more efficient than the other types of wire antenna. It is an omnidirectional antenna types.

The design of the dipole antenna is focused on the current path from the feed end to the terminal, which is a quarter wavelength, that is, the energy is strong to weak or weak to strong, so the whole resonant path is half wavelength as shown in Figure 3-1.

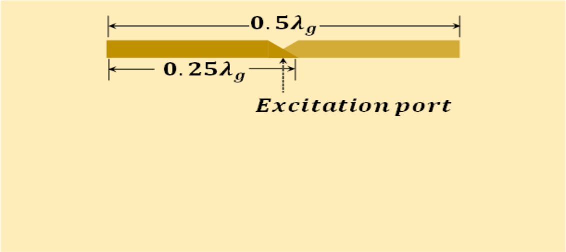


Figure 3-1: Half-wave dipole antenna

I. Design Parameters

To design the half wave dipole antenna, the following relationships are being used to calculate its dimensions at 6 GHz as in [45].

Total length of half-wave dipole antenna, $L = \frac{143}{fr} = 0.475x\lambda g = 23.8mm$ (3.1)

$$W_3 = \frac{L}{2} = \frac{23.8mm}{2} = 11.9mm$$

$$\lambda g = \frac{\text{c}}{\text{fr}} = \frac{3x10^8}{6x10^9} = 50mm \qquad (3.2)$$

Feeding gap of the antenna, $W_5 = \frac{L}{200} = 0.12mm$ (3.4)

Thickness(radius) of the wire, $W_4 = \frac{\lambda g}{1000} = 0.05mm$ (3.5)

Where λg=wavelength

fr = resonant frequency which is 6 GHz

c= speed of light which is 3x10^{8}m/s

The value of W_1 and W_2 are simply selected from the HFSS software. Choosing any values of this parameters have not any effect on the antenna performance.

For the half –wave dipole the far-field radiations are calculated by using the formula as in [27].

$$E_\theta \simeq \boldsymbol{j\eta I_0}\frac{\left(\frac{e^{-jkr}}{2\pi r}\right)[\cos(\pi/2\ cos\theta)]}{sin\theta} \tag{3.6}$$

Similarly,

$$H_{\phi\simeq}\frac{E_\theta}{\boldsymbol{\eta}} = \boldsymbol{jI_0}\frac{\left(\frac{e^{-jkr}}{2\pi r}\right)[\cos(\pi/2cos\theta)]}{sin\theta} \tag{3.7}$$

The time-average Poynting vector becomes

$$Wav = \frac{1}{2\boldsymbol{\eta}}|E_\theta|^2 = \frac{\boldsymbol{\eta I_0}^2}{8\pi^2 r^2}\frac{[\cos(\pi/2\ cos\theta)]^2}{(sin\theta)^2} \simeq \frac{\boldsymbol{\eta I_0}^2}{8\pi^2 r^2}(sin\theta)^3 \tag{3.8}$$

And the radiation intensity becomes

$$U = r^2 Wav = \frac{\boldsymbol{\eta I_0}^2}{8\pi^2}\frac{[\cos(\pi/2\ cos\theta)]^2}{sin\theta} \simeq \frac{\boldsymbol{\eta I_0}^2}{8\pi^2}(sin)^3 \tag{3.9}$$

The total Radiated power is

$$p_{r_{a\,d}} = \int_0^{2\pi}\int_0^{\pi} Wav\ sin\theta\ d_\theta\ d\phi = \int_0^{2\pi}\int_0^{\pi}\frac{\boldsymbol{\eta I_0}^2}{8\pi^2 r^2}\frac{[\cos(\pi/2\ cos\theta)]^2}{(sin\theta)^2} sin\theta\ d_\theta\ d\phi = \frac{\boldsymbol{\eta I_0}^2}{4\pi}\int_0^{\pi}\frac{cos^2(\pi/2\ cos\theta)}{sin\theta}d_\theta = \frac{\boldsymbol{\eta I_0}^2}{8\pi} * (2.435) = 36.56\ \boldsymbol{I_0}^2 \tag{3.10}$$

Then the directivity becomes,

$$D = 4\pi\frac{\left(Umax\middle|\theta = \frac{\pi}{2}\right)}{p_{r_{a\,d}}} = \frac{4}{2.435} = 1.64 \tag{3.11}$$

The radiation resistance for free-space, $\boldsymbol{\eta = 120}\pi$ is given by

$$Rrad = \frac{2p_{r_{a\,d}}}{\boldsymbol{I_0}^2} \simeq \frac{\boldsymbol{\eta}}{4\pi}(\boldsymbol{2.435}) \simeq 73\ ohm \tag{3.12}$$

Gain of dipole antenna

$$G = 4\text{Л}\ \frac{U}{Pin} = e.D = 1.64.e \tag{3.13}$$

Where e is radiation efficiency =Prad/pin

All dimensions of a 6 GHz dipole antenna are given in the Table 3-1.

Table 3-1: Design Parameters of 6 GHz dipole Antenna

Parameters(elements)	**Values(mm)**
W_1	32
W_2	19.5
W_3	11.9
W_4	0.05
W_5	0.12

Based on the given parametric value, a half wave dipole antenna is designed in the full-wave simulation software Ansoft HFSS with a center frequency of 6 GHz. The substrate used in this antenna design is Rogers' RO4003C with a plate thickness of 20 mil, a dielectric constant of 3.55, and a tangent loss of 0.0027. Dielectric constant, thickness, stiffness as well as loss tangent are important factors for substrate selection. The reason for choice of this types of substrates are low surface wave excitation, low moisture absorption, lowest electrical loss, uniform electrical properties over frequency, excellent chemical resistance and relative low cost.

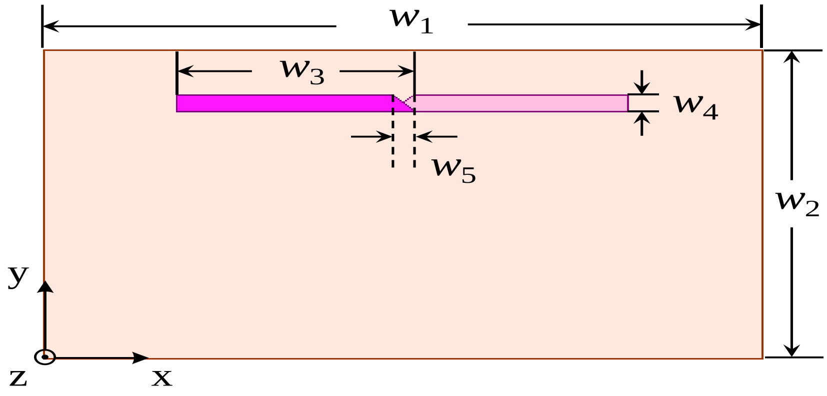


Figure 3-2: Prototype layout of 6 GHz dipole antenna

3.2.2 6 GHz Negative Magnetic Permeability Zero-Order Transmission Line Design

To design an antenna whose polarization direction is perpendicular to the dipole antenna and the radiation field is the same, a loop antenna of a negative magnetic permeability transmission line

(MNG-TL) is used here. Such an antenna can also be called a zero-order transmission line because its current path is in phase & uniform and an omnidirectional radiation pattern can be generated. The design concept is based on a periodic parallel plate structure, as shown in Figure 3-3.

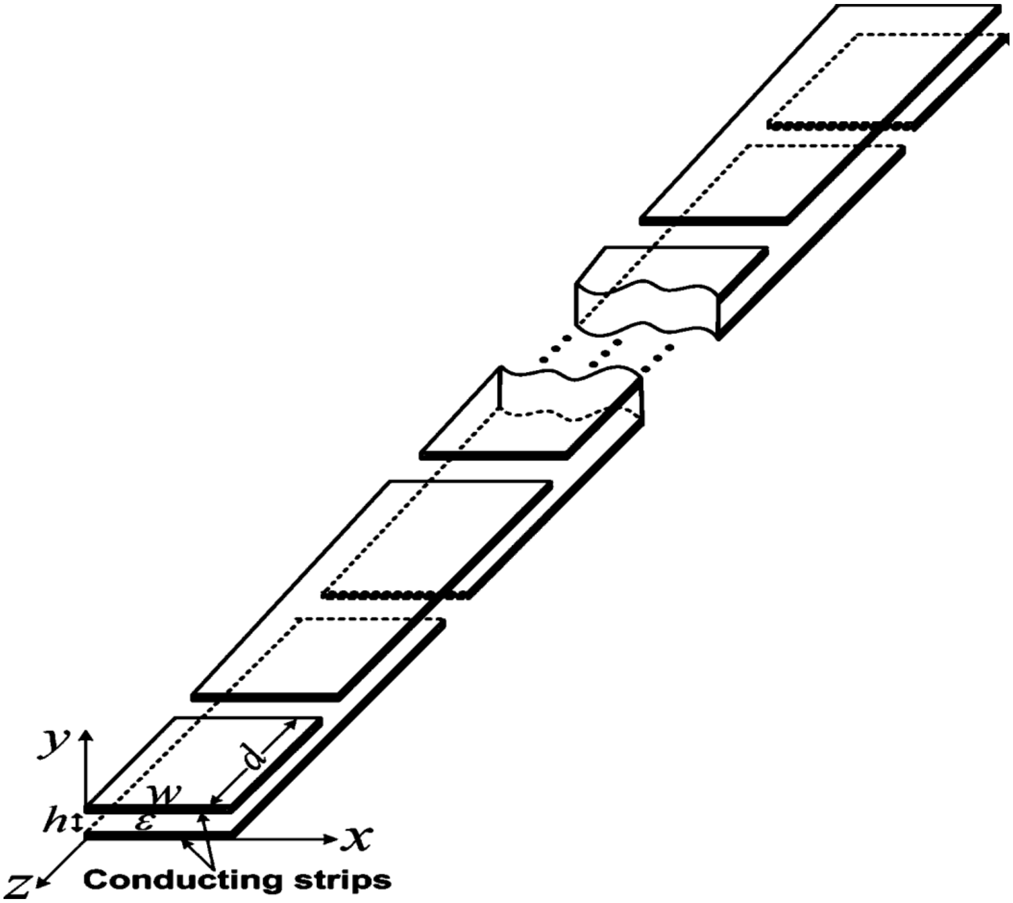


Figure 3-3: Overall configuration of the proposed periodically loaded parallel-plate lines [47].

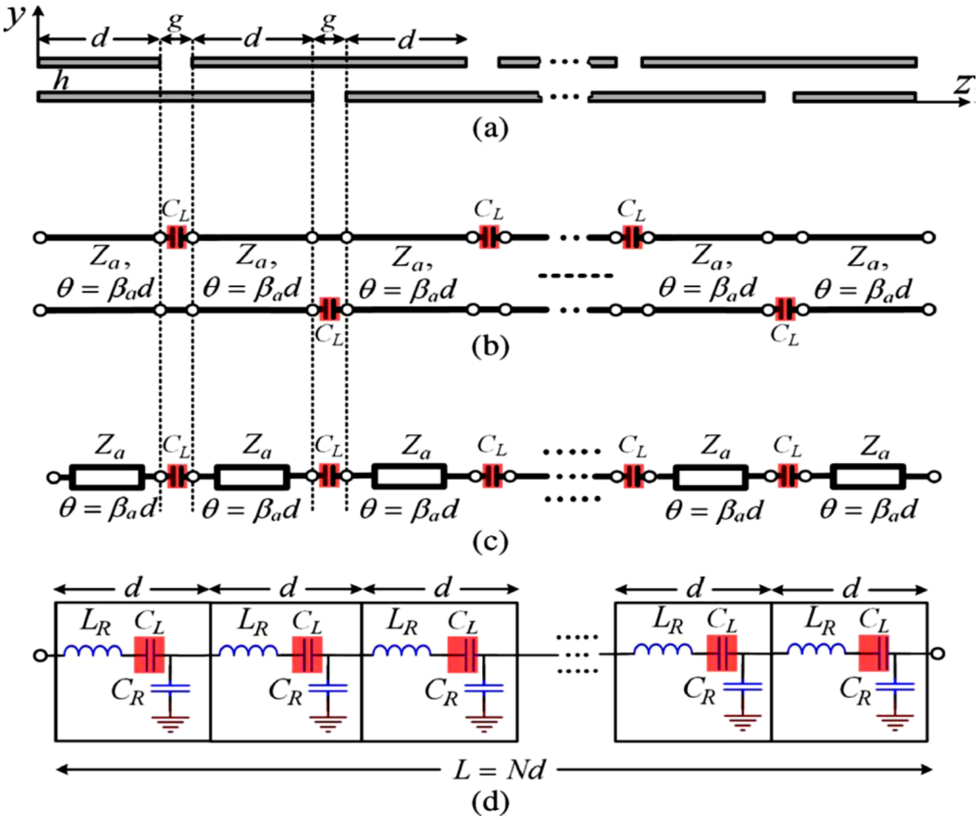


Figure 3-4: Periodic load parallel plate transmission line structure [47] (a) Side view of the proposed periodically loaded parallel-plate lines. (b) Corresponding equivalent circuit model neglecting the radiation resistances. (c) Corresponding equivalent TL circuit model. (d) Corresponding equivalent Lumped-element circuit model.

The parallel-plate line in this structure consists of two parallel conducting strips of width separated by a dielectric material of permittivity and height. As shown in Figure 3.4 (a), the proposed structure is composed of a plurality of the parallel-plate transmission line sections periodically gap loaded with a period of d. All the parallel-plate transmission line sections have the same characteristic impedance z_a and phase constant β_a. To observe the dispersion diagram of the zero-order transmission line the radiation resistances are neglected without affecting the resonance characteristic as shown in Figure 3.4(b). Therefore, the periodically loading series capacitance represents the coupling of the adjacent parallel-plate transmission line sections. The value of the capacitance can be estimated from a full-wave parameter extracting technique.

This model can be further illustrated as a TL circuit model shown in Figure 3.4 (c), which is represented by a plurality of TL sections with series capacitances. In order to examine the resonances of the structure further, it is instructive to replace the TL sections with their equivalent distributed inductance $\mathrm{L_R}$ and capacitance $\mathrm{C_R}$ as shown in Figure 3.4 (d), It can be observed that the equivalent circuit model has no parallel inductance, so the structure is a negative magnetic permeability transmission line (MNG-TL). The MNG-TL supports an infinite wavelength at the zeroth-order resonance ($\beta = 0, \mathrm{w} \neq 0$) where the effective permeability is zero. Assume that Figure 3.4 (a) is a simple TEM line segment, Then according to the literature [47] and through the Laplace's equation, the characteristic impedance is

$$\mathrm{z_a} = \eta * \frac{h}{w} = 377 \frac{\mathrm{h}}{\mathrm{w}\sqrt{\varepsilon}} \tag{3.14}$$

Where w= width of the two parallel conducting strips

ε = dielectric material of permittivity separated the two parallel conducting strips

h= height among the two parallel conducting strips

η= characteristic impedance of free space which is 377 ohms

The equivalent inductance and capacitance per unit length can be expressed as

$$\begin{cases} L'_R = \mu \frac{h}{w} \\ C'_R = \varepsilon \frac{\mathrm{w}}{\mathrm{h}} \end{cases} \tag{3.15}$$

$$\mathrm{L_R} = L'_R d \text{ and } C_R = C'_R d \tag{3.16}$$

Where d= is the periodically loaded gap

The value of periodically loading series Capacitance ($\mathrm{C_L}$) which is the coupling of the adjacent parallel-plate transmission line can be estimated from a full-wave parameter extracting technique. To verify whether the structure is a zero-order transmission line or not, we simulate a periodic load parallel plate transmission line structure of a unit component in the full wave simulation software (HFSS), as shown in Figure 3.5. Through the dispersive map, we can observe the corresponding mode of the structure of the super-material at different frequencies. From Figure 3.6, it is known that it is a structure of a zero-order mode at 6 GHz.

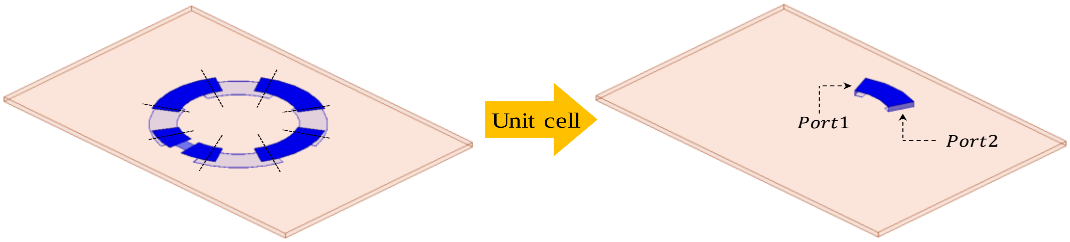


Figure 3-5: Periodic load parallel plate transmission line of unit components

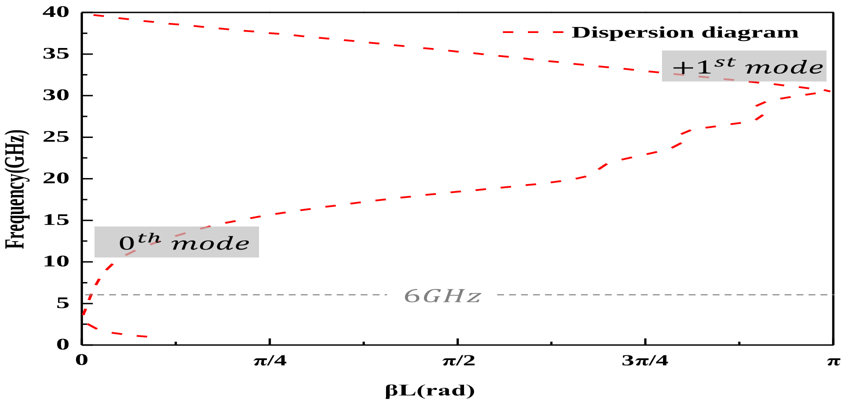


Figure 3-6: Dispersion diagram of 6 GHz unit component periodic load parallel plate transmission line

The unit components are repeatedly connected in series to form a complete loop. The design of the zero-order transmission line focuses on the current path from the feed end to the feed end, which is a phase current loop as shown in Figure 3.7.

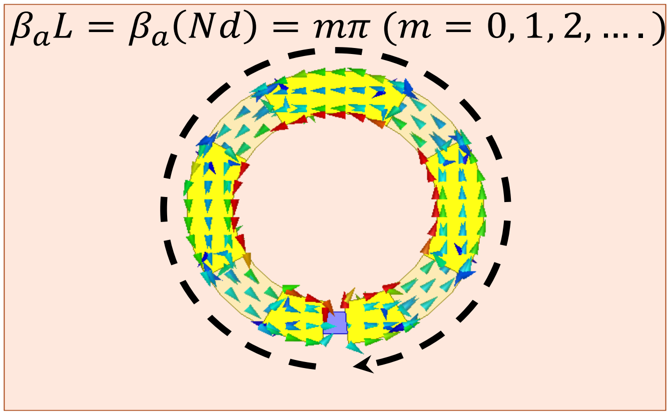


Figure 3-7: Current distribution of negative magnetic permeability zero-order transmission line

Since the structure is composed of a series inductor, a shunt capacitor and a series capacitor, it is a negative magnetic permeability(MNG) transmission line structure, as shown in Figure 3-8.

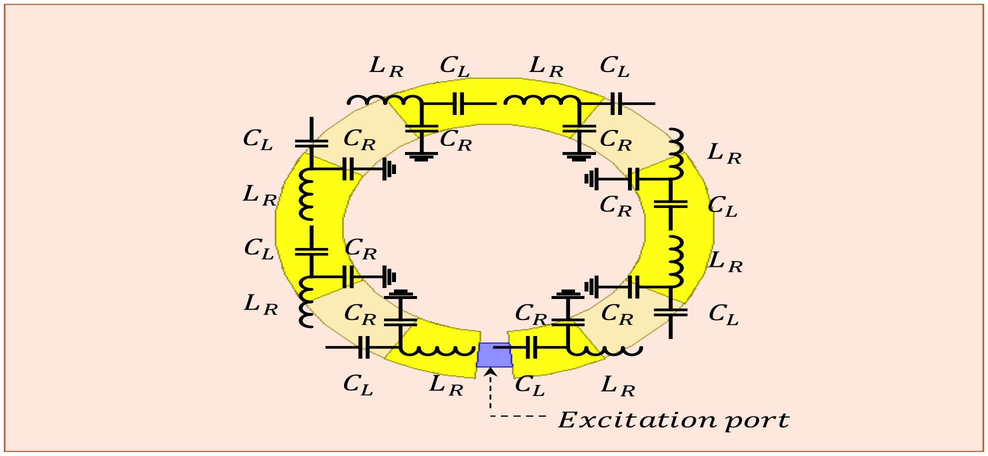


Figure 3-8: Equivalent model of negative permeability zero-order transmission line

The parallel-plate line as shown in Figure 3-3 consists of two parallel conducting strips of width(w) separated by a dielectric material of permittivity(ε)with height(h) and periodically loaded gap(d). The parameter values of w, ε, μ, d and h are chosen carefully from the HFSS software and values of L_R and C_R are obtained from equation (3.15) and (3.16). The value of the periodically loading series capacitance C_L is also obtained from dispersion diagram shown in Figure 3-6. The equivalent inductance and capacitance values are shown in Table 3-2.

Table 3-2 Equivalent inductance and capacitance values of 6 GHz negative permeability zero-order transmission line

Element	Value
L_R	1.36 nH
C_R	0.58 pF
C_L	0.2 pF

An optimized impedance matching can be determined according to the value of the parameters r_1, r_2, W_3,W_4 and W_5. So,the values of the parameters are obtained by carefully tuning on the HFSS software to have a matched impedance and given as shown in Table 3-3.

Table 3-3 Design parameters of 6 GHz negative permeability zero-order transmission lines

Parameters(elements)	**Values(mm)**
W_1	30
W_2	20
W_3	2.93
W_4	5.71
W_5	1.01
r_1	6.75
r_2	4.65

According to the values of the parameters, a negative permeability zero-order transmission line consisting of eight-unit components is designed in the full-wave simulation software Ansoft HFSS. The substrate used was Rogers' RO4003C with a plate thickness of 20 mm, a dielectric constant of 3.55, and a tangent loss of 0.0027, as shown in Figure 3-9.

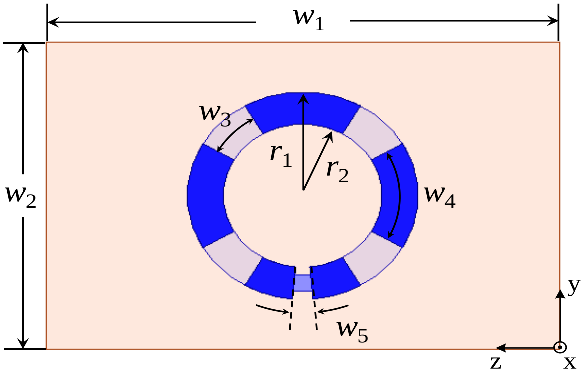


Figure 3-9: Prototype layout of 6 GHz negative permeability zero-order transmission line

3.2.3 Antenna Fed Design

As the main purpose of this thesis is to design omnidirectional circular polarized antenna, dual feed is used to generate circular polarization. Dual feed is working by having a 90-degree phase shift between the fields in the antenna. There are many types of dual feed. In this paper we used Wilkinson power divider types of dual feed which is more importantly used for circular polarized antenna that designed using antennas having different structure like in this paper which is designed using dipole antenna and the negative-conductivity zero-order transmission line because this types of dual feed has low loss and easy to match. And also the other types of feeding suffer from the disadvantage of not being matched at all ports, and it does not have isolation between output ports.

I. 6 GHz Two-Layer Parallel Strip Line Wilkinson Power Splitter Design

Since, in this thesis dipole antenna and negative permeability zero-order transmission line are both non-coplanar, a two-layer parallel strip line form which is called Wilkinson power splitter circuit which splits power equally as shown in Figure 3-10 is designed.

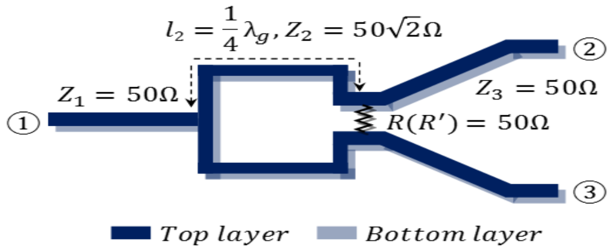


Figure 3-10: two-layer parallel strip line form (DSPSL) Wilkinson power splitter circuit [46]

The purpose of the Wilkinson Power Divider is to split the input power equally between two output ports, ideally without loss. It can also be used in the reverse direction as a power combiner. The properties of the Wilkinson power divider are that all ports are matched, the two output terminals are isolated from one another. Three port networks cannot be reciprocal and matched without being lossy [48]. The solution to this in the Wilkinson Power Divider is to add a resistor between the two outputs. This resistor absorbs energy if there is a mismatch between the outputs and it also helps isolating the two outputs when the circuit functions as a power combiner.

If the power ratio between ports 2 and 3 is $K2 = \frac{P3}{P2}$, then the following equations apply [46]:

$$z_2 = z_0\sqrt{\frac{1+k^2}{k^3}} \tag{3.17}$$

For equal power split K =1, then the above equation reduces to.

$$z_2 = z_0\sqrt{\frac{1+k^2}{k^3}} = z_0\sqrt{2} \tag{3.18}$$

Considering the need to combine the dipole antennas with zero-order transmission line of negative permeability, z_3 needs to be a 50-ohm transmission line due to space constraints. If z_3 is a line segment with an integral length of 180 degrees, the impedance can be any value, meaning that the part of z_3 can be a transmission line that is thinner than 50 ohms. Figure 3-11 is the layout in the full-wave simulation software (Ansoft HFSS), the dimensions of which are shown in Table 3-4.

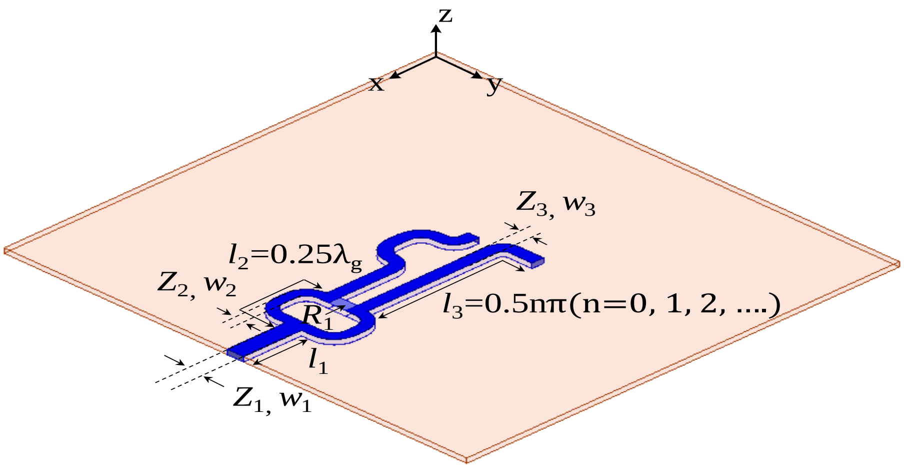


Figure 3-11: Prototype layout of the Wilkinson power splitter

Table 3-4 Design parameters of 6 GHz Wilkinson power splitter

Element	Value(mm)	Element	Value(Ω)
W_1	1.43	z_1	50
W_2	0.88	z_2	70.7
W_3	1	R_1	50
l_1	5		
l_2	7.07		
l_3	15.7		

3.2.4 Overall Structure of 6 GHz Omnidirectional Circular Polarized Antenna

The focus of this study is to design an antenna with an omnidirectional radiation field type and a circular polarization characteristic. So in this thesis an omnidirectional circular polarized antenna by doing a 90-degree combination in the physical space and connecting the two antennas with a two-parallel strip of Wilkinson splitter is designed. The over structure designed is shown in Figure 3.12 and the overall architecture dimensions are shown in Table 3-5.

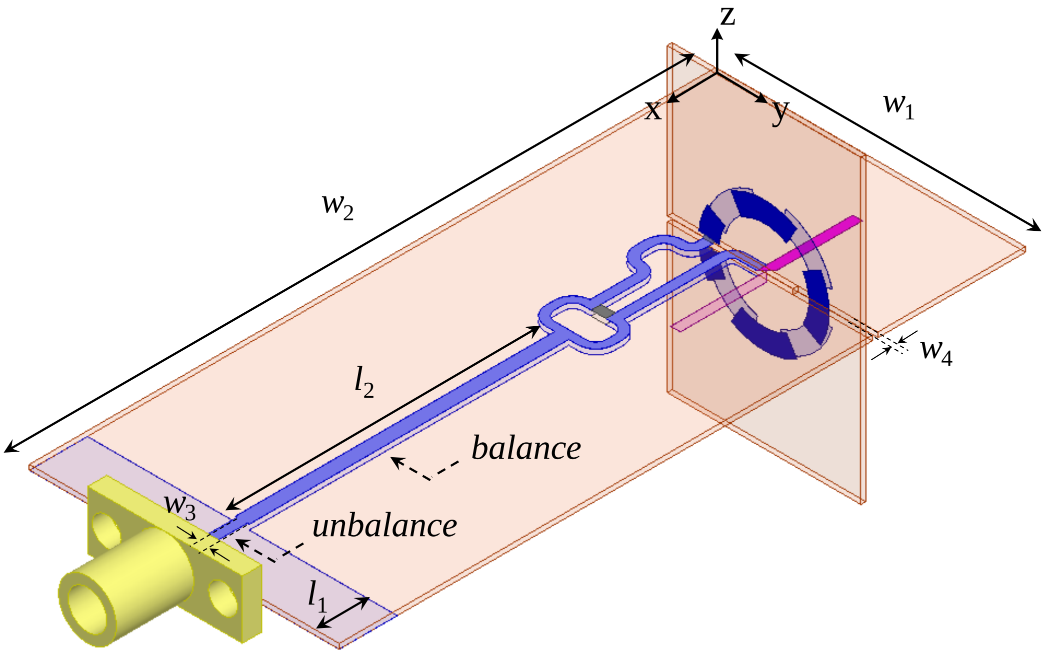


Figure 3-12: Prototype layout of the overall architecture of 6 GHz omnidirectional circularly polarized antenna

Table 3-5 Design parameters of a 6 GHz omnidirectional circularly polarized antenna

Element	Values(mm)
W_1	32
W_2	70.9
W_3	1.05
W_4	0.508
l_1	6
l_2	33

3.3 Design of Omnidirectional Circularly Polarized Antennas in 28 GHz band

3.3.1 Dipole Antenna Design

In the future, the fifth-generation mobile communication in addition to the sub-6 GHz it will also focus on the millimeter-wave frequency band, such as 28 GHz or 38 GHz. Therefore, in here an antenna architecture similar to the previous method at a center frequency 28 GHz is designed using the software Ansoft HFSS. The selected plate was Rogers' RO4350B with a dielectric constant of 3.66, a tangent loss of 0.004 and a plate thickness of 10 mm. The architecture of the dipole antenna is shown in Figure 3.13, and its dimensions are shown in Table 3-6.

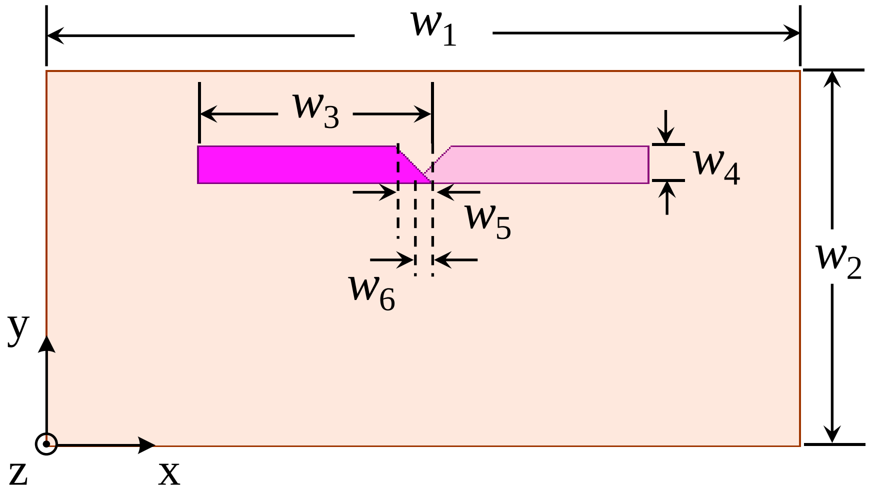


Figure 3-13: Prototype layout of 28 GHz dipole antenna

Table 3-6 Design parameters of 28 GHz dipole antenna

Element	Values(mm)
W_1	6
W_2	3
W_3	1.87
W_4	0.3
W_5	0.3
W_5	0.15

3.3.2 28 GHz Negative Magnetic Permeability Zero-order Transmission Line Design

The zero-order transmission line of the negative magnetic permeability of 28 GHz is designed here using similar method as it is designed at 6 GHz and it is shown in Figure 3-14, and its parameters are shown in Table 3-7.

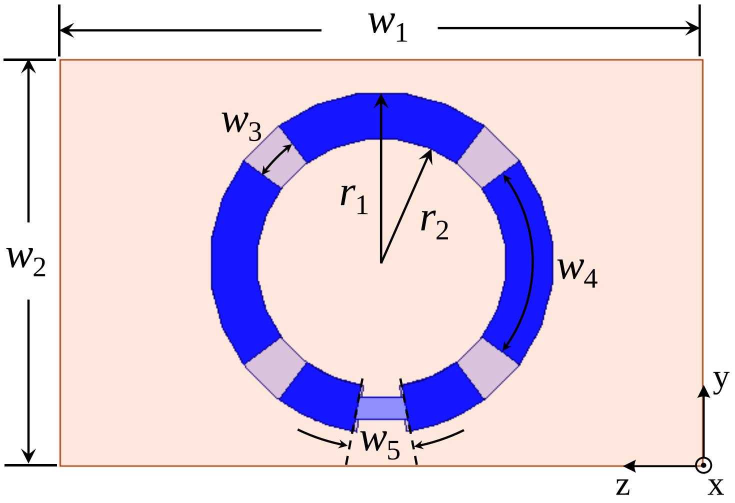


Figure 3-14: Prototype layout of 28 GHz negative permeability zero-order transmission line

Table 3-7 Design parameters of 28 GHz negative permeability zero-order transmission line

Element	Value(mm)
W_1	5.5
W_2	3.5
W_3	0.37
W_4	1.52
W_5	0.42
r_1	1.47
r_2	1.07

3.3.3 28 GHz Two-Layer Parallel Strip line Wilkinson Power Splitter Design

The design for Wilkinson power splitter of the double-layer parallel strip line in the millimeter wave 28 GHz band is also the same as it is designed in 6 GHz and is shown in Figure 3-15, and its parameters are shown in Table 3-8.

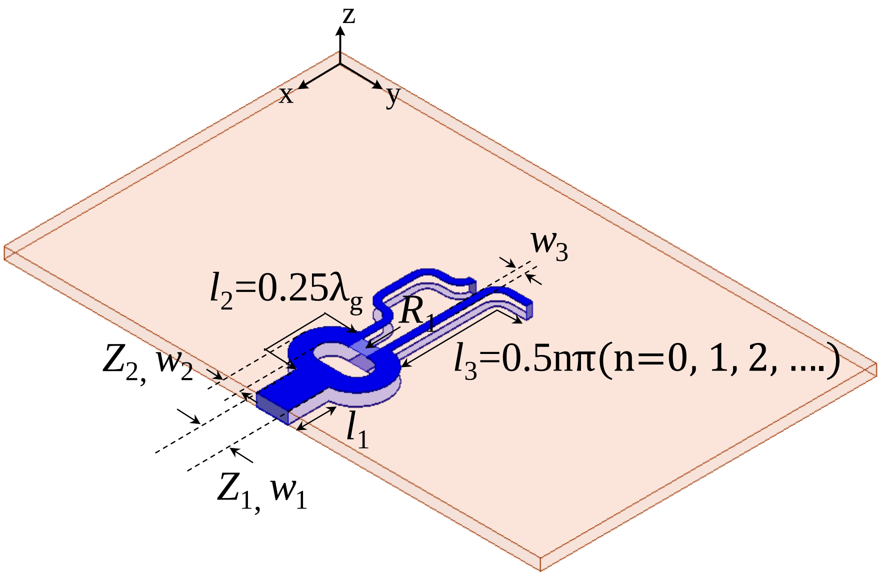


Figure 3-15: Prototype layout of the 28 GHz double-layer parallel strip Wilkinson power splitter

Table 3-8 Design parameters of 28 GHz Wilkinson power splitter

Element	Values(mm)	Element	Values(Ω)
W_1	0.7	z_1	50
W_2	0.4	z_2	70.7
W_3	0.15	R_1	50
l_1	0.91		
l_2	1.57		
l_3	3.45		

3.3.4 Overall Structure of 28 GHz Omnidirectional Circular Polarized Antenna

By combining the two antennas at 90-degree and connecting with Wilkinson power splitter similar to previous method, we designed28 GHz omnidirectional circular polarized antenna. Its designed is shown in Figure 3-16, and its parameters are shown in Table 3-9.

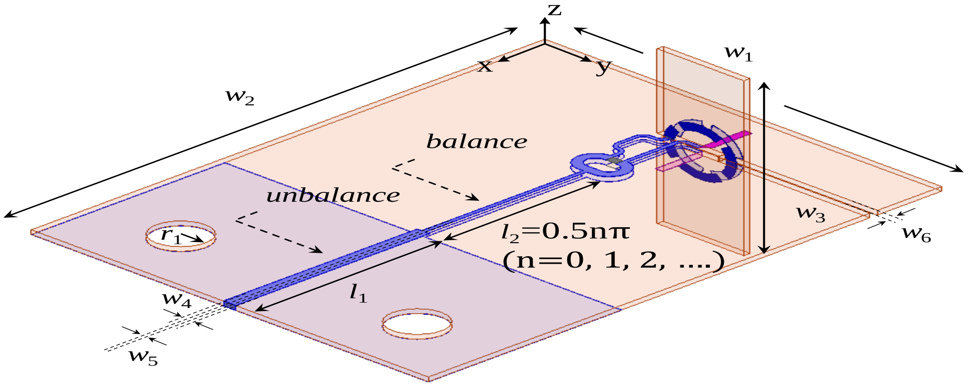


Figure 3-16: Prototype layout of the overall architecture of 28 GHz omnidirectional circularly polarized antenna

Table 3-9 Design parameters of a 28 GHz omnidirectional circularly polarized antenna

Element	Values(mm)	Element	Values(mm)
W_1	16	l_1	7.8
W_2	20.7	l_2	6.51
W_3	9.5	r_1	0.99
W_4	0.5		
W_5	0.15		
W_6	0.3		

The overall antenna architecture including connectors and coaxial cables is shown as in Figure 3.17.

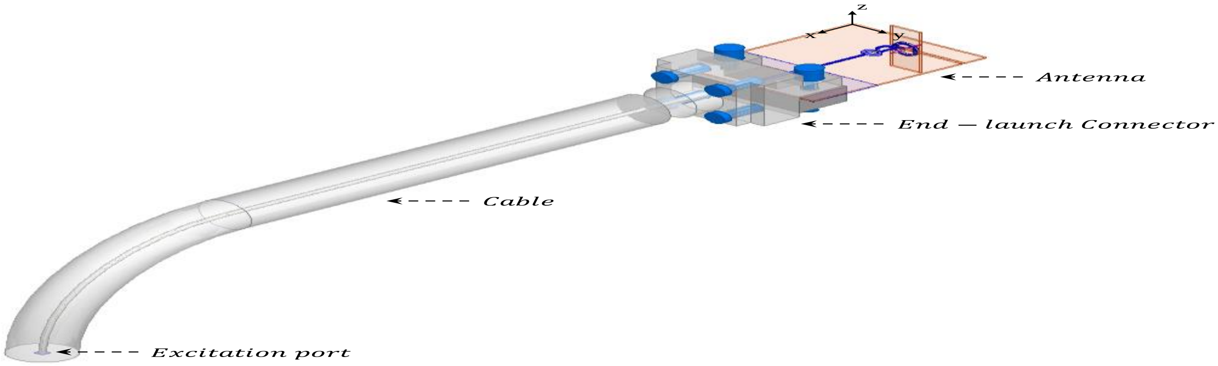


Figure 3-17: 28 GHz Omnidirectional Circularly Polarized Antenna with Connector and Coaxial Cable Overall Architecture

Chapter-Four

Simulation Result and Discussion

4.1 Introduction

In the previous chapters, the theoretical background and basic principles of omnidirectional circularly polarized antennas are reviewed and developed. This chapter presents the HFSS simulation results and discussions & comparison on the obtained results. The results of the performed computer simulations are presented in the form of tables and graphs.

4.2 Simulation Result and Discussion

After selecting the substrate, calculating values of parameters and an omnidirectional circular polarized antenna is designed at 6 GHz and 28 GHz the computer simulations are carried out using HFSS. In this thesis the return loss and radiation pattern of the two linear antenna and the two proposed antenna are simulated to analysis and compare based on its gain.

4.2.1 Simulation Result and Discussion of 6 GHz Omnidirectional Circular Polarized Antenna

In this part we first simulate separately the two designed antenna based on their return loss and radiation pattern and finally we simulated the return loss and radiation pattern of the overall structure of the proposed antenna.

A. Return Loss of 6 GHz Dipole Antenna

Return loss is a parameter that is used to measure the power reflected by the antenna due to the mismatch of the antenna. If the return loss is 0 dB there is nothing to radiate by the antenna because the power provided to the antenna is completely absorbed by the antenna or this means that the power input equal to the power reflected. The return loss of dipole antenna at 6 GHz is shown in Figure 4.1. A response of the return loss is taken from the magnitude of S_{11} (dB) versus frequency. When $\Gamma = 0$ and RL=∞, there is a perfect matching between the antenna and the transmitter which indicates that there is no power that is returned or reflected but when $\Gamma = \infty$ and RL = 0 dB, it indicates that the power that sent is all reflected back.

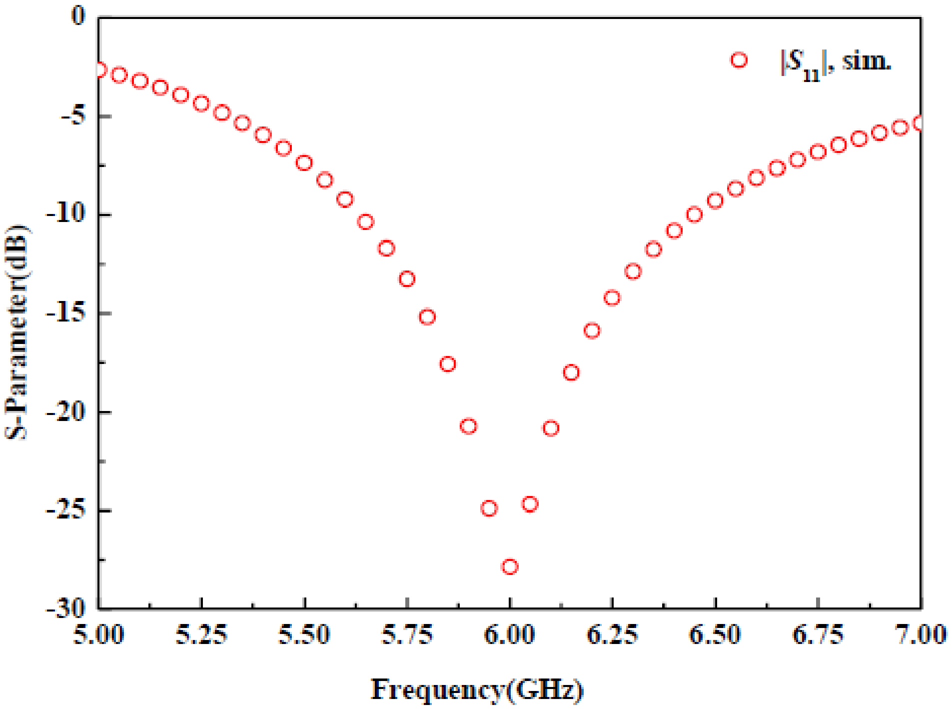
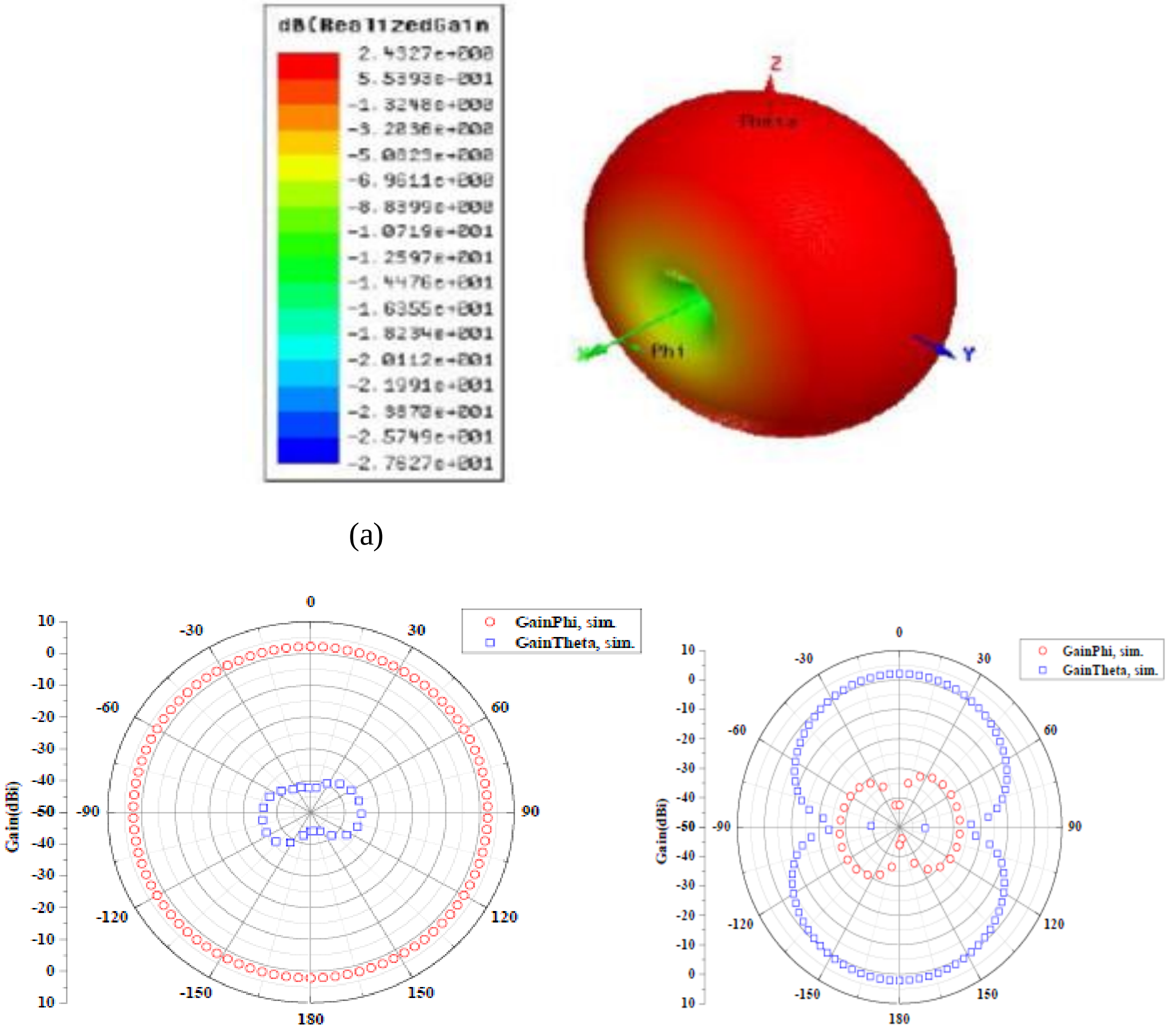


Figure 4-1: Reflection coefficient of 6 GHz dipole antenna simulation

This antenna design is acceptable since its return loss is under -10 dB. The value of S11= -10 dB is a threshold value to design a good antenna.

B. Radiation Pattern of 6 GHz Dipole Antenna

Since one of the focuses of this thesis is the omnidirectional radiation field type, the dipole antenna is the most basic and widely used structure. Its radiation pattern is shown in Figure 4-2, and the antenna gain is about 2.4 dBi and is linearly polarized.



(a)

(b)

(c)

Figure 4-2: Radiation pattern of 6 GHz dipole antenna simulation (a) Three-dimensional (b) Two-dimensional XY plane (c) Two-dimensional XZ plane

C. Return Loss of 6 GHz Negative Permeability Zero-Order Transmission Line

Similar to the dipole antenna the return loss of this antenna is also acceptable as shown in Figure 4-3.

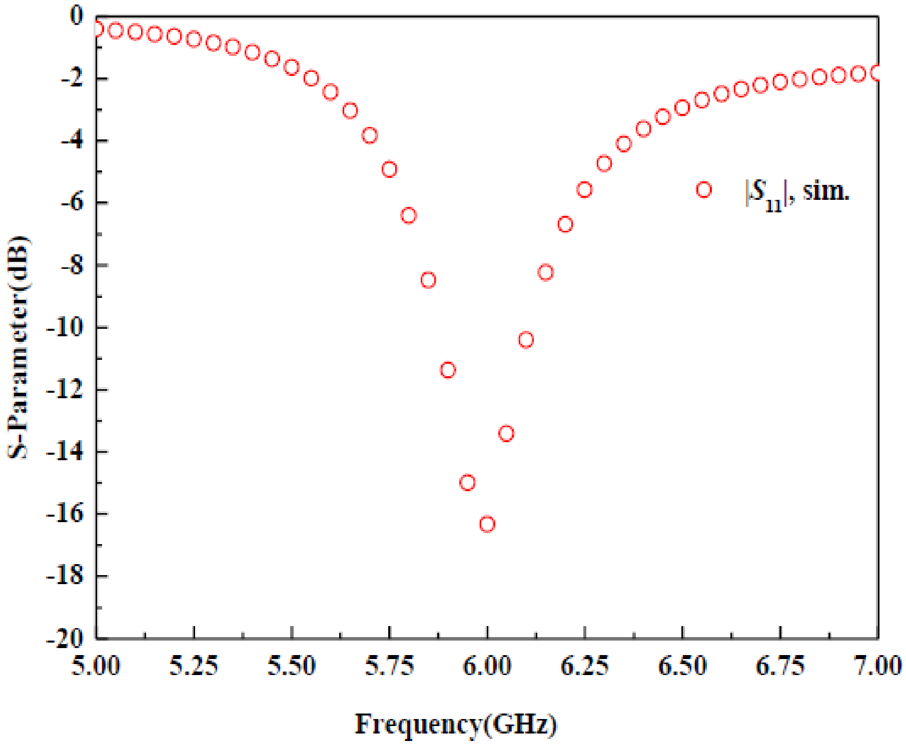
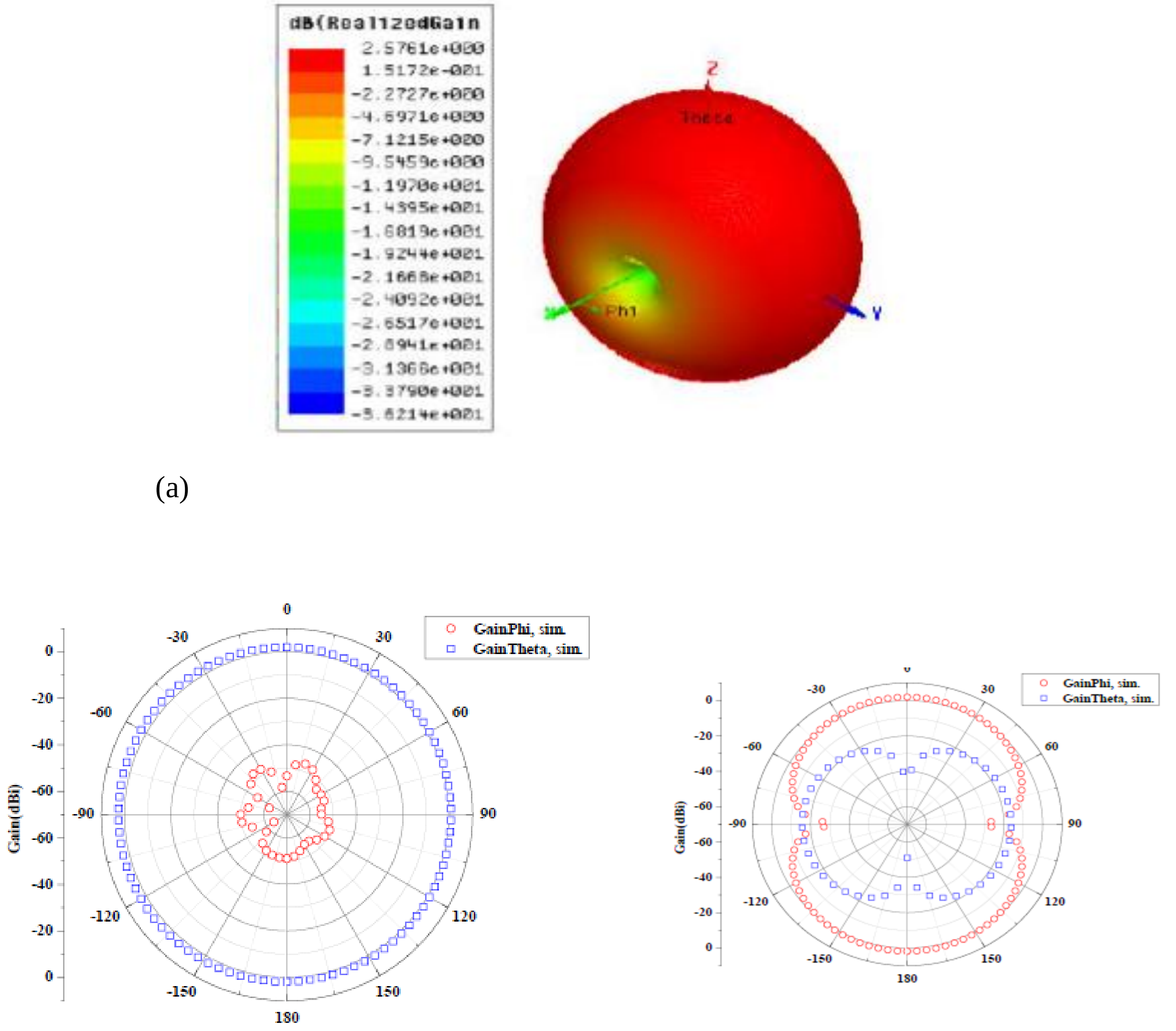


Figure 4-3: Reflection coefficient of 6 GHz negative permeability zero-order transmission line simulation

D. Radiation Pattern of 6 GHz Negative Permeability Zero-Order Transmission Line

As mentioned in previous chapter, in order to design an antenna having the same radiation field type and a polarization direction orthogonal to the dipole antenna, the zero-order transmission line of the negative magnetic permeability is vertically placed with respect to the dipole antenna. The radiation pattern is shown in Figure 4-4. The antenna gain is about 2.5 dBi and is linearly polarized.



(a)

(b)

(c)

Figure 4-4: Radiation pattern of 6 GHz negative permeability zero-order transmission line simulation (a) Three-dimensional (b) Two-dimensional XY plane (c) Two-dimensional XZ plane

E. Return loss of 6 GHz Omnidirectional Circularly Polarized Antenna

The reflection coefficient of the 6 GHz omnidirectional circularly polarized antenna is shown in Figure 4-5. From the figure it indicates that it is good antenna design, because it has low reflection coefficient.

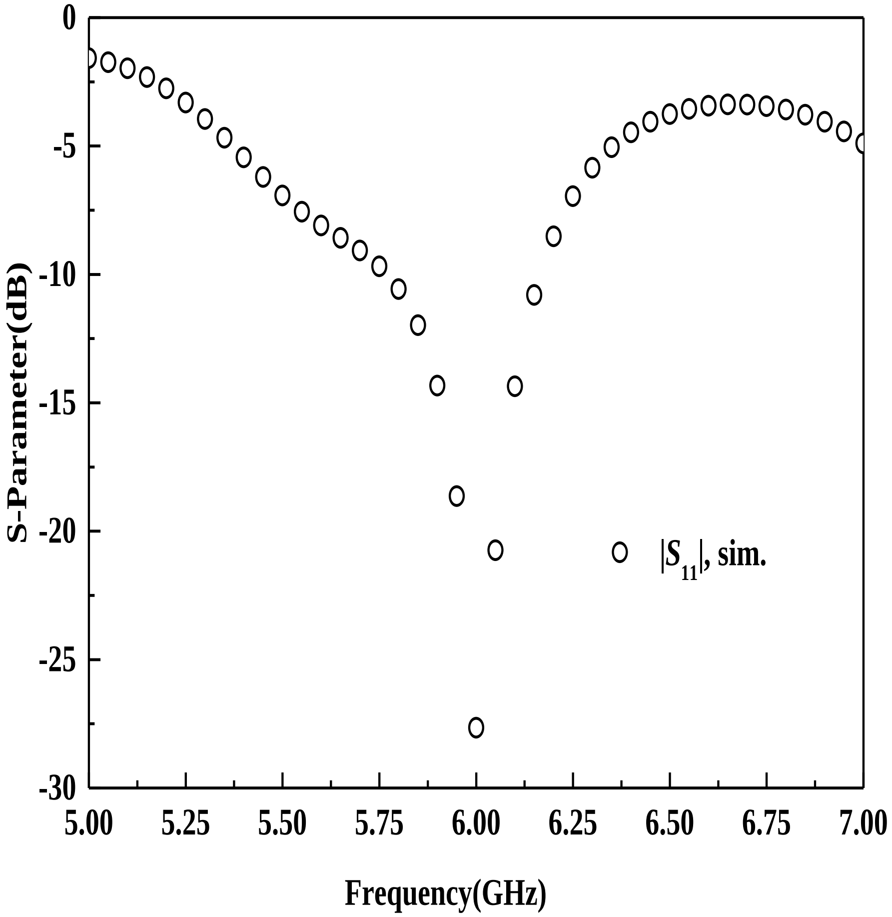


Figure 4-5: Reflection coefficient of 6 GHz omnidirectional circularly polarized antenna simulation

F. Radiation Pattern of 6 GHz Omnidirectional Circularly Polarized Antenna

The radiation field type of the omnidirectional circularly polarized antenna should be the same as the energy intensity of the primary and secondary polarizations and the axial ratio should be less than 3 dB in either direction of the plane space to have circular polarized antenna.

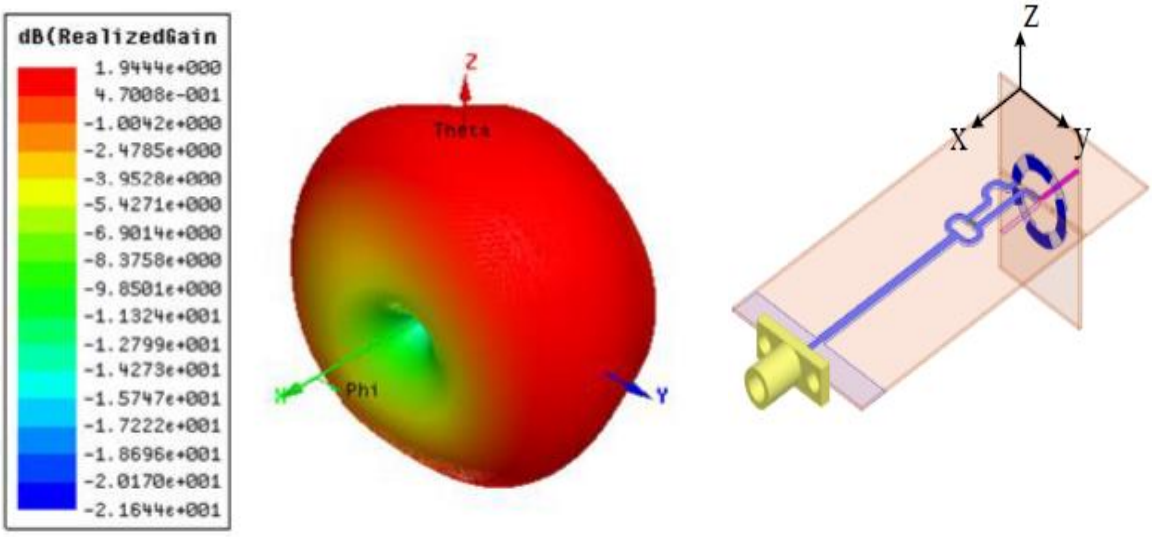
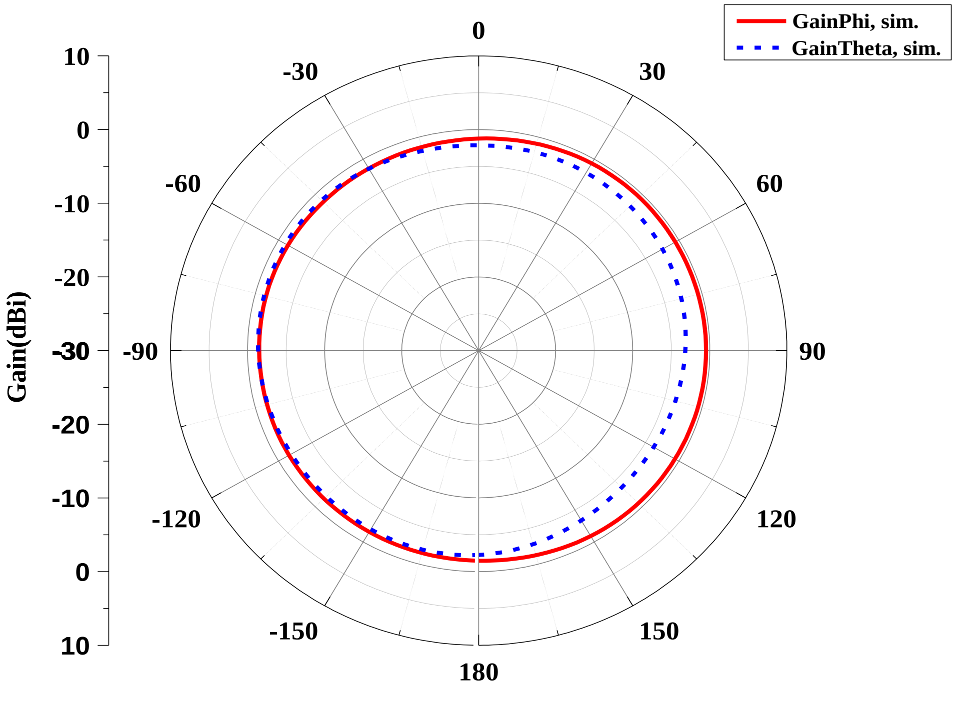
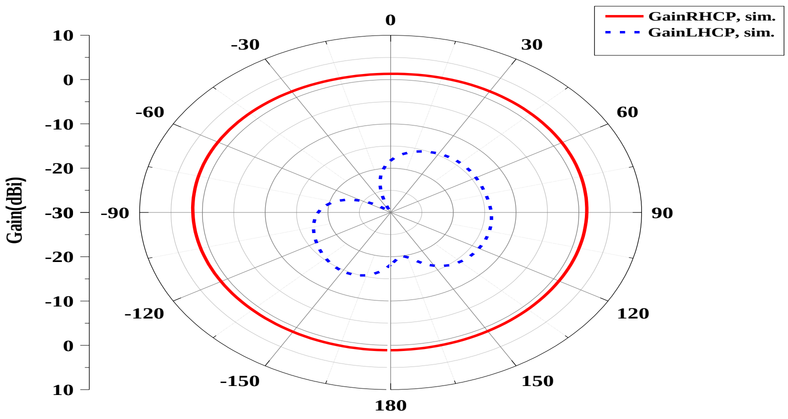


Figure 4-6: 3D radiation pattern simulated by 6 GHz omnidirectional circularly polarized antenna



(a)



(b)

Figure 4-7: XY plane radiation pattern for 6 GHz omnidirectional circularly polarized antenna simulation (a) primary polarization and secondary polarization (b) right-hand circular polarization and left-hand circular polarization

If the values of the right-hand circular polarization and the left-hand circular polarization are known, the value of the axial ratio can be calculated by the following formula.

$$\mathrm{CP} = |\mathrm{RHCP} - \mathrm{LHCP}|(dB) \quad (4.1)$$

$$AR = 20\ LOg\frac{1+10^{-\frac{CP}{20}}}{1-10^{-\frac{CP}{20}}} \quad (4.2)$$

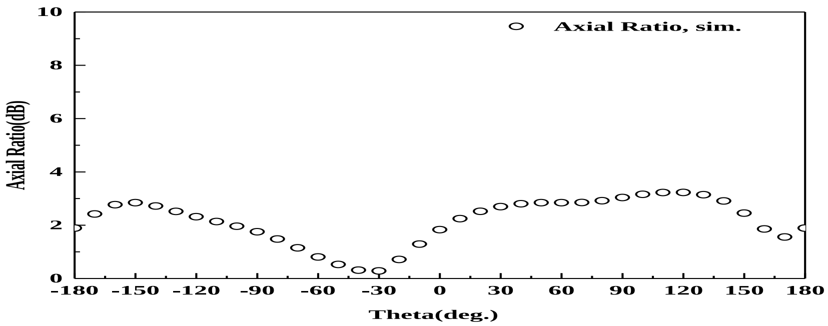
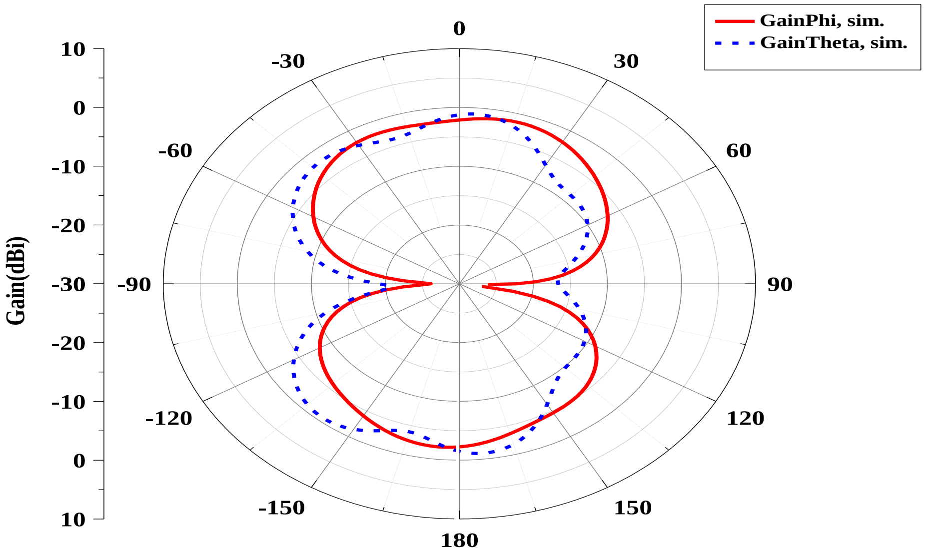
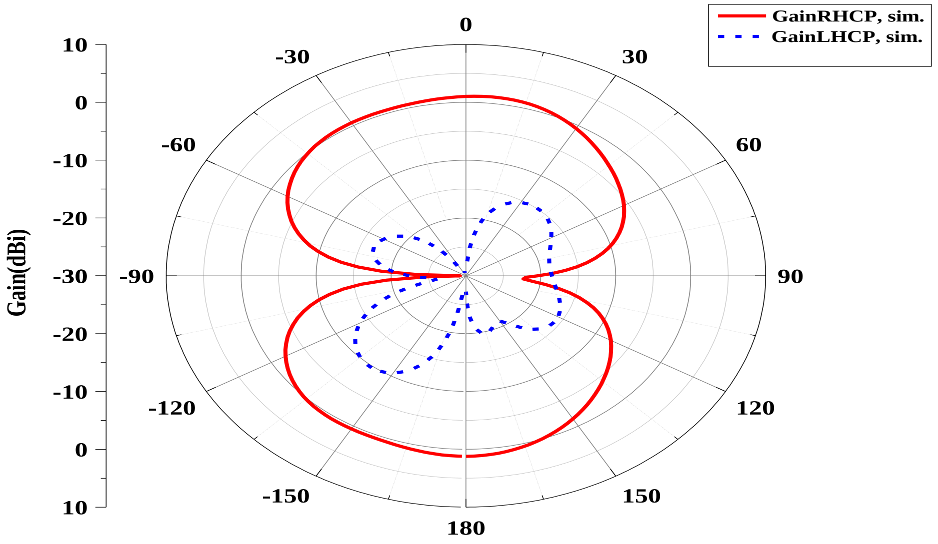


Figure 4-8: XY plane axis ratio of 6 GHz omnidirectional circularly polarized antenna simulation



(a)



(b)

Figure 4-9: XZ plane radiation pattern for 6 GHz omnidirectional circularly polarized antenna simulation (a) primary polarization and secondary polarization (b) right-hand circular polarization and left-hand circular polarization

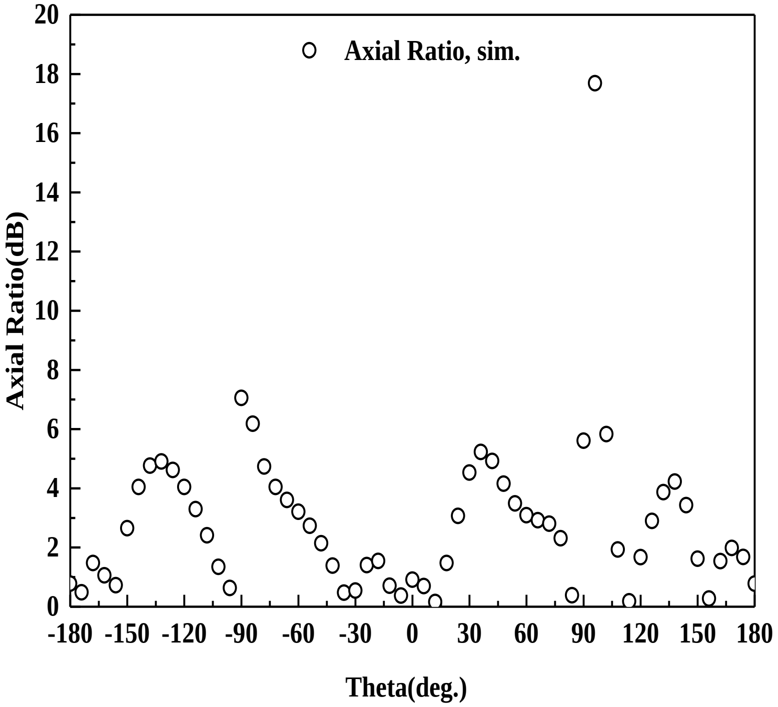


Figure 4-10: XZ plane axis ratio of 6 GHz omnidirectional circularly polarized antenna simulation

4.2.2 Simulation Result and Discussion of 28 GHz Omnidirectional Circular Polarized Antenna

In this part, only the return loss and radiation pattern of the overall structure of the proposed antenna is simulated but not for the two linear antenna.

A. Return loss of 28 GHz Omnidirectional Circularly Polarized Antenna

The reflection coefficient for 28 GHz omnidirectional circularly polarized antenna is shown in Figure 4-11.

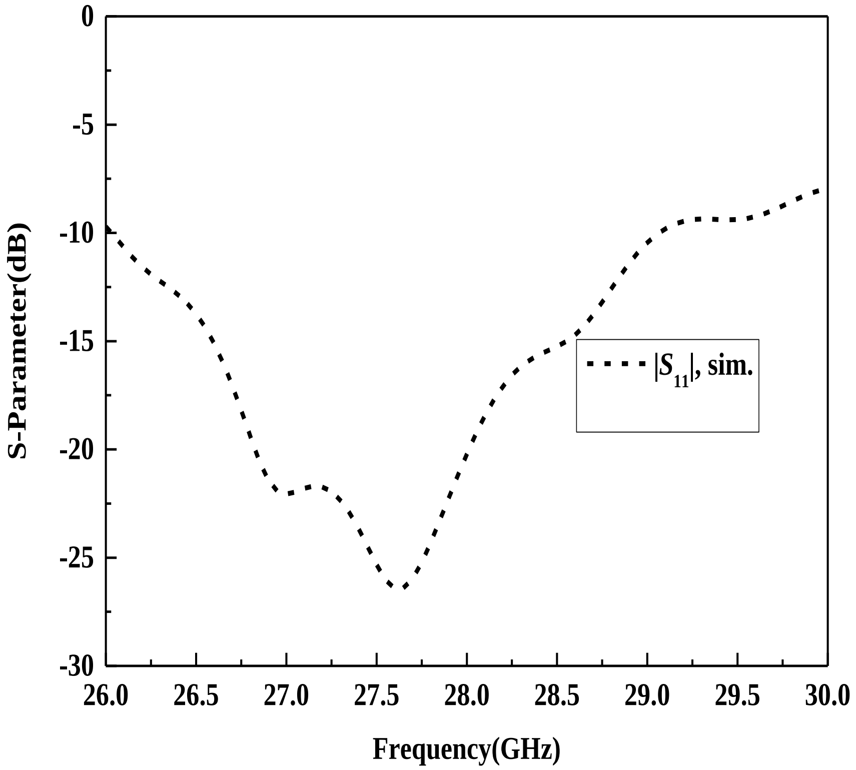


Figure 4-11: Reflection coefficient of 28 GHz omnidirectional circularly polarized antenna simulation

B. Radiation Pattern of 28 GHz Omnidirectional Circularly Polarized Antenna

The radiation pattern of 28 GHz omnidirectional circularly polarized antenna was simulated using the software Ansoft HFSS similar to the previous section as shown in Figure 4-12 and Figure 4-13.

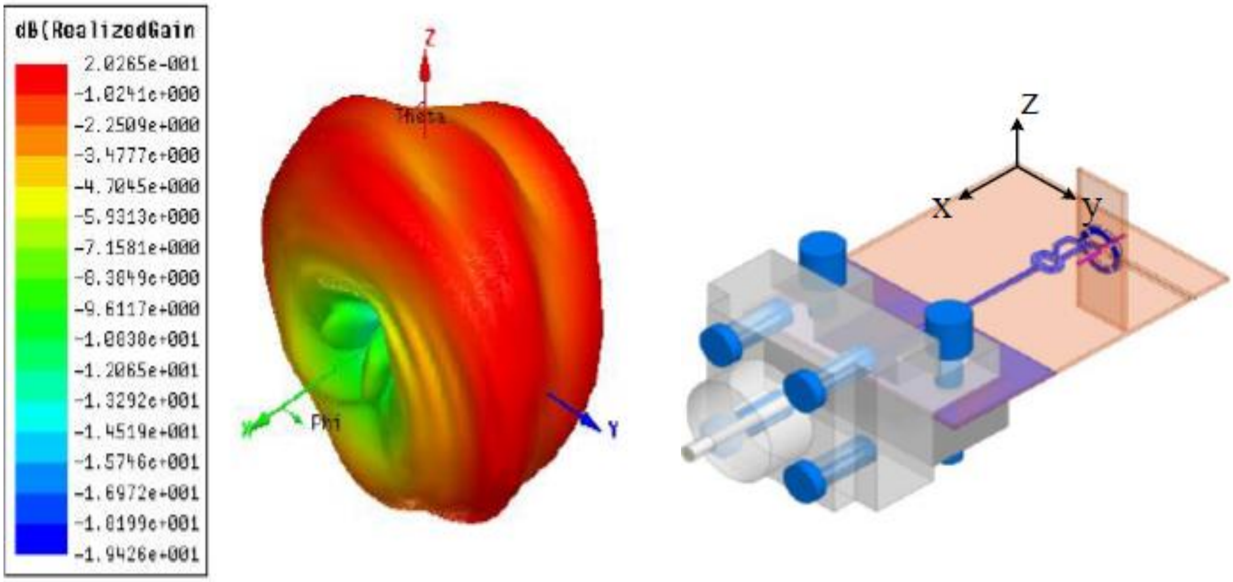
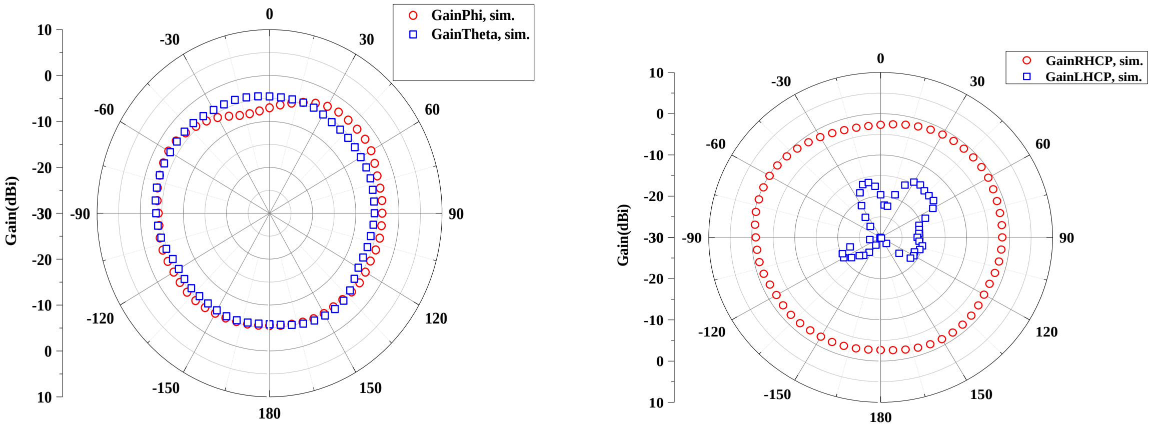


Figure 4-12: 3D radiation pattern of 28 GHz omnidirectional circularly polarized antenna simulation



(a) (b)

Figure 4-13: Simulation of the XY Plane Radiation Pattern of 28 GHz Omnidirectional Circularly Polarized Antenna (a) primary polarization and secondary polarization (b) right-hand circular polarization and left-hand circular polarization

As described in the previous section, if the values of the right-hand circular polarization and the left-hand circular polarization are known, the values of the axial ratio can be calculated by Equations 4.1 and 4.2.

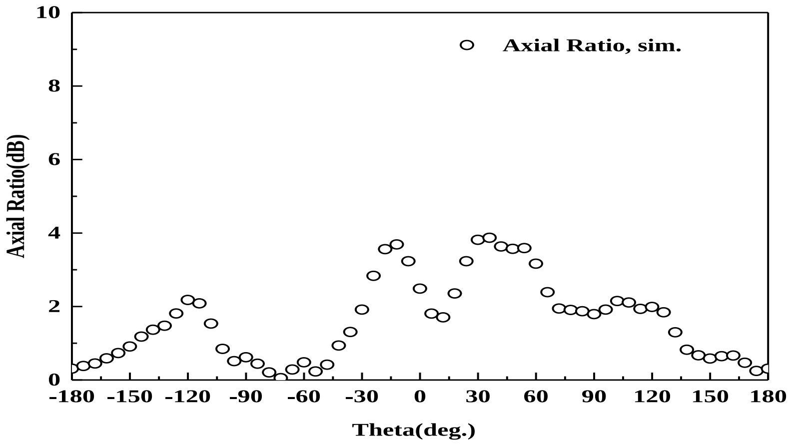
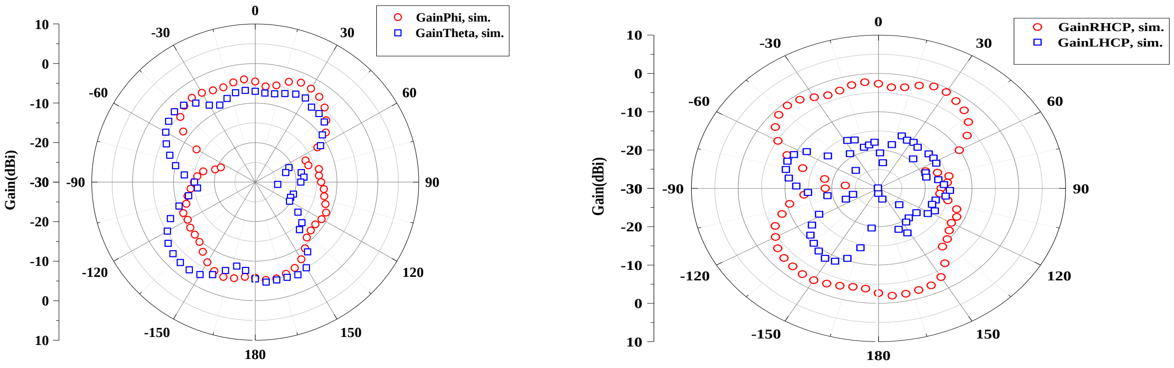


Figure 4-14: XY plane axis ratio of 28 GHz omnidirectional circularly polarized antenna simulation



(a)

(b)

Figure 4-15: XZ plane radiation pattern for 28 GHz omnidirectional circularly polarized antenna simulation (a) primary polarization and secondary polarization (b) right-hand circular polarization and left-hand circular polarization

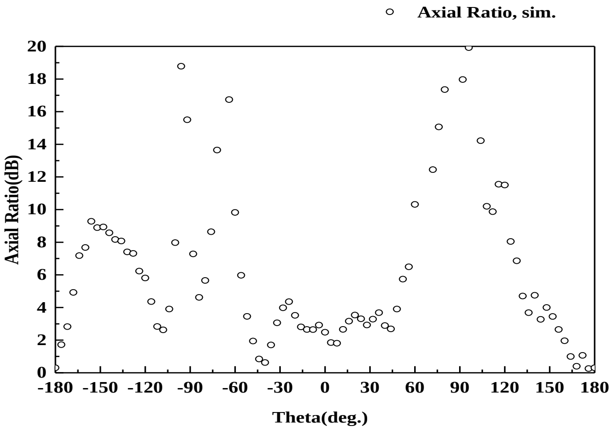


Figure 4-16: XZ plane axis ratio of 28 GHz omnidirectional circularly polarized antenna simulation

The application of the fifth-generation communication in this study is biased towards small base stations. Therefore, two planes need to be paid attention in the radiation field type, one of which is the plane of the omnidirectional radiation field type (XY plane). The significance of this plane is the same signal strength can be received in any one of the planes, and the other is a plane perpendicular to each other (XZ plane). The significance of this plane is to extend the receiving range so that the user does not have to be limited to XY. The reflection coffecient, radiation field type and the axial ratio of the two planes are particularly important in this thesis. The gap or difference between the RHCP and LHCP must be 15 dBi minimum to have a good circular polarized antenna, the higher the gap between the tow polarization i.e RHCP & LHCP makes the antenna to have a good circular polarized antenna . It is also possible to know either an antenna is good circular polarization or not using axial ratio which is the ratio of the major axis to the minor axis. To say it is good circular polarization the antenna axial ratio must be under 3 dBi.

From this simulation result, it is clear that good omnidirectional radiation with circular polarization in the azimuth plane (x-y plane) is obtained.

For the 6 GHz omnidirectional circularly polarized antenna the radiation pattern of the electric field along the ϕ and θ direction as shown in Figure 4-7(a) is omnidirectional, the bandwidth under -10 dB as shown in Figure 4-5 whch is from 5.8 GHz upto 6.2 GHz is 6.67%, the axial ratio of this antenna from -180 degree to 180 degree as shown in Figure 4-8 is under 3 dB standard and the difference in gain between the RHCP and LHCP is more than 15 dB, so it is good circularly polarized antenna because the higher the gap between the two polarization type makes the antenna to have good circularl polarization. This antenna is RHCP antenna type with the antenna gain 1.9 dBi.

Also for the 28 GHz antenna, the radiation pattern of the electric field along the ϕ and θ direction as shown in Figure 4-13(a) is omnidirectional but not as that of 6 GHz, the bandwidth under -10 dB as shown in Figure 4-11 whch is from 26 GHz upto 29.25 GHz is 11.77% and the difference between the RHCP and LHCP is more than 15 dB, so it is good circularly polarized antenna & it is also RHCP antenna type with antenna gain 2.0 dBi.

Generally, it is confirmed that the gain increases with increasing frequency. However, the axial ratio of 28 GHz omnidirectional circularly polarized antenna also increases which affects the circular polarization part of the antenna, because the size of the high frequency antenna is much smaller which makes difficulty to connect the Wilkinson power splitter with dipole and negative permeability zero-order transmission line. The reflection coefficient is also increase for the high frequency.

4.2.3 Compare with Other Research Results

He++re, the proposed omnidirectional CP antenna with others' work is compared as shown in Table 4-1 based on gain and radiation efficiency.

Table 4-1 Compare the proposed antenna with others' research results.

Antenna Types	**Reference number**	**Gain**	**Efficiency (%)**
Omnidirectional CP antenna	[7]	1.5 dBi	56
Novel compact omnidirectional circularly polarized antennas	[11]	1.78 dBi, 1.83 dBi and 1.87 dBi for three antennas at different frequency	78
Composite Right/Left-Handed Transmission Line Based Compact Resonant Antennas	[13]	0.3 dBi	64
Dual band omnidirectional CP antenna	[4]	-0.2 dBi	72
Omnidirectional CP antenna	[12]	-21 dBi	74.6
Proposed omnidirectional circularly polarized antenna at 6 GHz	Proposed	1.9 dBi	91
Proposed omnidirectional circularly polarized antenna at 28 GHz	Proposed	2 dBi	52

From this table ,it can be concluded that the proposed 6 GHz and 28 GHz omnidirectional circularly polarized antenna have higher gain than previous work.

Chapter 5

Conclusion and Future work

5.1 Conclusion

Nowadays, omnidirectional circularly polarized antenna are developing by many researchers for 5G communication. They design the antenna using different methods to enhance the performance based on their gain, efficiency, reflection coefficient and other parameters. Again, the focus of many studies are on the miniaturization of the antenna size.

In this thesis two omnidirectional circularly polarized antennas is proposed, successfully designed and simulated at a center frequency of 6 GHz band and millimeter wave band of 28 GHz, respectively for a 5G communication to enhance the performance of the antenna. The two antennas are omnidirectional and circularly polarized. In this study, it is mainly focused on the gain to improve the performance of the antenna and comparing the two designed antenna based on their gain.

Simulation result shows that the axial ratio is less than 3 dB and the antenna gains are 1.9 dBi and 2.0 dBi, in the 6 GHz and 28 GHz antennas respectively. Again, the simulated radiation efficiency of the two antennas are 91% and 52%, respectively. In the low-frequency design, it can be seen that the simulation has low gain, high simulated efficiency and low axial ratio, however, in the high-frequency design it has high gain, low simulated efficiency and high axial ratio compared with the low frequency. Based on the aforementioned simulation result it can be concluded that the 6 GHz omnidirectional circularly polarized antenna is preferable than that of 28 GHz omnidirectional circularly polarized antenna. Generally, the two proposed antennas are very compact in size and have a good gain which makes them suitable for use in wireless communication system.

5.2 Recommendation for Future Work

For mobile communication base station applications, an antenna array is required to increase the gain. Also fabrication of the two antennas are required to compare and verify the simulated value with the measured value, because the attenuation of the millimeter wave is relatively large than 6

GHz in real world. So, developing the antenna array and fabrication of the antenna is what is suggested as future work of this thesis.

References

1. A. Hemadeh, e. A. "Millimeter-wave communications: physical channel models, design considerations, antenna constructions, and link-budget. " IEEE Communications Surveys & Tutorials, vol. 20, pp. 870-913, 2018.
2. X. Wang, L. Kong, F. Kong, F. Qiu, M. Xia, S. Arnon and G. Chen, “Millimeter wave communication: A Comprehensive Survey,” IEEE Commun. Surveys Tuts., pp. 1-1, 2018.
3. G. R. Maccartney, et al., "Indoor office wideband millimeter-wave propagation measurements and channel models at 28 and 73 GHz for ultra-dense 5G wireless networks," IEEE Access, vol. 3, pp. 23882424, 2015.
4. Sun, Kai, Lin Peng, and Xing Jiang. "Design of a circularly polarized omni-directional ZOR antenna for 5G millimeter wave." 2017 Sixth Asia-Pacific Conference on Antennas and Propagation (APCAP). IEEE, 2017
5. AbdulSattar M. Ahmed, Salim Abdullah Hasan and Sayf A. Majeed. "5G MOBILE SYSTEMS, CHALLENGES AND TECHNOLOGIES: A SURVEY" arXiv preprint arXiv:1503.00674 (2015)
6. I. K. Jain, et al., "Limited by Capacity or Blockage? A Millimeter Wave Blockage Analysis," arXiv preprint arXiv:1808.01228, 2018.
7. Peng, Lin, et al. "EZR-MZR resonators for compact low-profile omnidirectional circular-polarized antenna design." IEEE Photonics Journal 9.4 (2017): 1-15.
8. Kawakami, H., Sato, G., and Wakabayashi, R.: "Research on circularly polarized conical-beam antennas", IEEE Trans. Antennas Propag.,1997, 39, (3), pp. 27–39
9. https://www.acma.gov.au/Home/theACMA/a-guide-to-small-cells
10. Verma, P.K., Kumar, R., and Singh, M.: "Design of a shaped omnidirectional circular waveguide antenna". Applied Electro-Magnetics Conf., Kolkata, India, December 2009, doi:10.1109/AEMC.2009.5430672
11. https://www.flnet.tw/FLNet_Sogi/article.aspx?ArticleID=6246784
12. J. M. Fernández, J. L. Masa-Campos, and M. Sierra-Pérez, “Circularly polarized omnidirectional millimeter wave monopole with parasitic strip elements,” Microw. Opt. Technol. Lett., vol. 49, no. 3, pp. 664–668, Mar. 2007.
13. Yu, Ang, Fan Yang, and Atef Z. Elsherbeni. "A dual band circularly polarized ring antenna based on composite right and left handed metamaterials." Progress In Electromagnetics Research 78 (2008): 73-81.

14. W.-W. Li and K.-W. Leung, “Omnidirectional circularly polarized dielectric resonator antenna with top-loaded alford loop for pattern diversity design,” IEEE Trans. Antennas Propagat., vol. 61, no. 8, pp. 4246-4256, Aug. 2013.
15. Lin, Wei, Richard W. Ziolkowski, and Thomas C. Baum. "28 GHz compact omnidirectional circularly polarized antenna for device-to-device communications in the future 5G systems." IEEE Transactions on Antennas and Propagation 65.12 (2017): 6904-6914.
16. Verma, P. K., Singh, M., & Kumar, R. (2014). “Ka-band circularly polarised omnidirectional antenna for wide elevation coverage”. Electronics Letters, 50(22), 1563–1564. doi:10.1049/el.2014.2898
17. Y. Fan, X.-L. Quan, Y. Pan, Y.-H. Cui and R.-L. Li, “Wideband omnidirectional circularly polarized antenna based on tilted dipoles,” IEEE Trans. Antennas Propagat., vol. 63, no. 12, pp. 5961-5966, Dec. 2015.
18. Sakaguchi, K. (1995). “A circularly polarized omnidirectional small helical antenna”. Ninth International Conference on Antennas and Propagation (ICAP). doi:10.1049/cp:19950359
19. Y. Yu, Z. Shen and S. He, “Compact Omnidirectional Antenna of Circular Polarization,” IEEE Antennas Wireless Propag. Lett., vol. 11, pp. 1466-1469, Apr. 2012.
20. Ma, Y., Li, J., & Xu, R. (2017). “Design of an Omnidirectional Circularly Polarized Antenna”. IEEE Antennas and Wireless Propagation Letters, 16, 226–229. doi:10.1109/lawp.2017.2682958
21. Rajmohan, I. J., Nasimuddin, & Alphones, A. (2013). Omni-directional circularly polarized microstrip antenna using dual-patch radiators. 2013 Asia-Pacific Microwave Conference Proceedings (APMC). doi:10.1109/apmc.2013.6695017
22. Li, B., & Xue, Q. (2013). Polarization-Reconfigurable Omnidirectional Antenna Combining Dipole and Loop Radiators. IEEE Antennas and Wireless Propagation Letters, 12, 1102–1105. doi:10.1109/lawp.2013.2280757
23. Xue-Xia Yang, Bing-Cheng Shao, Fan Yang, Elsherbeni, A. Z., & Bo Gong. (2012). A Polarization Reconfigurable Patch Antenna With Loop Slots on the Ground Plane. IEEE Antennas and Wireless Propagation Letters, 11, 69–72. doi:10.1109/lawp.2011.2182595
24. Verma, P. K., R. Kumar, and M. Singh. "Ka-band circularly polarised omnidirectional antenna for wide elevation coverage." Electronics Letters 50.22 (2014): 1563-1564.
25. Rudge, Alan W., et al., eds. The handbook of antenna design. No. 15. Iet, 1982.

26. Johnson, Richard C., and Henry Jasik. "Antenna engineering handbook." New York, McGraw-Hill Book Company, 1984, 1356 p. No individual items are abstracted in this volume. (1984).
27. Balanis, Constantine A. Antenna theory: analysis and design. John wiley & sons, 2016.
28. . https://www.mathworks.com/help/antenna/gs/antenna-classification.html
29. D.M.Pozar,MicrowaveEngineering,2nd Edition,JohnWileyandSonsInc,1998.
30. C. A. Balanis, Antenna Theory Analysis and Design, 3rd edition, New Jersey,John WileyandSonsInc,2005
31. Satya Prakash Sinha and Kapil Bhushan, "A Circularly Polarized Multi Band Stub Loaded Slot Antenna for GPS", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol.4, Issue10,2015.
32. Ashish Kumar Sahu ,"design and analysis of polarization reconfig urable microstrip patch antennas" , master thesis, India, institute of Rourkela,Odisha,769008,2015,pp22-33
33. Randy Bancroft, Microstrip and Printed Antenna Design, 2nd edition, IET Publication, July2008.
34. Steven (Shichang) Gao, Qi Luo and Fuguo Zhu. "circular polarized antenna" University of Kent, UK, 2014.
35. LUAN Xiu-hen, et al. "Research on Small Circular Micro strip Patch Antenna", 3rd

International Conference on Microwave and Millimeter Wave Technology Proceedings,2002.

36. Wang, C. W., and T. Keech. "Antenna models for electromagnetic compatibility analyses." US Department of Commerce (2012).
37. Buriak, I. A., et al. "Metamaterials: Theory, Classification and Application Strategies." 8,№ 4 (2) (2016): 04088-1.
38. Ziolkowski, Richard W. "Metamaterial-based antennas: Research and developments." IEICE transactions on electronics 89.9 (2006): 1267-1275.
39. Gangwar, Kaushal, and R. P. S. Gangwar. "Metamaterials: Characteristics, process and applications." Advance in Electronic and Electric Engineering 4.1 (2014): 2231-1297.
40. Alves, José Manuel Tapadas." Metamaterials with Negative Permeability and Permittivity: Analysis and Application." Diss. Instituto Superior Técnico, 2010.
41. K.Gi.Cho. Et al. "Ku-band high efficiency antenna with corporate series-fed microstrip array," in antenna & propagation society international symposium, 2003, IEEE,2003, pp.690-693 vol.4
42. Jagadish M.T Ramya, Pradeep A S. " Design and performance analysis of compact MIMO antenna by mutual coupling suppression between elements", Vol.3-issue 12 (December -

2014) international journal of engineering research & technology (DERT) . ISSN: 2278-0181 www.ijert.org

43. Theodore S. Rappaport and Shu Sun, " Millimeter Waves Mobile Communication for 5G Cellular", Board of Governors of IEEE Vehicular Technology Society (VTS) (May 2013), INSPEC ISSN No: 2169-3536, DOI: 10.1109/ACCESS.2013.2260813
44. Uzma Siddique and Hina Tabassum, " Wireless backhauling of 5G small cells" Department of Electrical and Computer Engineering, University of Manitoba (July 2015) ,ISSN No: 1536-1284 DOI: 10.1109/MWC.2015.7306534
45. Parminder Singh, Ankita Sharma, Neha Uniyal,Richa Kala, “Half-Wave Dipole Antenna for GSM Applications”, International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970), Volume-2 Number-4 Issue-6 December-2012
46. D.M. Pozar, Microwave Engineering, Third Edition, John Wiley & Sons: New York, 2005
47. K. Wei, Z. Zhang, Z. Feng and M. F. Iskander, “A MNG-TL loop antenna array with horizontally polarized omnidirectional patterns,” IEEE Trans. Antennas Propagat., vol. 60, no. 6, pp. 2702-2710, Jun. 2012.
48. http://www.microwaves101.com/encyclopedia/Network_theory.cfm#threeport
49. Y. Yu, Z. Shen, and S. He, “Compact omnidirectional antenna of circular polarization,” IEEE Antennas Wireless Propag. Lett., vol. 11, pp. 1466–1469, 2012.
50. B. C. Park and J. H. Lee, “Dual-band omnidirectional circularly polarized antenna using zeroth- and first-order modes,” IEEE Antennas Wireless Propag. Lett., vol. 11, pp. 407–410, 2012.
51. B.C. Park and J.H. Lee, “Omnidirectional circularly polarized antenna utilizing zero th order resonance of epsilon negative transmission line,” IEEE Trans. Antennas Propag. vol. 59, no. 7, pp. 2717–2721, 2011.