The Islamic University Gaza
Higher Education Deanship
Faculty of Engineering
Electrical Engineering
Communication Systems

الجامعة الإسلامية – غزة
عمادة الدراسات العليا
كلية الهندسة
الهندسة الكهربائية
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LTE Antenna's Parameter Enhancement for Mobile Communication Applications

Submitted by:

Eng. Ahmed Hamdi Abo absa

Supervised by:

Dr. Mohamed Ouda

Dr. Ammar Abu Hudrouss

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THESIS ABSTRACT

Long Term Evolution (LTE) is a fourth generation standard for wireless communications of high data speed at the user terminal. This evolved technology needs a cutting edge system component to be designed for the node B (Base station) and the user mobile device.

In any wireless device, the performance of radio communications depends on the design of an efficient antenna. The objective of this research work is to design printed antennas suitable for use within LTE mobile terminals. To satisfy the antenna size of LTE devices, meander line technology is used to reduce the resonant length of the antenna. Professional design software (HFSS) is used to design and optimize a 0.78 and 2.5 GHz single element Meander Line Antenna and E-shape MLA as anew shape to give an enhancement the bandwidth and the small gain.

We used in this thesis two techniques: the first technique is parametric study where study each variable in the antenna then study the effect each of them on the antenna, after that go to other type and make the work until finish all the variables. The second technique is optimization technique using Genetic Algorithms. This technique can be effectively used in the design of various complex antenna and millimeter dimension circuits, where the performance of this technique to design the antenna is a good precision design of antenna elements for low and high frequency applications. MATLAB codes were written to determine the resonant frequency and the bandwidth for each study in this thesis.

Dedicated to

My Parents

Their prayers and perseverance led to this accomplishment

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In the name of Allah, the Most Gracious and the Most Merciful All praises and glory is to Allah (SWT) for blessing me with opportunities abound and showering upon me his mercy and guidance all through the life. I pray that He continues the same the rest of my life. And may peace and blessings of Allah be upon Prophet Muhammad, a guidance and inspiration to our lives.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The fourth generation of cellular networks will use a new high performance air interface for cellular mobile communication systems called Long Term Evolution (LTE). LTE is the evolution of Mobile Telecommunication System and will considerably increase the capacity and speed of mobile telephone networks by employing several enabling technologies.

In choosing an antenna topology for LTE design, several factors must be taken into account including physical characteristics, compatibility, impedance bandwidth, radiation efficiency, and radiation pattern. Within the framework of antenna, there are two challenges for the LTE handset application. The first challenge is to design a small antenna fitting in the limited space of the hand size terminals. The second challenge, the antenna should be mostly available within the wider bandwidth as well as the multiple communication standards covering from the whole 3G to LTE schemes. And this broadband performance requires the expansion of physical antenna dimensions **[1].**

Accordingly, many techniques to increase the impedance bandwidth of small antennas and to optimize the characteristics of LTE antennas are found in many published papers. The research focused in some of these problems and work on developing new antennas that have wide bandwidth and considerable gain in order to be compatible with LTE application with high performance.

In this chapter we will say about mobile communication generations, thesis motivation and thesis objective.

1.2 REVIEW OF MOBILE COMMUNICATION STANDARDS

The mobile communication technology has growth from the first-generation (1G) analogue voice-only communication to the second-generation (2G) digital voice communication. These 2G technologies became popular worldwide including GSM (Global System for Mobile Communications) in Europe, IS-136 (also known as US-TDMA and Digital AMPS) in the U.S., and PDC (Personal Digital Communications) in Japan. Currently, the third generation (3G) mobile communication technology does not only provide digital voice services, it also provides video telephony, internet access and video/music download services. Furthermore, the forthcoming fourth generation (4G) mobile telephone technology aims to provide on-demand high quality video and audio services [**2**].

This section will address the evolution of mobile communication standards, from its first generation, 1G, to the latest 3G and give a look of on the future of 4G.

1.2.1 INTRODUCTION

New mobile generations do not pretend to improve the voice communication experience but try to give the user access to a new global communication reality. The aim is to reach communication every time and everywhere and to provide users with a new set of services. The growth of the number of mobile subscribers over the last years led to a saturation of voice-oriented wireless telephony. From 214 million subscribers in 1997 to 1162 million in 2002 [**3**], it is predicted that by 2016 there will be 1.43 billion subscribers worldwide [**4**]. It is now time to explore new demands and to find new ways to extend the mobile concept. The first steps have already been taken by the 2.5G, which gave users access to data networks (e.g. Internet access and MMS - Multimedia Message Service). However, users and applications demanded more communication data rates. In response to this demand a new generation with new standards has been developed - 3G.

In the last years, benefiting from 3G constant delays, many new mobile technologies were deployed with great success e.g. Wi-Fi (Wireless Fidelity). Now, all this new technologies (e.g. UMTS, Wi-Fi, and Bluetooth) can only be achieved by a new mobile generation. This new mobile generation to be deployed must work with many mobile technologies while being transparent to the final user.

1.2.2 THE FIRST MOBILE GENERATIONS (1G TO 2.5G)

In 1G, a narrow band analogue wireless network is used, with this we can have the voice calls and can send text messages. These services are provided with circuit switching. The 2G narrow band wireless network also uses the circuit switching model but provides more voice clarity as compared to 1G.

Both 1G and 2G deal with voice calls and sending messages i.e. SMS (Short Message Service). The latest technologies such as GPRS (General Packet Radio Service), is not available in these generations. But the greatest disadvantage to 1G is that it can be used only within a particular nation, where in the case of 2G, the roaming facility is a semi-global one.

In between 2G and 3G there is another generation called 2.5G. Initially, this mid generation was introduced mainly for involving latest bandwidth technology with addition to the existing 2G generation.

1.2.3 THIRD MOBILE GENERATION NETWORKS (3G)

To overcome the limitations of 2G and 2.5G, 3G was introduced. In 3G a Wide Band Wireless Network is utilized with which the clarity increases and gives the perfection as like that of a real conversation. The data are sent through a technology called Packet Switching .Voice calls are interpreted through Circuit Switching.

With the help of 3G, we can access many new services too. One such service is global roaming. In 3G we can also have several entertainments services such as Fast Communication, Internet, Mobile T.V, Video Conferencing, Video Calls, Multi Media Messaging Service (MMS), 3D gaming, Multi-Gaming etc.

Table 1 shows some specifications for some of the standards used in the first three generations such as data rate, bandwidth and bands.

1.2.4 FUTURE MOBILE GENERATION NETWORKS (4G)

The objective of 3G was to develop a new protocol and new technologies to further enhance the mobile experience. In contrast, the new 4G framework to be established will try to accomplish new levels of user experience and multi-service capacity by also integrating all the mobile technologies that exist (e.g. GSM – Global System for Mobile Communications, GPRS, IMT-2000 - International Mobile Communications, Wi-Fi, and Bluetooth). [**7**]

In addition to the services of 3G, 4 G will have some additional features such as Multi-Media Newspapers and T.V programs with the clarity as to that of an ordinary T.V.

In addition, we can send data much faster than that of the previous generations. Due to some key enabling technologies 4G systems are given the standard name Long Term Evolution (LTE)

Table 1.1: Transport Technologies [5], [6]

Transport Technology	Description	Data Rate	Bandwidth	Bands	Pros/cons
TDMA	Time Division Multiple Access is 2G technology	Up to 9.6kbps	-	850 MHz and 1.9 GHz	□□Low battery consumption □□Transmission is one-way □□Speed pales next to 3G technologies
GSM	Global System for Mobile Communications is a 2G digital cell phone technology	Up to 9.6 kbps	0.2 MHz	900 MHz or 1800 MHz	□□Popular around the globe. □□Worldwide roaming in about 180 countries. □□GSM's short messaging service (GSM-SMS) only transmits one-way. □□Can only deliver messages up to 160 characters characters long
GPRS	General Packet Radio Service is a 2.5G network that supports data packets	Up to 115 kbps	0.2 MHz	900 MHz or 1800 MHz	□□Messages not limited to 160 characters, like GSM SMS
EDGE	Enhanced Data GSM Environment is a 3G digital network	Up to384 kbps	0.2 MHz	900 MHz or 1800 MHz	□□May be temporary solution for operators □□unable to get

					W-CDMA Licenses
CDMA	Code Division Multiple Access is a 2G technology developed by Qualcomm that is transitioning to 3G	Up to 115kbps	1.23 MHz	800-MHz and 1.9-GHz	□□Although behind TDMA in number of subscribers, this fast-growing technology has more capacity than TDMA
W-CDMA (UMTS)	Wideband CDMA (also known as Universal Mobile Telecommunications System-UMTS) is 3G technology.	Up to 2 Mbps initially. Up to 10 Mbps by 2005, according to designers	1.25 MHz	850, 900, 1700, 1900, 2100, MHz	□□Likely to be dominant outside the United States. □□Good for roaming globally □□Commitments from U.S. operators are currently lacking, though AT&T Wireless performed UMTS tests in 2002. □□Primarily to be implemented in Asia-Pacific region
CDMA2000 1xRTT	A 3G technology, 1xRTT is the first phase of CDMA2000	Up to 144kbps	1.25 MHz	850, 900, 1700, 1900, 2100, MHz	□□Proponents say migration from TDMA is simpler with CDMA2000 than W-CDMA □□Spectrum use is more efficient □□W-CDMA will likely be more common in Europe
CDMA 2000 1xEV-DO	Delivers data on a separate channel	Up to2.4Mbps	1.25 MHz	850, 900, 1700, 1900, 2100, MHz	□□(see CDMA2000 1xRTT above)
CDMA 2000 1xEV-DV	Integrates voice and data on the same channel	Up to2.4Mbps	1.25, 3.75 MHz		□□(see CDMA2000 1xRTT above)

1.3 LONG TERM EVOLUTION (LTE)

Figure 1.1 shows the evolution of wireless communication standards from 1990 to 2010. Mobile networks continue to develop at an exciting pace. In ten years, mobile networks may well support services beyond that of today's multi-megabit fixed connections, while the amount of data traffic on mobile networks could surpass that of today's broadband connections in the next decade. As consumer demand grows forever richer services and connected lifestyles, mobile networks will be developed, and the mobile industry is already hard at work defining the technical solution that will allow mobile networks to meet the growing demand for wireless broadband services. The radio access technologies enabling these networks have been given the name Long Term Evolution of Universal Terrestrial Radio Access Network – or LTE for short.
LTE will be used for mobile, fixed and portable wireless broadband access, and will offer a number of benefits to operators, aimed at increasing capacity, reducing network complexity and thus lowering deployment and operational costs. It will enable operators to meet the growing demand for mobile data solutions, making it possible for richer services to be delivered to consumers more cost effectively [**9**].

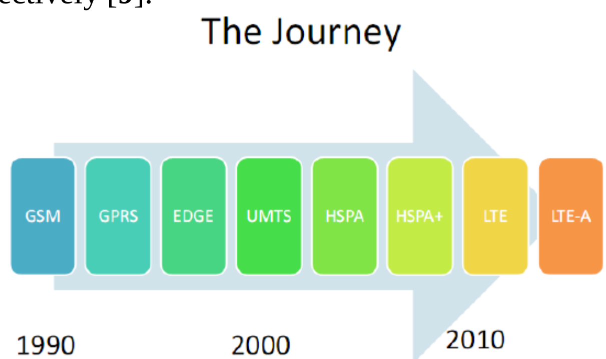

Figure 1.1: The Evolution of Wireless Communication Standards [8]

1.3.1 WHAT IS LTE?

LTE (Long Term Evolution) is the trademarked project name of a high performance air interface for cellular mobile telephony. It is a project of the 3rd Generation Partnership Project (3GPP), operating under a named trademarked by one of the associations within the partnership, the European Telecommunications Standards Institute. The recent increase of mobile data usage and emergence of new applications such as mobile TV, MMOG (Multimedia Online Gaming) and streaming contents have motivated the use of (LTE) standards. LTE is the latest in the mobile network technology that ensures competitive edge over its existing standards: GSM/EDGE and UMTS/HSxPA [**10**], where HSPA means High Speed Packet Access is a collection of two mobile telephony protocols, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing WCDMA protocols.
LTE, whose radio access is called "Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)", is expected to substantially improve end-user throughputs, sector capacity and reduce user plane latency, bringing significantly improved user experience with full mobility. With the emergence of Internet Protocol (IP) for carrying all types of traffic, LTE is scheduled to provide support for IP-based traffic with end-to-end Quality of service (QoS). Voice traffic will be

supported mainly as Voice over IP (VoIP) enabling better integration with other multimedia services. [**10**].

LTE uses Evolved Packet Core (EPC) network architecture to support the EUTRAN which reduces the number of network elements, simplifies functionality, improves redundancy, but most importantly allows for connections and hand-over to other fixed line and wireless access technologies in a flawless manner. The aggressive performance of LTE rely on physical layer technologies, such as, Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input Multiple-Output (MIMO) systems and Smart Antennas to achieve these targets. The main objective of LTE is to minimize the system and user-equipment complexities for high data throughput and reduced latency.

1.3.2 LTE BANDS

There are a large number of allocations or radio spectrum that has been reserved for FDD (Frequency Division Duplex) LTE use. Table 2 shows the 14 E-UTRAN band used by the LTE standard for each downlink and uplink for both UE (User Equipment) and eNB (evolved NodeB) with the minimum and maximum frequencies for downlink and uplink for every band. Also it shows more than 18000 channels divided to these bands.

Table 1.2: LTE FDD Frequency Bands and Channel Numbers [6]

E-UTRAN Band	Downlink (DL) (UE Receive, eNB Transmit)		Channel Numbers (N_{DL})	Uplink (DL) (UE Transmit, eNB Receive)		Channel Numbers (N_{UL})
	f_{DL_Low} (N_{UL}) (MHZ)	f_{DL_High} (MHZ)		F_{UL_Low} (MHZ)	F_{UL_High} (MHZ)	
1.	2110	2170	0-599	1920	1980	13000-13599
2.	1930	1990	600-1199	1850	1910	13600-14199
3.	1805	1880	1200-1949	1710	1785	14200-14949
4.	2110	2155	1950-2399	1710	1755	14950-15399
5.	869	894	2400-2649	824	849	15400-15649
6.	875	885	2650-2749	830	840	15650-15749
7.	2620	2690	2750-3449	2500	2570	15750-16449
8.	925	960	3450-3799	880	915	16450-16799
9.	1844.9	1879.9	3800-4149	1749.9	1784.9	16800-17149
10.	2110	2170	4150-4749	1710	1770	17150-17749
11.	1475.9	1500.9	4750-4999	1427.9	1452.9	17750-17999
12.	728	746	5000-5179	698	716	18000-18179
13.	746	756	5180-5279	777	787	18180-18279
14.	758	768	5280-5379	788	798	18280-18379

1.3.3 PERFORMANCE GOALS FOR LTE

E-UTRA is expected to support different types of services including web browsing, FTP (File Transfer Protocol), video streaming, VoIP (Voice over Internet Protocol), online gaming, real time video, push-to-talk and push-to-view. Therefore, LTE is being designed to be a high data rate and low latency system as indicated by the key performance criteria shown in Table 3. The bandwidth capability of a UE is expected to be up to 20 MHz for both transmission and reception. The service provider can however deploy cells with any of the bandwidths listed in Table 3. This gives flexibility to service providers to tailor their offering dependent on the amount of available spectrum or the ability to start with limited spectrum for lower upfront cost and grow the spectrum for extra capacity.

TABLE 1.3: LTE PERFORMANCE REQUIREMENTS [10]

Metric	Requirements
Peak Data Rate	DL: 100Mbps UL: 50Mbps (For 20MHz Spectrum)
Mobility Support	Up to 500Kmph but optimized for low speeds from 0-15kmph
Control Plane Latency (Transition Time to Active State)	<100ms (For Idle to Active)
User Plane Latency	<5ms
Control Plane Capacity	>200 users per cell (For 5MHz spectrum)
Coverage (Cell Size)	5-100Km with slight degradation after 30Km
Spectrum Flexibility	1.25, 2.5, 5, 10, 15 and 20 MHz

LTE has an instantaneous downlink peak data rate (DL) of 100 Mbps within a 20 MHz downlink spectrum allocation (5 bps/Hz) and an instantaneous uplink peak data rate (UL) of 50 Mb/s (2.5 bps/Hz) within a 20 MHz uplink spectrum allocation**.** The Control plane latency has a transition time of less than 100 ms from a camped state to an active state and less than 50 ms from a dormant state and an active state. The control plane capacity is at least 200 users per cell and is supported in the active state for spectrum allocations up to 5 MHz. The user plane latency is of less than 5ms in unloading condition (i.e. single user with single data stream) for small IP packet. The downlink average user throughput per MHz for 4G networks is 3 to 4 times larger and the uplink average user throughput per MHz is 2 to 3 times larger as compared to 3G networks**.** The target for spectrum efficiency of downlink in a loaded network is 3 to 4 times larger and for uplink it is 2 to 3 times larger. E-UTRAN should be optimized for low mobile speed from 0 to 15 km/h**.** The higher mobile speed between 15 and 120 km/h should be supported with high performance and mobility across the cellular network shall be maintained at speeds from 120 km/h to 350 km/h (or even up to 500 km/h depending on the frequency band).Throughput, spectrum efficiency and mobility targets above should be met for 5 km cells, and with a slight degradation for 30 km cells and the cells in a range up to 100 km should not be precluded.
Co-existence in the same geographical area and co-location with GERAN/UTRAN on adjacent channels is also accounted for. GERAN is an abbreviation for GSMEDGE Radio Access Network. The standards for GERAN are maintained by the 3GPP (Third Generation Partnership

Project). GERAN is a key part of GSM, and also of combined UMTS/GSM networks. GERAN is the radio part of GSM/EDGE together with the network that joins the base stations and the base station controllers. The network represents the core of a GSM network, through which phone calls and packet data are routed from and to the PSTN and Internet to and from subscriber handsets. A mobile phone operator's network comprises one or more GERANs, coupled with UTRANs in the case of a UMTS/GSM network.
A GERAN network without EDGE is a GRAN, but is otherwise identical in concept. A GERAN network without GSM is an ERAN

1.4 High Frequency Structure Simulator HFSS V. 12

HFSS is the industry-standard simulation tool for 3D full-wave electromagnetic field simulation. HFSS provides E- and H-fields, currents, S-parameters and near and far radiated field results. Intrinsic to the success of HFSS as an engineering design tool is its automated solution process where users are only required to specify geometry, material properties and the desired output. From here HFSS will automatically generate an appropriate, efficient and accurate mesh for solving the problem using the proven finite element method.

The core of the program HFSS is based on the **finite element method (FEM)** (its practical application often known as **finite element analysis** (FEA)) where it is a numerical technique for finding approximate solutions to partial differential equations (PDE) and their systems, as well as (less often) integral equations. FEM is a special case of the more general Galerkin method with polynomial approximation functions. The solution approach is based on eliminating the spatial derivatives from the PDE. This approximates the PDE with

- a system of algebraic equations for steady state problems,
- a system of ordinary differential equations for transient problems.

These equation systems are linear if the underlying PDE is linear, and vice versa. Algebraic equation systems are then solved using numerical linear algebra methods. Ordinary differential equations that arise in transient problems then numerically integrated using standard techniques such as Euler's method, Runge Kutta, etc.

There is a large number of open source and commercial finite element softwares. More recently, first web browser-based FEA applications became available such as in NC Lab.

In solving partial differential equations, the primary challenge is to create an equation that approximates the equation to be studied, but is numerically stable, meaning that errors in the input and intermediate calculations do not accumulate and cause the resulting output to be meaningless. There are many ways of doing this, all with advantages and disadvantages. The finite element method is a good choice for solving partial differential equations over complicated domains (like cars and oil pipelines), when the domain changes (as during a solid state reaction with a moving boundary), when the desired precision varies over the entire domain, or when the solution lacks smoothness. For instance, in a frontal crash simulation it is possible to increase prediction accuracy in "important" areas like the front of the car and reduce it in its rear (thus reducing cost of the simulation). Another example would be in Numerical weather prediction, where it is more important to have accurate predictions over developing highly nonlinear phenomena (such as tropical cyclones in the atmosphere, or eddies in the ocean) rather than relatively calm areas.

HFSS software automatically generates an appropriate, efficient and accurate mesh for solving the problem using the proven finite element method. With HFSS, the physics define the mesh; the mesh does not define the physics.

To solve the most demanding high-frequency simulations all of the HFSS solvers are equipped with High-Performance Computing (HPC) options including Domain Decomposition and Distributed Processing. These HPC options will decrease computation time and leverage existing computer resources to solve very large simulations.

Engineers rely on the accuracy, capacity, and performance of HFSS to design high-speed components including on-chip embedded passives, IC packages, PCB interconnects, and high-frequency components such as antennas, RF/microwave components, and biomedical devices **[11].**

1.5 THESIS MOTIVATION

In the recent years, there has been rapid growth in wireless communications. With the increasing number of users and limited bandwidth available, operators are trying hard to optimize the network for larger capacity and improved quality coverage. This has led to the field of antenna engineering to constantly evolve and accommodate the need for wideband, low-cost, miniaturized and easily integrated antennas [**12**].

Since LTE will be the technology used for the next generation of mobile communication which will be implemented by the end of this year and will be commercialized by the coming years, there will be a huge demand for it. Because of these reasons, mobile phones should be compatible with the technology mentioned above and in order to achieve this, mobile antennas should be properly designed according to the new LTE standards.

In this thesis, we propose an enhancement for the meander line antenna for designing an antenna within the LTE specifications in 0.78 and 2.5 GHz; where the band 0.7-0.8 GHz was used at 2010 in UEA and the band from 2.3-2.6 GHz will be used at 2015 in the Middle East [**13**].

1.6 THESIS OBJECTIVES

The objectives for this work are the following:

A. Analyze, design and optimize a single element meander line antenna system for LTE standards. The design should fit within a cellular phone handset size and satisfy the following requirements.
   a. Operating frequency of 0.780 and 2.5 GHz with a bandwidth greater than 40 MHz
   b. Size of the antenna should be small.

B. Select the best enhancement of the antenna that deal with satisfaction of LTE.

C. Design a new modification for the LTE antenna standards.

1.7 THESIS OVERVIEW

The thesis is organized in five chapters as follows:

Chapter 2 of this thesis starts with an introduction of the types of mobile printed antennas and electrically small antennas and it summarizes the reviewed literature. In Chapter 3, the analysis and design of a Meander Line Antenna (MLA) in 0.78GHz is described and compare it with the antenna for LTE in 0.78 GHz as shown in **[13].** Chapter 4 describes the analysis and design of an E-shape Meander Line Antenna in 2.5 GHz. The simulated (HFSS) radiation characteristics associated with the designed antenna will be discussed in this chapter also. Finally chapter 5 describes the conclusions drawn from this research work and recommendations on future work to be carried on this subject.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The development of small integrated printed antennas plays a significant role in the progress of rapidly expanding wireless communication applications. They are increasingly used in wireless communication systems due to advantages of being lightweight, compact and conformal.[**1**].

In mobile communications, meander line antennas are recently favored over other printed antennas due to its simplicity and ease in integration.

A more compact design of a meander line antenna was designed to operate at 2.4-GHz for WLAN application [2]. The researchers described two different designs of meander line antenna with and without conductor line. The designed antennas were fabricated on a double-sided FR-4 printed circuit board using standard PCB technique and tested with a Network Analyzer. A bandwidth of 152 MHz and return loss of -37.7dB were obtained at the operating center frequency of 2.4 GHz. The effect on the antenna radiation and reflection properties with varying the MLA length, width, number of turns and conductor dimensions are also discussed in this paper.

In [**3**], a meander line antenna with smaller dimensions (40 x 40 cm) is presented. The designed antenna exhibited a bandwidth of 274 MHz and return loss of -25 dB at a center frequency of 1.575 GHz.

Reference [**4**], discusses the design process of two electrically small printed antennas, suitable for mobile communication handsets. In this design, the resonant frequency of the antenna is significantly reduced by employing shorted patches, which maximizes the length of the current path for a given area. In the literature, reductions in operating frequencies are also achieved using different methods, such as; shorting posts [**5**], high dielectric constant material [**6**], resistive loads [**7**], and deformation of the conductor shape (in addition to using a shorting post) [**8**], each with their relative merits and disadvantages.

It is evident from the literature review that most of the designed antenna with reduced element size have the trend to use higher frequency bands (i.e. 2.4 GHz and 5.5 GHz) [**5**][**7**][**8**][**9**]. But very little references are available for designing low frequency antennas with limited size; the best of them is shown in [10], where the authors design the antenna for LTE mobile in 800 MHz but the antenna has a very small gain -16 dB. Similar antenna is available in [**11**], but it needs to be improved in terms of antenna efficiency and cost effectiveness.

In this research work, a 0.78 GHz and 2.5 GHz antennas with limited dimensions will be analyzed and designed for 4^{th} generation (LTE) of cellular.

2.2 PRINTED ANTENNA FOR MOBILE DEVICES

Planner antennas are low profile, cost-effective and flat in appearance which makes them suitable for recent communication systems, such as the Global System for Mobile (GSM; 890-960 MHz), the Digital Communication System (DCS; 1710-1880 MHz), the Personal Communication System (PCS; 1850-1990 MHz), the Universal Mobile Telecommunication

System (UMTS; 1920-2170), the Wireless Local Area Networks (WLANs) in the 2.4 GHz (2400-2484 MHz) and 5.2 GHz (5150-5350 MHz) bands [**11**] and Long Term Evolution (LTE) in the 700 MHz (758-798 MHz). LTE is a new standard for wireless communication that FCC has recently agreed to adopt for the 4th generation cellular phones. Before LTE antennas can be designed with confidence, basic characteristics of antennas in general needs to be understood.

2.2.1 ANTENNA BASICS

According to the IEEE Standard Definitions, the antenna or aerial is defined as "a means of radiating or receiving radio waves" [**12**]. In other words, antennas act as an interface for electromagnetic energy, propagating between free space and guided medium. Amongst the various types of antennas that include wire antennas, aperture antennas, reflector antennas, lens antennas etc., microstrip patches are one of the most versatile, conformal and easy to fabricate antennas.

Good antenna design is a critical factor in obtaining good range and stable throughput in a wireless application. This is especially true in low power and compact designs where antenna space is less than optimal. To obtain the desired performance, it is required that users have at least a basic knowledge about how antennas function and the design parameters involved. These parameters include selecting the correct antenna, antenna tuning, matching, gain/loss, and knowing the required radiation pattern.

2.2.1.1 BASIC ANTENNA PARAMETERS:

Some of the basic antenna characteristics that a designer should be familiar with before starting the design process are briefly described below:

Antenna gain

Relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions (isotropically) and has no losses.

Gain is 4π times the ratio of an antenna’s radiation intensity in a given direction to the total power accepted by the antenna. Peak gain, in turn, is the maximum gain over all the user-specified directions of the far-field infinite sphere.

The following equation is used to calculate the gain

$$Gain = 4\pi \frac{U}{P_{acc}}, \dots 2.1$$

where, $\{U\}$ is the radiation intensity in watts per steradian in the direction specified and $\{P_{acc}\}$ is the accepted power in watts entering the antenna.

Gain can be confused with directivity, since they are equivalent for lossless antennas. Gain is related to directivity by the radiation efficiency of the antenna. If the radiation efficiency is 100%, they are equal.

Peak Realized Gain

Realized gain is 4π times the ratio of an antenna’s radiation intensity in a given direction to the total power incident upon the antenna port(s).

Peak realized gain, in turn, is the maximum realized gain over all the user-specified directions of the far-field infinite sphere.
The following equation is used to calculate realized gain [**13**]

$$Realized\ Gain = 4\pi \frac{U}{P_{incident}}, \ldots 2.2$$

where, $\{U\}$ is the radiation intensity in watts per steradian in the direction specified, and $\{P_{\text{incident}}\}$ is the incident power in watts.

Antenna Directivity
It is defined by direction to the radiation intensity averaged over all directions.

$$D = D_{max}(\theta, \varphi) = \frac{\rho_{max}}{\rho_{ave}} = \frac{U_{max}}{U_{ave}}, \ldots 2.3$$

Peak Directivity
Directivity is defined as the ratio of an antenna's radiation intensity in a given direction to the radiation intensity averaged over all directions. Peak directivity, in turn, is the maximum directivity over all the user-specified directions of the far-field infinite sphere. [**13**]
Directivity is a dimensionless quantity represented by

$$Directivity = 4\pi \frac{U}{P_{rad}}, \ldots 2.4$$

where, $\{U\}$ is the radiation intensity in watts per steradian in the direction specified and $\{P_{\text{rad}}\}$ is the radiated power in watts.

• For a lossless antenna, the directivity will be equal to the gain. However, if the antenna has inherent losses, the directivity is related to the gain by the radiation efficiency of the antenna.

Antenna Bandwidth
The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations. [**12**].

Antenna Radiation Patterns
An antenna radiation pattern is a 3-D plot of its radiation far from the source. Antenna radiation patterns usually take two forms, the elevation pattern and the azimuth pattern. The elevation pattern is a graph of the energy radiated from the antenna looking at it from the side (E-Plane). The azimuth pattern is a graph of the energy radiated from the antenna as if you were looking at it from directly above the antenna (H-Plane).

Maximum intensity (Max U)

The radiation intensity $\{U\}$ is the power radiated from an antenna per unit solid angle. The maximum intensity of the radiation is measured in watts per steradian and is calculated by [**13**]

$$U(\theta,\varphi) = \frac{|E|}{\eta_0} r, \dots 2.5$$

where, $\{ U(\theta,\varphi)\}$ is the radiation intensity in watts per steradian, $\{|E|\}$ is the magnitude of the E-field, $\{\eta_0\}$ is the intrinsic impedance of free space and it is equal to 376.7 ohms, $\{r\}$ is the distance from the antenna, in meters.

Radiated Power

Radiated power is the amount of time-averaged power (in watts) exiting around? a radiating antenna structure through a radiation boundary.

For a general radiating structure, radiated power is computed as [**13**]

$$P_{rad} = Re\left\{\iint_s E \text{ x} H^{*}. ds\right\}, \dots 2.6$$

where, $\{P_{rad}\}$ is the radiated power in watts; {Re} is the real part of a complex number, $\{s\}$ represents the radiation boundary surfaces, $\{E\}$ is the radiated electric field, $\{H^*\}$ is the conjugate of **H** and $\{ds\}$ is the local radiation boundary unit normal directed out of the 3D model.

Accepted Power

The accepted power is the amount of time-averaged power (in watts) entering a radiating antenna structure through one or more ports. For antennas with a single port, accepted power is a measure of the incident power reduced by the mismatch loss at the port plane. [**13**]

For a general radiating structure, accepted power is computed as

$$P_{acc} = Re\left\{\iint_A E \text{ x} H^{*}. ds\right\}, \dots 2.7$$

where, $\{P_{acc}\}$ is the accepted power in watts, {Re} is the real part of a complex number, $\{A\}$ is the union of all port boundaries in the model, $\{E\}$ is the radiated electric field, $\{H^*\}$ is the conjugate of **H** and $\{ds\}$ is the local port-boundary unit normal directed into the model.

For the simple case of an antenna with one lossless port containing a single propagating mode, the above expression reduces to [**13**]

$$P_{acc} = |a|^2(1 - |S_{11}|^2), \dots 2.8$$

where, $\{a\}$ is the complex modal excitation specified, $\{S_{11}\}$ is the reflection coefficient of the antenna.

Incident Power

Incident power is the total amount of time-averaged power (in watts) incident upon all port boundaries of an antenna structure.

For the simple case of an antenna with one lossless port containing a single propagating mode, the incident power $P_{incident}$ is given by [**13**]

$$P_{incident} = |a|^2, \ldots 2.9$$

where, $\{a\}$ is the complex modal excitation specified.

Radiation Efficiency

The radiation efficiency is the ratio of the radiated power to the accepted power given by [**13**]

$$e = \frac{P_{rad}}{P_{acc}}, \ldots 2.10$$

where, $\{P_{rad}\}$ is the radiated power in watts, $\{P_{acc}\}$ is the accepted power in watts.

Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse.

Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna.

With linear polarization the electric field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omnidirectional antennas always have vertical polarization. With horizontal polarization, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized.

In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be righthand or lefthand. Choice of polarization is one of the design choices available to the RF system designer.

Input Impedance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same.

Transceivers and their transmission lines are typically designed for 50Ω impedance. If the antenna has impedance different from 50 Ω, then there is a mismatch and an impedance matching circuit is required.

2.2.1.2 MINIATURIZATION TRADE-OFFS

To satisfy the object of this project, an LTE printed antenna needs to be designed with pre-specified dimensions. Since these dimensions are small, size of the existing printed antennas needs to be reduced. But reducing the size of the antenna results is reduced performance. Some of the parameters that suffer in this process are:

- Reduced efficiency (or gain)
- Shorter range
- Smaller useful bandwidth
- More critical tuning
- Increased sensitivity to component and PCB spread
- Increased sensitivity to external factors

Several performance factors deteriorate with miniaturization, but some antenna types tolerate miniaturization better than others. How much a given antenna can be reduced in size depends on the actual requirements for range, bandwidth, and repeatability. In general, an antenna can be reduced to half its natural size with moderate impact on performance. However, after a 1/2 reduction, performance becomes progressively worse as the radiation resistance drops off rapidly. As loading and antenna losses often increase with reduced size, it is clear that efficiency drops off quite rapidly [**14**].

2.2.1.3 TYPES OF PRINTED ANTENNA

The leading printed antennas commonly used in embedded applications are: Microstrip Lines/Patch, Planar Inverted 'F' (PIFA), Meander Line (MLA) etc. Microstrip lines are an extension of the monopole. They can be easily fabricated by etching a copper strip of the radio circuit board. While very inexpensive to make, its performance is limited by surrounding electronics on the circuit board. Microstrip monopole is also only a single-frequency solution. Patch antennas are a good choice for a system that requires a beam pattern focused in a certain direction. Patches are fabricated out of square or round copper clad on the top surface of a circuit board. Their radiation beam is normal to the surface of the board. One antenna type becoming increasingly popular is planar inverted F antenna (PIFA). The PIFA antenna literally looks like the letter 'F' lying on its side with the two shorter sections providing feed and ground points and the 'tail' providing the radiating surface. PIFAs make good embedded antennas in that they exhibit a somewhat omnidirectional pattern and can be made to radiate in more than one frequency band.

PIFA has a low profile, and it can easily be incorporated into wireless handsets. PIFA antennas are generally used with a ground plane, which is generally the cellular phone circuit board ground plane. The Meander Line Antenna (MLA) is a new type of radiating element, made from a combination of a loop antenna and frequency tuning meander lines.

The electrical length of the MLA is made up mostly by the delay characteristic of the meander line rather than the length of the radiating structure itself. MLAs can be designed to exhibit broadband capabilities that allow operation on several frequency bands. For the base stations classical dipoles are very common. The common dipole has long been recognized as an efficient radiator when cut to the appropriate frequency length. It is made from bending the end of an open circuit two-wire transmission line into a 'T' shape, where the top of the 'T' is the radiating section of the antenna. The length of the top is lambda, the wavelength of the signal. In some applications also monopole antennas with $\lambda/2$ or $\lambda/4$ length mounted over ground plane are used. There are also special antenna constructions for special applications. When you need to flood a wide but defined area with RF energy, such as for perimeter security systems, tunnels, and cellular- or 802.11-system interior zones, one approach is to use an RF-leaky feeder cable to provide controlled radiation.

2.2.1.3.1 MICROSTRIP PATCH ANTENNA

In its simplest form a microstrip antenna consists of a dielectric substrate sandwiched between two conducting surfaces: the antenna plane and the ground plane.

The simplified microstrip patch antenna is shown in Figure 2.1.

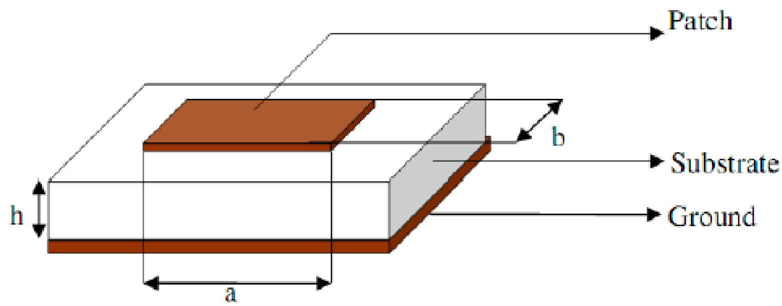
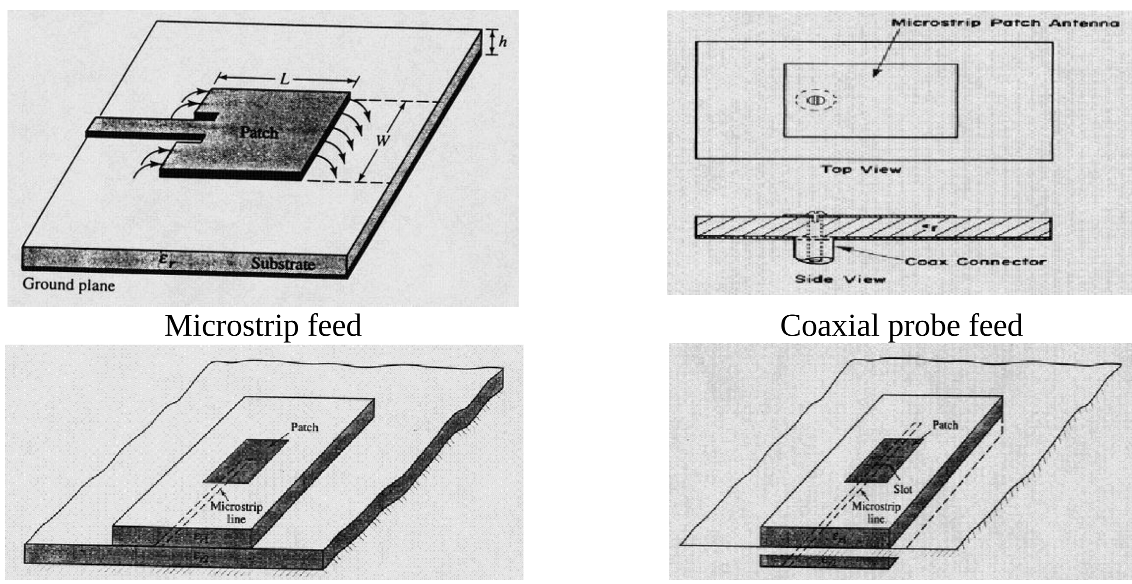


Figure 2.1: Basic rectangular microstip patch antenna construction

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. Since the propagating EM fields lay, both in the substrate and in free space, a quasi-TEM mode is generated. The length and width of the patch are given by (*a*) and (*b*) respectively. The substrate thickness is given by *h*.
Microstrip antennas are often fed using; Microstrip Line feed [**15**], Coaxial feed [**16**], Proximity coupled and Aperture coupled [**17**] techniques, each with their own advantages and disadvantages as shown in Figure 2.2 [**12**].



Microstrip feed — Coaxial probe feed

Proximity coupling — Aperture coupling

Figure 2.2: Microstrip Antenna Feeding Methods

Along with a number of advantages [**18**] microstrip antennas also suffer from some disadvantages [**15**] [**16**] like narrow bandwidth, low efficiency, low Gain, spurious radiation and surface wave excitation. While spurious radiation and surface waves can be eliminated by using the right feed mechanisms and substrate thickness [**15**], the issues of major concern are poor bandwidth and low radiation efficiency. [**15**]
In order to achieve greater bandwidth and gain we must increase substrate thickness but this could result in surface waves [**16**].

2.2.1.3.2 PLANAR INVERTED F ANTENNA

The planar inverted F antenna is popular for portable wireless devices because of its low profile, small size, and built-in structure [**19**]. The other major advantages are easy fabrication, low manufacturing cost, and simple structure [**20**]. Conventional PIFA has limited bandwidth of 4 % to 12 % for a -10 dB return loss [**21**]. Also, PIFA's inherent bandwidth is higher than the bandwidth of the conventional patch antenna (since a thick air substrate is used). The basic PIFA is a grounded patch antenna with λ/4 patch lengths instead of the conventional λ/2. As shown in Figure 2.2, a PIFA consists of a ground plane, a top plate element, a feed wire feeding the resonating top plate, and a DC shorting plate that is connecting the ground and the top plate at one end of the resonating patch.

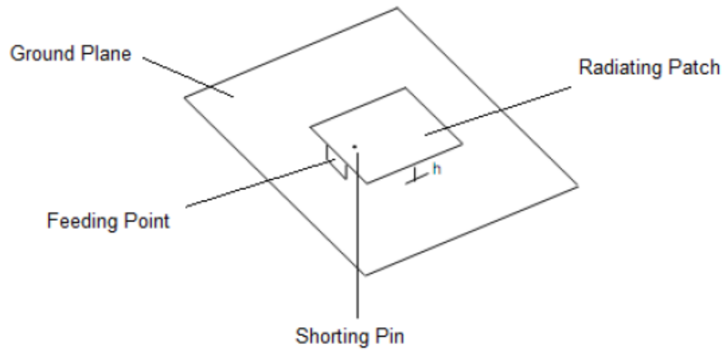


Figure 2.3: Planar Inverted F Antenna

PIFA creates an exceptionally uniform 3D signal sphere through its inverted-F design, which generates an Omni-directional signal field.

2.2.1.3.3 MEANDER LINE ANTENNA

Meander Line Antenna is a type of printed antenna that achieves miniaturization in size by embedding the wire structure on a dielectric substrate. MLA technology was originally developed by BAE SYSTEMS (a former Lockheed Martin Company) [**22**], for the Information and Electronic Warfare Systems (IEWS), which require high performance antennas for both satellite and terrestrial communications. Recently, this class of antennas are found to be suitable for application mobile handsets; wireless data networking for laptops, PC cards and access points. In basic form meander line antenna is a combination of conventional wire and planer strip line. Benefits include configuration simplicity, easy integration to a wireless device, inexpensive and potential for low Specific Absorption Rate (SAR) features. **SAR** is a measure of the rate at which energy is absorbed by the body when exposed to a radio frequency (RF) electromagnetic field. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram. In comparison to other popular two-dimensional antenna types, such as IFA (Inverted-F Antenna) and PIFA (The Planar Inverted F Antenna), the 3D signal generated by the cubic structure of IFA and PIFA-type antennae offers double the surface area of other antennas guaranteeing the highest levels of antenna efficiency for enhanced transmission and reception.

2.2.1.3.3.1 DESIGNING OF MEANDER LINE ANTENNA

In a meander line antenna (also called rampart line antenna), the radiating element consists of a meandering microstrip line formed by a series of sets of right angled compensated bends, as shown in Figure 2.4. The fundamental element in this case is formed by four right angled bends and the radiation mainly occurs from the discontinuities (bend) of the structure. The right angle bends are chamfered or compensated to reduce the right angled discontinuity susceptance for impedance matching. The current directions are changing in every half wavelength and there are more than four half wavelength changes in this design. The radiations from the bend add up to produce the desired polarization depending on the dimensions of the meander line antenna.

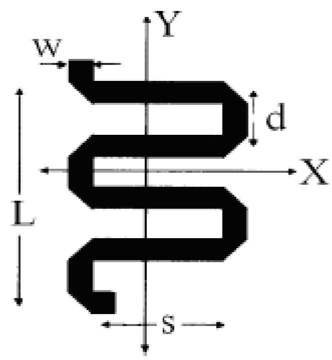


Figure 2.4: The Fundamental Section of the Meander Line Antenna

2.3 ELECTRICALLY SMALL ANTENNA

The fundamental limits on small antenna performance are available in the literature. In 1947 [**23**], Wheeler investigated the effects of antenna effective volume on radiation efficiency and bandwidth. Wheeler described an electrically small antenna as one with a maximum geometrical dimension much less than the radian length. The radian length is a distance measurement equal to $\lambda/2\pi$. This is a convenient definition because a sphere with diameter equal to the radian length contains most of the stored near-field energy of the electrically small antenna. A year later, Chu derived an approximate lower limit for the radiation Q of an electrically small antenna [**24**] Recently, McLean derived an exact lower limit and corrected apparent errors in the derivation of Q. [**25**]. In 1987 the monograph Small Antennas by Fujimoto, Henderson, Hirasawa and James summarized the approaches used to design electrically small antennas (ESA) [**26**].

2.3.1 FUNDAMENTAL LIMITATIONS

Since an ESA is contained within a given volume it has an inherent minimum value of Q thus there exists a limit on the attainable maximum impedance bandwidth of an ESA [**3**]. Note that antennas operating at frequencies outside their normal operating range of Q-factor (also called Quality Factor) are of little practical utility. Electrically small and low-profile antennas are both subject to performance limitations due to size reduction. These classes of antennas have low efficiencies, and are difficult to match to a transmission line due to low input resistance and high input reactance. In addition, ESAs typically exhibit narrow impedance bandwidth, which is an important parameter in the antenna design process.

2.3.2 LIMIT ON RADIATION EFFICIENCY

Generally Q is defined in terms of the ratio of the energy stored in the resonator to the energy being lost in one cycle:

$$Q = 2\pi \frac{Energy\ Stored}{Energy\ Dissipated\ Per\ Cycle}, \dots 2.11$$

The Q factor is commonly used to describe the ratio of the reactance to the resistance in a device. So equation (2.11) can be written as

$$Q = \frac{2\pi X}{R}, \dots 2.12$$

where X is the reactance or stored energy, and R is the ohmic resistance. Analogously, Chu defines the radiation Q for an antenna as

$$Q = \frac{2\omega W}{P_{rad}}, \dots 2.13$$

where ω is the radian frequency, P_{rad} is the radiated power, and W is the time-averaged, non-propagating, stored electric or magnetic energy, whichever is greater [**24**]. Electrically small antennas have high input reactance and low input resistance.
Therefore, they have high Q and low frequency bandwidth. ESAs also have low radiation efficiency. The radiation efficiency of an antenna is defined by

$$\eta_a = \frac{R_r}{R_r + R_m}, \dots 2.13$$

where R_r is the radiation resistance of the antenna and R_m refers to the ohmic losses in the antenna structure and any matching device. The radiation efficiency (η_a) of a receiving antenna is the fraction of energy delivered by the antenna from free space to a load representing the receiver [**25**]. Every small antenna can be made to perform like a lumped reactance, specifically, a capacitor, inductor, or some combination of the two. An electric dipole, or dipole antenna, behaves like a capacitor. A magnetic dipole, or loop antenna, behaves like an inductor. Either antenna can be represented by some combination of a reactive and a resistive lumped element. The reactance in the equivalent circuit describes the portion of the input energy that is stored in the near-field of the antenna. The resistive element represents the radiation resistance of the antenna. Wheeler models the magnetic dipole as a series inductance and resistance and the electric dipole as a shunt capacitance and susceptance [**25**]. This representation is consistent with circuit duality. Both equivalent circuits are illustrated in Figure 2.5.

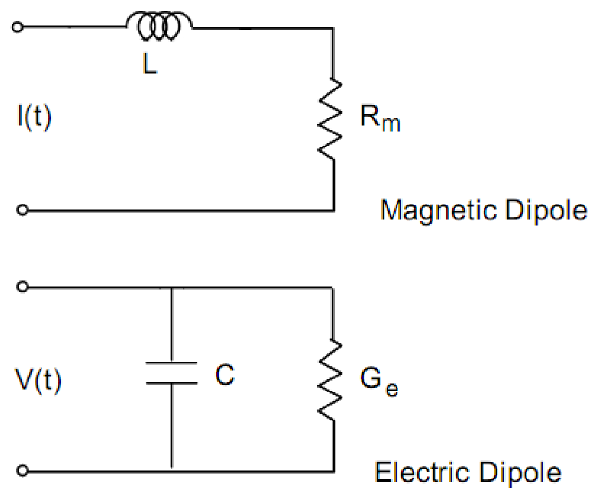


Figure 2.5: Equivalent Circuits of a Magnetic and Electric Dipole

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CHAPTER 3

ANALYSIS AND DESIGN OF MEANDER LINE ANTENNA FOR LTE MOBILE COMMUNICATIONS IN 0.78 GHZ

3.1 INTRODUCTION

In chapter 2, we described some types of MLA that deal with LTE in the band 0.78 and 2.5 GHz. In this chapter, we will analyze and design the structure that has better gain and bandwidth for LTE mobile communications.

A microstrip patch antenna consists of a dielectric substrate, with a ground plane on the other side. Due to its multiple advantages such as low weight , low profile planar configuration, low fabrication cost and capability to integrate with microwave integrated circuits technology, the microstrip patch antenna is very well suited for applications such as wireless communications system, cellular phones, pagers, radar systems, and satellite communications systems [1].

The development of small-integrated antennas plays a significant role in the progress of the rapidly expanding military and commercial communication applications.

The gain, the bandwidth enhancement and its return loss improvement without increasing antenna size and production process are important to apply this antenna to the modern mobile communication systems and need to be carried out [2].

The MLA in [3] was designed for GSM mobile application in 0.9 GHz as shown in Figure 3.1. In this chapter, we modify this antenna for LTE mobile communication (as shown in Figure 3.2) is designed at resonant frequency 0.78 GHz and we will in this chapter describe how to reach this design antenna.

A comprehensive parametric study has been carried out to understand the effects of various dimensional parameters as shown in section 3.2. Because electromagnetic optimization parameters can be either continuous, discrete, or both, making the design process slow and complicated, many researchers have applied genetic algorithms to the design of broadband patch antennas [4-5]. A Genetic algorithms optimum approach of the dimension of MLA based on the combination of GA with the commercial electromagnetic simulation tool, the FEM based software, HFSS by ANSOFT. The attractiveness of GA optimization is that improved bandwidth performance doesn’t increase overall dimensions or manufacturing cost. The design process of MLA optimization with GA is described in Section 3.3. In Section 3.4 the GA optimized antenna designs and results are proposed. In section 3.5 we apply this antenna on other substrate materials. Finally the conclusion is written in Section 3.6.

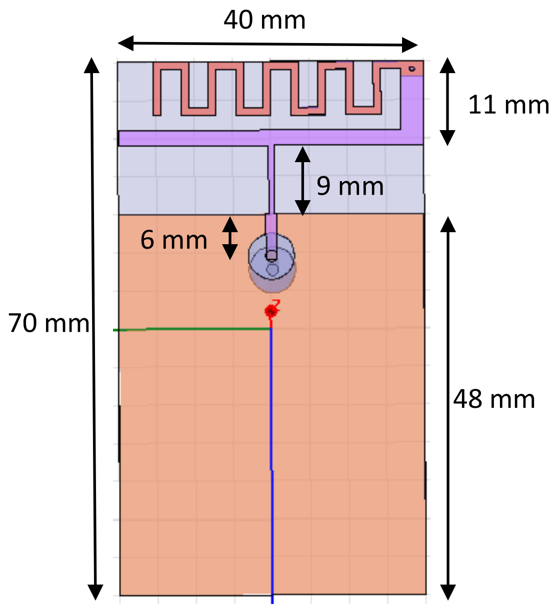


Figure 3.1: MLA Antenna in [3]

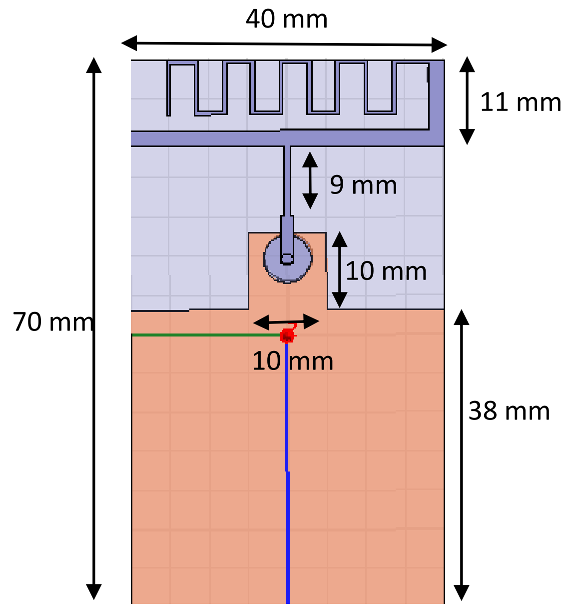


Figure 3.2:MLA antenna for LTE in 0.78 GHZ

3.2 PARAMETRIC STUDY

A substrate with dielectric permittivity of 4.7 and thickness of 0.8 mm is selected to obtain a compact radiation structure that at the same time meets the demanding bandwidth specification. The antenna is fed by a 50-Ω SMA connector.

The technique of setting value of some parameters for the resonant frequency can be done step by step. The first consideration is to design the dimensions of antenna as shown in Figure 3.2, where the initial value for all the dimensions in the antenna is 0.5 mm. The parameters w_1, w_2, w_3 *and* w_4 are set as variables and to show how their effects on the bandwidth and the gain of the MLA.

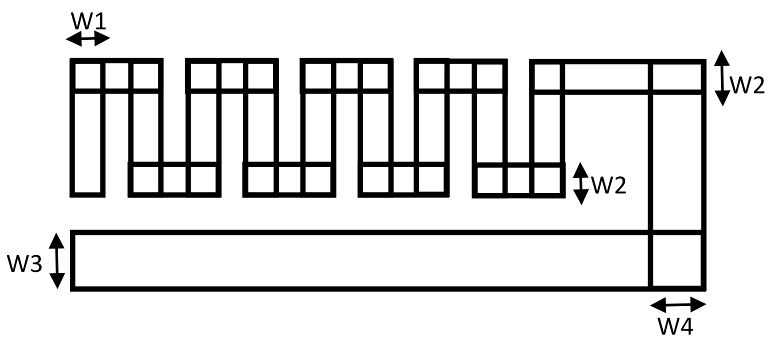


Figure 3.3: Parameters in MLA

Step 1:

- Change the height of the ground from 40 mm to 50 mm with step 0.5mm and fix the other parameters.

- The simulation result of return loss S11 is shown in Figure 3.4.

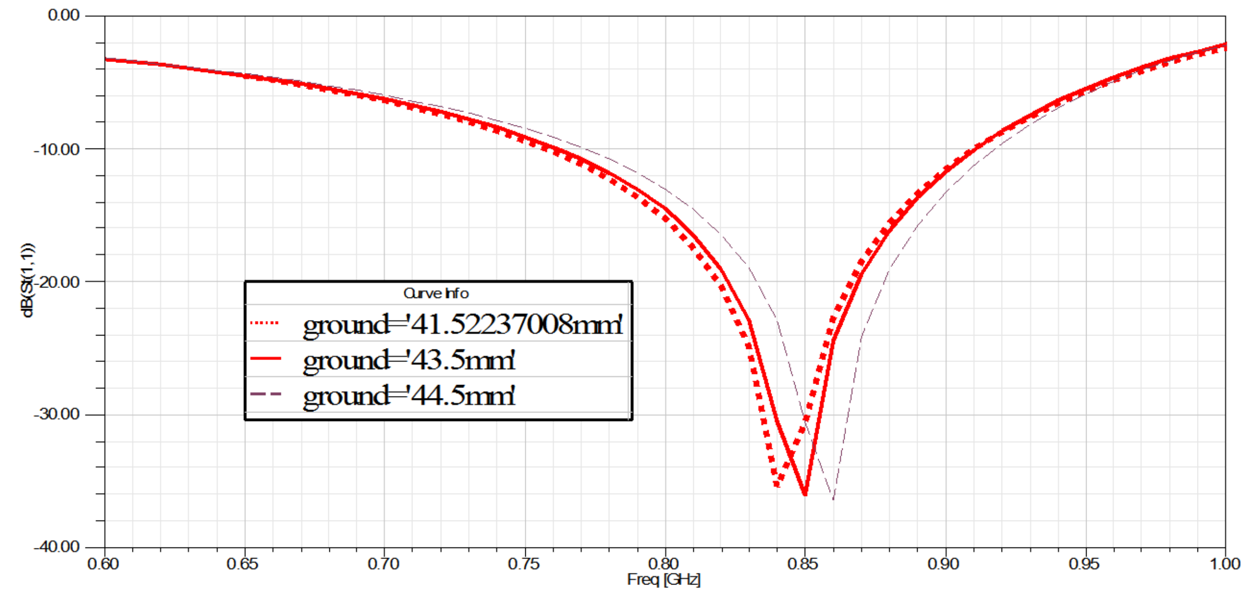


Figure 3.4: Return loss for the different height of the ground

Figure 3.5 shows that the resonant frequency is increasing when the height of the ground is increased. The best result is obtained when the ground height is 41.5 mm, where it has the bandwidth of 155 MHz. In the next step we study the effect of the other parameters.

Step 2:

- Choosing the optimum result of S11 from step 1 (*height of the ground is 41.5* mm), and varying the width $w_1$by a step of 0.5 mm from 0.0 mm to 2.5 mm and fixing the other parameters. The return loss is shown in Figure 3.5. It can be seen that when the width w_1 is increasing, the resonant frequency is also increasing. In this case, increasing width w_1 could affect the resonant frequency and bandwidth as shown in Figure 3.6, where the best value is obtained when increasing w_1 is 0.0 mm. The resonant frequency is 0.8 GHz, the bandwidth is 130 MHz and the maximum gain for the entire phi and theta is shown in Figure 3.7 and 3.8. Now in the next step we study the effect of the other parameters.

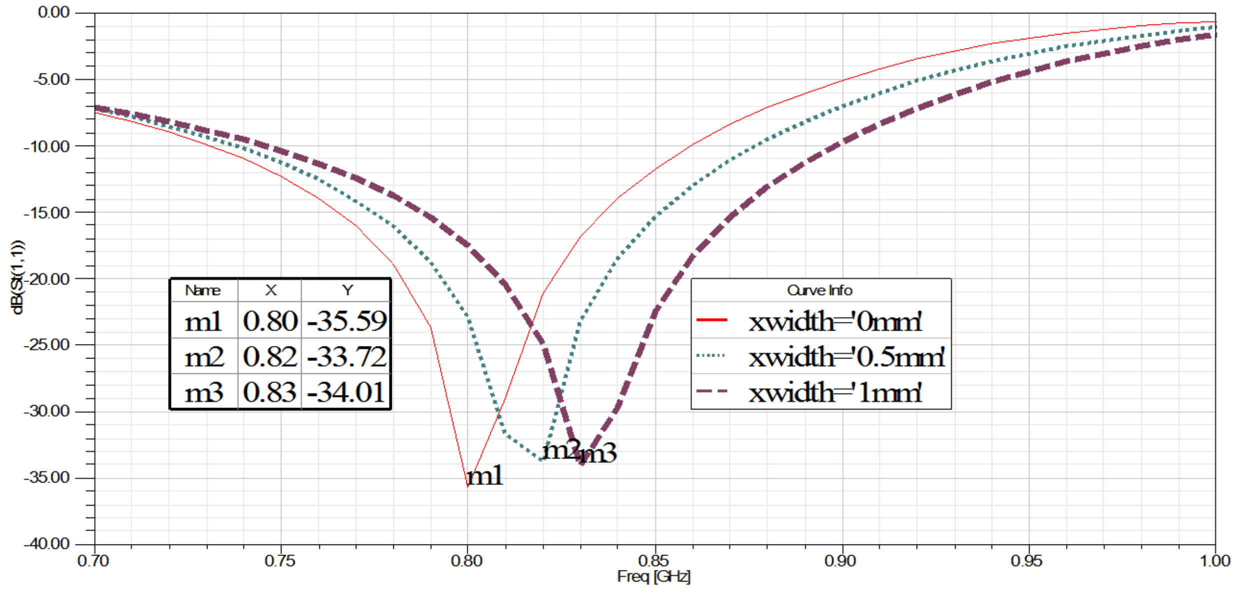


Figure 3.5: Return loss for the different values for the width w1

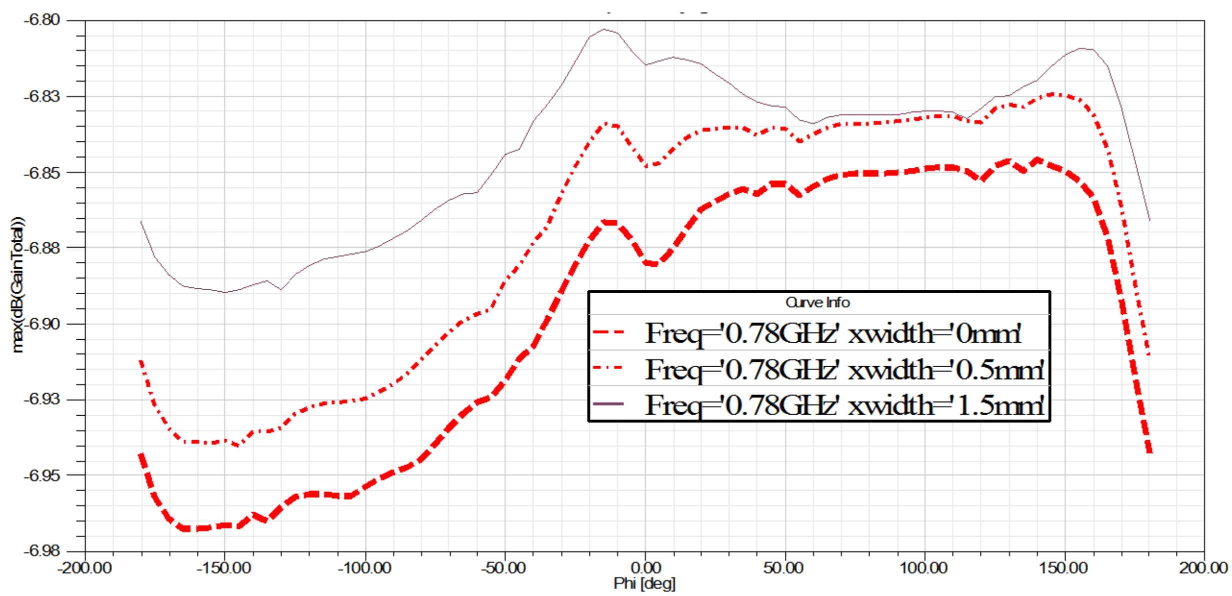


Figure 3.6: Max gain for the resonant frequency at the phi from -180^0 to 180^0 for different values of w1

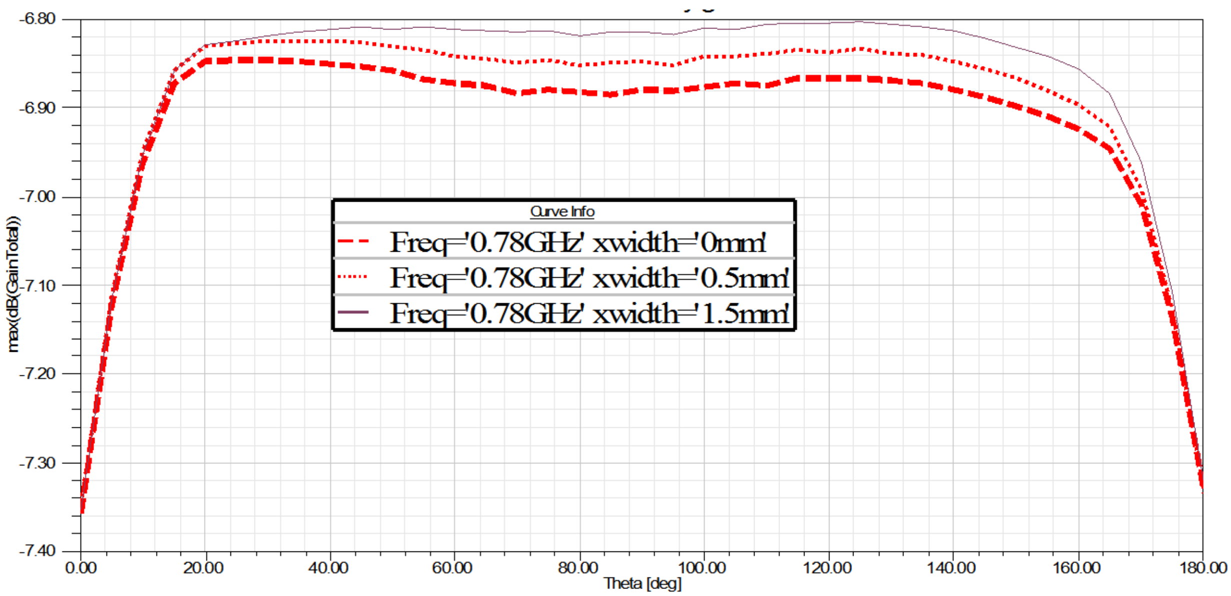


Figure 3.7: Max gain for the resonant frequency at the theta from 0^0 to 180^0 for different values of w1

Step 3:

- Choosing the optimum result of S11 from step 1 (*height of the ground is 41.5 mm and w_1=0.0 mm*), and vary width w_2 by step 0.5 mm from 0.0 mm to 2.5 mm and fix all other parameters.

- The characteristic of the return loss is shown in Figure 3.8. It is shown that, when the width w_2 is increasing, the resonant frequency increases. In this case, increasing width w_2 could affect the resonant frequency and bandwidth, where the best value is found when increasing w_2 equal 0.0 mm too, where the resonant frequency is 0.79 GHz, the bandwidth is 130 MHz and the maximum gain at the resonant frequency for entire phi and theta is shown in Figure 3.9 and 3.10. Now in the next step we will parameterize the width w_3.

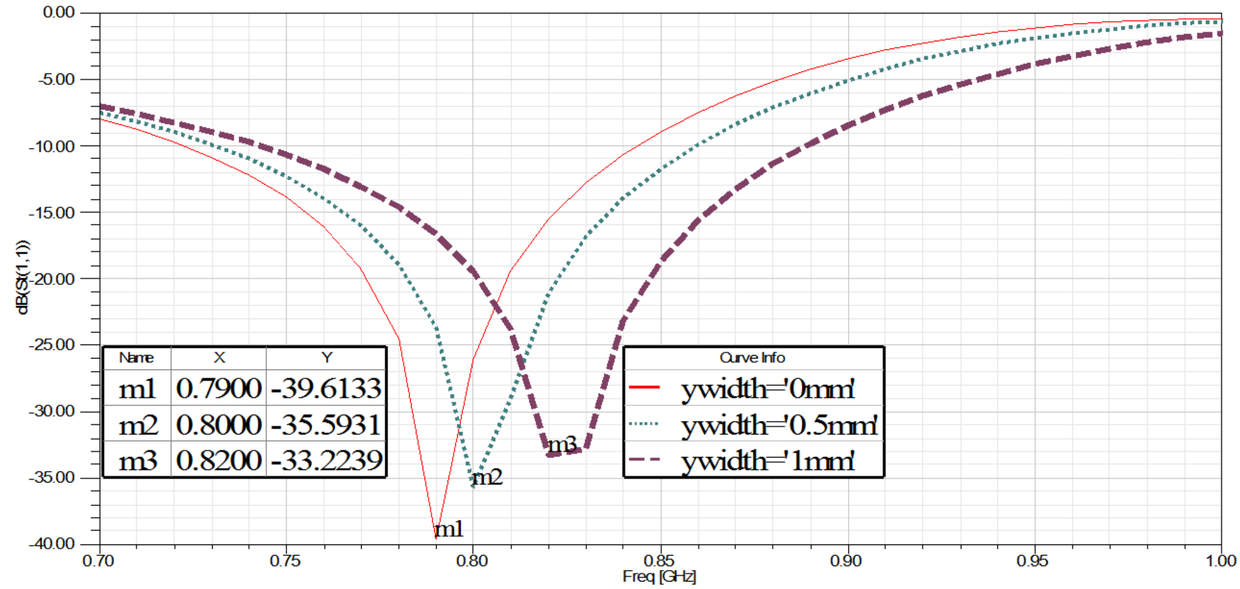


Figure 3.8: Return loss for varying the width w2

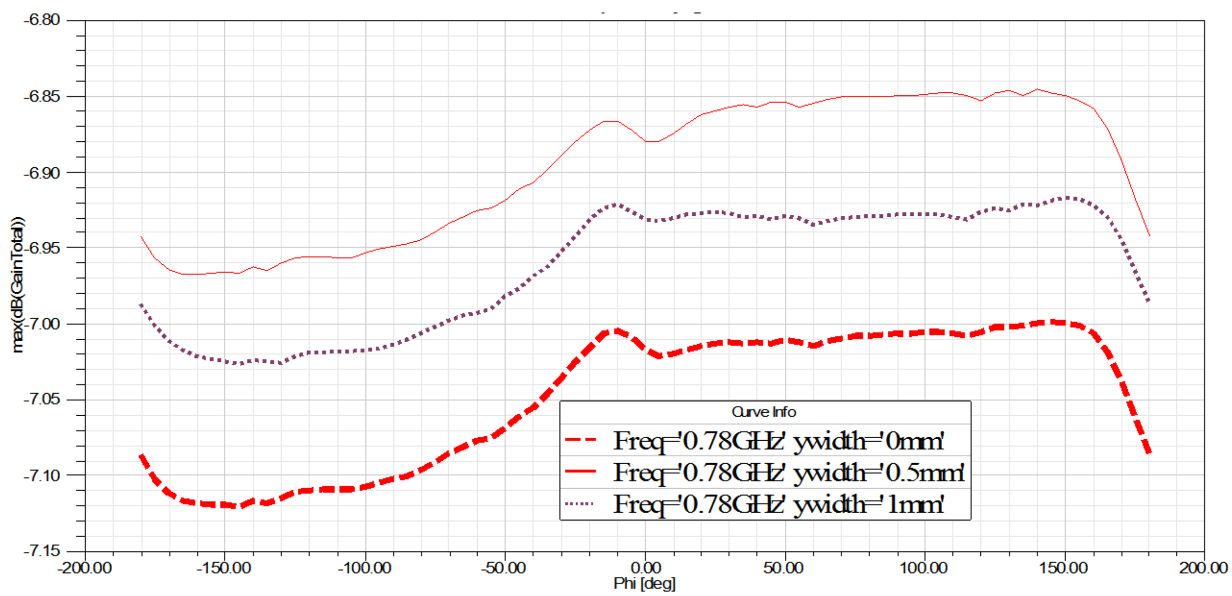


Figure 3.9: Max gain for the resonant frequency at the phi from -180^0 to 180^0 for different values of w2

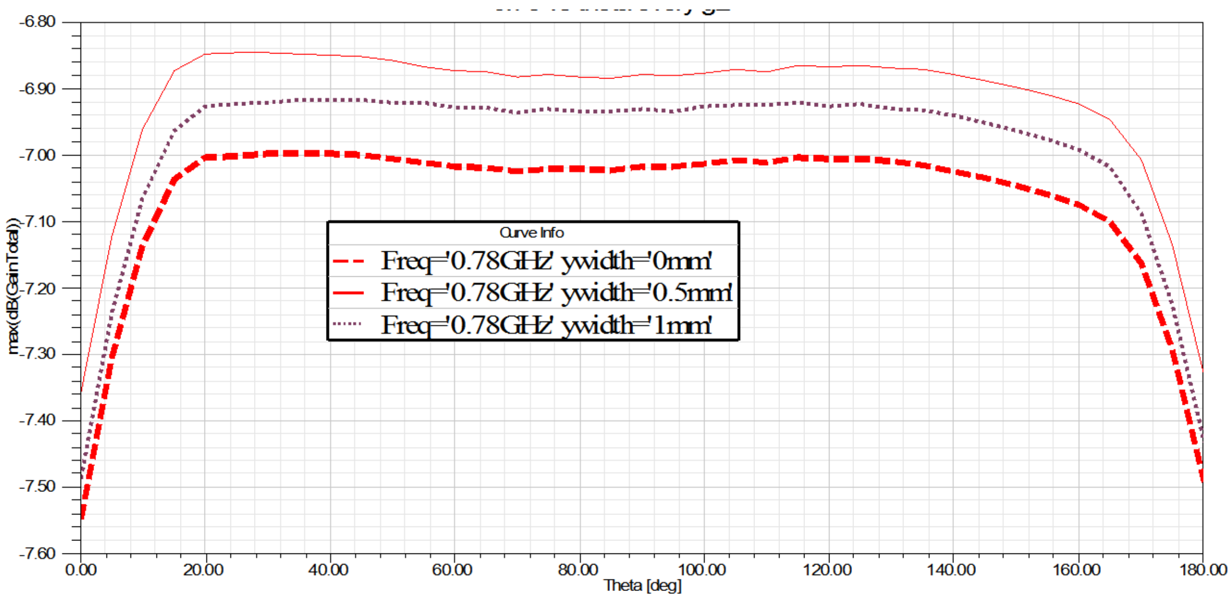


Figure 3.10: Max gain for the resonant frequency at the theta from 0^0 to 180^0 for different values of w2

Step 4:

- Choosing the optimum result of S11 from step 3 (*height of the ground is 41.5, w_1=0.0 and w_2 =0.0 mm*), and vary width w_3 by step up 0.5 mm from 0.0 mm to 2.5 mm and fix all other parameters.

- The characteristic of return loss is shown in Figure 3.11. It is shown also that, when the width w_3 is increasing, the resonant frequency increases. In this case, increasing width w_3 could affect the resonant frequency and bandwidth, where the best value is found when w_3 equal 1.3 mm, where the resonant frequency is 0.78 GHz, the bandwidth is 120 MHz and the maximum gain at the resonant frequency for entire phi and theta is shown in Figure 3.12 and 3.13. Now in the next step we will parameterize the width w_4.

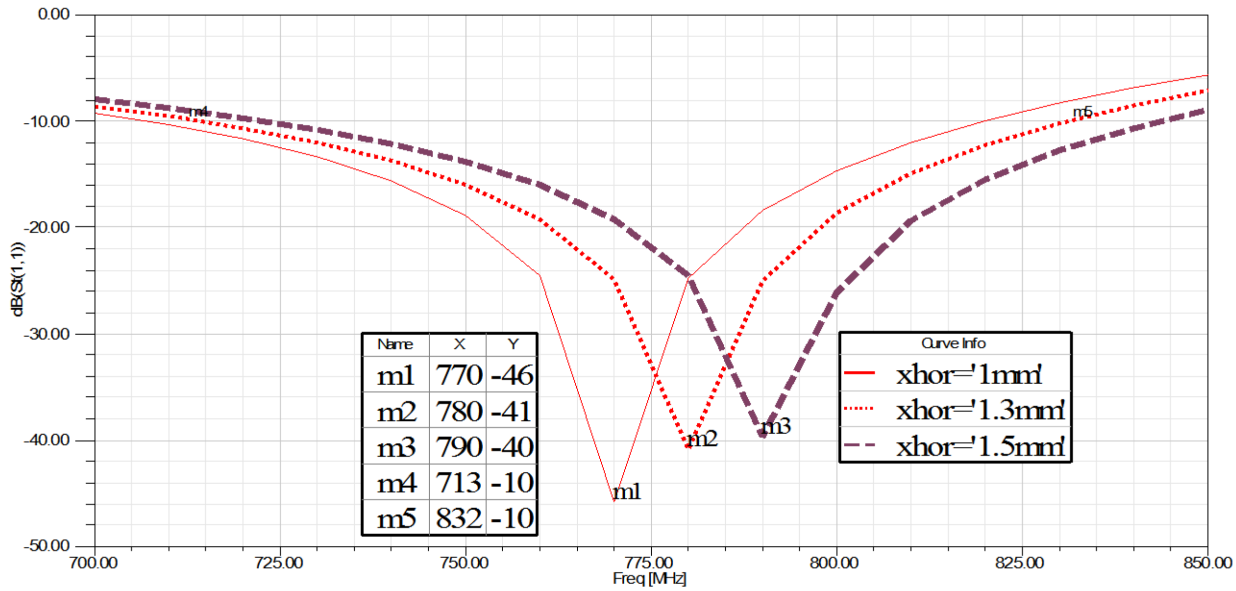


Figure 3.11: Return loss for the different width of w3

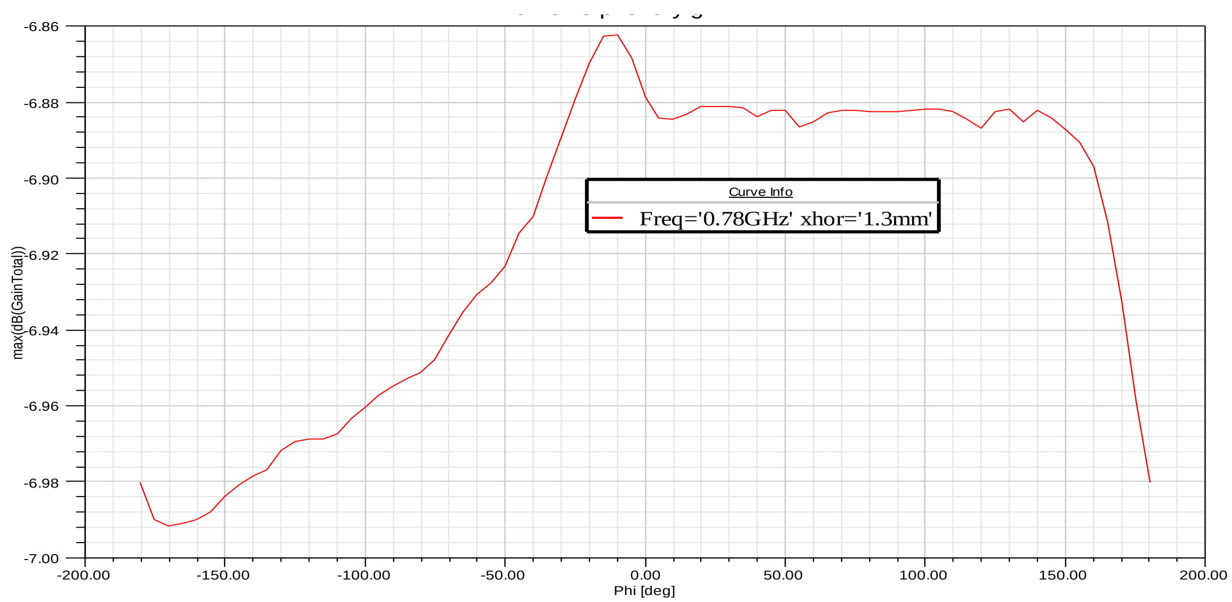


Figure 3.12: Max gain for the resonant frequency at the phi from -180^0 to 180^0 for different values of w3

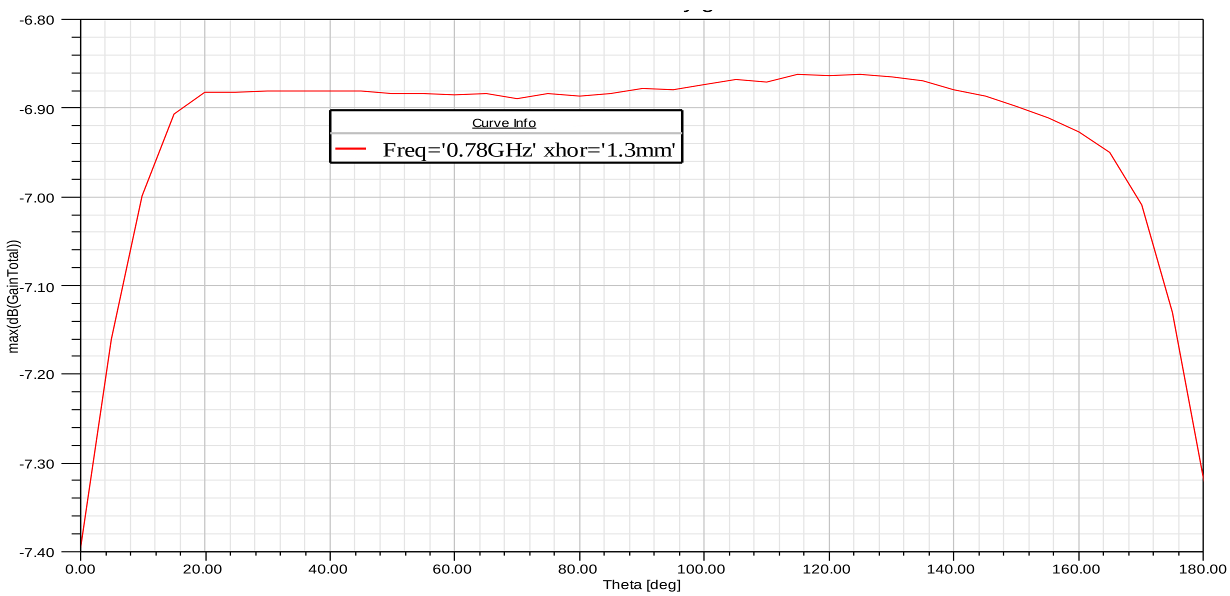


Figure 3.13: Max gain for the resonant frequency at the theta from 0^0 to 180^0 for different values of w3

Step 5:

- Choosing the optimum result of S11 from step 3 (*height of the ground is 41.5 mm, w_1=0.0, w_2= 0.0 mm and w_3=1.3 mm*), and vary width w_4 by step up 0.5 mm from 0.0 mm to 2.5 mm and fix all other parameters.

- Finally, the characteristic of return loss is shown in Figure 3.14. It is shown that, when the width w_4 is increasing, the resonant frequency is increasing. In this case, increasing width w_4 could affect the resonant frequency and bandwidth as shown in Figure 3.15, where the best value is found when w_4 equal 1.5 mm, where the resonant frequency is 0.78 GHz, the bandwidth is 120 MHz and the maximum gain at the resonant frequency for entire phi and theta is shown in Figure 3.16 and 3.17.

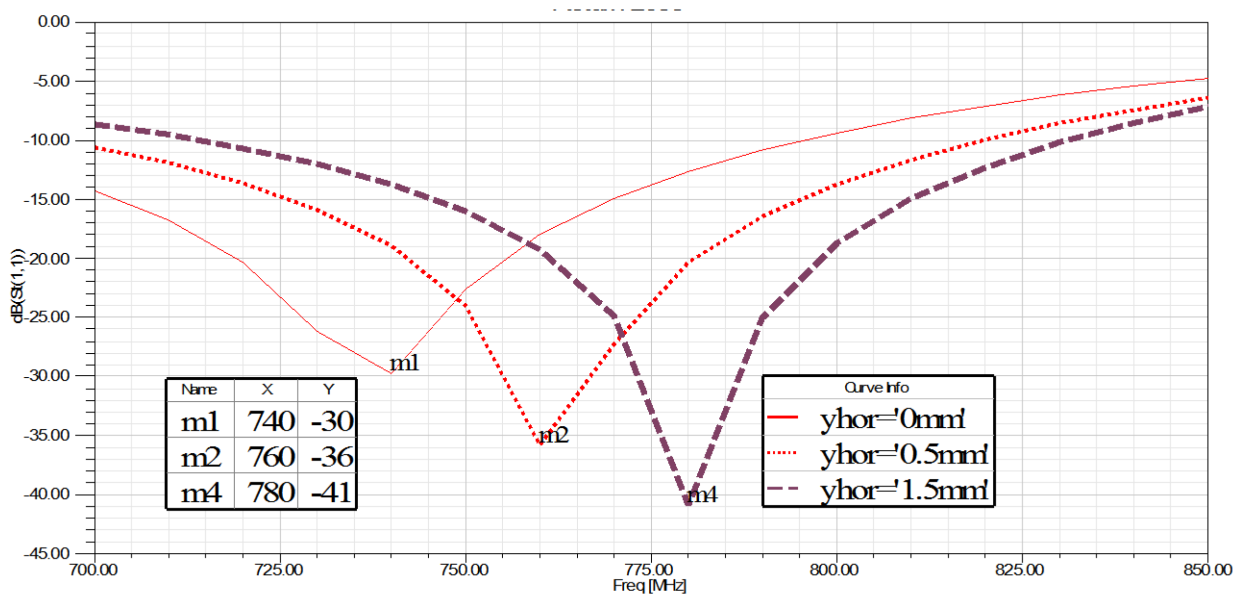


Figure 3.14: Return loss for the different width w4

The final design of the MLA is shown in Figure 3.17 where the return loss and the gain are shown in Figure 3.18 and Figure 3.19 respectively. But any one will ask can we change all the parameters to obtain the result that satisfy the LTE mobile handset? The answer of the question it takes a lot number of probabilities to change all the parameters at the same time, but by using optimization techniques we can do it as shown in the next section.

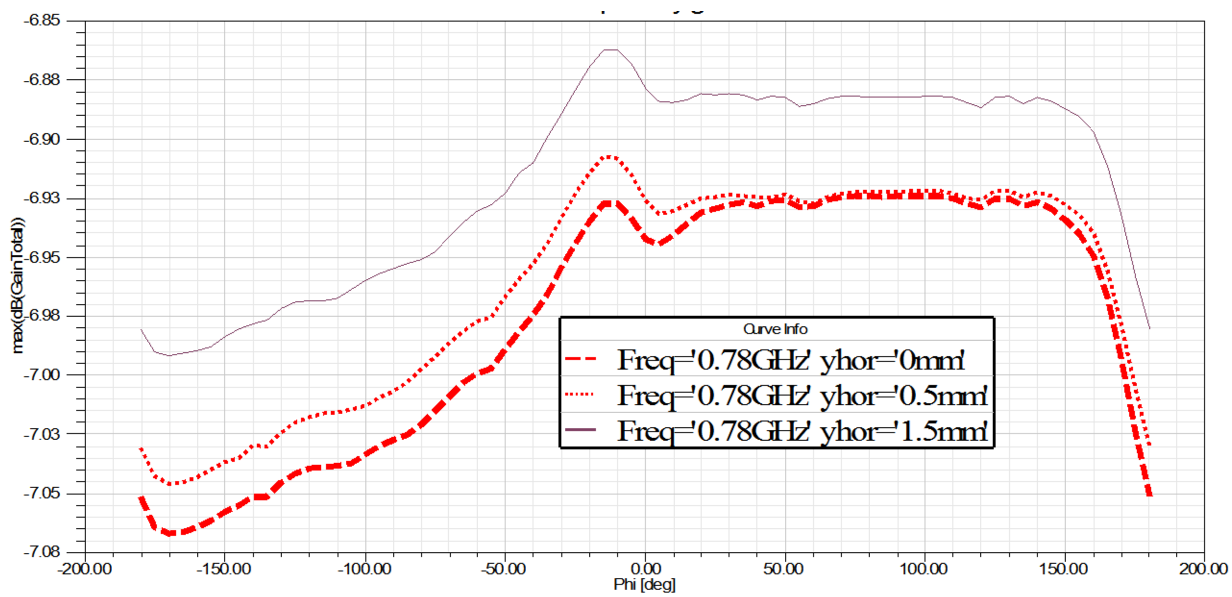


Figure 3.15: Max gain for the resonant frequency at the phi from -180^0 to 180^0 for different values of w4

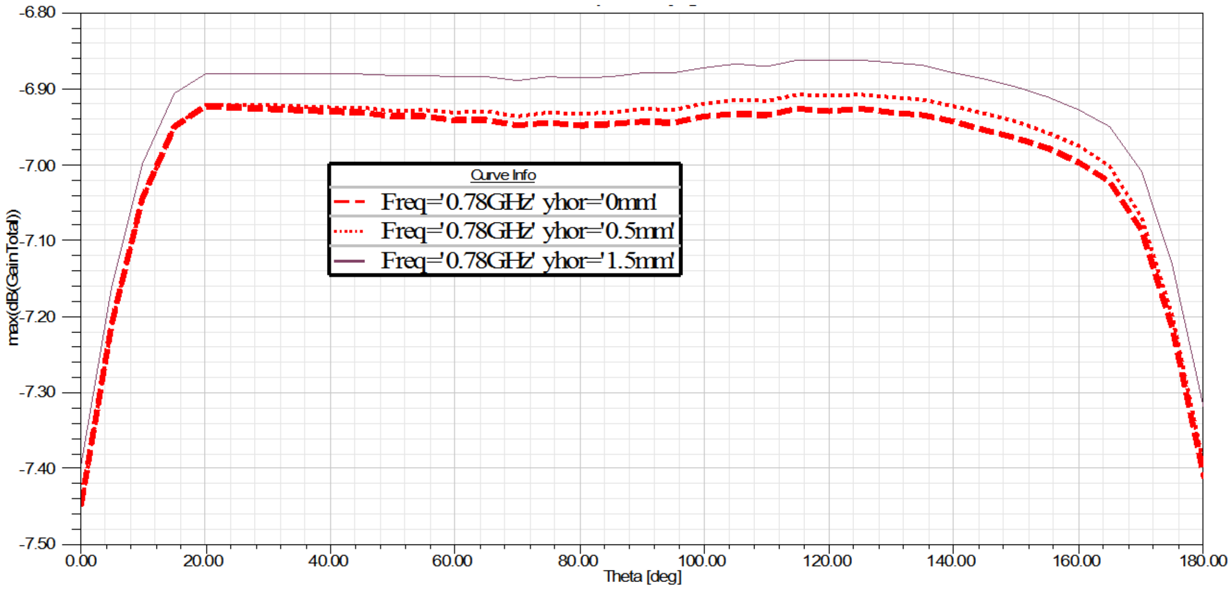


Figure 3.16: Max gain for the resonant frequency at the theta from 0^0 to 180^0 for different values of w4

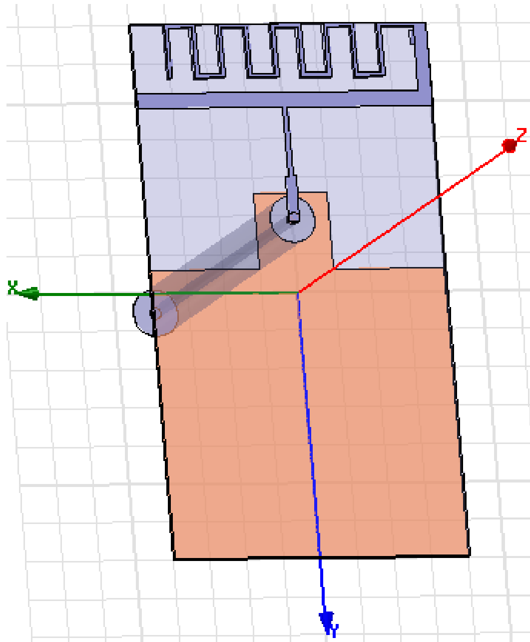


Figure 3.17: The final design for the MLA using parametric study

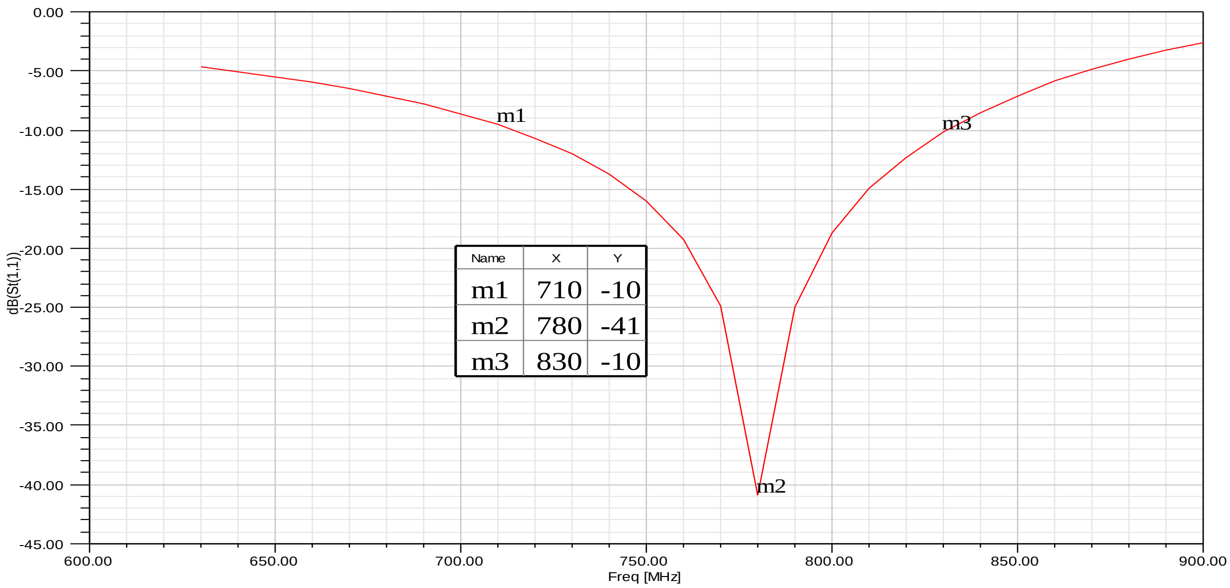
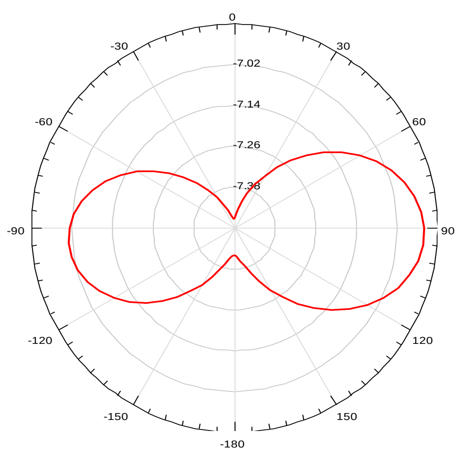


Figure 3.18: The return loss for the final design for the MLA using parametric study



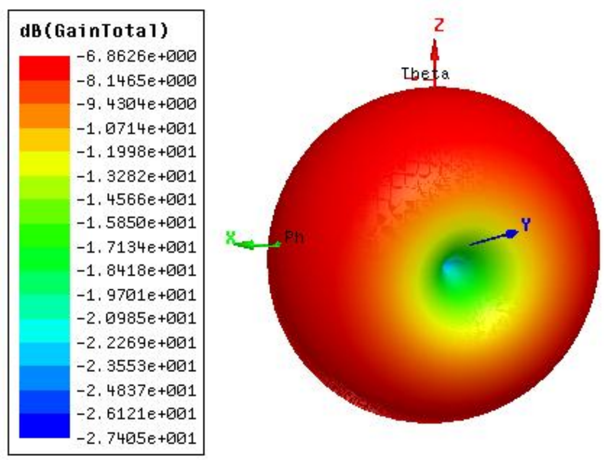


Figure 3.19: The radiation pattern for the final design for the MLA using parametric study

Figure 3.20: The gain for the final design for the MLA using parametric study

3.3 THE OPTIMIZATION OF MLA WITH GENETIC ALGORITHM

Genetic algorithms were first described by John Holland in the 1960s and were developed by Holland and his students and colleagues. Genetic algorithms in engineering electromagnetic have been widely used. The GA procedure based on the Darwinian principle of survival of the fittest is capable of facing multi-variable problems, such as the design of antennas. A block diagram of the GA optimizer is shown in Figure 3.21. Six basic tasks must be performed in a simple GA: encode the solution parameters in the form of chromosomes, create a string of the genes to form a chromosome, initialize a starting population, evaluate fitness values to individuals in the population, perform reproduction through the fitness weighted selection of individuals from population, and perform recombination and mutation to produce of the next generation **[6]**.

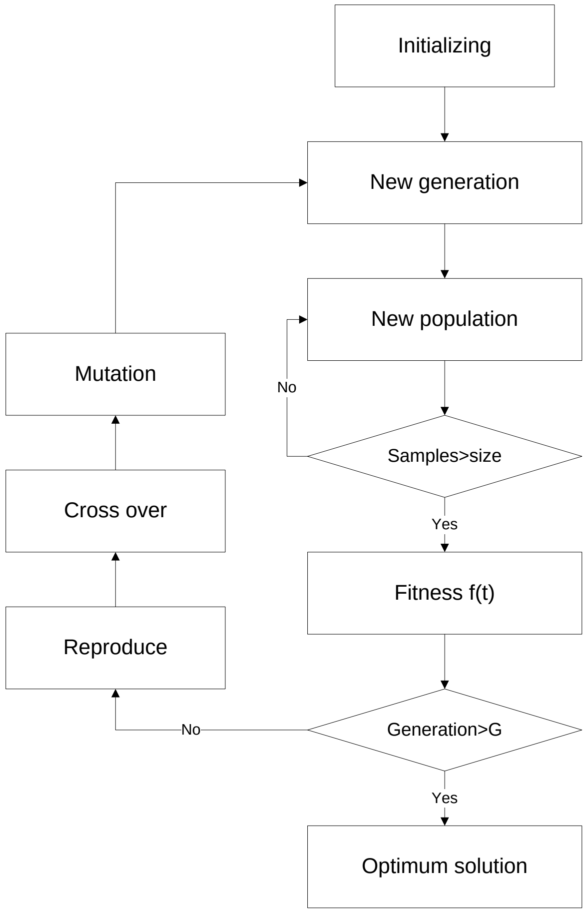


Figure 3.21: The optimization flowchart of GA technique

In order to find an optimum MLA structure with resonant frequency 0.78 GHZ, the method of GA is applied. A strategy for the combination of genetic algorithm with HFSS is illustrated in Fig 19, where version 12 supports GA, where it generates the parameters of each structure. The calculation of fitness values are compiled by HFSS. The calculated fitness values are then returned to genetic algorithm module for GA model. The electrical characteristic parameters of MLA are justified by a comparison with an evaluation of a fitness function. If the fitness meets the requirement, the procedure is completed. Otherwise, new structures are produced by a GA procedure. The new structures are used in the next iteration for HFSS analysis to justify their performances with respect to the expectations. The GA operation specifies the parameters to produce a new structure based on selection, crossover and mutation. GA optimizer parameters are set up as shown in Table 3.1.

The design goal is to achieve the LTE mobile handset standard that has small size, resonant frequency 0.78 GHz, minimum bandwidth is 100 MHz and maximum gain is 0 dB [7]. In our case, the parameters that described in section 3.2 are selected to optimize the antenna. To achieve this goal, the fitness function is defined as the following:

$$fitness1 = \frac{1}{N}\sum_{i=1}^{N}|S_{11}(f_i)| \leq -10\ dB,\ldots (3.1)$$

$$fitness2 = 10\log\left(\frac{P_{out}}{P_{in}}\right) \leq 0\ dB,\ldots (3.2)$$

In the equation above, *i is* the sampling frequency, N is the number of the sample.

TABLE 3.1. SPECIFICATIONS OF THE GA

Population Size	30
Maximum number of iterations	4 hours
Crossover Rate	0.8
Mutation Rate	0.02
Number of sample	200

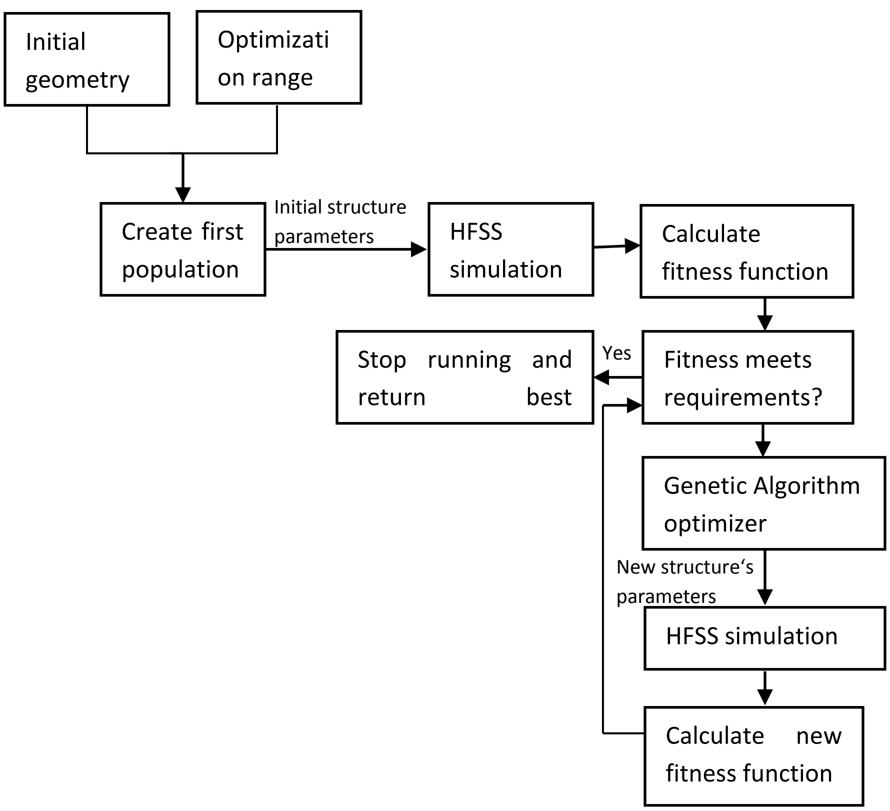


Figure 3.22: Using GA technique in HFSS

3.4 THE MLA DESIGN AND SIMULATION RESULTS USING GENETIC ALGORITHMS

From section 3.2, we show in Figure 3.3 the configuration of the MLA and its some dimensional parameters. In this section we will add the ground plate height that characterized by variable *ground* .The width w_1 is characterized by *xwidth*, the width w_2 are characterized by *ywidth*, the width *w*3 is characterized by *xhor* and the width w_4 is characterized by *yhor*. The ranges of these parameters to be optimized and the optimal results are shown in Table 3.2.

TABLE 3.2: THE PARAMETERS WERE OPTIMIZED BY USING GA IN HFSS (ALL PARAMETERS ARE GIVEN IN MM)

Parameters	**Xwidth**	**Ywidth**	**Xhor**	**Yhor**	**ground**
Max	2.5	2.5	2.5	2.5	50
Min	0.0	0.0	0.0	0.0	40
Optimal value	1.443	1.867	0.309	0.0352	48.194

The design of the antenna and the results are shown in Figure 3.23 until 3.28. In these figures, we can see that resonant frequency is 0.79 GHz, the bandwidth is 150 MHz that can be determined in terms of 10 dB return loss and the gain is -6.83 dB. The proposed antenna has an available bandwidth about 20% of the resonant frequency.

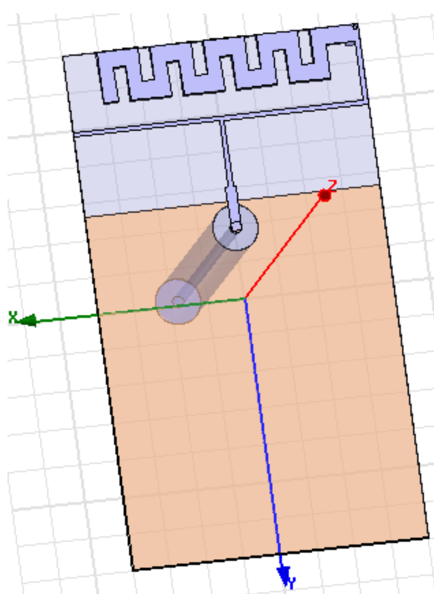


Figure 3.23: The final design of the MLA using GA.

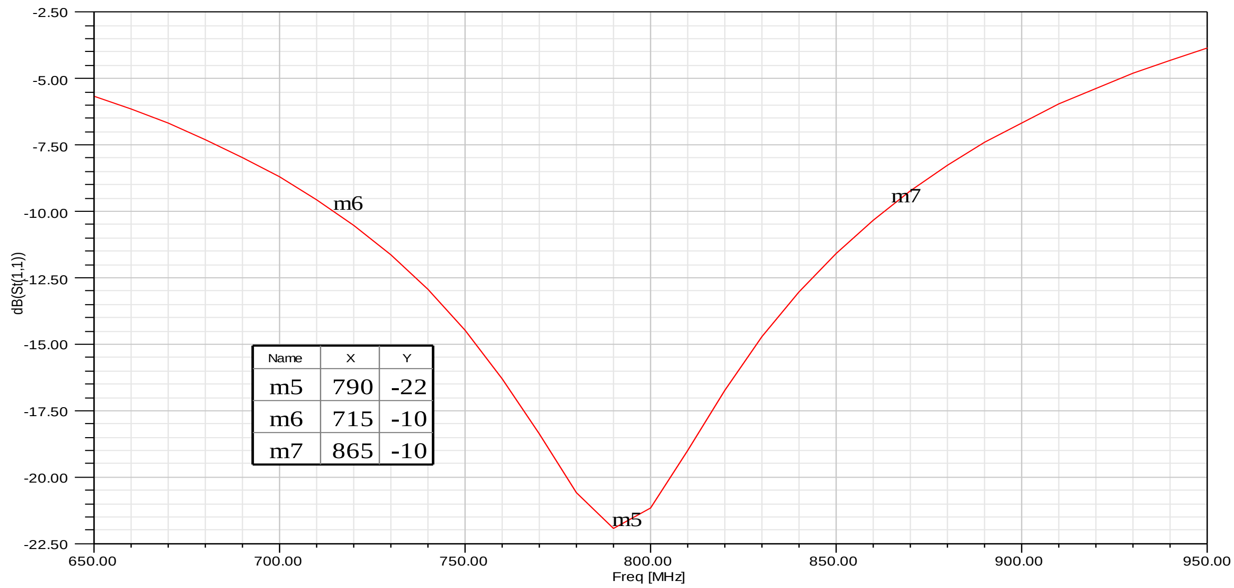


Figure 3.24: The return loss for the final design of MLA using GA.

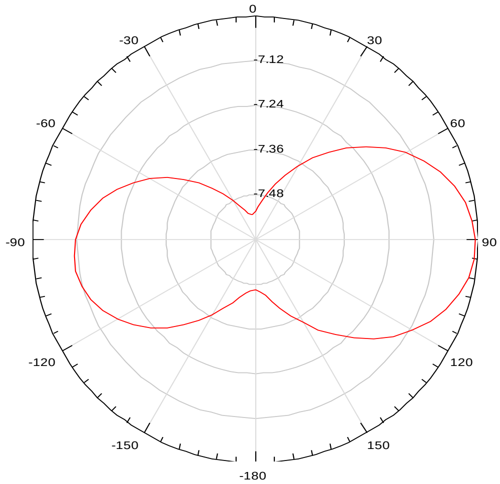


Figure 3.25: The radiation pattern for the final design of MLA using GA

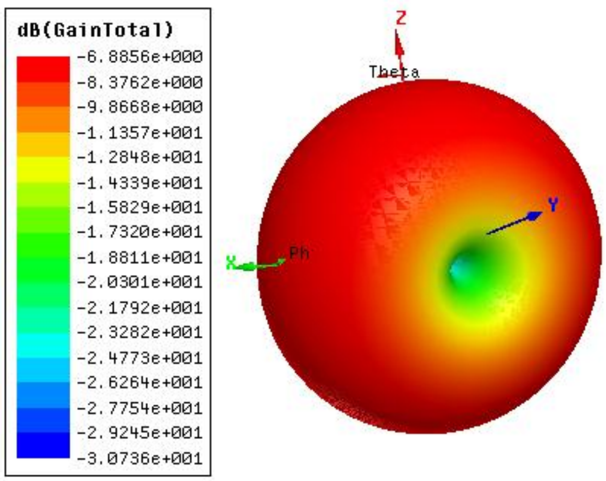


Figure 3.26: The gain for the final design of the MLA using GA.

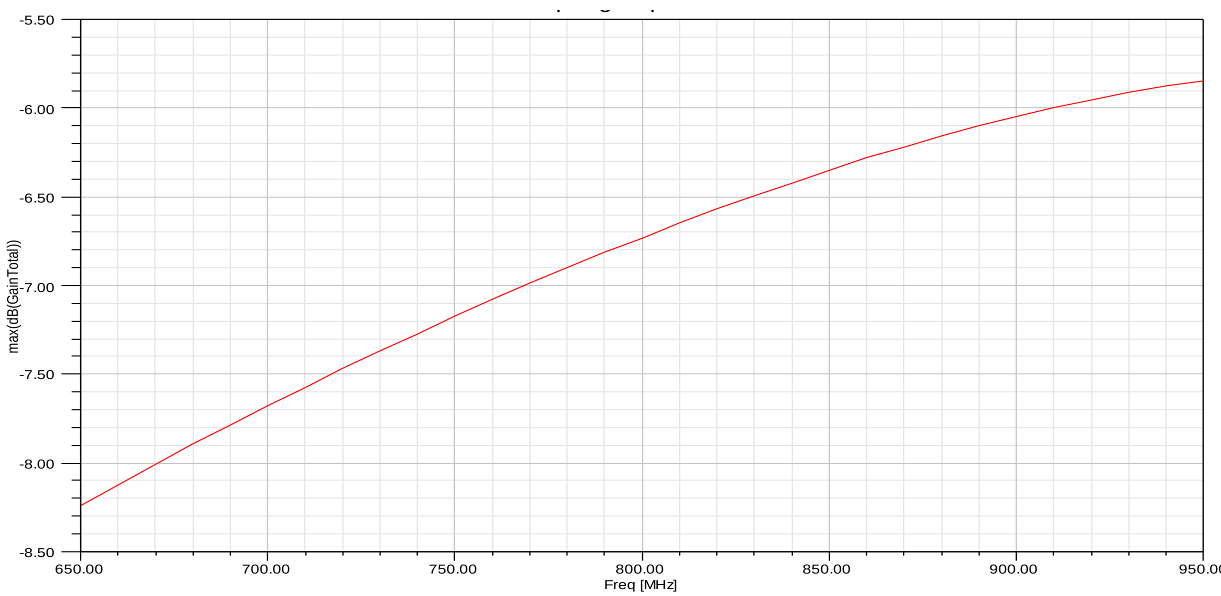


Figure 3.27: The maximum gain for each frequency at phi=0.

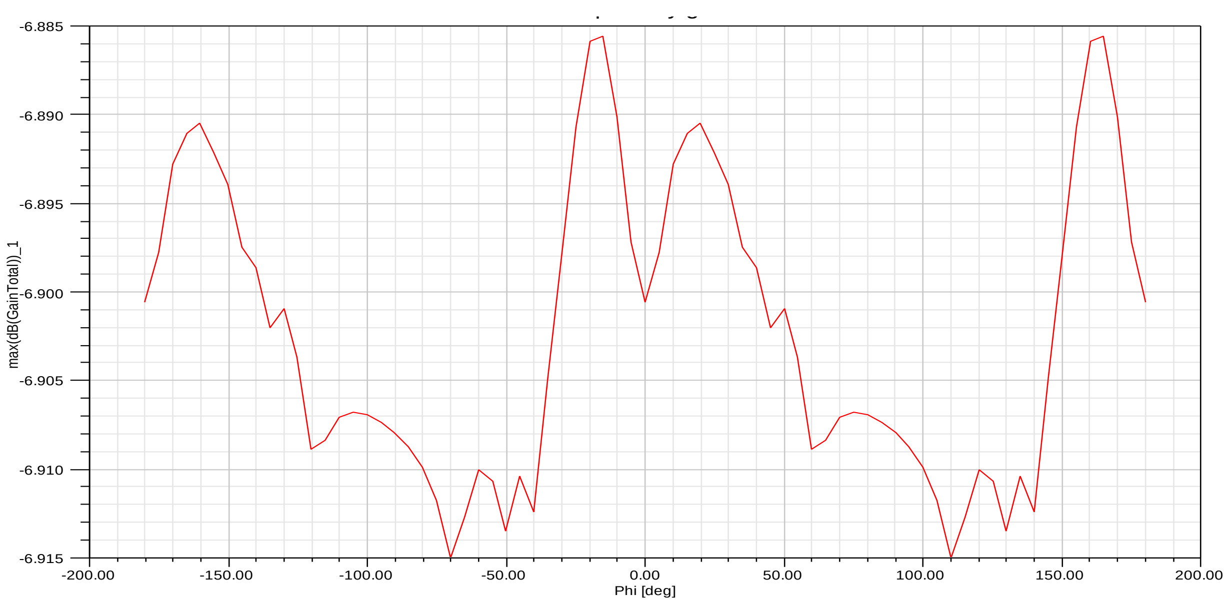


Figure 3.28: Max gain for the resonant frequency at the phi from -180^0 to 180^0

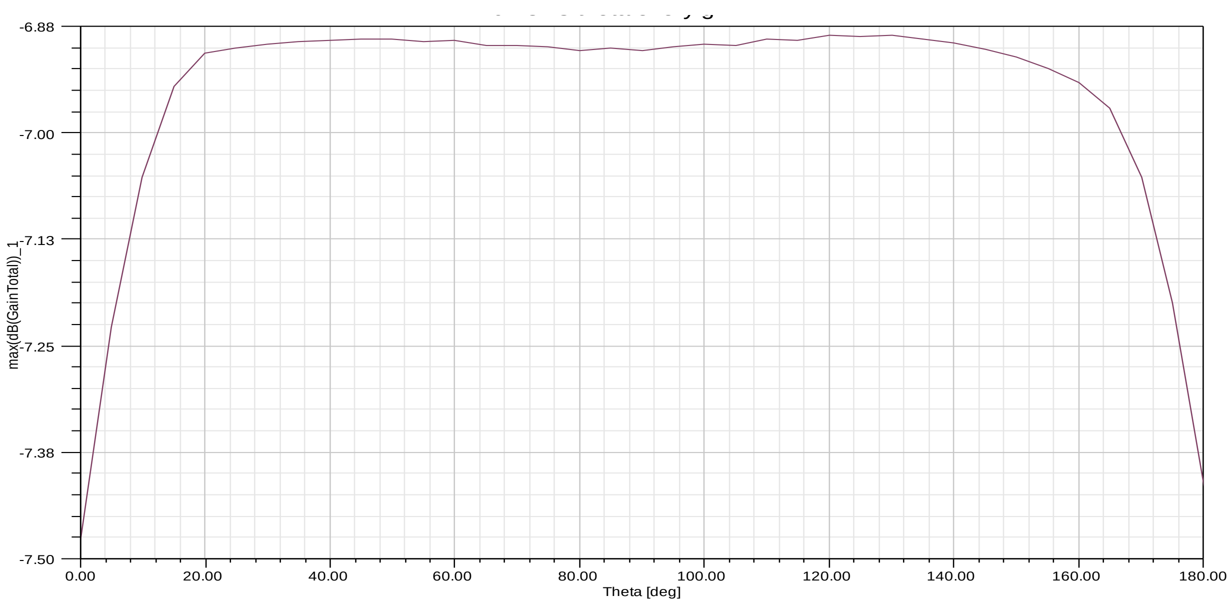


Figure 3.29: Max gain for the resonant frequency at the theta from 0^0 to 180^0

The difference between the final designs MLA by using the parametric and the optimization technique are shown in Table 3.3.

TABLE 3.3: THE DIFFERENCE BETWEEN THE FINAL DESIGN USING PARAMETRIC AND OPTIMIZATION METHOD

Parameters	The final design using parametric method	The final design using optimization method
Resonant Frequency	0.78 GHZ	0.79 GHZ
Max Return Loss	41 dB	22 dB
10dB bandwidth	120 MHz	150 MHz
Max Gain	-6.863	-6.886

3.5 COMPARISON BETWEEN OUR MLA FOR LTE AND MLA FOR LTE IN [8]

We described in Chapter 2, the authors in **[8]** design an LTE antenna for mobile communication in 0.78 GHz where the HFSS designed model of the antenna is shown in Figure27 which consist from a substrate of FR-4 material which is a dielectric constant of 4.4 and ground plane with area of 20x40 mm^2 and a patch antenna with area of 15.5x13 mm^2. Table 3.4 summarizes the specifications for this antenna. Figure 28 shows the reflection coefficient of this antenna that operates at our required frequency with a value of -37 dB and has a band width of 250 MHz as shown in Figure 29, and the 3D radiation pattern is shown in Figure 30.

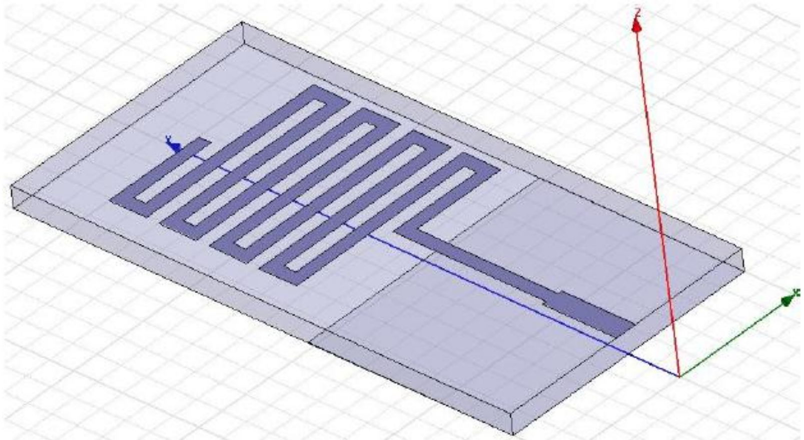


Figure 3.30: HFSS Model for the MLA Antenna in [8]

TABLE 3.4: MLA FOR LTE IN [8] SPECIFICATIONS

Frequency	Dielectric Constant	NO. of Turns	Substrate Thickness	Substrate Length	Substrate Width
0.78 GHz	4.4	4	1.6 mm	40 mm	20 mm

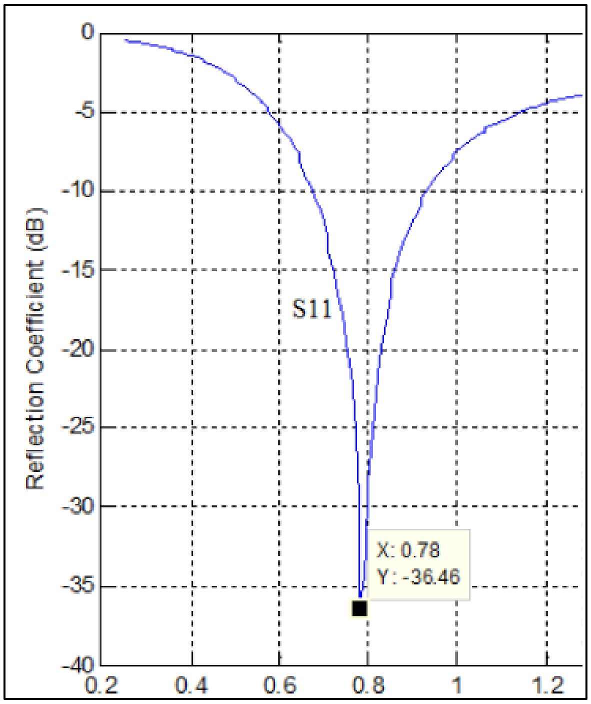


Figure 3.31: Reflection Coefficient for the Designed MLA

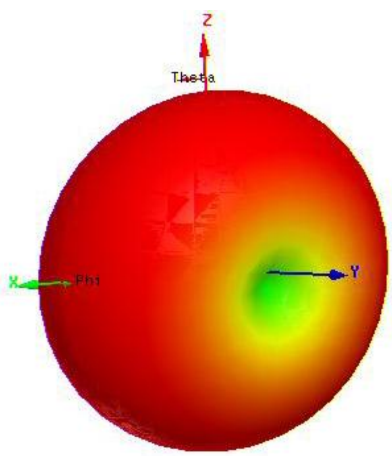


Figure 3.32: 3D Radiation Pattern

We show the previous antenna is a good design for LTE standard in mobile handset but it has a very small gain (-16 dB), but in our MLA the gain is -6.9 dB, so the antenna satisfy the gain enhancement where the enhancement percentage is 57%. In addition the thickness in our MLA has the half thickness than the MLA in [8]. The defference between the MLA in [8] and our MLA is shown in Table 3.5.

TABLE 3.5: DIFFERENCES BETWEEN OUR MLA AND MLA IN [8]

	Our MLA	MLA in [8]
Gain	-6.68 dB	-16 dB
Bandwidth	150 MHz	260 MHz
Length	70 mm	40 mm
Width	40 mm	20 mm
Thickness	0.8 mm	1.6 mm

3.6 CONCLUSIONS

An electrically small MLA operating at the 0.78 GHz was studied in this chapter using HFSS software package. We apply parametric and optimization technique using genetic algorithms to achieve the antenna for the standard LTE mobile handset. The antenna provided a significant gain enhancement. Finally we compare the MLA with the antenna in [8] where Table 3.5 summarizes the differences between the two designed antennas. It is evident that our MLA antenna is more suitable for use due to its thickness height is much less than the antenna in [8] in addition with the enhancement gain.

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CHAPTER 4

ANALYSIS AND DESIGN E-SHAPE MEANDER LINE ANTENNA FOR LTE MOBILE COMMUNICATION IN 2.5 GHZ

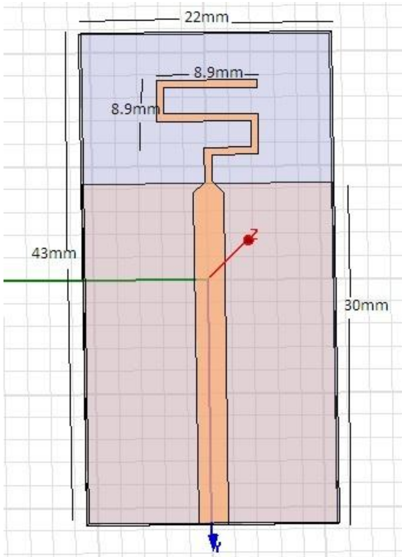
4.1 INTRODUCTION

In previous chapter we described the design antenna for LTE mobile communication in 0.78 GHz frequency band by applying two methods: parametric study and optimization technique. In this chapter, we will analyze and design a new antenna for LTE mobile communication that has better gain and bandwidth.

The bandwidth of microstrip antenna may be increased using air substrate [1]. However, dielectric substrate must be used if compact antenna size is required [2]. A few approaches can be applied to improve the microstrip antenna bandwidth. These include increasing the substrate thickness, introducing parasitic element either in coplanar or stack configuration, and modifying the shape of a common radiator patch by incorporating slots. The last approach is particularly attractive because it can provide excellent bandwidth improvement and maintain a single-layer radiating structure to preserve the antenna's thin profile characteristic. The successful examples include E-shaped patch antennas [3–7], U-slot patch antennas [8], and V-slot patch antennas [9].

The authors in [10] proposed a meander-line structure for PCMCIA cards at 2.4 GHz as shown in Figure 4.1. The maximum gain of the antenna is 2.76 dB and a return loss of about -17dB at the resonant frequency. The substrate material was used is FR4 with ε_r = 4.5 and tanδ = 0.0150, dielectric height, H = 1.5 mm.

In this chapter, the E-shape MLA for LTE mobile communication (as shown in Figure 4.2) is designed at a resonant frequency 2.5 GHz.



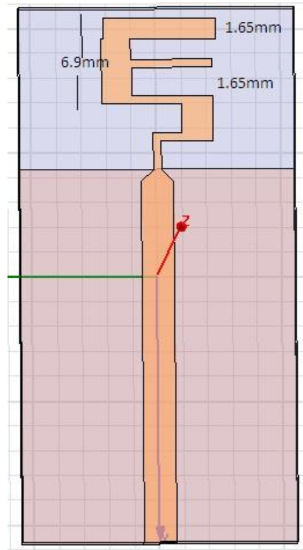


Figure 4.1: MLA Antenna shape in [10] **Figure 4.2: The E-shape MLA antenna**

The analysis of the E-shape MLA is described in section 4.2. A comprehensive parametric study has been carried out to understand the effects of various dimensional parameters as shown in section 4.3. Because electromagnetic optimization parameters can be either continuous, discrete, or both, making the design process slow and complicated, many researchers have applied genetic algorithms to the design of broadband patch antennas [11-12]. A Genetic Algorithms (GA) optimum approach of the dimension of E-shape MLA based on the combination of GA with the commercial electromagnetic simulation tool, the FEM based software, HFSS by ANSOFT. The attractiveness of GA optimization is that improved bandwidth performance doesn't increase overall dimensions or manufacturing cost. The design process of E-shape MLA optimization with GA is described in Section 4.4. In Section 4.5 the GA optimized antenna designs and results are proposed. In section 4.6 we apply this antenna on other substrate materials. Finally the conclusion is written in Section 4.7.

4.2 E- SHAPE MLA ANALYSIS

The width and length of the microstrip antenna are determined as follows [13]:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}, \text{-----} \ (4.1)$$

where v_0 is the free space velocity of the light.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}, \text{-----} \ (4.2)$$

where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant ε_{reff} and the width to- height ratio (W/h), and the normalized extension of the length, is

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \text{-----} (4.3)$$

The actual length of the patch (L) can be determine as

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \text{-----} (4.4)$$

When two symmetrical parallel slots are incorporated into the rectangular microstrip antenna, it becomes an E-shaped as shown in Figure 4.3.

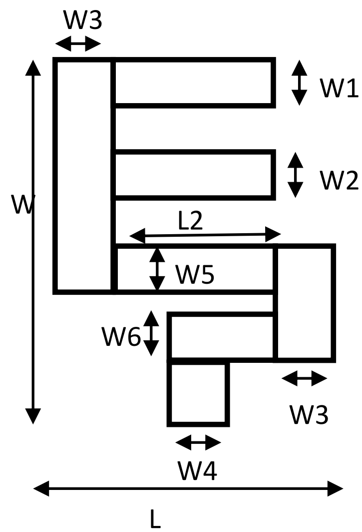


Figure 4.3: E-shape MLA

First, a rectangular microstrip patch antenna is designed based on the standard design procedure to determine the length (L) and width (W) for the resonant frequency at 2.5 GHz. Two parallel slots are incorporated to perturb the surface current path, introducing local inductive effect that is responsible for the excitation of a resonant mode. The slot length (L2), slot width (W2), and the center arm dimensions of the E-shape control the frequency of the second resonant mode and the achievable bandwidth [14], but the second resonant frequency is out of the our area where it has 5.1 GHZ resonant frequency.

A common rectangular patch antenna can be represented by means of the equivalent circuit of Figure 4.4(a).

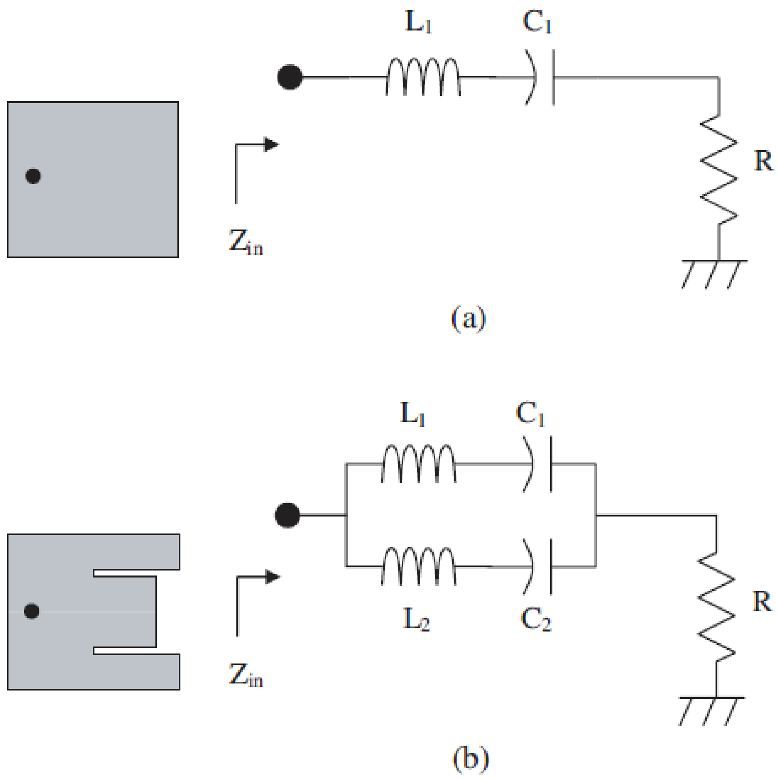


Figure 4.4: Equivalent circuits of (a) rectangular patch and (b) E-shape antenna [14]

The resonant frequency is determined by L_1C_1. At the resonant frequency, the impedance of the series LC circuit is zero, and the antenna input impedance is given by resistance R. When a pair of slots is incorporated, the equivalent circuit can be modified into the form as shown in Figure 4.4(b). The second resonant frequency is determined by L_2C_2. Analysis of the circuit network shows that the antenna input impedance is given by

$$Z_{in} = R + j\frac{(wL_1 - 1/wC_1)(wL_2 - 1/wC_2)}{w(L_1 + L_2) - (1/wC_1 + 1/wC_2)} \text{----- (4.5)}$$

The imaginary part of the input impedance is zero at the two series resonant frequencies determined by L_1C_1 and L_2C_2, respectively. Of course, this is by no mean the exact model of the E-shaped antenna because the equation shows that there is a parallel-resonant mode between the two series-resonant frequencies. Nevertheless, it serves to explain the operating principle of the antenna design. If the two series resonant frequencies are too far apart, the reactance of the antenna at the mid band frequency may be too high and the reflection coefficient at the antenna input may be unsatisfactory. If the two series-resonant frequencies are set too near to each other, the parallel-resonant mode may affect the overall frequency response and the reflection coefficient near each of the series-resonant frequencies may be degraded. The question now is: how would the slot length, slot width, slot position and the length of center arm affect the values of the E-shape MLA? The results of a parametric study are reported in the next section.

4.3 PARAMETRIC STUDY

A substrate with dielectric permittivity of 4.5 and thickness of 1.5 mm is selected to obtain a compact radiation structure that at the same time meets the demanding bandwidth specification. It is fed by a 50-Ω SMA connector.

The technique of setting value of some parameters for the resonant frequency can be done step by step. The first consideration is to design the dimensions of antenna as shown in Figure 4.3. The parameters w_1, w_2, w_3, w_4, w_5 *and* w_6 are set as variables and to show how their effects on the bandwidth and the gain of the E-shape MLA.

Step 1:

- Change the height of the ground from 29 mm to 32 mm with step 0.1mm and fix the other parameters.

- The simulation result of return loss S11 is shown in Figure 4.5.

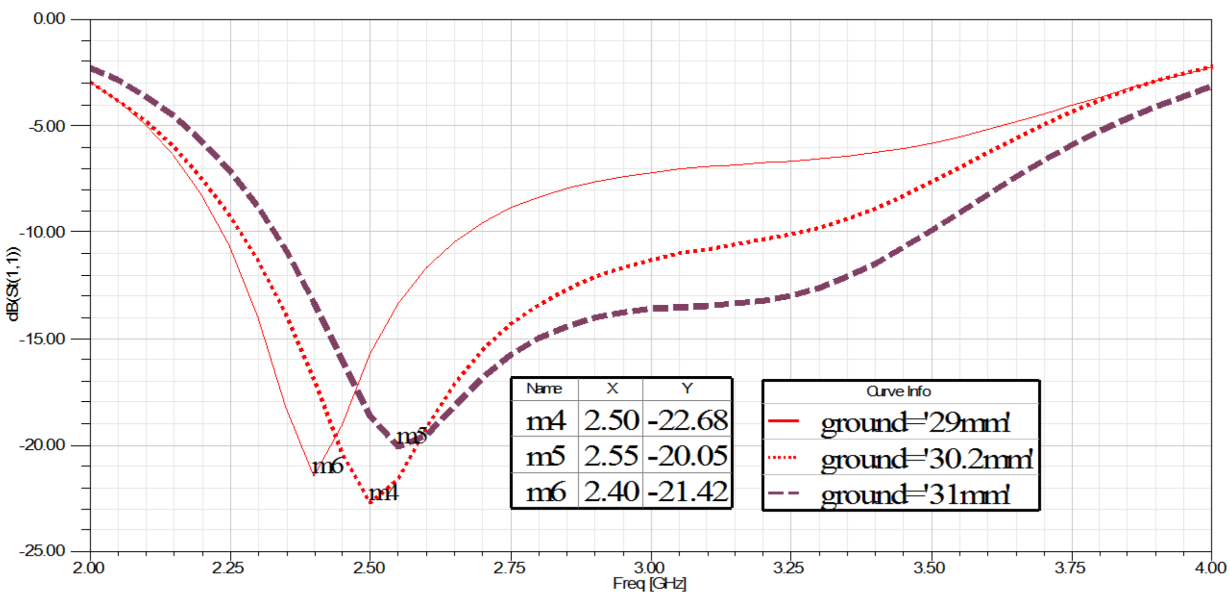


Figure 4.5: Return loss for the different height of the ground

Figure 4.5 is shown that the resonant frequency is increasing when the height of the ground is increased. To determine the bandwidth for each step we will write a small program in Matlab software to determine it, the best result is viewed a shaded row in Table 4.1, where it has the bandwidth of 0.95 GHz but in the antenna in [12] the bandwidth is 0.6 GHz. The maximum gains for the best values are shown in Figure 4.6, where the values are between 2.7 and 2.8 dB at the resonant frequency 2.5 GHz. In the next step we study the effect of the other parameters as shown in Figure 4.3.

Table 4.1: The ground height effect on the E-shape MLA

Ground Height (mm)	BW (GHz)	Return Loss	Resonant Frequency (GHz)
30.0	0.6	21.6185	2.5
30.2	0.95	22.6769	2.5
30.4	1.05	20.9935	2.55
30.6	1.15	21.9947	2.55
30.8	1.05	33.7555	2.55
31.0	1.15	20.0518	2.55
31.2	1.15	20.362	2.6
31.4	1.15	21.3559	2.65
31.6	1.1	24.0754	2.7

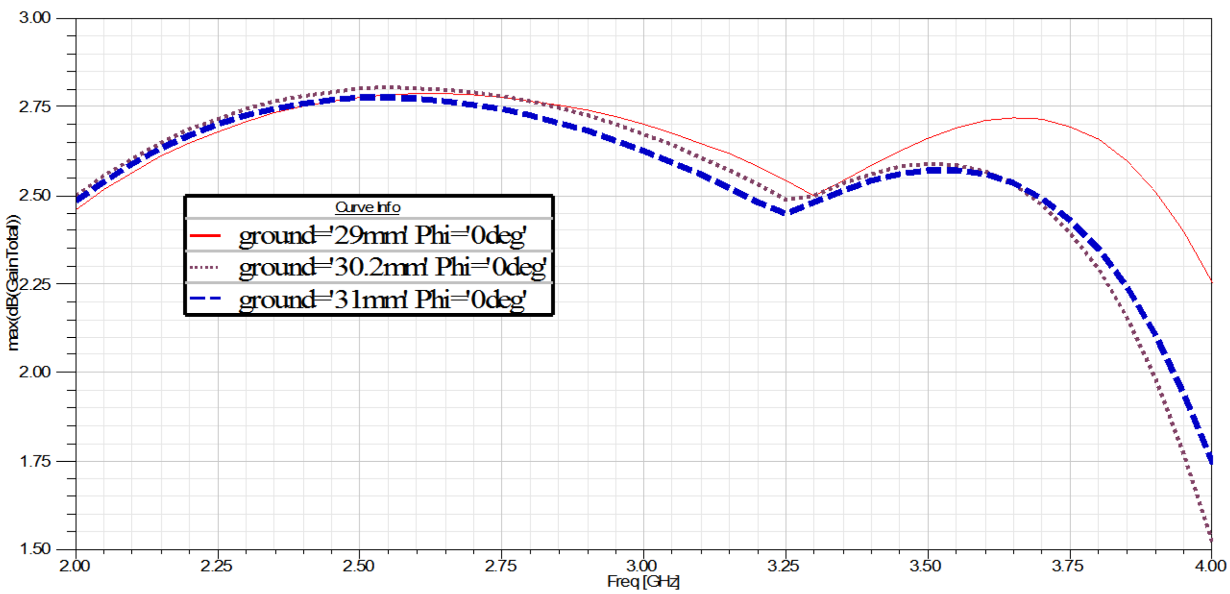


Figure 4.6: Max gain for each frequency input at phi = 0

Step 2:

- Choosing the optimum result of S11 from step 1 (*height of the ground is 30.2* mm), and varying the width w_3 by step of 0.1 mm from 0.5 mm to 4.5 mm and fixing the other parameters. The return loss is shown in Figure 4.6. It can be seen that when the width w_3 is increasing, the resonant frequency is also increasing. In this case, increasing width w_3 could affect the resonant frequency and bandwidth as shown in Table 4.2, where the shaded row is the best value for the bandwidth. The maximum gain for each frequency is shown in Figure 4.7, where the values are between 2.5 and 2.8 dB at the resonant frequency 2.5 GHZ. Now in the next step we study the effect of the other parameters.

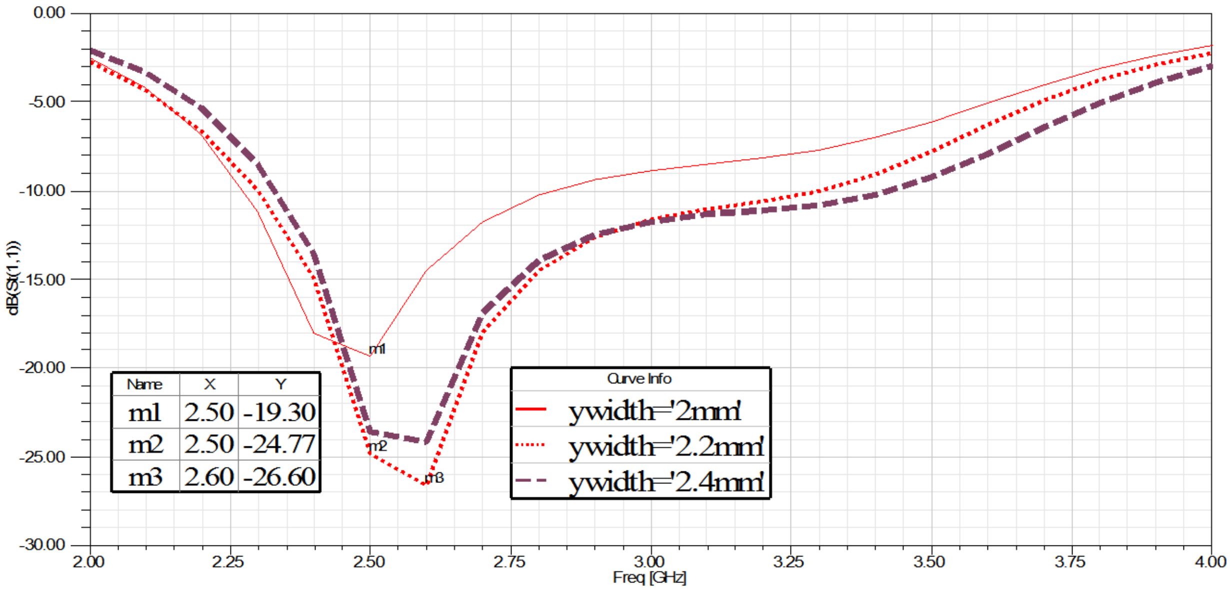


Figure 4.7: Return loss for the different values for the width w3

Table 4.2: The width w3 affecting on the E-shape MLA

Width w3 mm	**BW (GHz)**	**Return Loss**	**Resonant Frequency (GHz)**
1.5	0.3	16.2088	2.4
2.0	0.5	19.3024	2.5
2.1	0.6	21.9603	2.5
2.2	1	26.6006	2.5
2.3	0.8	23.1233	2.5
2.4	1	24.1494	2.6
2.5	1.1	29.5219	2.6

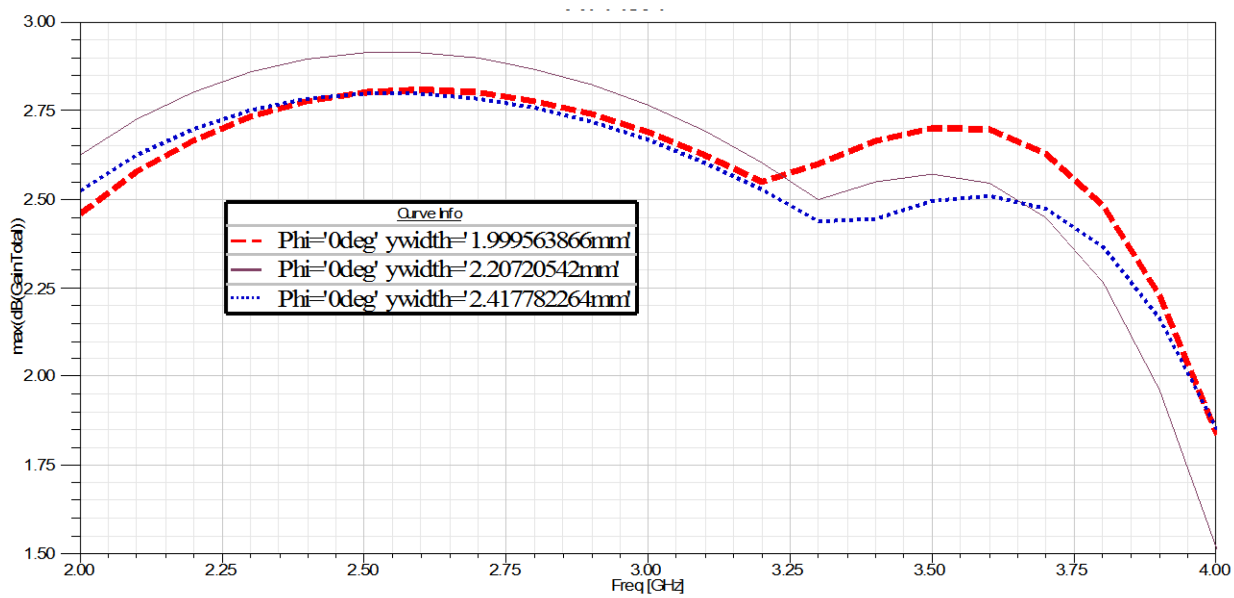


Figure 4.8: Max gain for each frequency at phi=0

Step 3:

- Choosing the optimum result of S11 from step 2 (*height of the ground is 30.2 mm and w3=2.2 mm*), and vary widths w_1, w_5 and w_6 by step 0.2 mm from 0.6 mm to 2.5 mm and fix all other parameters.

- The characteristic of the return loss is shown in Figure 4.8. It is shown that, when the width w_3 is increasing, the resonant frequency increases. In this case, increasing width w_3 could affect the resonant frequency and bandwidth as shown in Table 4.3, where the shaded rows are the best values for the bandwidth. The maximum gains for the best values are shown in Figure 4.9, where the values are between 2.5 and 2.8 dB at the resonant frequency 2.5 GHz. Now in the next step we will parameterize the width w_2.

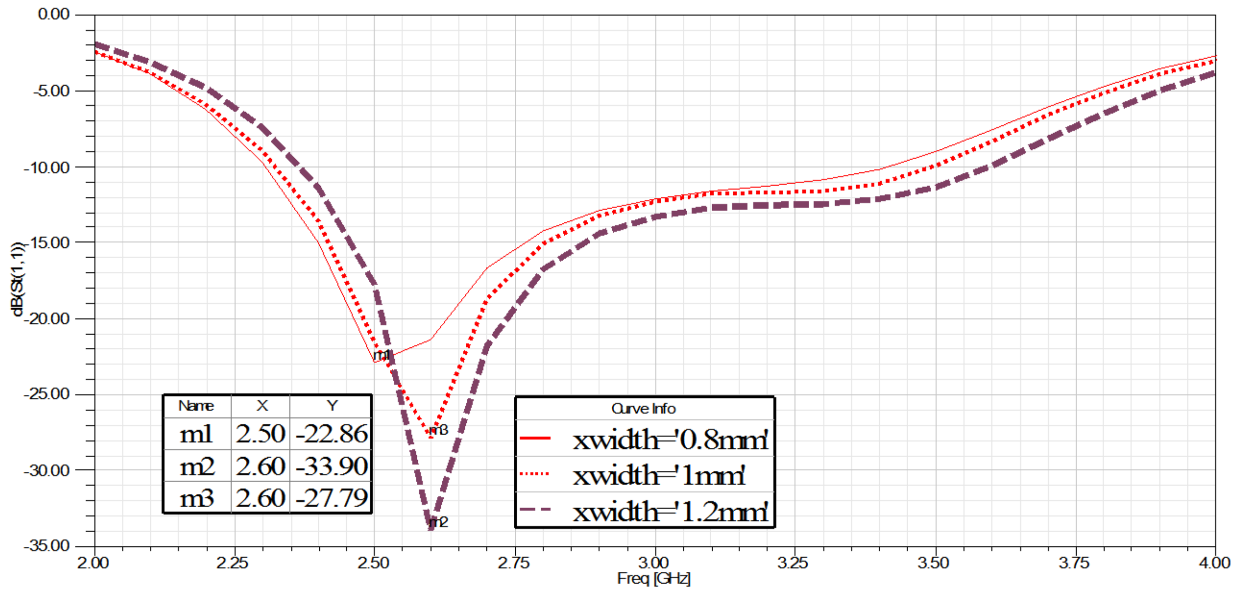


Figure 4.9: Return loss for varying the width w1, w5 and w6

Table 4.3: The width w1, w5 and w6 effect on the E-shape of the MLA

Width w1.w5 and w6 (mm)	**BW (GHz)**	**Return Loss**	**Resonant Frequency**
0.6mm	1	28.0486	2.6
0.7mm	1.1	42.1789	2.6
0.8mm	1.1	25.5697	2.6
0.9mm	1.1	22.5168	2.6
1.0mm	1.3	19.6113	2.6
1.1mm	1.2	19.9286	2.7

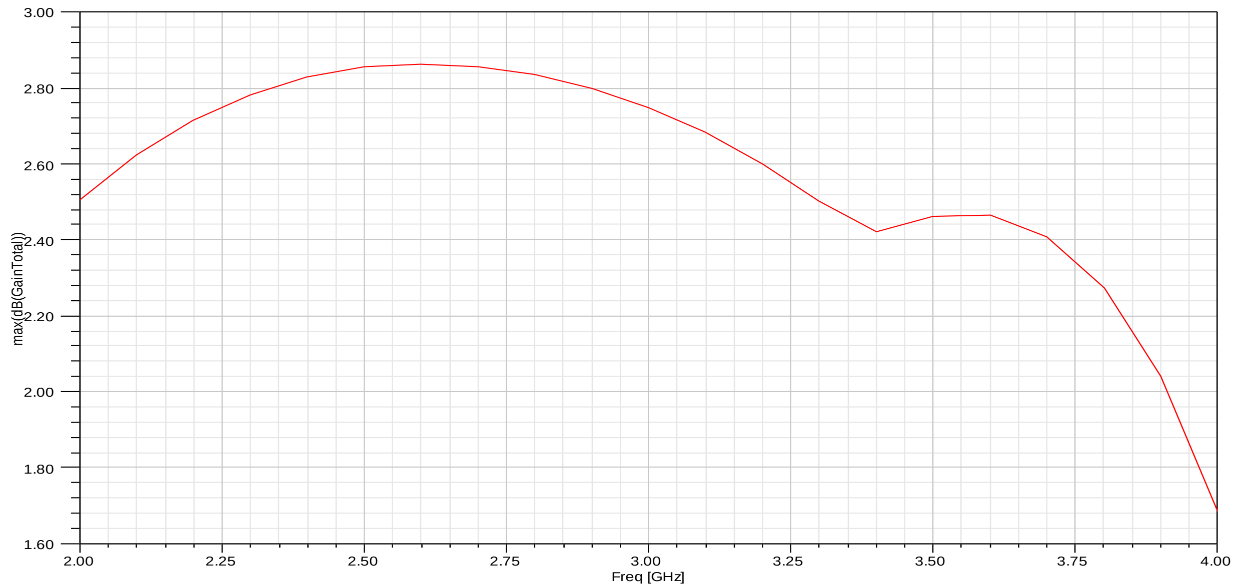


Figure 4.10: Max gain for each frequency at phi=0 when varying the width w1, w5 and w6

Step 4:

- Choosing the optimum result of S11 from step 3 (*height of the ground is 30.2,* w_3*=2.2 and* w_1=w_5=w_6*=1 mm*), and vary width w_2 by step up 0.1 mm from 0.6 mm to 2.5 mm and fix the other parameters.

- The characteristic of return loss is shown in Figure 4.10. It is shown that, the increasing of w_2 has no effect on the resonant frequency and the bandwidth, but affects the gain as shown in Figure 4.11. So in this step, we will select the best width w_2 =1 mm that have a gain equals 2.96 dB. Now in the final step we will parameterize the width w_4.

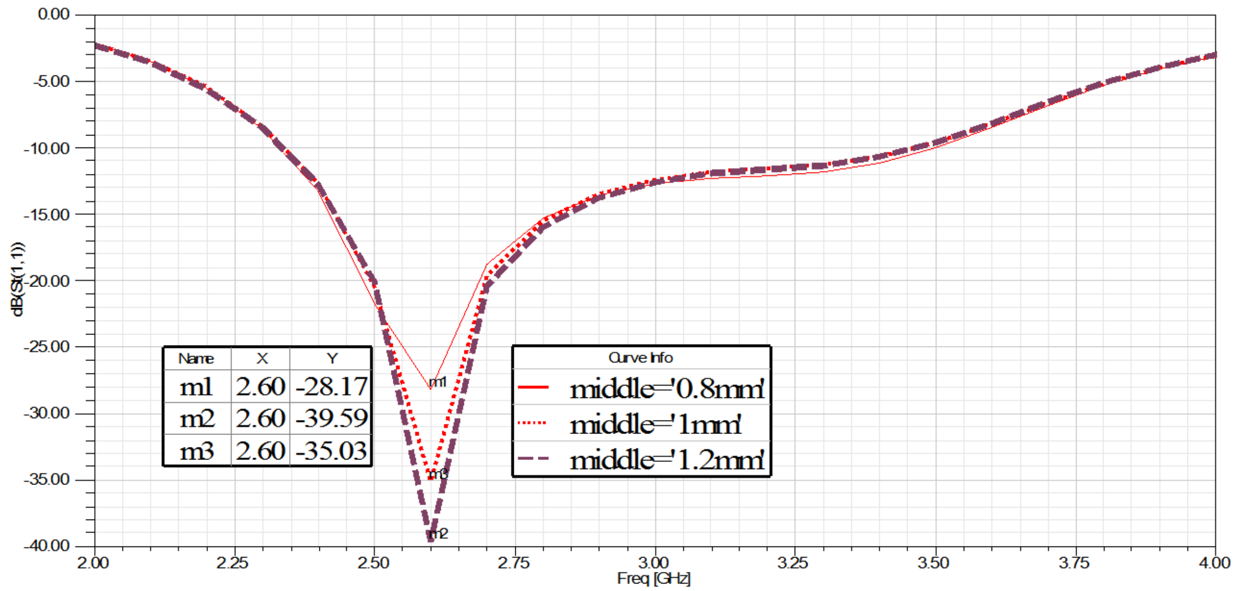


Figure 4.11: Return loss for the different width w2

Table 4.4: The width w2 affecting on the E-shape MLA

Width w2 (mm)	**BW (GHz)**	**Return loss (dB)**	**Resonant frequency (GHz)**
0.7	1.1	30.9043	2.6
0.8	1	17.8739	2.6
0.9	1.1	23.6682	2.6
1.0	1.1	24.1902	2.6
1.1	1.1	32.3731	2.6
1.2	1.1	34.8308	2.6
1.3	1.1	26.5678	2.6
1.4	1.1	20.7099	2.6
1.5	1.1	32.3669	2.6
1.7	1	26.8416	2.6
2.0	1.1	36.0749	2.6

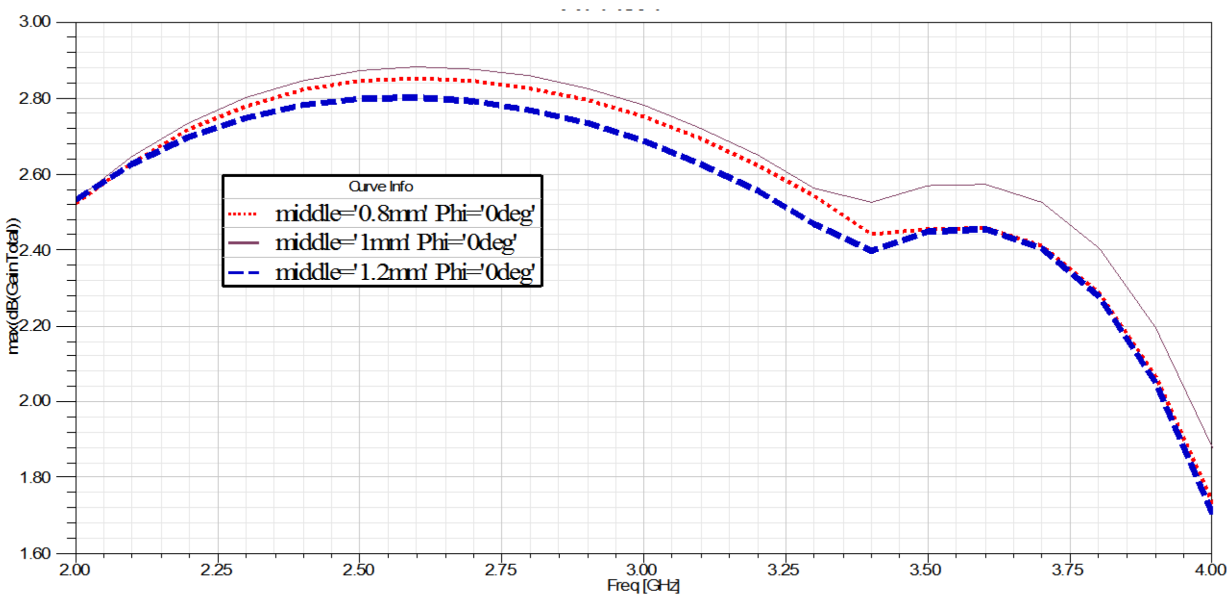


Figure 4.12: Max gain for each frequency at phi=0

Step 5:

- Choosing the optimum result of S11 from step 4 (*height of the ground is 30.2 mm, w_3=2.2, w_1=w_5=w_6=1mm and w_2=1mm*), and vary width w_4 by step up 0.1 mm from 0.6 mm to 2.5 mm and fix the other parameters.

- Finally, the characteristic of return loss is shown in Figure 4.12. It is shown that, when the width w_3 increasing, the resonant frequency shift to the right. In this case, increasing width w_3 could affect the resonant frequency and bandwidth as shown in Table 4.5, where the shadow rows are the best values for the bandwidth. The maximum gains for the best values are shown in Figure 4.13, where the values are between 2.5 and 2.8 dB at the resonant frequency 2.5 GHz. Now in the next step we will parameterize the other parameters.

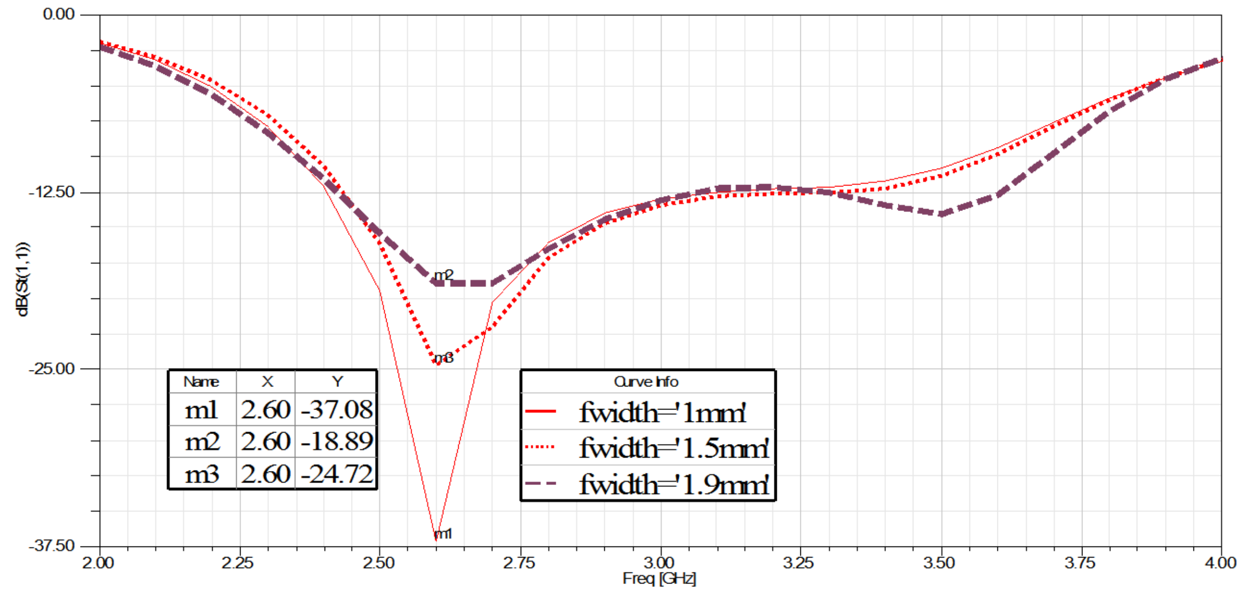


Figure 4.13: Return loss for the different width w4

The best value of feed width is 1.9 mm and the gain is 3.02 dB

Table 4.5: The width w2 affecting on the E-shape MLA

Width w_4 (mm)	**BW (GHz)**	**Return Loss dB**	**Resonant Frequency (GHz)**
0.6	1	29.5674	2.6
0.7	1.1	32.478	2.6
0.8	1.1	41.8838	2.6
1.0	1.1	37.0826	2.6
1.5	1.1	24.7193	2.6
1.9	1.2	18.9055	2.6
2.0	0.5	14.78	2.6

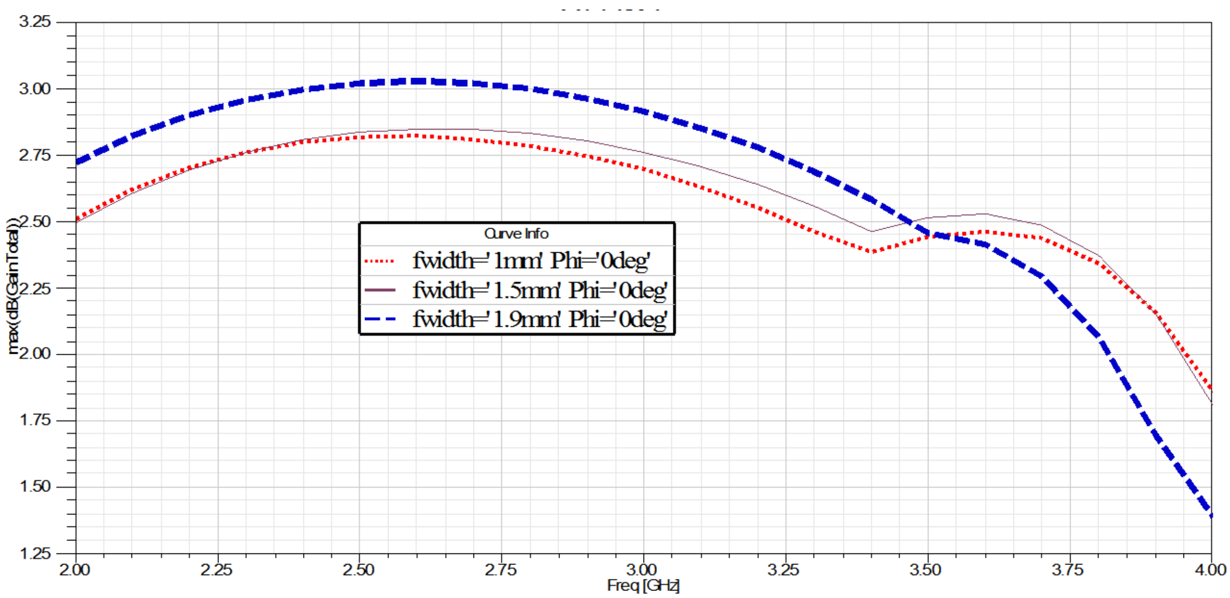


Figure 4.14: Max gain at each frequency at phi=0

The final design of the E-shape MLA is shown in Figure 4.14 where the return loss and the gain is shown in Figure 4.15 and Figure 4.16 respectively. But any one will ask can we change all the parameters to obtain the result that satisfy the LTE mobile handset? The answer of the quation it takes a lot number of probabilities to change all the parameters at the same time, but by using optimization techniques we can do it as shown in the next section.

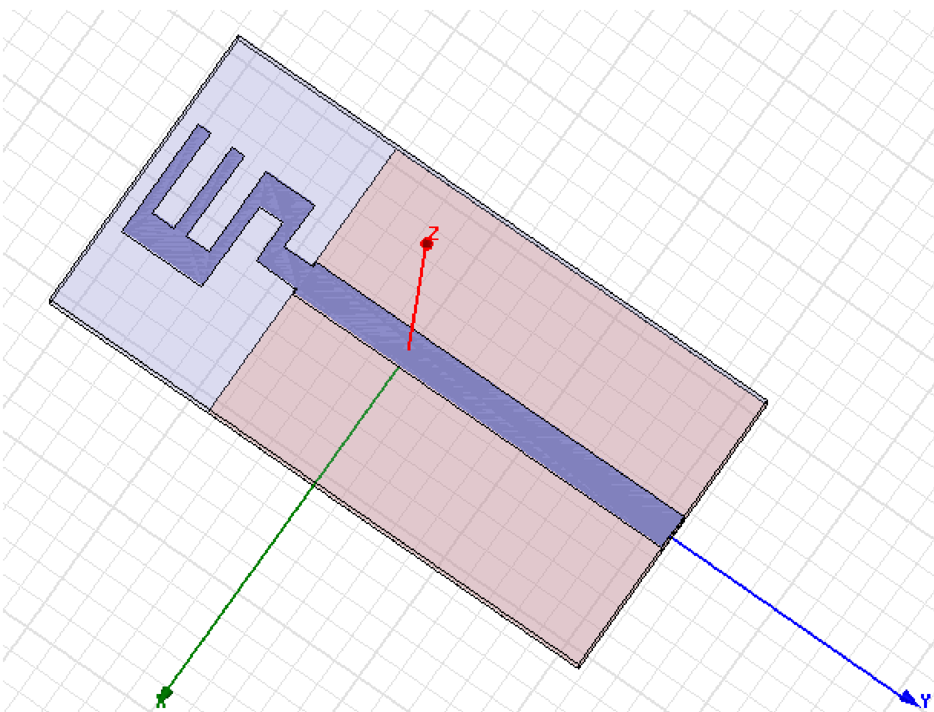


Figure 4.15: The final design for the E-shape MLA using Parametric study

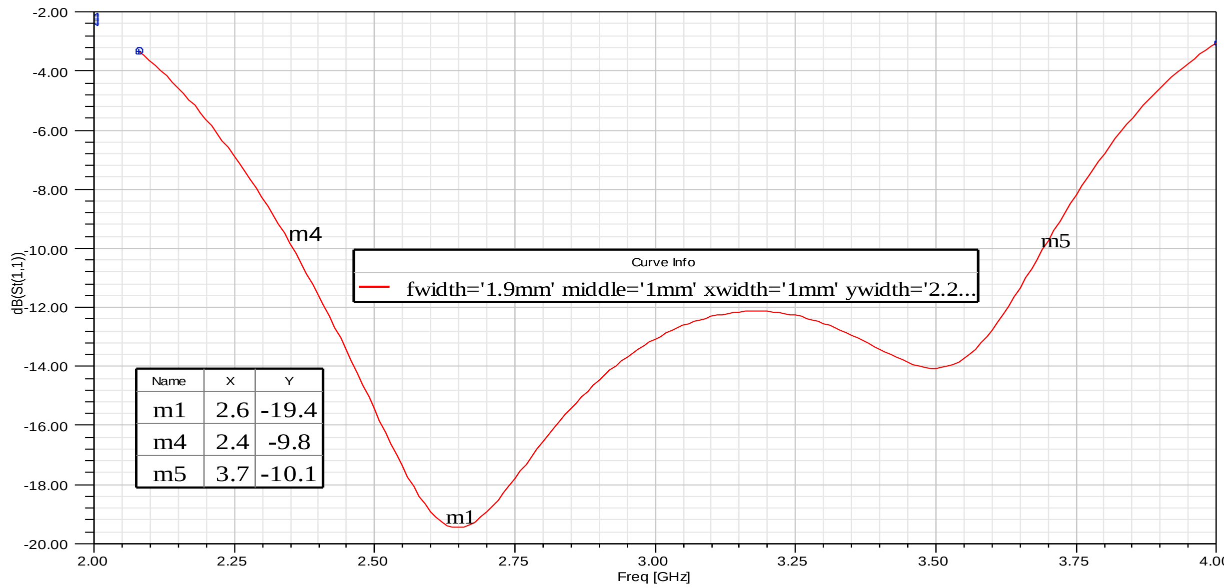


Figure 4.16: The return loss for the final design for the E-shape MLA using Parametric study

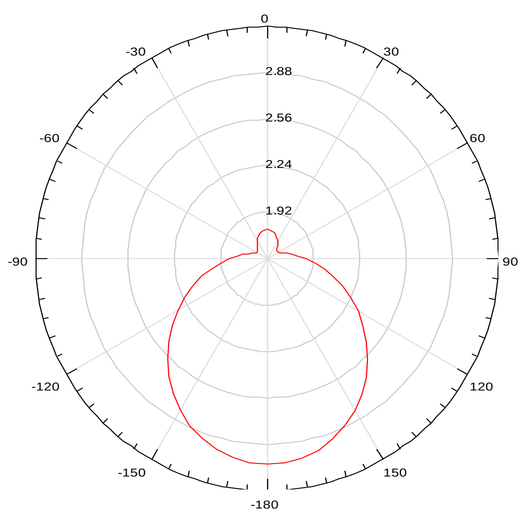


Figure 4.17: The radiation pattern for the final design for the E-shape MLA using Parametric study

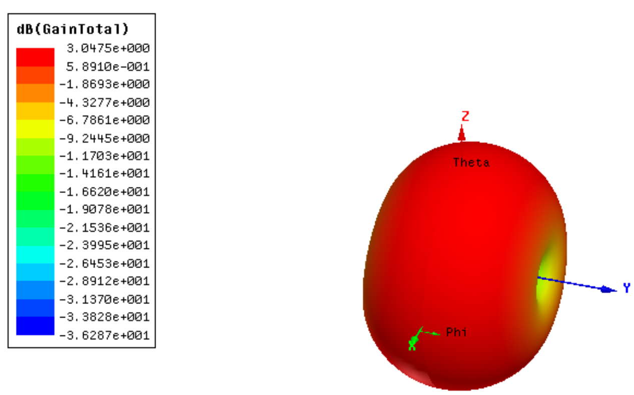


Figure 4.18: The gain for the final design for the E-shape MLA using Parametric study

4.4 THE OPTIMIZATION OF E-SHAPE MLA WITH GENETIC ALGORITHM

In order to find an optimum E-shape MLA structure with resonant frequency 2.5 GHZ, the method of GA is applied. A strategy for the combination of genetic algorithm with HFSS is illustrated in Figure 4.19, where in version 12 is support GA, where it generates the parameters of each structure .The calculation of fitness values are compiled by HFSS. The calculated fitness values are then returned to genetic algorithm module for GA model. The electrical characteristic parameters of E-shape MLA are justified by a comparison with an evaluation of a fitness function. If the fitness meets the requirement, the procedure is completed. Otherwise, new structures are produced by a GA procedure. The new structures are used in the next iteration for HFSS analysis to justify their performances with respect to the expectations. The GA operation specifies the parameters to produce a new structure based on selection, crossover and mutation. GA optimizer parameters are set up as shown in Table 4.6.

Table 4.6. Specification of the GA

Population Size	30
Maximum number of iterations	4 hours
Crossover Rate	0.8
Mutation Rate	0.02
Number of sample	200

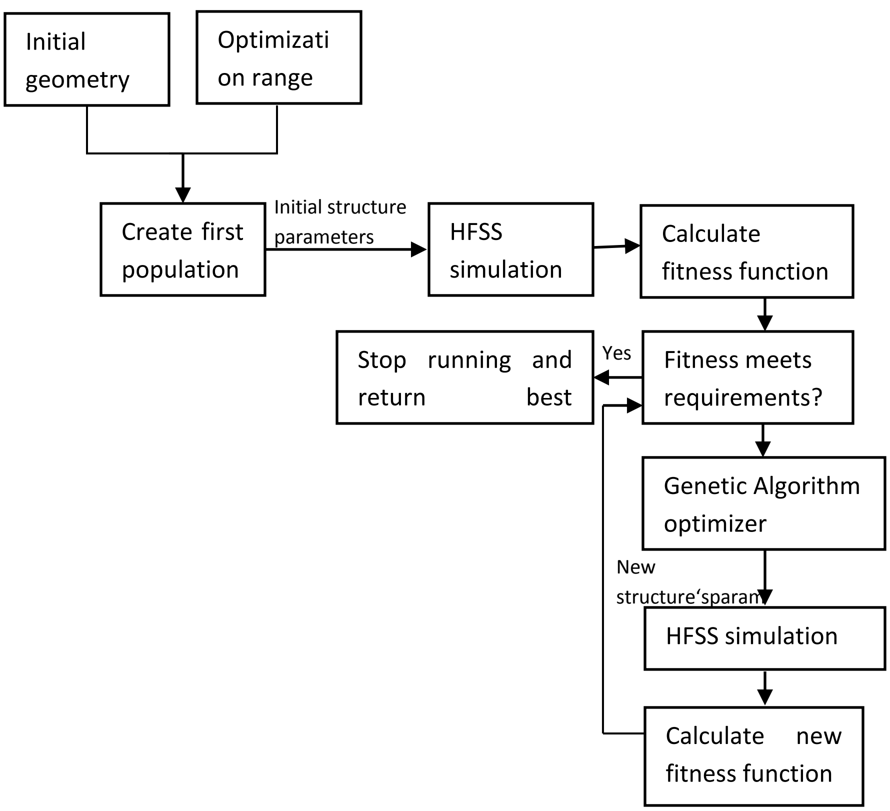


Figure 4.19: Using GA technique in HFSS

The design goal is to achieve the LTE mobile handset standard that has small size, resonant frequency 2.5 GHZ, minimum bandwidth is 40 MHZ and maximum gain is 3dB [15]. In our case, the parameters that described in section III are selected to optimize the antenna. To achieve this goal, the fitness function is defined as the following:

$$fitness1 = \frac{1}{N}\sum_{i=1}^{N}|S_{11}(f_i)| \leq -10\ dB \ldots (4.6)$$

$$fitness2 = 10\log\left(\frac{P_{out}}{P_{in}}\right) \leq 3\ dB \ldots (4.7)$$

In the equation above, *i is* the sampling frequency, N is the number of the sample.

4.5 THE E-SHAPE MLA DESIGN AND SIMULATION RESULTS USING GENETIC ALGORITHMS

From section 4.2, we show in Figure 4.3 the configuration of the E-shape MLA and its some dimensional parameters. In this section we will add the ground plate height that characterized by variable *ground* .The width w_3 is characterized by *ywidth*, the width w_1, w_5 and w_6 are characterized by *xwidth*, the width w2 is characterized by *middle* and the width w_4 is characterized by *fwidth*. The ranges of these parameters to be optimized and the optimal results are shown in Table 4.7.

Table 4.7: The parameters were optimized by using GA in HFSS

Parameters	**Xwidth**	**Ywidth**	**Middle**	**Fwidth**	**ground**
Max	2.5	2.5	2	2.5	20
Min	0.6	0.6	0.6	0.6	35
Optimal value	2.1589	1.53708	1.14618	1.4205	27.1496

The design of the antenna and the results are shown in Figure 4.20-4.21. In these figures, we can see that resonant frequency is 2.5 GHZ, the bandwidth is 1.15 GHZ that can be determined in terms of 10 dB return loss by using Matlab software and the gain is 2.9 dB. The proposed antenna has an available bandwidth about 50% of the resonant frequency. Figure 4.22-4.24 illustrate the radiation pattern of the optimized E-shape MLA at 2.5 GHz.

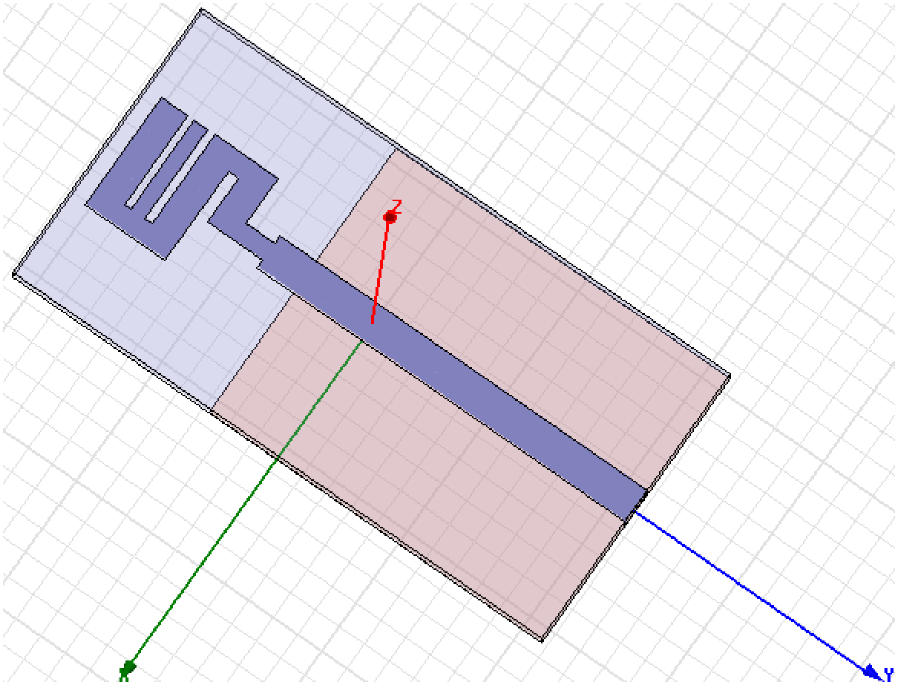


Figure 4.20: The final design of the E-shape MLA using GA.

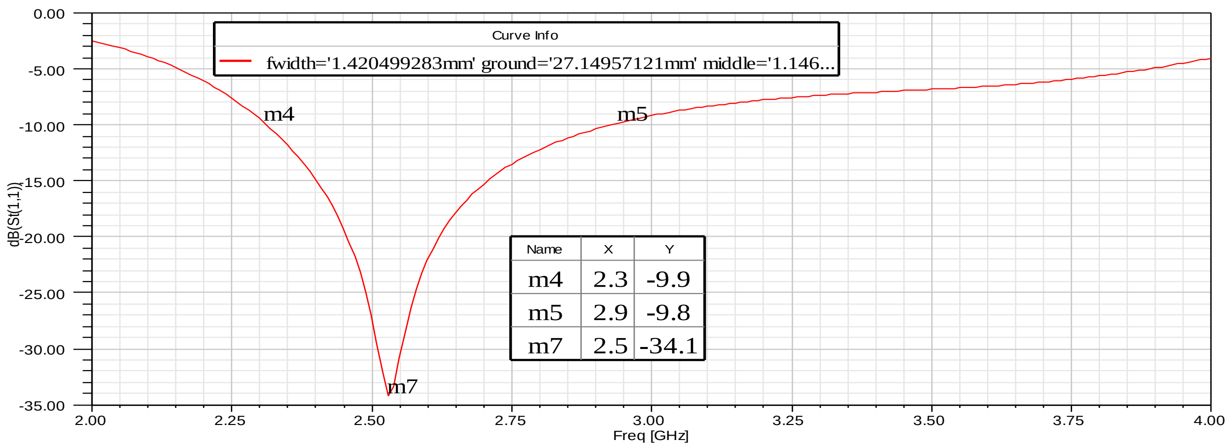


Figure 4.21: The return loss for the final design of the E-shape MLA using GA.

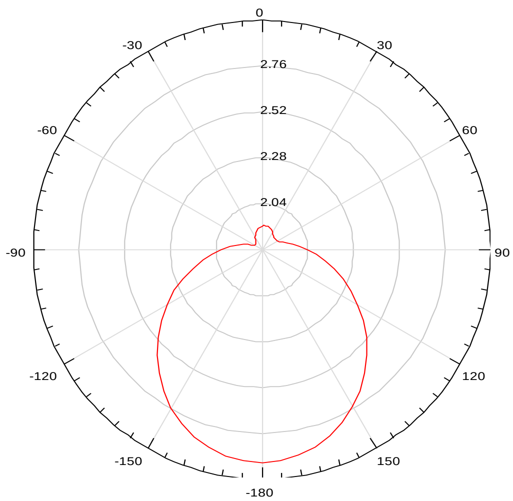


Figure 4.22: The radiation pattern for the final design of the E-shape MLA using GA.

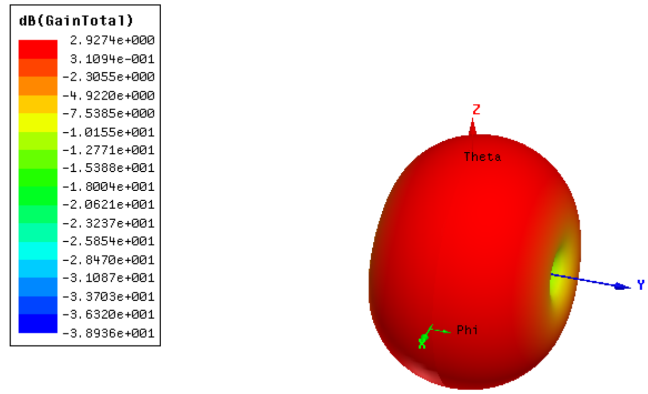


Figure 4.23: The gain for the final design of the E-shape MLA using GA.

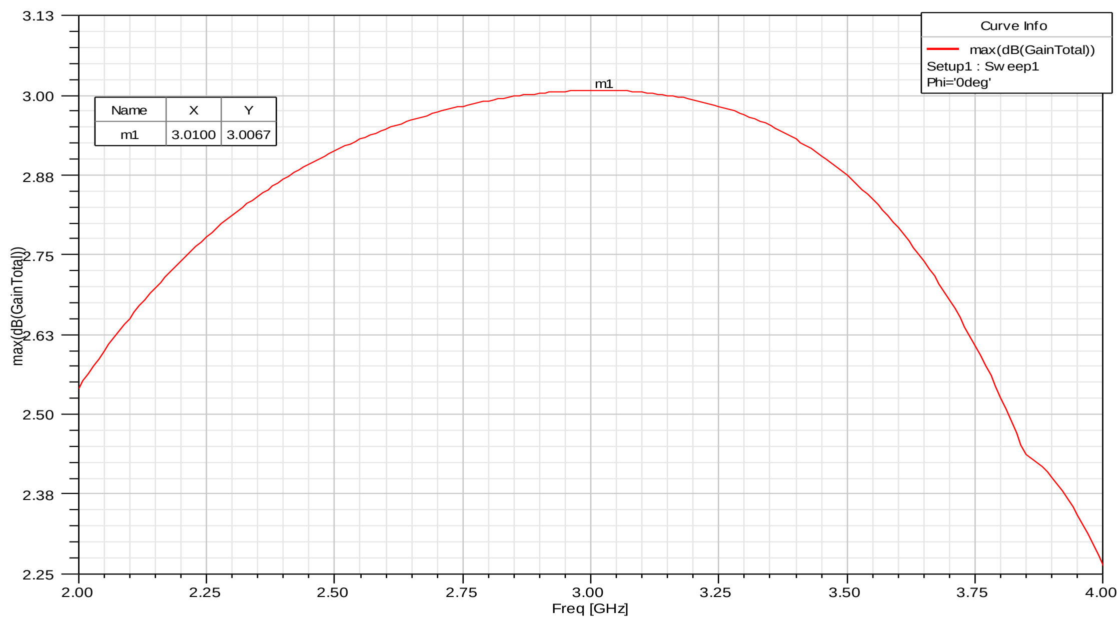


Figure 4.24: The maximum gain for each frequency at pi=0.

The difference between the final designs E-shape MLA by using the parametric and the optimization technique are shown in Table 4.8.

TABLE 4.8: THE DIFFERENCE BETWEEN THE FINAL DESIGN USING PARAMETRIC AND OPTIMIZATION METHOD

Parameters	The final design using parametric method	The final design using optimization method
Resonant Frequency	2.6 GHZ	2.5 GHZ
Max Return Loss	19 dB	34 dB
10dB bandwidth	1.2 GHZ	0.65 GHZ
Max Gain	3.02	2.93

4.6 THE OPTIMIZATION OF E-SHAPE MLA WITH GENETIC ALGORITHM ON DIFFERENT SUBSTRATES

In the previous sections, we apply the parametric and optimization on the E-shape MLA that has a substrate material FR4 with $\varepsilon_r = 4.5$ and tanδ = 0.0150, dielectric height and h = 1.5 mm. In this section we will apply the same parameters on other substrate materials as shown in Table 4.9.

Table 4.9: The difference between the different substrate materials

Substrate material	Relative Permittivity	Substrate Height (mm)
FR4	4.5	1.5
RO5880	1.96	1.5
RO3003	3	1.5

The results for the different substrate materials are shown in Table 4.10.

Table 4.10: The antenna parameters for the different substrate materials

Parameters	Substrate 1	Substrate 2	Substrate 3
Resonant Frequency	2.5 GHZ	2.6 GHZ	2.5 GHZ
Return Loss	34 dB	20.37 dB	28 dB
10db bandwidth	0.65 GHZ	0.57 GHZ	0.43 GHZ
Max Gain	2.93	2.81	2.74

4.7 CONCLUSIONS

An electrically small E-shape MLA operating at the 2.5 GHz was studied in this chapter using HFSS software package. We apply parametric and optimization technique using genetic algorithms to achieve the antenna for the standard LTE mobile handset. The antenna provided a significant bandwidth enhancement and small gain enhancements. The E-shape MLA depicts an overall fair performance and it could be a promising candidate to overcome the deficiencies of the low profile small antennas. Finally, we apply the antenna on different substrates.

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CHAPTER 5

CONCLUSION

5.1 CONCLUSION

In this research work, a printed antenna is designed using meander line technique to demonstrated lager impedance bandwidth for considerably small dimensions. Two types of Meander Line antennas have been studied in this thesis. The first type is the design of MLA for LTE mobile application in 0.78 GHz band and the second is the design of E-shape MLA for LTE mobile application in 2.5 GHz band.

The first contribution of this research work, we analysis and design MLA for LTE mobile application in 0.78 GHz band that has a correct selection of MLA dimensions that deal with it. And we show that as tabulated in the conclusion section of chapter 3, The MLA in this research has better gain comparing with MLA was used for it.

The second contribution of this research work is to analysis and design E-shape MLA for LTE mobile handsets in 2.5 GHz band, where is the new shape antenna developed from the original MLA. And we show the antenna has better bandwidth and gain for MLAs were used for the same subject as described in chapter 4.

We used in this thesis two techniques: the first technique is parametric study where study each variable in the antenna then study the effect each of them on the antenna, after that go to other type and make the work until finish all the variables. We show the results from this technique is a good method for enhancement the gain an the bandwidth but not the optimal solution.

The second technique is optimization technique using Genetic Algorithms at various times (4 hours, 1 day and 3 days) was found in HFSS v.12. This technique can be effectively used in the design of various complex antenna and millimeter dimension circuits, where the performance of this technique to design the antenna is a good precision design of antenna elements for low and high frequency applications as shown the results in chapter 3 and 4. MATLAB codes were written to determine the resonant frequency and the bandwidth for each study in this thesis.

5.2 FUTURE WORK

- Fabricate the two types of MLA and compare it with the simulation results.
- Use Meta-material based substrates to further reduce the antenna size and introduce enhancement the bandwidth and the gain.
- Design and implement MIMO antenna systems for LTE standards of mobile phones with reduced correlation coefficient. This is particularly challenging due to the size limitations and usage of 0.78 and 2.5 GHz band for this system.
- Design the LTE antenna in 1.8 GHz band where it will used in the Middle East at 2016.
- Apply other optimization techniques such as particle swarm optimization (PSO), bacterial foraging (BF) and compare the results with genetic algorithms.