Edge Truncated Planar Inverted F Antenna for High Band LTE Applications

Dissertation submitted in partial fulfillment of the requirements for the award of the degree of

Master of Engineering

In

Wireless Communications

Submitted By

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DECLARATION

I, Atipriya Sharma hereby declare that the work which is being presented in the dissertation entitled " **Edge Truncated Planar Inverted F Antenna for High Band LTE Application**", by me in partial fulfillment of the requirement for the award of degree of M.E. in Wireless Communications submitted in Electronics and Communication Engineering Department of Thapar University, Patiala is an authentic record of my own work carried out under the guidance of **Dr. Rajesh Khanna** (Professor), Electronics & Communication Engineering Department. The matter presented in this dissertation has not been submitted in any other University/Institute for the award of degree.

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This is to certify that the above statement made by the student is correct to the best of my knowledge and belief.

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ABSTRACT

With recently higher growth in the use of mobile technology applications, the demand becomes higher in the use of voice and data services. It gives the motivation to the growth of the Long Term Evolution (LTE) and LTE advance. LTE advance is also known as 4G technique and it gives better mobile telle communication system as its performance is much better than older 3G system. In 4G many antenna can be used like advance dipole antenna, microstrip antenna, printed antenna and PIFA antenna etc. PIFA antenna prefers due to its various advantages over other one like its compact size, Low cost, light weight, and minimized backward radiation for minimizing SAR. At the same time, PIFA has some disadvantages also like bandwidth is narrow and low gain, due to its disadvantage it cannot be used in many applications.

In this thesis a compact size edge truncated planar inverted F antenna for high band LTE applications (PIFA) is designed, simulated, fabricated and tested. The main aim of this thesis is designing of PIFA which works on LTE upper band. The structure of antenna should be compact so that it can be easily adjusted in small space, by this optimization of space can be achieved. The bandwidth should be broad and higher gain can be achieved over all bandwidth.

The optimized dimension of the edge truncated planar inverted F antenna for high band LTE applications has been found by parametric studies. After optimum designing, the PIFA is simulated by CST software. The return loss, gain, VSWR results has also been showed in this thesis. Here, PIFA is also fabricated by using FR4 substrate. After fabrication PIFA is tested with the help of Agilent E5071C vector network analyzer. To enhance the gain another structure is designed and simulated. The simulated results have of gain enhanced structure also been showed. Also, the comparison between measured and simulated results of edge truncated planar inverted F antenna for high band LTE applications is shown.

TABLE OF CONTENTS

LIST OF ABBREVATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
QoS	Quality of Service
NTT	Nippon Telegraph and Telephone
PTT	Push To Talk
MTS	Mobile Telephone Systems
AMTS	Advance Mobile Telephone Systems
IMTS	Improved Mobile Telephone Service
SMS	Short Message
CDMA	Code Division Multiple Access
GPRS	General Packet Radio Service
EDGE	Enhanced Data Rates for GSM Evolution
GSM	Global System for Mobile Communication
WLAN	Wireless Local Area Network
UMTS	Universal Mobile telecommunication system
HSDPA	High Speed Downlink Packet Access
MMS	Multi Media Messaging Service
LTE	Long Term Evolution
3GPP	Third Generation Partnership Project
VoIP	Voice-over Internet Protocol
GPRS	General Packet Radio Services
GSM	Global Services for Mobile
WCDMA	Wideband Code Division Multiple Access
HSDPA	High-speed Downlink Packet Access

HSUPA	High Speed Uplink Packet Access
OFDM	Orthogonal Frequency Division Multiplexing
FDMA	Frequency Division Multiplexing
SC-FDMA	Single Carrier FDMA
IP	Internet Protocol
CAPEX	Capital Expenditures
OPEX	Operational Expenditure
SON	Self Organizing Network
UL	Uplink
DL	Downlink
MIMO	Multiple Input Multiple Output
FDD	Frequency Duplex
TDD	Time Duplex
IFA	Inverted F-antenna
PIFA	Planar Inverted-F Antenna
CST	Computer Simulation Technology
VNA	Vector Network Analyzer
PCB	Printed Circuit Board

LIST OF FIGURES

LIST OF TABLE

Chapter 1

INTRODUCTION

1.1Overview

The capability, to share or exchange the ideas or any information among people wirelessly, has been developed, since Marconi, first establish radio services to provide continuous connection with planes, ships etc. The wireless technique spread in a very short time span. In the few past decades, the mobile wireless development proceeded from (1G) First Generation to(2G) Second Generation, (3G) Third Generation,(4G) Fourth Generation and now (5G) fifth generation systems are being developed with the focus on high (QoS) Quality of Service, performance and efficiency. Nowadays Mobile wireless technology has extended to 4G or 5G [1].

1.1.1 First Generation (1G)

1G cellular networks were introduced in the 1980s. All 1G system was purely analog systems generally known as early cellular phone technology. The Japan launched (the 1G generation) first commercially automated cellular network by the name NTT (Nippon Telegraph and Telephone) in 1979, originally in the urban area of Tokyo. In 1G systems an antenna whose radiation pattern was omni directional was used for example half wave dipole antenna [1].

Technologies under 1G

1G encompassed the following Mobile technologies: Push To Talk (PTT) Mobile Telephone Systems (MTS), Advance Mobile Telephone Systems (AMTS), and Improved Mobile Telephone Service (IMTS)[1].

Issues with 1G

Analog technique was not secure. Anybody can listen to other's conversation. Long call delay, hard hand off etc. were the major problems that occurred in 1G.

1.1.2 Second Generation (2G)

2G is the second generation cellular technology. In 1991, introduced by Radiolinja in Finland, 2G was commercially launched on the GSM standard [1]. 2G uses digital information for voice communication. Its speed was up to 64 kbps and it also gives the provision of SMS (Short Message Service).2G uses the 30 - 200 KHz bandwidth range. In this technology sectoring is done due to this directional antennas are used at base stations and in mobile phones helix, monopole antenna patch antenna etc. are being used.

Technologies under 2G

2G encompasses the some mobile technologies that is Global System for Mobile Communication (GSM), (CDMA) Code Division Multiple Access, (GPRS) General Packet Radio Service, (EDGE) Enhanced Data Rates for GSM Evolution Some major merits of 2GNetwork over 1G were that, Digital Encryption was introduced in 2G and also hold up by 2G systems[2]. Due to this we get higher efficient on network spectrum. Further, 2G bring several facilities for mobile, the most eminent and famous one is text messages.

Issues with 2G

In 2G use of codec the technique became complex. During good conditions, digital signals experienced better performance. Under bad conditions, analog signals experienced constant, while digital has periodic dropouts. As conditions become more and more worse, digital signals can completely fail [2].

1.1.3 Third Generation (3G)

"3G" is the third generation mobile communication technology. It is a type of cellular mobile communication technology which can assist high-speed data communication [2]. 3G services can transfer data and voice (call) information (video conferencing, email, www etc). Generally the speed is higher than a 300 Kbps. Data rate of 3G is very higher as compared to 1G and 2G, third generation is a current generation of mobile transmissions systems which merge multimedia communications and wireless with the

Internet [2]. It can transfer images, audio, video and other data streaming including web surfing, e-commerce, conference calls, and many other data services [1]. In order to provide this service, wireless networks must be capable of maintaining at least 1MBps (MB / sec) data transfer speed in the outdoor, indoor and vehicular atmosphere.

Technologies underneath 3G

3G Technology consist of Wideband CDMA, (UMTS) Universal Mobile telecommunication Systems, High Speed Downlink Packet Access (HSDPA). Data are transmitted via packet switching. Voice data are explicate by circuit switching.3G also provides provisions like Mobile T.V, Global Roaming, Clarity in voice calls, Internet, Fast Communication, Video Calls ,Video Conferencing, (MMS) Multi Media Messaging Service ,Multiplayer-Gaming and 3D gaming.

Issues related to 3G

It provides higher data rates compared to 2G, but 3G techniques are costlier as compared to previous one. As it offers very high bandwidth, so its consumption of power is also increased due to this the battery life of device become gets reduced.

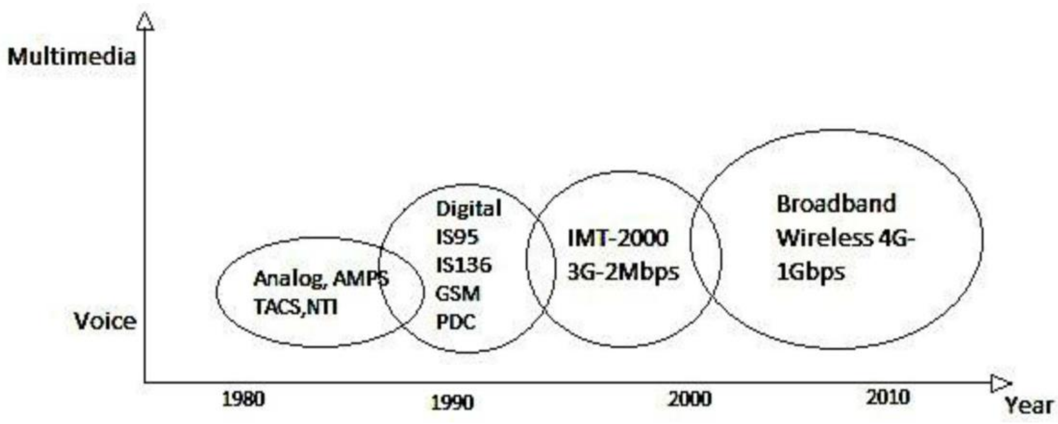


Figure 1.1 Various standards [2]

With recently higher growth in the use of mobile technology applications, the demand for higher voice and data services have increased manifold. It gives the motivation to the growth of Long Term Evolution (LTE) in recent years. The Long Term Evolution (LTE) system has been designated by the Third Generation Partnership Project (3GPP) forthcoming towards fourth-generation (4G) mobile[2].

There has been exponential increase in the use of mobile devices for net surfing for examples, Facebook, whatsapp, hike, Twitter, video streaming, Voice-over Internet Protocol (VoIP) applications for internet calls on Skype, medical applications that run on real-time data, voice and video calls and a number of modern applications that have greater demands for high data rates. The most notable factor is that the service providers have been trying hard to supply the demanded rates to their customers as customer wants to get a higher data rate with wider coverage has lead to a bigger discussion.

According to the Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, for 2015-2020, "the overall mobile data traffic is expected to grow to 30.6 Exabytes per month by 2020, a 13-fold increase over 2012" as shown in figure 1.2.

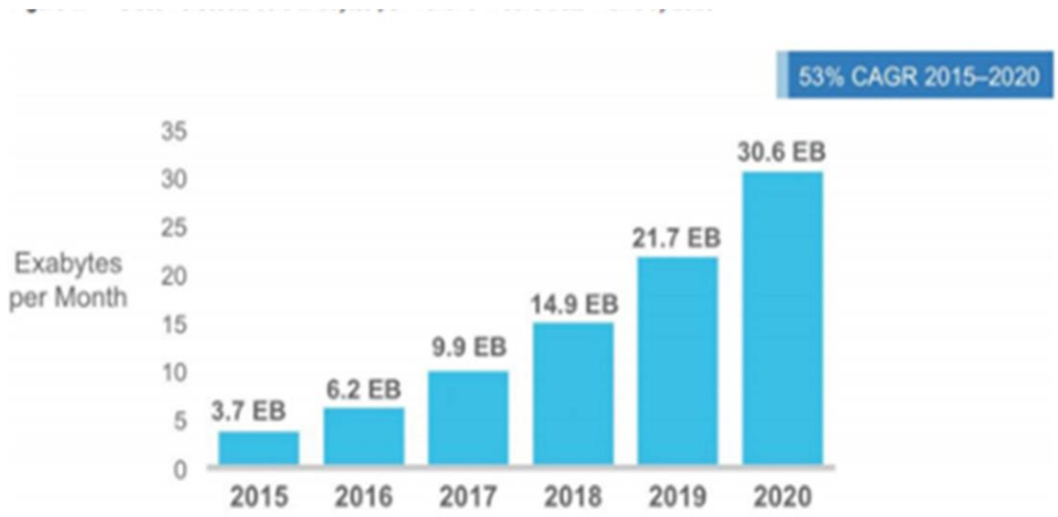


Figure 1.2 Cisco Forecasts [3]

The figure 1.2 shows that Cisco Forecasts30.6 Exabytes per Month of Mobile Data Traffic by 2020[3]. In addition, it is expected that there will be hybrid annual Growth Rate (HAGR) of 53% from 2015 to 2020 for mobile data rate [3]. Providers of mobile service have been working hard to design ingenious solutions to expanding networks and the unique growth rates in demands. Few are the solutions that have been provided in reducing these demands are the allocation of smaller cell sizes like microcells and nanocells to increase gain capacity in higher populated areas, underground motor ways, basements, high building areas and many others. After exploring, it has found that the utilization of these solutions(microcells and nanocells)are effective but the respective costing, designing and planning with their corresponding apparatus cost, power source does not formulate these the best approach to reduce the growing demand. Various communication standards are shown in table 1.1.

Table 1.1 Various Communication Standards

Wireless Communication Service		Allocated Frequency Band
UMTS 2000	Universal Mobile Telecommunications Systems	1920-2170 MHz
3G IMT-2000	International Mobile Telecommunications – 2000	1885-2200 MHz
4G LTE 700 4G LTE 1700 4G LTE 2300 4G LTE 2600	Fourth Generation Long Term Evolution	704-716 MHz, 734-746 MHz 1710-1755 MHz, 2110-2155MHz, 2300-2400 MHz 2500-2570MHz, 2620-2690 MHz
ISM 2.4 ISM 5.2 ISM 5.8	Industrial, Scientific, Medical	2400-2484 MHz 5150-5350 MHz 5725-5825 MHz
UWB	Ultra Wide Band	3.1 – 10.6 GHz
WiMAX	Worldwide Interoperability for Microwave Access	3400-3600 MHz

1.2 Long Term Evolution (LTE)

As growth of data rate is very high, as well as customer wants a continually good quality of service and as number of users increases, data rate must be increased. To fulfill all these requirements the existing mobile communication system and networks are not sufficient. There is a need to extend the technology and extra components and extra elements that means the increase in infrastructure. The technology is initiated as 3GPP Long Term Evolution, which is a real standard and mobile packet-data oriented transmission system. LTE is the developing system to give the higher data rate, higher capacity and higher bandwidth. Due to this the system becomes simple, its impact also shown on transmission delays that means exactly on the QoS. The Long term evolution (LTE) is a one step towards the (4G) fourth generation technology. Typically the work on LTE standardization started out in 7 years ago that is in 2004 that basically concentrated on the possible transformation of UMTS. It gave a developing path to higher speed, reduced latency and similarly sufficient use of the operator’s limited range resources; depend on the framework of the 3GPP class of mobile communication systems such as GPRS, GSM and WCDMA (HSPA). Typically the very first report of LTE standard, (R8) release 8, consist of the primary functionality that sustain the enforcement of the wireless communication systems. Most particularly, this new standard has grown up to deliver greater data rate i.e. about 300 Mbps, and to get higher spectral efficiency, and minimum user plane dormancy of less than 5ms, higher frequency versatility and a flat architectonics to reduce cost with good operation. Within contrast to the current 3GPP networks, it is orthodox to provide impressive performance. The downlink maximum user throughput is (3-4) three to four times higher than regarding Release 6 High-speed Downlink Packet Access (HSDPA) and the uplink peak user throughput is (3-4) times larger than Release 6 High Speed Uplink Packet Access (HSUPA) [1,2].

In LTE system Orthogonal Frequency Division Multiplexing (OFDM) technology is mostly used. In OFDMA a Single Carrier FDMA (SC-FDMA) for the UL is used and for the DL OFDM Access (OFDMA) is used. Additionally, it uses larger bandwidth of approximately 20 MHz and 64 QAM modulation techniques and very complex (FEC) forward error correction technique. Along with LTE system is based on some another techniques such as multiple inputs and multiple output MIMO system or MIMO antennas and beam forming. The basic purpose to use all the above approaches is made for LTE system so that to expedient the performance need and most importantly increase the radio performance of the system [1,2].

LTE system came into existence to improve capacity and data transmission speed. These are the fundamental terms and are a very basic expansion of prior mobile communication and systems 'essence, data rates become higher and latencies become lower therefore delay is also reduced. These types of advancements must be attained by- the illumination of the whole system, all these improvements are to be realized through the vivification of the overall system, we get optimization by the automated development of system management. To reduce the extra system complexity, we can introduce or use both the packet switching and circuit switching domain, but for better results circuit switching domain is used in LTE system. The system-external subsystems for example IMS are introduced to supersede the conventional SMS that is text messaging and voice services. It provides outstanding mobility and security. As of today the basic need is to access the internet from anywhere, and the established connection should be secure. For this purpose LTE is the best technique as it is based on IP(internet protocol) system. Due to this the evolved base stations efficiency on mobility is increased. As the mobile phones and some other similar devices which have restrained battery capacity are being related with mobile terminals. In that event a narrow bandwidth system is required (for uplink transference we need low frequencies) and automatic signal power-level exaggeration must be constituted into LTE. Due to the practical implementation of any new system adds to building and construction costs, but LTE is implemented in such way so that we require minimum investment, and so we can use as much as the current mobile communication infrastructure as more as possible.

To sum up some of targets and needs for the LTE release [4], are:

(i) Delay should be less so that latency time should be minimum.

(ii) Data rate should be high so more numbers of users can accommodate.

(iii) Increased in cell edge bit rate should be higher, so that better services are provided to customers.

(iv) To upgrade spectral efficiency we should reduce the cost per bit.

(v) The spectrum flexibility should be high.

(vi) It should be better and very simple network architecture.

(vii) Higher mobility so that users can easily access anywhere, anytime.

(viii) Consumption of power should be low for mobile and other similar devices so that users get more battery life of devices.

(ix) Most importantly, some of the basic needs for the LTE are high demand for maximum data rates along with high (QoS) quality of service, latency time should be less,(CAPEX) and (OPEX) that is Capital Expenditures and Operational Expenditure respectively should be low design, complexity should be low, as the design is less complex automatically due to simplification of LTE networks the (OPEX) cost will be reduced [4,42].

(x) For better and upgraded network planning and to reduce the cost self-optimization and self-configuration of network must be there which is introduced by (SON) Self Organizing Network.

In more technical language, some of the LTE requirements are given below [4]:

1. The frequency in terms of bandwidths should be flexible and extendable to 1.25, 2.5, 5.0, 10.0 and 20.0 MHz.
2. Basic higher data rate scaled with system bandwidth for Uplink (UL) for a single Channel transmission at maximum rate of 50 Mbps in frequency of 20 MHz channel and for Downlink (DL) for two receiver Channel (multiple input multiple output)MIMO at peak rate of 100 Mbps in frequency of 20 MHz channel
3. By use of scheduled process and by supporting progressive multi-antenna (MIMO)configurations which improves data rates, with DL -2 ×2 4×2, 1×2 and 1×1and with UL - 1×1and 1×2.
4. Spectrum efficiency - DL 3 to 4 ×HSDPA Release 6 and UL 2 to 3×HSUPA Release 6.
5. Latency – For(C-plane) Control plane latency should be less than 50 - 100 ms to originate (U-plane) User plane and for User-plane latency should be less than 10 ms from UE to server. Moreover single way latency should below than 5ms which provide the means 10 ms Round Trip
6. In terms of Mobility, supports optimized for low speeds (< 15 km/hr); high performance for speeds up to 120 km/hr; and maintained link for speeds upto 350 km/hr (and targeted speeds of up to 500 km/hr with frequency band consideration).

7. Coverage radius up to 5 km it should give full performance, a very little degradation 5 km - 30 km is allowable and its operation should support up to 100 km and should not be discontinue by standard. All over, the LTE system needs are basically depend upon System Capability (Latency and maximum Data Rates); System Performance (Spectral efficiency, Throughput, Mobility, Coverage and Multicast Services/ Enhanced Multimedia Broadcast,(eMBMS); System Architecture;

8. System Spectrum Allocation; and Cost Reductions.

1.2.1 LTE Band

As mobile telecommunication users are increased, therefore the radio spectrum of particular frequency band is also increased so LTE system is accepted to function in a widespread spectral frequency bands. The spectrum of frequency from 1.4 MHz to 20 MHz is allotted to LTE which has only one carrier. For all that nowadays most of the frequency spectrum are used by many other technologies, LTE can coexist with earlier radio access technologies. In Europe where there are more than 600MHz of spectrum that can be accessed by mobile operators. In Japan the LTE implementations is started with 2100 band and after that they included some other bands that is 800, 1500 and 700 frequency bands and in the USA, the LTE was originally built on 700 and 1700/2100 frequency bands [4][5][6].

LTE supports the operation of FDD, TDD, and half-duplex in a integrate design to provide a great amount of commonality which simplifies the deployment of multimode terminals and because of this a global roaming is achieved. The list of frequency bands for TDD and FDD functions in LTE is given in Table 1.2[4] in detail, presently there are 17 bands and 8 bands describe for FDD and TDD respectively [4][5][6].

Table1.2 LTE frequency bands

LTE Band	**Uplink enode B receive UE transmit (MHz)**	**Downlink enode B transmit UE receive (MHz)**	**Duplex Mode**
1	1920 - 1980	2110 - 2170	
2	1850 - 1910	1930 - 1990	
3	1710 - 1785	1805 - 1880	

4	1710 - 1755	2110 - 2155	**FDD**
5	824 - 849	869 - 894	
6	830 - 840	875 - 885	
7	2500 - 2570	2620 - 2690	
8	880 - 915	925 - 960	**FDD**
9	1749.9 - 1784.9	1844.9 - 1879.9	**FDD**
10	1710 - 1770	2110 - 2170	**FDD**
11	1427.9 - 1447.9	1475.9 - 1495.9	
12	699 - 716	729 - 746	
13	777 - 787	746 - 756	
14	788 - 798	758 - 768	
15	1900 - 1920	2600 - 2620	
16	2010 - 2025	2585 - 2600	
17	704 - 716	734 - 746	
18	815 - 830	860 - 875	
19	830 - 845	875 - 890	
. . .			
33	1900 - 1920	1900 - 1920	**TDD**
34	2010 - 2025	2010 - 2025	
35	1850 - 1910	1850 - 1910	
36	1930 - 1990	1930 - 1990	
37	1910 - 1930	1910 - 1930	**TDD**
38	2570 - 2620	2570 - 2620	
39	1880 - 1920	1880 - 1920	
40	2300 - 2400	2300 - 2400	

1.3 LTE Advanced

LTE-Advanced is a direct transformation of LTE standard. LTE-Advanced data rate provides high data rate in very cost efficient way along with it has a potential to fulfill all the requirements which are set by ITU for IMT advance. This is also known as 4G technique and it gives better mobile telecommunication system performance which is much better than its predecessor 3G system. This LTE-Advanced standard was initiate in 2011 by 3GPP group. The main motive of LTE- Advanced system is to bring higher data rate, higher spectral efficiency, raise network capacity, to increase the cell edge performances with best (QoS) quality of service and lessened deployment cost. In spite of it was needed to produce high data rate that which is of 1 Gbps in the DL and 500 Mbps in the UL, but basically, LTE-Advanced delivered higher data rate up to 3 Gbps in the DL and 1.5 Gbps in the UL, means we have total (BW) bandwidth of 100 MHz. Moreover, the LTE terminals can easily divulge with the LTE-Advanced network as it was already designed and has features so that it can be compatible with LTE systems [5].

The main technologies used in LTE-Advanced are; carrier aggregate for sharing of spectrum and wider-band transmission, support multi-point transmission, relay nodes support and lastly the use of multi-antenna solutions. In 4G we use many antenna like advance dipole antenna, microstrip antenna, printed antennas and PIFA antenna etc. PIFA antennas are preferred due to their various advantages over other antennas.

1.4 Structure of PIFA antenna

Inverted F-antenna (IFA) was introduced earlier for improved understanding of planar inverted-F antenna. Actually, IFA antenna is borrowed from monopole antenna. The main purpose of borrow IFA from monopole antenna to reduce the height of monopole antenna because of smooth integration through the small mobile terminals and also for good impedance matching. The diagram of the inverted-F antenna element is shown in figure 1.3 [9]. It contains both the feeding point and shorting strip so that they act like a shunt inductor respectively [8].

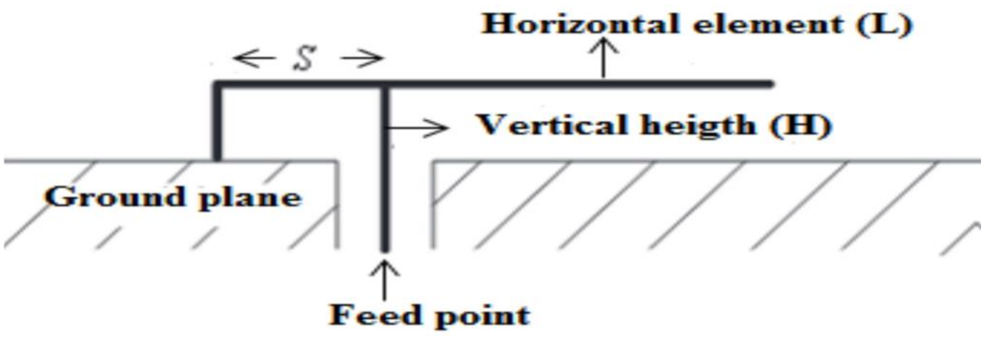


Figure 1.3 Inverted-F antenna element [9]

In order to get contraction in the height of antenna, Inverted-F antenna is used which is a modification of the monopole antenna, to maintain the resonant trace length and become parallel to the ground plane the top section of monopole antenna has been folded down. By the parallel part of the antenna to the input hindrance of the antenna the capacitance is introduced. The ground is linked to the stub's end. In Inverted-F Antenna the important role played by the ground plane of the antenna, in its working as the excited current in reproduced IFA causes stimulation of currents in the ground plane too. Hence the produced EM field is found by the interaction of the Inverted-F antenna with image of itself beneath the ground plane. The monopole behaves as a perfect energy reflector when the ground plane is infinite in its dimensions [9]. In general, the measurement of the ground plane is one quarter (λ/4) of the operating wavelength any other way it may lead to degraded performance or multiple lobes.

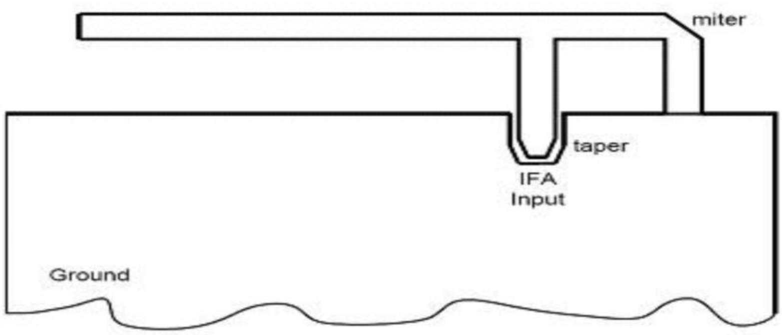


Figure 1.4 Inverted F-antenna [9]

The PIFA (Planar inverted-F antenna) can be expressed as the modified form of IFA antenna. It can be designed by expanding the radiating straight horizontal strip of the inverted-F antenna and change it with a rectangular planar either patch component which is usually placed alongside to the conducting ground plane. As a result, planar inverted-F antenna vibration frequency is practically vulnerable on the area of the planar element. So, the planar conductor component increases the area engrossed by the radiating inverted-F antenna above the ground plane, thus widening the bandwidth. The ground plane beneath the Planar inverted-F antenna network plays an important role by diminishing the effect of the RF reflected energy, when the phone is brought near to the head. The main design of the Planar inverted-F antenna can be shown in Figure 1.5 [16].Distance between the ground plane and the horizontal planar is H, the length L and width W are used to tune the required frequency, the distance between feeding point and the ground strip is S, that drives the matching of the PIFA antenna [7,8,9]

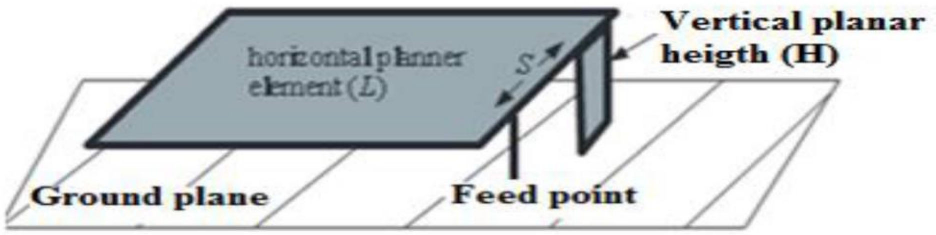


Figure1.5 Planar inverted antenna [8].

The bandwidth of Inverted-F Antenna was very confined and therefore a wire is replaced by a plate so that the bandwidth of the antenna can be extend, hence Planar Inverted-F Antenna was invented. PIFA(Planar Inverted-F Antenna) is also called as short-circuited microstrip antenna, as the plate is used by the ground plane and to short circuit the radiator [10]. In designing of Planar Inverted- F Antenna the important role is played by the size of ground plane and can be used to enhance the antenna for multi-band frequencies and wide-band. In a various wireless communication applications PIFAs find their advantages mainly in mobile phone devices because of to its easy integration, compact size, low weight and low profile. Different shape of slots introduced on ground plane and radiator are used to get different configurations in order to obtain single and multiple frequencies. These structures have self-resonating design. By Varying the distance, location and length of the feed and shorting point, length of the radiator the performance parameters of the antenna can further improved [11],[12],[13].

Planar Inverted-F Antenna structures have discrete advantages when relate to other conventional antennas such as that it can be placed inward to the mobile housing just over the battery when proportionate to rod/helix antennas. Planar Inverted-F Antenna structures produce contracted electromagnetic radiations in the backward side toward the user's body and hence minimize Specific Absorption Rate (SAR). PIFA design also shows moderate to high gain in both horizontal and vertical states of polarization. Apart from discrete advantages the efficiency of PIFA is minimized by many losses such as mismatch losses, ohmic losses, transmission losses in feed line, edge power losses, external parasitic resonances, etc. The resonant frequency of Planar Inverted-F Antenna can be calculated using expressions which are written below:

$$L_1 + L_2 = \lambda/4 \quad (1.1)$$

$$\text{when } W/L_1=1 \text{ then } L_1 + h = \lambda/4 \quad (1.2)$$

$$\text{when } W=0 \text{ then } L_1 + L_2 + h = \lambda/4 \quad (1.3)$$

The (PIFA) Planar Inverted-F Antenna vibrates at $\lambda/4$(quarter-wavelength)because of the shorting pin presence at one end. In the above said expressions L_1 and L_2 are the lengths and width is W of the shorting pin that starts at one end of the antenna. From the ground plane the patch is placed at height (h). The resonant frequency of Planar Inverted-F Antenna is decided by Shorting Plate width W [12].

The improvement of the handheld device antenna structures from monopole antennas to the Planar Inverted-F Antenna depicts that the wire is the important component of a handset antenna whereas the stub(s) slot(s) and patch(s) and compensates for the mismatch among various components and develop the radiation characteristics [14].

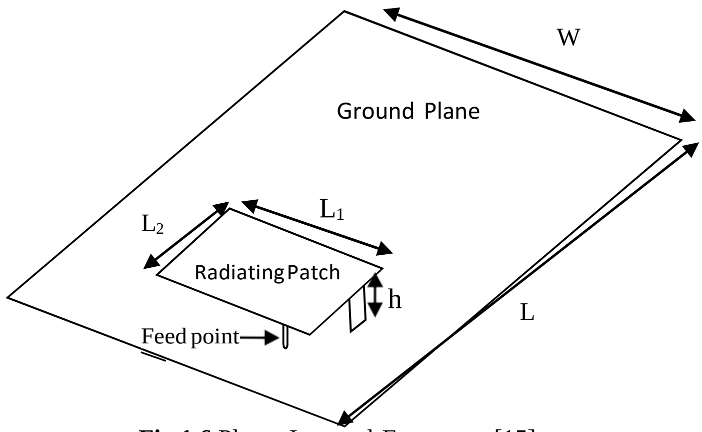


Fig 1.6 Planar Inverted-F antenna [15]

Table 1.3depicts comparison between handheld device antennas used for number of applications that is microstrip antenna and PIFA. Comparison is in terms of parameters, antenna applications, merits.

Table 1.3 Comparison between Commonly used Antennas in Wireless Device

Antenna Type/ Parameters	**Micro Strip Patch**	**PIFA**
Radiation Pattern	Pattern is directional	Pattern is Omni directional
Gain	High gain achieved	Medium to high gain achieved
Modeling and Fabrication	Modeling and fabrication is easy	By using PCB Fabrication is easy
Applications	Satellite Communication devices, Aircrafts	In Mobile phones as Internal antennas
Merits	Light weight, cost is low, Easy in integration	Low cost, Small in size, minimized backward radiation for minimizing SAR
Problems	No band pass filtering effect, surface-area requirement	Bandwidth characteristic is Narrow

1.5 Brief Study of PIFA

Planar Inverted-F Antenna is the frequently used inside antenna in commercial wireless devices due to its robustness and low profile structure. PIFA is an upgrade version of microstrip patch antenna as to a height H the patch of the antenna is raised using shorting plate and hence it is also called as short-circuited microstrip antenna. To minimize the size of Planar Inverted-F Antenna structure the shorting plate placed near the feed point [11], but a confined impedance bandwidth is noticed after this. In PIFA (Planar Inverted-F Antenna) structures the major limitations is a narrow bandwidth when it is used in wireless mobile devices [16].

1.5.1 Pros and Cons of Planar Inverted F Antenna (PIFA)

Pros

- PIFA antenna has compact structure and light in weight.
- Has good operating bandwidth and high efficiency.
- Planar Inverted-F Antenna who covers Multiband has an important feature that its area is almost the same as that of a PIFA who covers single band with slots etched on ground and radiating patch [20].
- Planar Inverted F Antenna obtains dual polarization. In any orientation mobile transceivers can receive the signals.
- Robust in nature.
- Power Handling Capability is low.

Cons

- Narrow Bandwidth
- Moderate gain
- Feed radiations contributes to the radiation pattern

In order to overcome major limitation of confined bandwidth following techniques are used to improve the bandwidth of PIFA

- The dimensions of the ground plane play a crucial role in the bandwidth coverage of different frequency bands [19]. By enlarging the dimensions of the ground plane, extra bands can be covered. But an proper size has to be decided so that it does not violate the compactness of the antenna.
- To lower the Q factor, massive substrates are used which in turn increases the bandwidth.
- By adjusting the space between two shorting posts, the bandwidth can be further enhanced accordingly.
- The stacked component with air substrate in between also increase the Bandwidth.

Several approaches can be used to confine the size of antenna. When the radiator of the antenna and the ground plane are shortened, the size of the antenna is miniaturizing to great extent. However, this hindrance at the terminals is affected by this approach. Capacitive top loading is used to recompense theses effects. The use of capacitive loading cut back the resonance length from quarter wavelength (λ/4) to less than λ/8 but results in poor matching and narrow bandwidth. When a plate is added alongside to the ground it performs as a parallel plate capacitor leading to capacitive load [13].

Table 1.4 Effect the dimensions of PIFA on its properties

Parameters	**Effects**
Length	Increase inductance of the antenna and defines resonance frequency
Width	Impedance matching is controlled by width.
Height	Bandwidth is Controlled by width
Width of shorting plate	Bandwidth increased and also anti-resonance is affected
Position of feed from shorting plate	Bandwidth and resonance frequency is affected.

1.6 Various Feeding Mechanisms

By using various methods PIFA structures can be fed. These methods can be categorized into two main classes: non-contacting and contacting [18]. In the method of contacting, the radiating patch is fed with the excitation by using a connecting element directly. In the method of non-contacting, to transfer the power between microstrip line and radiating patch source is coupled using electromagnetic field coupling. Most famous feeding techniques used are explained below briefly

1.6.1 Coaxial Feed

The most common feeding methods used in PIFA Planar Inverted F Antennas is coaxial fed also known as a probe feed. It is shown in Fig. 1.7. In this the internal conducting element of the coaxial cable extend through the dielectric substrate to the head patch, while the external conducting element of the coaxial cable is joined to the ground plane [21].

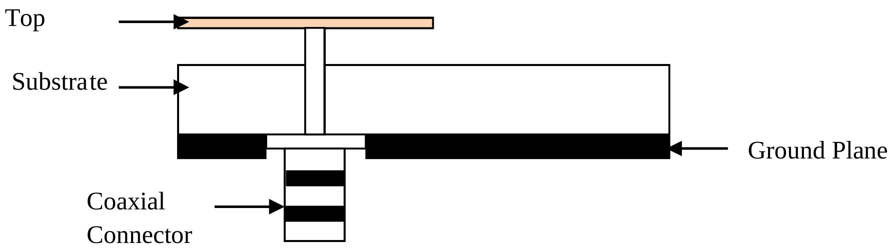


Figure1.7 Coaxial Feed for PIFA [25]

1.7 Gaps in Study

- Antenna with good gain characteristic is desired.
- LTE high band has wider bandwidth so antenna should support this bandwidth requirement.
- For current portable devices the compact antenna is required.

1.8 Objective of Thesis

- Simulation and designing of a new compact PIFA antenna for LTE high band.
- Parametric study of proposed PIFA antenna to optimize its dimensions and to make it to cover wideband
- Fabrication and testing of proposed PIFA antenna.
- Comparison of simulated results with measured results.

1.9 Methodology

The flow chart shown in fig 1.8 depicts all the work done in this thesis.

- To find out the research gaps and to find the various techniques used by various researchers worldwide literature survey is must.
- Now designing of antenna is done by using some equations and then simulate this structure by using CST software.

- If result is acceptable then fabrication is done by using PCB technique but if results are not acceptable then optimize the structure further and again simulate the structure by CST software. This process is repeated till optimized structure is not obtained.
- After simulation the optimized structure next step is fabricate the antenna by using PCB techniques.
- After simulation, testing is done by using vector network analyzer and comparisons between simulated and fabricated results are presented.

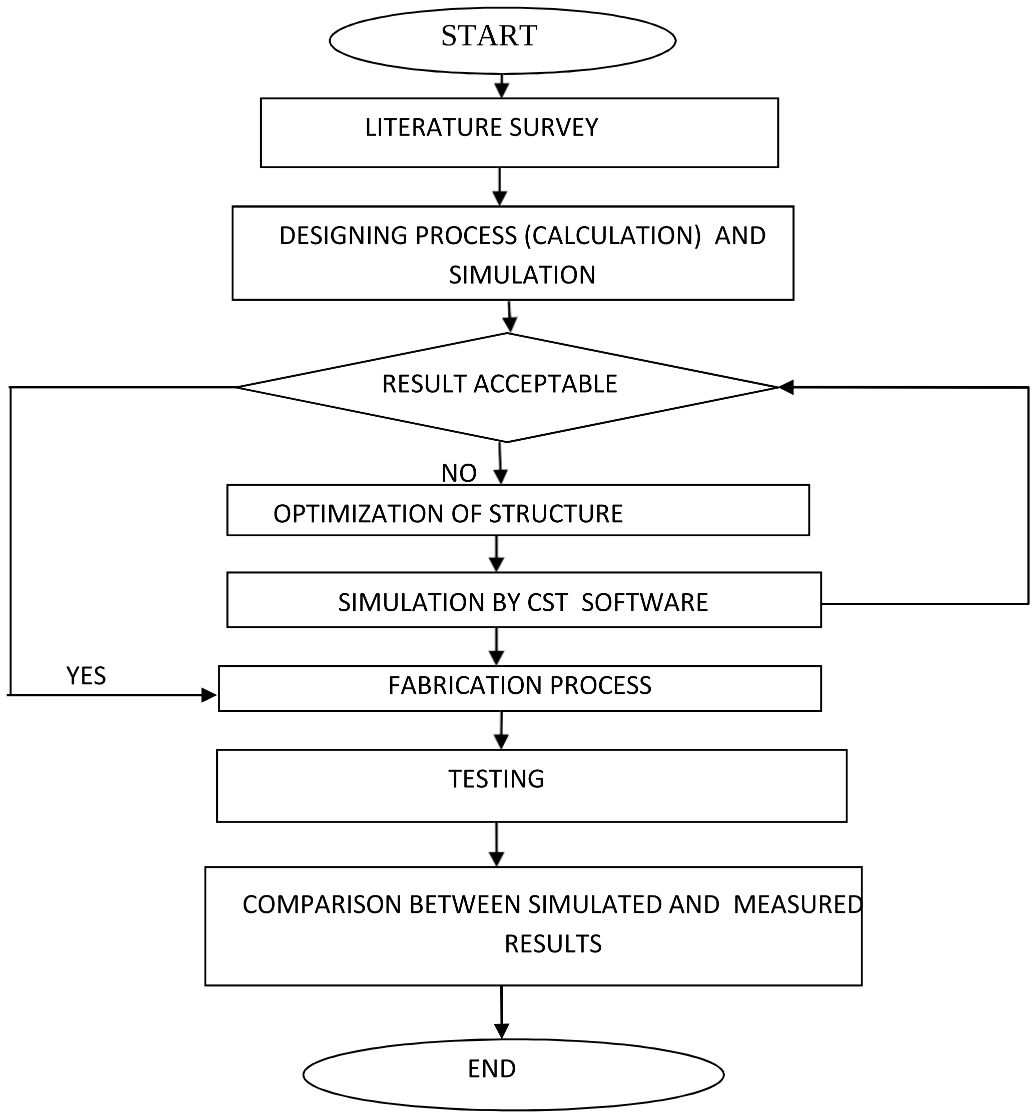


Figure 1.8 Flow chart depicting the entire thesis work

1.10 Thesis Organization

- In **Chapter 2** literature survey is given. Before starting the thesis there should be knowledge of work done in a particular field by researchers to understand the objectives of thesis, to find out the research gaps and to find the various techniques used by various researchers worldwide. In this chapter nutshell of some of research papers is given by different researchers.

- In **Chapter 3** simulation and designing of edge truncated planar inverted F antenna is presented, for high band LTE applications. In this chapter a brief introduction about the structure of antenna is given along with its dimensions. Parametric studies has been carried on the proposed PIFA antenna, the dimensions of all different parts of PIFA antenna are varied. To get the optimum value of the dimensions that is length, width, height of the ground plane, patch, feeding plane and the shorting pin as well as the dimensions of torus and the structure drawn on patch the parametric studies are must.

- In **Chapter 4** a new antenna is designed to enhance the gain, by introducing the slots on ground plane. The simulation results of edge truncated planar inverted F antenna with ground slotted for high band LTE applications are also shown.

- In **Chapter 5** fabrication and testing of edge truncated planar inverted F antenna for a high band LTE application (without slot) is discussed. The comparison between measured and simulated results is also discussed in this chapter.

- In **Chapter 6** conclusion and future scope of the work is presented.

Chapter 2

LITERATURE SURVEY

2.1 Introduction

In order to start the project, the first step is to study the research papers that have been published previously by other researchers. The papers that are related to this title are chosen studied are given below.

PIFA is a planar inverted-F antenna, which resonate on multi bands, which is the major requirement of today world. It should also be compact in size, means it occupies very small volume due to this the size of wireless devices also compact. There are numerous advantage of this antenna over another one. As PIFA antenna fulfill the main needs of today world therefore it is used commonly and so much research take place on this antenna ,some of the research papers are shown below.

2.2 Literature Survey

Karmakar *et al.* [22] has proposed a planar inverted-F antenna (PIFA) with single feed whose one side is shorted and integrated with RF switch array to make it tunable. Proposed antenna works on dual band that is L and S band. In L-band the insertion loss and isolation comes around 0.45 db and 10 dB respectively at 1.2 GHz frequency and we get 1GHz bandwidth. Proposed PIFA is tunable, which provides 100% frequency tune ability at 800 MHz BW and at 1.9 GHz band it provides 5% BW. The measured radiation patterns are omni directional (fan shaped). At 800 MHz this design provide gain of 2.2 dBi and at 1.9 GHz. 4.5 dBi gain was obtained.

Sheen Row *et al.* [23] proposed a PIFA with U shape slot on ground. Dimensions of ground is 50 x 50 mm^2, as the width of the shorting strip is reduced the central frequencies shifted lower end. In this paper author takes different width of shorting plate and observed that central frequencies reduced as bandwidth increased, and in this paper author also varies the dimensions of ground and observed that the upper band of frequency bandwidth is decreased by more than 20% by varying the width of the ground from 50×50mm to 30×30 mm.

Yuan *et al.* [24] proposed a dual polarized PIFA by using different feed ports, obviously by using different ports polarization can be obtained. By polarization diversity better performance can be achieved. The cost and covered space for antennas is reduced which is good for wireless mobile devices, and this is the new way over the previous one that is by using multiple antennas for polarization diversity. But by shifting different ports it takes time due to this delay occurs, but when the switching time is ignored we can use concurrent signals and this technique is used as a polarization diversity scheme.

Sheen Row *et al.* [25] presents a triangle shaped PIFA with a single feed with a V-shaped slot. Because of the existence of the V-shaped slot, two triangular PIFAs are established that is one is inner PIFA and one is outer PIFA, and by varying the shorting plate width resonant frequency can be varied, resonant frequency also depend upon dimension of triangular plates. By properly selecting the shorting- plate width , the elementary resonant frequency of triangular that is inner PIFA can be integrated with the base note which was introduced by the V-slot, and due to this a wide-band is obtained in the higher frequency band. Due to this a wide operating bandwidth is obtained, 36%wider bandwidth is observed. 4 dB and 4.3 dB gain for the lower and higher frequency bands are obtained.

Ghali *et al.* [26] introduced a miniature Planar inverted F antenna PIFA which is working at 4 bands that is quad band with single feed. Two techniques are proposed to reduce the physical size of antenna. First of all, author placed a U-shaped long narrow cut inside the antenna-radiating plane. By different U shape long narrow cut placed at suitable position 4 center frequencies are obtained i.e. GSM band, DCS band, (IEEE802.11a) ISM band/Bluetooth, and (IEEE802.11b) WLAN band, respectively. By this method the size of regular PIFA is decreased by about 30%. Author proposed a second method in which a stacked capacitive plate in the middle of ground and the radiating surface due to this size of original PIFA reduces by almost 55%.

Ook Park *et al.* [27] proposed a PIFA which works on hepta- band, this PIFA operates at DCS (1710–1880 MHz), GSM (880–960 MHz), PCS (1880–1990 MHz), WiBro (2300–2390 MHz), UMTS (1900–2170 MHz), WLAN (5.0–5.5 GHz), and Bluetooth (2.4–2.48 GHz), frequency bands. As today's basic need is the internal antenna which should be small in size, so that the wireless device size can be minimized, this is achieved by using an L-patch under the standard PIFA element. Overall $1.8cm^3$ volume is decreased by this technique, which makes it so useful for modern applications.

Chan *et al.* [28] introduced a PIFA with capacitive loading. Beneath the radiating plate by inserting a via-patch capacitive coupling effect is created due to this operating frequency reduces. The antenna size is reduced by half in contrast to the conventional PIFA. This PIFA operates at 2.4 GHz ISM band, overall bandwidth is 8.91% for this particular frequency bands. In this approach coaxial feeding is directly connected to the radiating element while the capacitive patch is connected to the ground through a via. This is different from other capacitive-loading techniques, as in techniques the capacitive patch is connected to the coaxial feed, rather than radiating element which gives reduction in size but does not provide frequency tuning. But in this antenna by simply replacing a via with the help of screw and by regulating the height of the via-patch by turn on-off screw, tuning is obtained in the range of 0.8 GHz from 2.5–3.3 GHz.

Nguyen *et al.* [29] introduced a simple PIFA tunable internal antenna, which is used for communication purposes. A varactor diode is used for tuning over a wide range. Proposed antenna can cover seven frequency bands: WiBro (2300–2390 MHz), DCS (1710–1880 MHz), UMTS (1900–2170 MHz), PCS (1880–1990 MHz), WLAN (5.2 and 5.8 GHz), ISM band (2500–2700 MHz) and Bluetooth (2400–2480 MHz). The antenna's size is 19.5 mm× 9.5 mm ×4 mm^3, due to this it is acceptable to be used in 4G handset. Overall $0.741cm^3$size of antenna is reduced.

Chung Yu and Tarng *et al.* [30] proposed a PIFA with a miniature single feed. In older designs of PIFA, mostly the shorting plate works as a capacitive loading which helps for impedance matching purpose, as this shorting plate provides capacitive effect, the size of antenna and size of ground is large, and also due to this bandwidth is narrow. In proposed PIFA shorting pin works as a short-circuit load, due to this current resonant paths are effectively controlled. Due to this multiband requirement is also fulfilled; this is a very simple method to achieve multiband, smaller dimensions of antenna and ground. In short we get a multiple band smaller antenna with a better radiation pattern as compared to older one by this method.

Sydanheimo *et al.* [31] proposed an E shape antenna, whose working principle is similar to the PIFA. The shape of this antenna is same to the inverted E alphabet that is why the antenna is called as E antenna. This antenna works at ultrahigh frequency that is frequency of 868 MHz. To minimize the size of antenna, shorting of the radiating path and the ground plane is done. By doing this we get compact, small and a less costly antenna. E antenna has a good radiation pattern and higher gain, this is a convenient and simpler method which is suitable for many wireless systems, it has a omni-directional radiation pattern.

AbuTarboush *et al.* [32] proposed a PIFA which works for WiMAX application. This structure is very simple in which four slots on the radiating patch are added so that this antenna can work on three bands of WiMAX that is 2.6, 3.6 and 5.6 GHz. The bandwidth and the band is entirely depend upon the number of slot introduced in the radiating patch. **Bhatti, TaekIm and Park** *et al.* [33] introduced a Planar inverted-F antenna (PIFA) which is covering ten frequency bands. The bands are (GSM-900) Global System for Mobile Communications, Personal Communication Service (PCS), Digital Communications System (DCS), Universal Mobile Telecommunications System (UMTS), WiMAX at 3.5 GHz, Bluetooth, WiBro at 2.35 GHz, Satellite-Digital Multimedia Broadcasting (SDM-B) at 2.65 GHz and) for the wireless Local Area Network (WLAN) standards the two bands are (5.15–5.35 GHz and 5.725–5.875 GHz. This structure is little bit complex but it covers ten bands of frequency. Coupled parasitic patch is used which is shorted to the main patch, the feed strip is connected with a quarter-wave resonator parallel with the main patch and four long and narrow cut on the main radiator ,which helps the antenna so that it can excite on different current modes. As the number of slits vary the radiation pattern and bands of frequency also varies. This structure of antenna is so much flexible and also independent tuning of many targeted bands of frequency can be obtained.

Sung *et al.* [34] introduced a planar inverted-F antenna (PIFA) which is suitable for mobile and wireless handset applications. This antenna has a small size and flat construction, due to this it is easy to fabricate and manufacture. This antenna operates over PCS (1880–1990 MHz), GSM (880–960 MHz), PCS (1880–1990 MHz), WiBro (2300–2390 MHz), UMTS (1920–2170 MHz), WiBro (2300–2390 MHz), and Bluetooth (2400–2480 MHz) bands. A very good gain, substantial and omni-directional radiation pattern get over the whole bandwidth. By merging the second harmonic component of antenna with the resonance of the short radiator of the PIFA, due to this in the higher band broadband characteristics is obtained.

Lauder and Azremi *et al.* [35] proposed a F-PIFA, fractal planar inverted F antenna The dimension of F-PIFA is 27 mm x 27 mm^2 and it is designed to work on UMTS (Universal Mobile Telecommunication System), GSM (Global System for Mobile Communication) and HiperLAN (High Performance Radio LAN). The range of frequency are from 1885 to 2200 MHz for 3G, 1900 MHz to 2100 MHz, and 4800 MHz to 5800 MHz for HiperLAN respectively. A supplementary copper strip is attached so that it can excite for a low resonant frequency for GSM900. Due to this it is more sensitive to the both horizontal and vertical polarization which is very important for mobile communication.

Lee and Min *et al.* [36] introduced a patch antenna with a fan structured element which operated at UHF band of the LTE (Long Term Evolution). The proposed antenna has dimensions of 30×24 mm^2. In this it was extravagate line structure introduced so that this antenna can resonate at LTE Band. To regulate the radiation pattern’s directivity, a radiator structure which is of fan-shaped was sketched and performed. The radiator’s bandwidth is approximately 50 MHz (740~790 MHz) whose return loss is below -10 dB at LTE band. Isolation between 1and 2 position is about -7 dB at this band. At E-plane the direction of Radiation pattern of 1 and 2 shows difference almost 90°. Therefore by this we can also make PIFA MIMO.

Caso, Alessandro, Serra, Nepa, and Manara *et al.* [37] proposed a PIFA which operates at WiMAX band (3300–3800 MHz) and DVB-T band (470–862 MHz). The antenna was designed so that it can combine with the monitor device. This antenna shows a good impedance matching performance that is reflection coefficient is about 6 dB in the DVB-T frequency band and 10 dB in the WiMAX band and produces a gain between 3.3 and 4.0 dBi in the WiMAX band and between 2.7 and 4.8 dBi in the DVB-T band. The dimensions of the design is 225×31× 20 mm^3 (l×w×h). It is mixture of a series of branches, which are appropriately dimensioned and are properly separated from each other to generate the necessary resonances. This all has been achieved with the help of 0.4-mm thick aluminum foil, then properly cut it and fold it properly.

Nepa, Serra and Giuliano Manara *et al.* [38] proposed a PIFA which is small in size and works on multiband i.e. WiMAX band (3300 – 3800 MHz) and DVBT band (470 - 862 MHz) band. The volume of antenna is equal to 225x30x20mm^3that is (LxWxH) and this has been designed so that it can be durable even in the presence of so many parts of metal which are nearer to antenna. One side of the antenna looks like a hook- shaped, therefore its name is HPIFA (H-shaped Planar Inverted-F Antenna). In this process a 0.4mm thick foil made up of aluminum is firstly cut and then folded it properly to get the better results. This antenna manifest good performance in which reflection coefficient are <-6dB and <-10dB respectively for WiMAX band and DVBT band , and gain is between 2.72 and 3.6 dBi and 59% impedance matching over whole bandwidth and almost 4 dBi in the DVBT and 3.5WiMAx band subsequently.

Dalia and Abdallah *et al.* [39] presented a PIFA which works on Multi-band, and this antenna is fed by coplanar waveguide-feed, along with the transmission line. (DFS) double folded slot transmission line is used in this propose antenna. This PIFA antenna resonant at multi bands that are GSM whose frequency is 1.8 GHz /0.9 GHz and (LTE) long term evolution band covering the frequency range from 1.47 GHz to 1.5 GHz along with 2.4 GHz to 2.7 GHz, industrial, scientific and medical (ISM) 2.45 GHz and many other wireless communications bands.

Chattha, Abbasi, Yi Huang and AlJa'afreh *et al.* [40] designed a PIFA which is very compact in size, less costly. This antenna works on (LTE) Long Term Evolution band, WLAN whose frequency is 2.45 GHz and as well as on Worldwide Interoperability for Microwave Access (WiMAX) band whose frequency is 2.5–2.7 GHz. This antenna has also a application in MIMO and diversity schemes. In this polarization diversity is achieved by placing two feeding plates which are perpendicular to one another. The reason behind the use of this method is that two ports in perpendicular are act as a cross-polarized. To provide the isolation between these two ports a slot is introduced on the ground plane.

Bharti, Pandey and Meshram *et al.* [41] introduced a compact PIFA design and (MIMO) multiple input multiple-output of PIFA which is used for applications for Interoperability for Microwave Access (WiMAX) and other wireless frequency band like Personal Communication Service (PCS1900) and Long Term Evolution (LTE). By inserting the inter digitized a long strip into a slot, In this way tri band is obtained that is of LTE band 13 (765-787MHz), PCS1900 (1850-1920MHz), and WiMAX (3.05-3.65GHz). Over all three band a very low mutual coupling that is Envelope Correlation Coefficient (ECC) is obtained that is less than 0.01 for whole frequency range, and below -10db isolation is obtained.

Redzwan, Ali, Tan and Miswadi *et al.* [42] proposed a PIFA which works on two band that is 2600 MHz for (LTE) Long Tem Evolution Band and 3500 MHz for WiMAX, means it is dual band PIFA, which is obtained by inserting a parasitic element in the form of rectangular structure, beneath the main patch of the PIFA that is radiating patch. This antenna is made up with Flame Retardant 4 (FR4) dielectric substrate and to connect the ground plane with radiating patch a shorting plate is used. The ground plane is placed along with base of the substrate. The dimensions of antenna radiator are17.8 mm x 16.5 mm $\times 5mm^3$.

Naser and Sayidmarie *et al.* [43] proposed a PIFA antenna which operate on the lower band of LTE band. The major challenge is to design an antenna for limited space of handset and it should work on large wavelength of low frequency band of LTE.A meandered-line is composed with PIFA structure to fulfill both requirements. The volume of antenna is $(65x110x1.6)mm^3$ which is very compact. The antenna design is made as such it can achieve desired specifications of all configurations. The antenna shape is developed so that it can accomplish the bandwidth requirements that is of 58 MHz centered at 765 MHz and obtain VSWR of 1.04. The antenna resonates at second band whose center frequency at 2160 MHz which can deliver so much other applications, for example (LTE band class 1), UMTS B and I (IMT-2000) , Wi-Fi and Bluetooth.

Verma and Chauhan *et al.* [44] proposed a small size PIFA which works on4G LTE, PCS, DCS, UMTS, WiMAX bands. The dimension of this antenna is 20 x 10 x 3.57 $mm^3$and easy design which is easy to fabricate. This antenna can easily be used in mobile phones. Proposed antenna has a rectangular slot is introduced on a main radiated patch which plays a very important role to obtain multi-band and due to this bandwidth is also increased, more gain is obtained and the size of antenna is reduced by 41.89% when compared to conventional one. The maximum gain which is obtained by this antenna are 6.3668 Db and 2.8577 dB.

Redzwan, Ali, Tan, Miswadi *et al.* [45] proposed a Tri-band PIFA which is designed for mobile telecommunication, fabricated by inserting two parasitic elements which is of rectangular shape. These elements are placed beneath the radiating patch of this antenna that is PIFA so in order to procure a tri-band. This PIFA antenna operated at three different frequencies that is 2600 MHz for LTE Application 2100 MHz, for UMTS2100 and 3500 MHz for WiMAX Application. The middle band whose frequency is 2600MHz and a lower band whose frequency is 2100 MHz is controlled by 1st (first) patch which is placed at the left and 2ndparasitic element which is placed at right edge of the ground plane. While the upper band whose frequency at 3500 MHz controlled by a basic radiating patch of PIFA antenna. The maximum gain of this antenna lies between 2 dBi to 5 dBi. This antenna is having the ability to work for LTE band 7 (2600 MHz), UMTS (2100 MHz) and WiMAX (3500 MHz) bands at -10 dB return loss.

Khaled, Bilal, Abou *et al.* [46] proposed a Wide-Band Flower shaped PIFA which is used for mobile handsets because of its small size, wider bandwidth and gain. Proposed PIFA operates on numerous wireless and mobile communication standards like UMTS for frequency of 1920 – 2170 MHz, PCS for frequency of 1850 – 1990 MHz, WLAN 802.11 b/g for frequency of 2400 – 2484 MHz, WIMAX for frequency of 3.4 - 3.6 GHz and WIMAX for frequency of 2.5 - 2.69 GHz. This one is the newest structure made up of flower which is hold up by three shorting pins. On the patch slots are placed which is in shape in the form of Allah written in Arabic language. A capacitive feedingis used in this structure.

Freh, Huang, Xing *et al.* [47] presented a PIFA for diversity applications having miniature size and it covers wideband and work as a MIMO and diversity antenna for wireless applications. Proposed antenna works on the frequency of 2.35–3.25 GHz with a bandwidth of 32%. This antenna also resonant at WiFi frequency bands and LTE bands 7, 38, 40, 41.The main aim of this design is to reduce the mutual coupling effect by using a new feeding arrangement when compared to other feeding arrangements. Polarization diversities have attained by stimulating two orthogonal modes. In Feed 1 radiation is occur because of the slot is present on open ground plane, and In Feed 2 radiation is occur because of PIFA loop mode. The isolation between feeding achieved because of the slot is present on the L-shaped ground plane.

Zhang, Chen, Feng, Iskander and Zhao *et al.* [48] designed a small size novel compact planar inverted-F antenna (PIFA) which works for GSM, PCS, DCS applications. This antenna is of V-shape whose only one branch is lap into three planes which is designed to reduce the dimensions. This antenna occupies a very small space which is $50\times7\times7$ mm^3. Two feeding strips are used in this structure to increase the bandwidth. Dual feeding strips are designed to excite two different matching working states of the antenna to broaden the bandwidth.

Jegadeesan, Mansouri *et al.* [49] designed a multiband PIFA antenna resonant at GSM 1800, GSM 900, WLAN 2400MHz, WiMAX, Bluetooth, 3G, UWB, 4G and frequency which is from 3.1-10.6 GHz. On the surface of ground plane due to the presence of stubs or Slots lower frequencies are resonant. To obtain ultra wide band, taper feeding line is used. The antenna is fabricated on FR4 substrate, whose cost is less with εr is equals to 4.4the dimensions of antenna is120mm×60mm^{2}and height of substrate is 1.6 mm. This antenna achieved high gain from 2 to 6.5 dBi and the radiation pattern of this antenna is Omni directional.

Saini, Satbir Singh and Naveen Kumar *et al.* [50] presents a small size PIFA antenna whose return loss is much better than -10dB which works on multiband. The space occupied by this antenna is37 mm × 35 mm × 5mm^{3}which is very small in size. On the top side of the radiating patch T-shaped slot is introduced, and on the ground plane a rectangular slot is etched. The radiation pattern, reflection coefficient and antenna gain shows that this antenna resonate at multiband which are 4G LTE whose frequency is2.3 GHz, WiBRO whose frequency is2.35 GHz, 802.11g whose frequency is 2.4 GHz, m-WiMAX whose frequency is 2.5 GHz, DCS1800 UL band whose frequency is 1.70 GHz, Wi-Fi/Bluetooth 802.11g whose frequency is 2.4 GHz, Wi-Fi 802.11a whose frequency is 5.2 GHz and WiMAX whose frequency is 3.5 GHz communication standards.

Bhattacharya, Garg *and* Tarun *et al.* [51] presented a small size folded-strip printed inverted-F antenna (FS-PIFA) whose radiation pattern is almost similar to dipole radiation pattern. This antenna works on 2.45-GHz band and it also offers 5.75% overall bandwidth. In this proposed antenna folded strips are used as a passive element and with the help of FS-PIFA as a driven element a Yagi–Uda antenna is presented. This Yagi–Uda antenna also operates at same band that is 2.45-GHz band, and gain of Yagi–Uda antenna is 4.6 dBi and its front to back ratio is 17 dB . The FS-PIFA's radiation pattern is same to a dipole antenna, and therefore due to this it is possible to make a Yagi–Uda antenna by using PIFA. Finally, with the help of two Yagi antennas placed back to back in such way that they can share a common reflector, a small pattern diversity antenna is obtained.

2.2 Conclusion

From this chapter it was observed that various PIFAs are designed, simulated, fabricated and tested for different applications. But there are some drawbacks in the discussed literature survey such as the dimension of antenna is not so much compact and some antenna works on multiband , to get the multi frequencies the different type of slots has been cut from radiating or ground plane. Due to this structure become complex, and there are many more drawbacks are there. Following chapters will define the work which has been done to minimize the drawbacks and also tried to fulfill the gap of research work.

Chapter 3

DESIGN OF EDGE TRUNCATED PLANAR INVERTED F ANTENNA FOR HIGH BAND LTE APPLICATIONS

3.1 Introduction

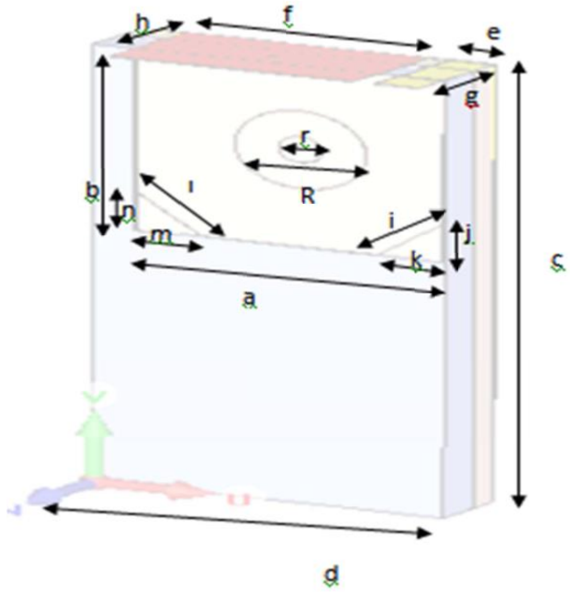
In this chapter a new structure of PIFA has been designed, and simulated for high band LTE application. The dimension of an antenna structure is also discussed along with parametric studies. Parametric studies have been done to get the optimum dimensions of a PIFA structure. The simulated results are also shown in this chapter.

3.2 Antenna design

The PIFA antenna proposed in this chapter consists of a top radiating patch, ground plane, shorting pin/plate and feed point. The dimensions of the ground are$36\times16mm^2$ and the dimensions of patch are $14\times16mm^2$. FR4 substrate is used whose dielectric constant is 4.5 and loss tangent is 0.0024. Antenna is fed at the edge using coaxial feeding. The distance between the shorting pin and the feeding line along with the width of shorting pin is responsible to get the resonant frequency and the bandwidth. The front view and the back view of this structure is shown in figure 3.1 and 3.2 respectively. Dimension of ground, feeding plate, shorting plate and patch are written in table 3.1, 3.2, 3.3, 3.4 respectively. In table 3.4 dimension of patch is written along with the dimension of torus and dimension of triangle.

Table 3.1 Dimension of ground

Symbols	**Dimensions in mm**
c (length of ground)	34
d (width of ground)	16
Height of ground	0.035



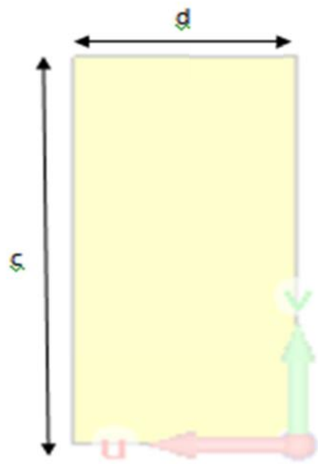


Figure 3.1

Diagram of front side of antenna

Figure 3.2

Diagram of back side of antenna

Table 3.2 Dimension of feeding plate

Symbols	**Dimensions in mm**
e (width)	2
g (length)	6.035
Height of shorting pin	0.035

Table 3.3 Dimensions of shorting plate

Symbols	**Dimensions in mm**
f (width)	11
h (length)	6.035
Height of ground	0.035

Table 3.4 Dimensions of patch

Symbols	**Dimensions in mm**
r(small radius)	1
R (Large radius)	3
i (side of triangle)	4
j (side of triangle)	7
k (side of triangle)	7
l (side of triangle)	15
m (side of triangle)	16
n (side of triangle)	16
a (width of patch)	14
b (length of patch)	9

3.3 Parametric studies of the proposed PIFA

There is a need to obtain an optimum value of all parameters so that the PIFA can resonate at desired frequency, as resonate frequency depends upon dimension of a PIFA. The parametric studies are shown below with their corresponding graphs.

3.3.1 Varying the radius of outer circle and inner circle.

During this analysis the radius of outer circle and inner circle which is drawn on patch is varied. By varying the radius of inner and outer circle the optimum value of radius is obtained where desired results are obtained. The plot of S11 parameter is shown in figure 3.3. In this figure the radius of inner circle is varied. It can be seen from the figure that by varying the radius of the inner circle from 1mm to 2.5mm in a step of 0.5mm these is hardly any change in the S11 parameter. Hence the radius of the inner circle is chosen as 1mm.

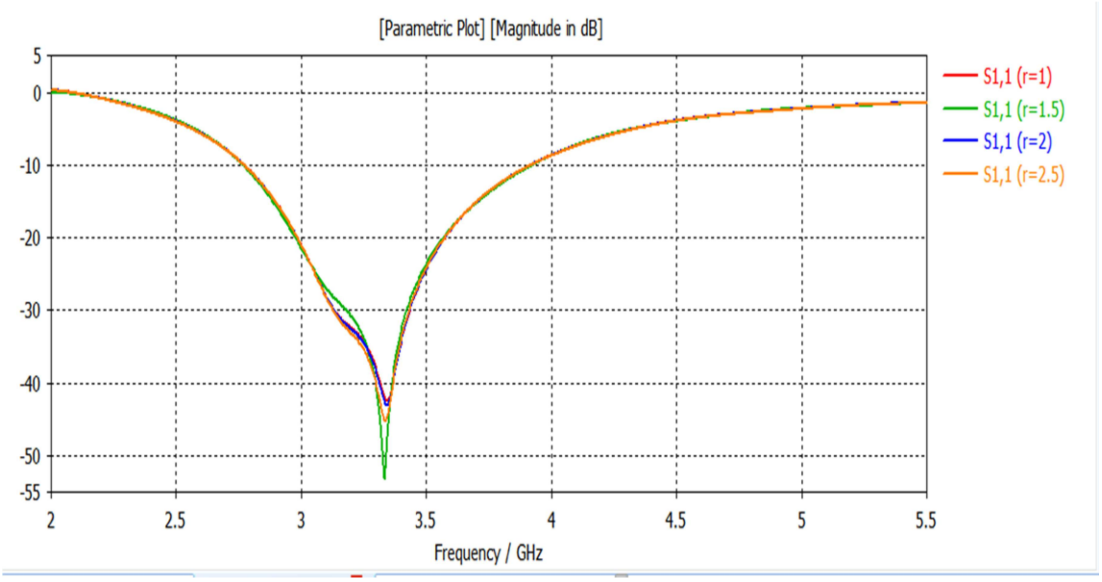


Figure 3.3 Graph of S11 parameter by varying inner radius of circle

In figure 3.4 the plot of S11 parameter is shown in which the radius of outer circle is varied to get the optimum value of the radius. The outer radius is varied from 3mm to 5mmwith a step size of 0.5mm. It is observed as the outer radius is increased the resonant frequency gets shifted towards lower side. As the antenna is designed for LTE band hence the optimum value of outer radius is chosen as 3mm.

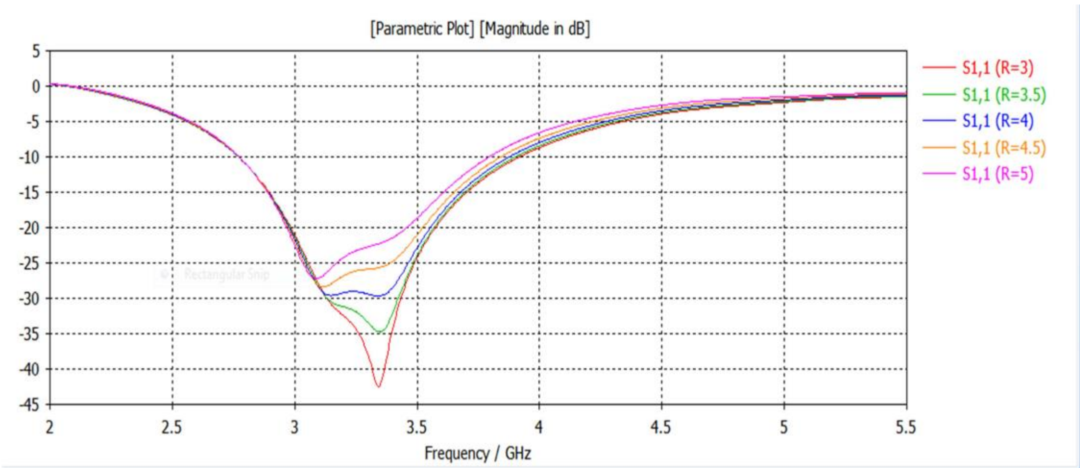


Figure 3.4 Graph of S11 parameter by varying outer radius of circle

3.3.2 Varying the length of patch

In this parameter many of times the length of patch is varied. By varying the length of patch a optimum value is obtained on which good enough bandwidth is obtained. The graph of the S11 by varying the length of patchis shown in figure 3.5. The length of the patch is varied from 5mm to 19mm with a step size of 2mm. It can be seen that as the length of the patch is increased from 5mm to 19mm the antenna became resonant and at the optimum value of length of 19mm the bandwidth is maximised.

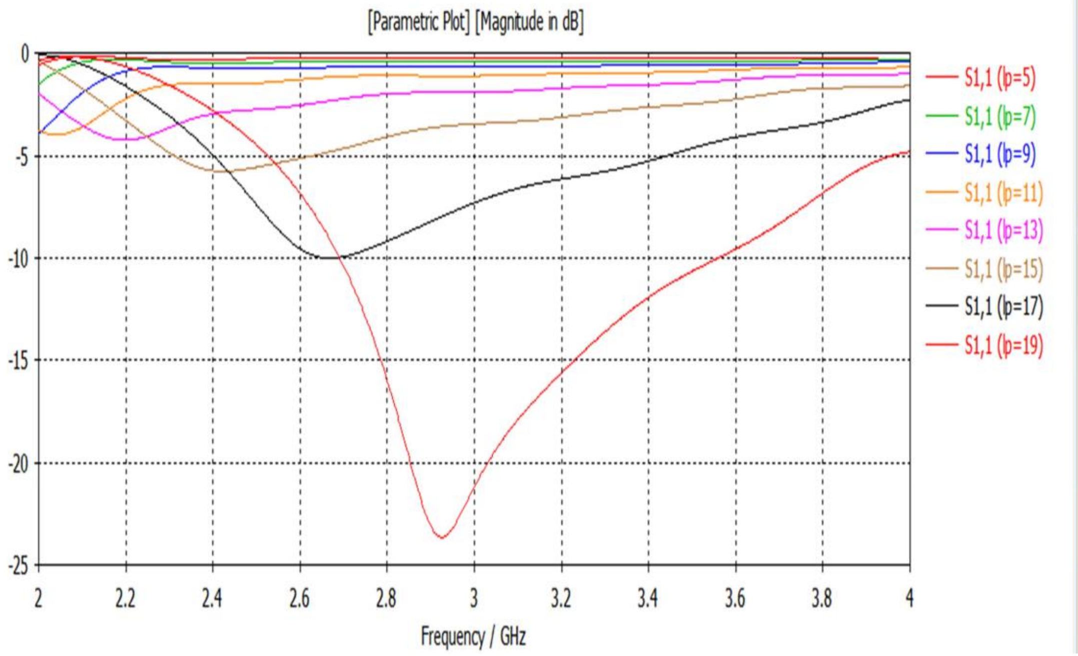


Figure 3.5 Graph of S11 parameter by varying length of patch

3.3.3 Varying the feeding plate width

In this case the gap between shorting pin and the feeding plane should also be taken care of because the bandwidth and resonant frequency depends upon this gap. The width of feeding plate is varied, after analyzing the width of feeding plate the optimum value is obtained which is 11mm. The (S11) graph of this parameter is shown in figure 3.6. The width of the feeding plate is varied from 3mm to 11mm with a step size of 2mm.

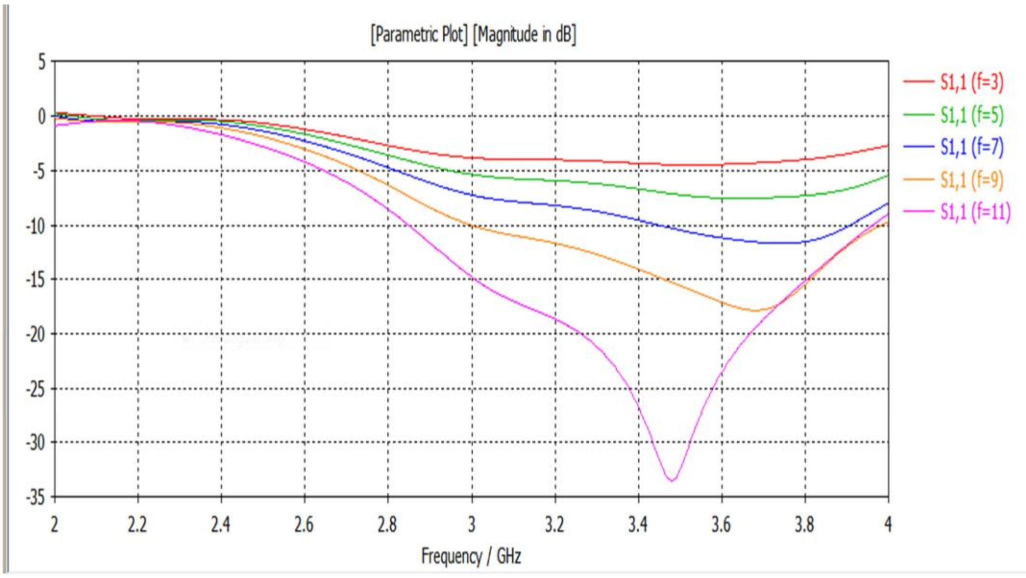


Figure 3.6 Graph of S11 parameter by varying width of feeding plate

3.3.4 Varying the width of shorting plate

The shorting plate width is varied which is responsible for bandwidth. The graph of S11 parameter by varying width of shorting plate is shown in figure 3.7, which shows that the optimum dimension of width of shorting plate is 15mm. On this particular value good results are obtained as compared to other and during these parameters a study it also should take care of length of the shorting plate too which is indirectly depend upon the width of the patch, ground and the width of air substrate.

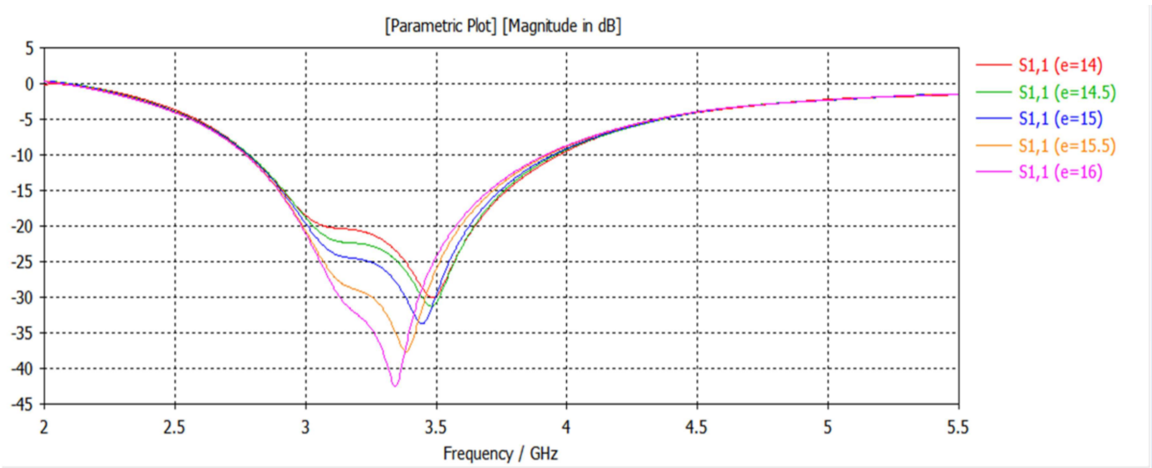


Figure 3.7 Graph of S11 parameter by varying width of shorting plate

3.3.5 Varying the length of ground

The length of the ground plane is varied which is responsible for bandwidth and the resonance variation. The optimum value is 34 mm where good results are obtained as compared to other ones. So during the selection of dimensions of length of ground all other parameters also be considered. The (S11) graph of this parameter is shown in figure3.8.

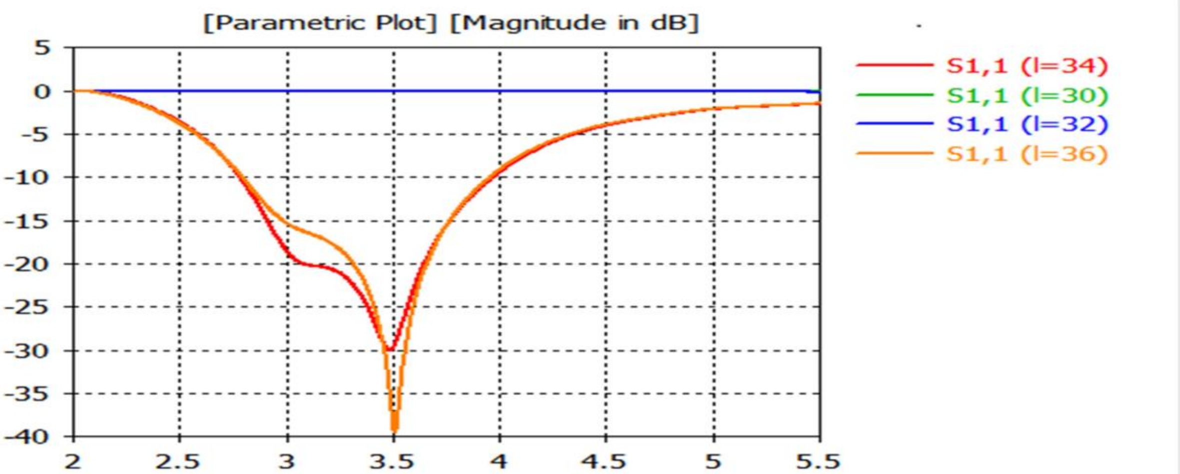


Figure 3.8 Graph of S11 parameter by varying the length of ground plane

3.4 Results Of Planar Inverted F Antenna for High Band LTE

3.4.1 Return Loss

For designing and simulation CST Studio Suite software is used.The frequency versus reflection coefficient plot of proposed antenna is shown in figure 3.9. This proposed antenna covers upper LTE band whose range is 3.4 to 3.6 Ghz . The entire bandwidth is 1.16 Ghz, whose range is from 2.78 to 3.94 Ghz.This diagram depicts the difference between reflected and forward power, which is called return loss. At resonant frequency which is 3.455, the return loss is -28.762 dB is obtained. To get proper impedance matching the feed line by which antenna is fed it should be of 50**Ω** [28]. The return loss is depending upon the length and width of patch as well as width of shorting plate.

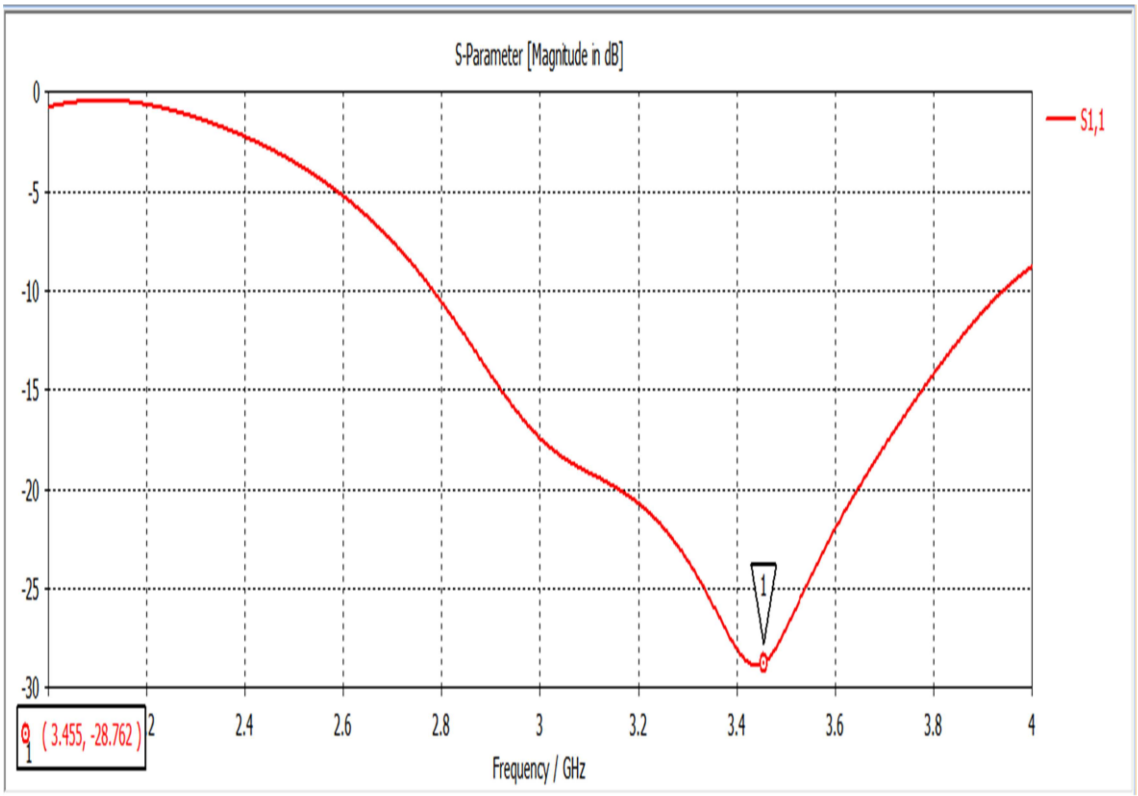


Figure 3.9 Simulated reflection coefficient versus frequency plot of proposed antenna

3.4.2 Voltage Standing Wave Ratio (VSWR)

Another parameter which is essential to analyze the performance of the proposed antenna is VSWR. The VSWR plot of proposed antenna is shown in figure3.10. When the VSWR value lies between 1 to 2, it means maximum of the power is radiated and minimum amount of power is reflected back. If the value of VSWR is more than 2 it means the maximum amount of power is radiated back and antenna is not properly working. At resonant frequency i.e. 3.4 GHz the VSWR is obtained is 1, which shows good performance of an antenna. There is a relation between VSWR and reflection coefficient which is depicted by this formula

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

Where Γ is reflection coefficient.

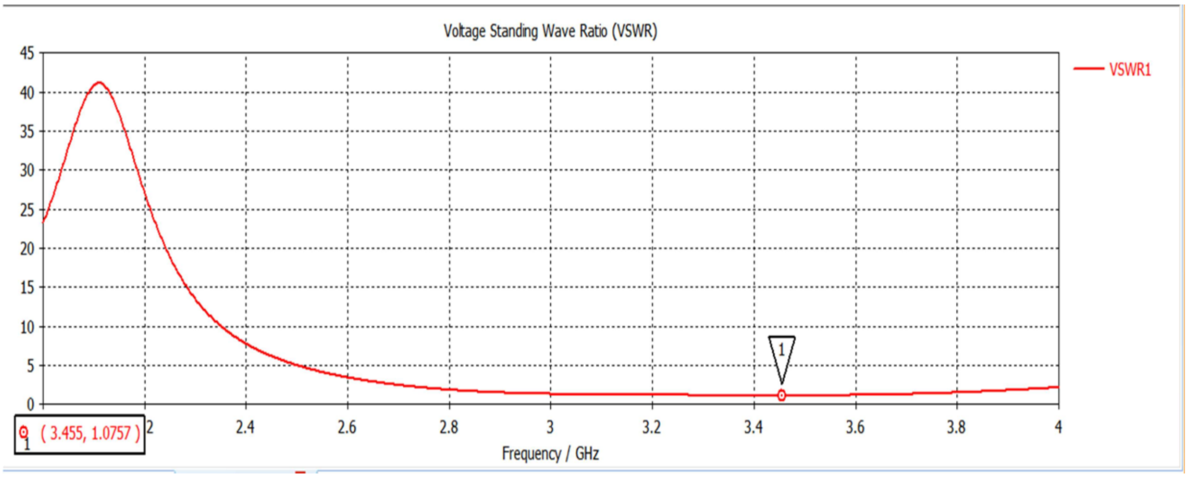


Figure 3.10 Simulated results of VSWR of proposed antenna

3.4.3 Gain

Gain is another important parameter which is used to analyze the performance of an antenna. Directivity of the antenna and efficiency of an antenna is entirely depend upon gain. It can also be defined as how much the input power is radiated in a particular direction with respect to an isotropic source. The plot of gain is shown in figure 3.11, which shows that at resonant frequency 3.57 dB gain is obtained. For the entire band of interest the gain lies above 3 dB.

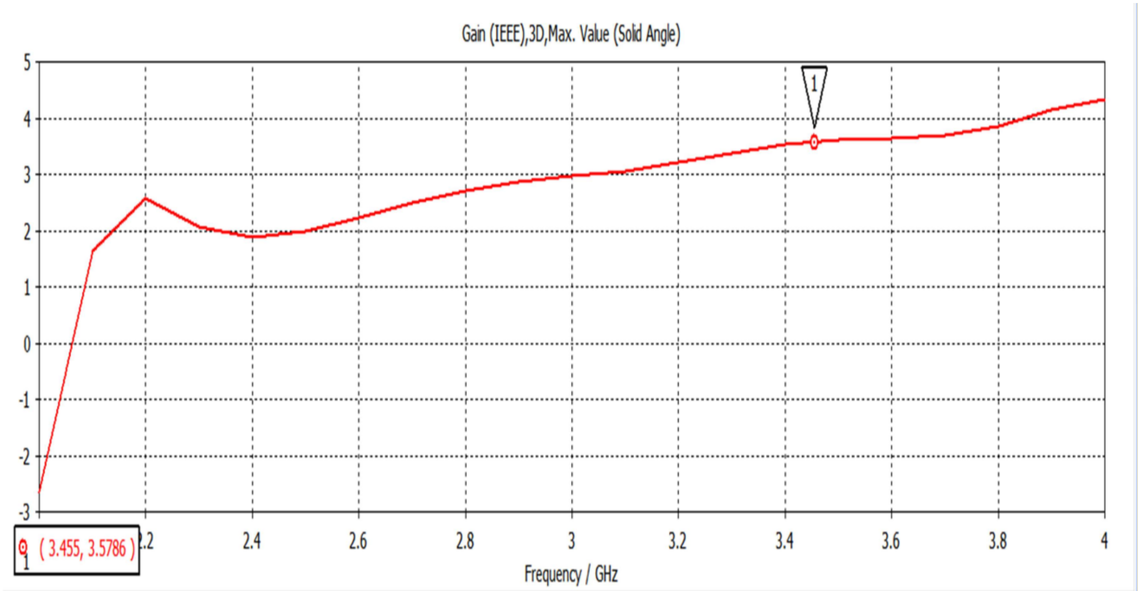


Figure 3.11 Graph of gain of a proposed antenna

The maximum gain over -10 dB bandwidth ranging from 2.78 to 3.94 GHz of the propsed antenna is 4.34 dB. The graph of maximum gain of propsed antenna is shownin figure3.12. The plot also depicts that antenna radiates mostly in the front side of patch.

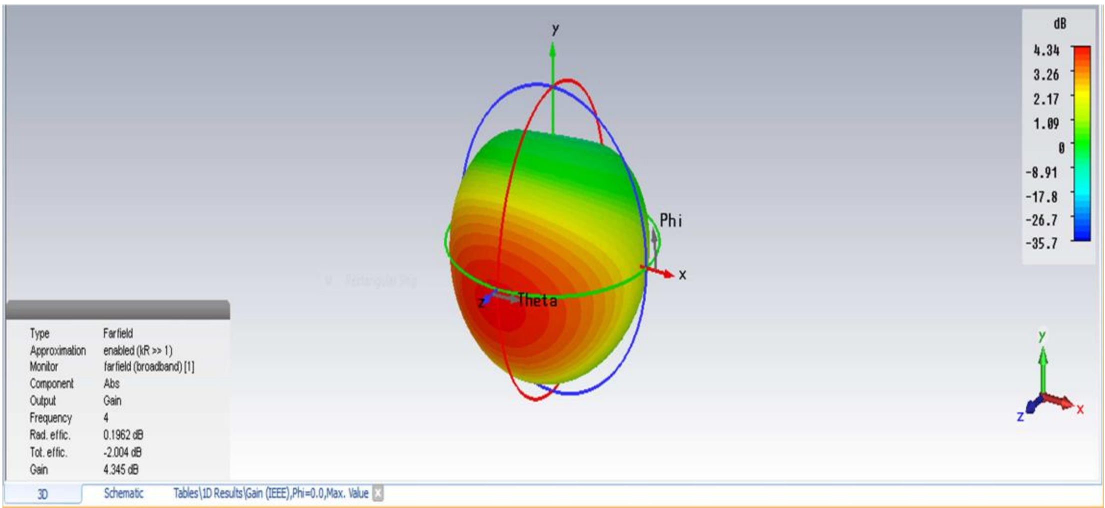


Figure 3.12 Graph of peak gain of proposed antenna

3.5 Conclusion

In this chapter a design of new antenna is proposed which works on LTE band, along with parametric studies has been done to get the optimized value of the dimensions of structure. By varying the dimensions of different parameters like feeding plate, shorting pin, length of patch and ground, radius of circle. The results of every parametric studies is also shown. The simulated results of the proposed antenna is also shown.

Chapter 4

DESIGN OF HIGH GAIN EDGE TRUNCATED PLANAR INVERTED F ANTENNA WITH GROUND SLOTTED FOR HIGH BAND LTE APPLICATIONS

4.1 Introduction

In this chapter a new structure of PIFA has been designed and simulated for high band LTE application. In this chapter a ground slotted PIFA antenna is proposed. Slot is designed and cut from the ground plane to enhance the gain of an antenna. The dimension of all the structure is same as previous structure. The simulation result of this structure is also shown in this chapter.

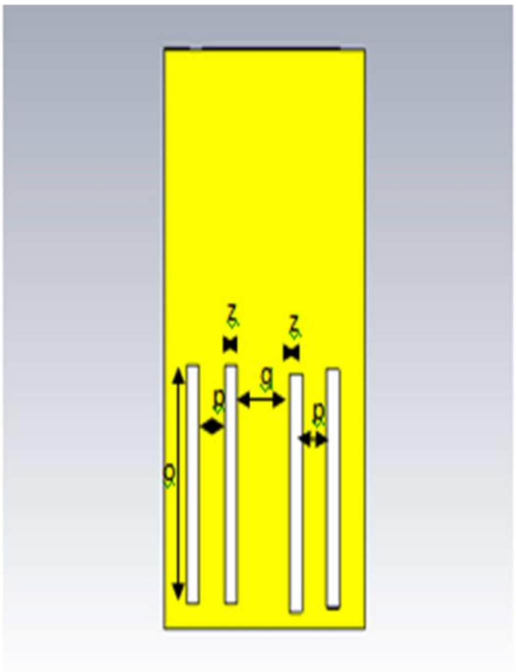
4.2 Antenna design

The PIFA antenna proposed in this chapter consists of a top radiating patch, ground plane, shorting pin/plate and feed point. The dimensions of the ground are$36\times16mm^2$ and the dimensions of patch are $14\times16mm^2$. FR4 substrate is used whose dielectric constant is 4.5 and loss tangent is 0.0024. Antenna is fed at the edge using coaxial feeding. The front view and the back view of this structure is shown in figure 4.1 and 4.2 respectively. In figure 4.2 it shows that there are four slots are cut in the ground plane. Due to this the resonant frequency and the return loss also varies and the overall gain over entire bandwidth is also increased. The dimensions of the front view of proposed antenna with gain enhanced structure is similar to the previous one but the back view that is ground plane dimensions is changed and dimensions of slots are shown in table 4.1.

Table 4.1 Dimensions of slots

Symbols	Dimensions in mm
Z(width of slot)	1
P(distance between two slots)	3

q(distance between two slots)	4
O (length of slot)	14



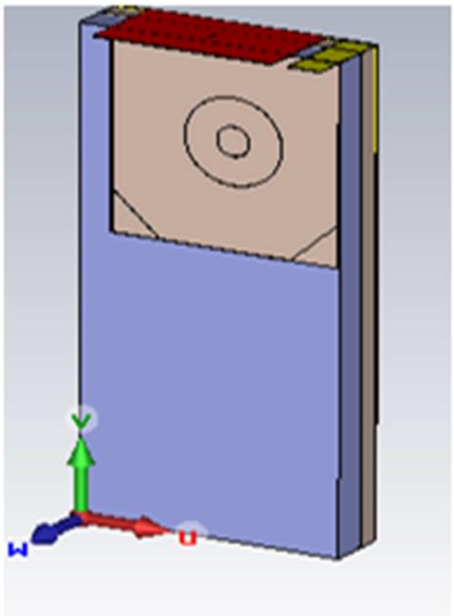


Figure 4.1 Back view of proposed antenna with gain enhanced structure

Figure 4.2 Front view of proposed antenna with gain enhanced structure

4.3 Results of proposed antenna with slotted ground plane

4.3.1 Return loss

The simulated frequency versus reflection coefficient of proposed antenna with Gain enhancement structure is shown in figure 4.3. This proposed antenna covers upper LTE band whose range is 3.4 to 3.6 Ghz.The plotpresente the difference between reflected and forward power, which is called return loss.The resonant frequency is 3.5 GHz at which returrn loss obtained is -29.064 dB.

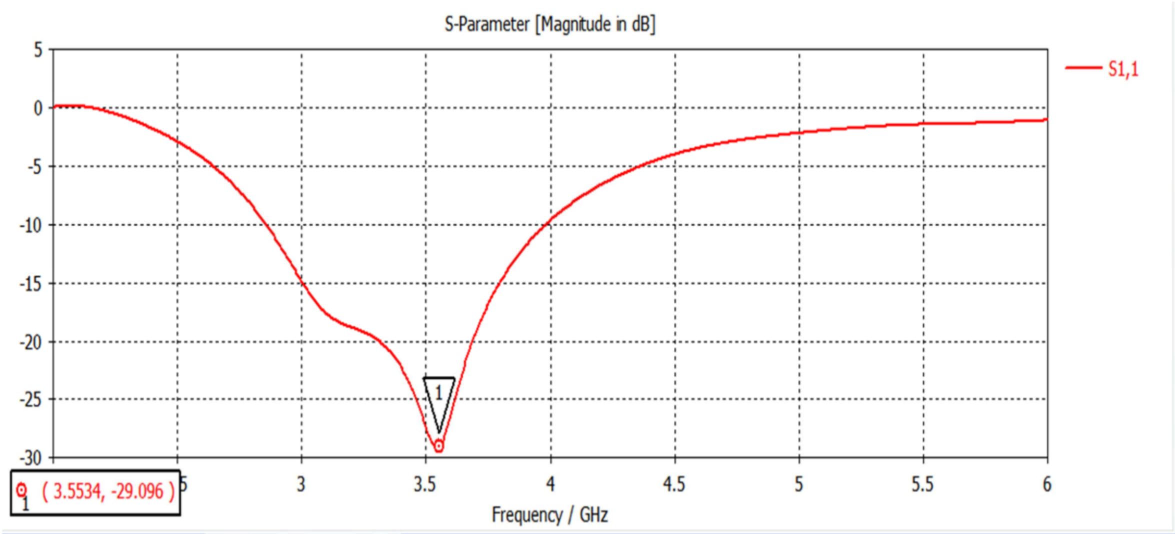


Figure 4.3 Simulated results of S11 of proposed antenna with gain enhanced structure

4.3.2 Gain

Gain is one of the important parameter which is used to analyze the performance of an antenna. Directivity of the antenna and efficiency of an antenna is entirely depend upon gain. It can also be defined as how much the input power is radiated in a particular direction with respect to isotropic source. The plot of gain is shown in figure 4.4 which shows that at resonant frequency 3.8 dB of gain is achieved.

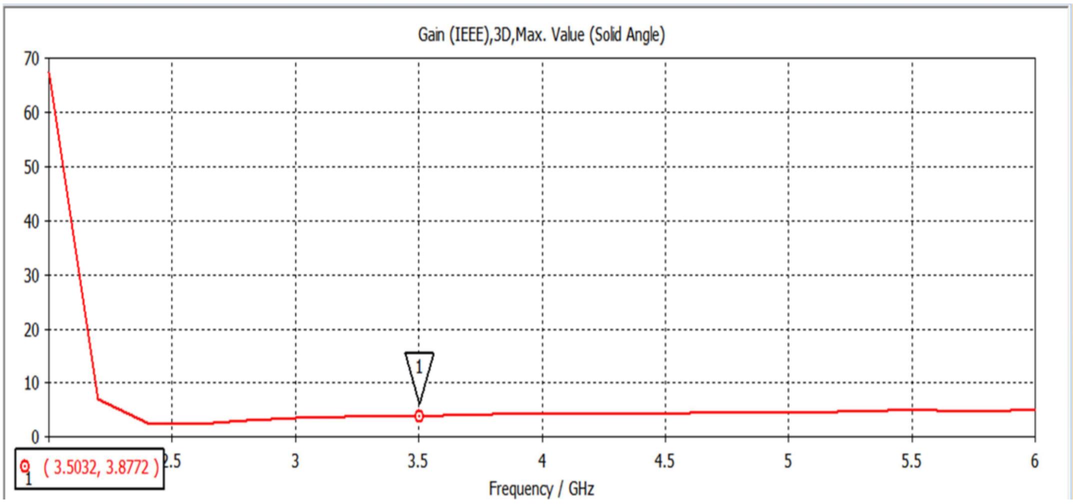


Figure 4.4 Graph of gain of a proposed antennawith gain enhanced structure

The maximum gain over -10 dB bandwidth of the proposed antenna is 5.14 dB. The graph of maximum gain of propsed antenna is shown in figure 4.5.

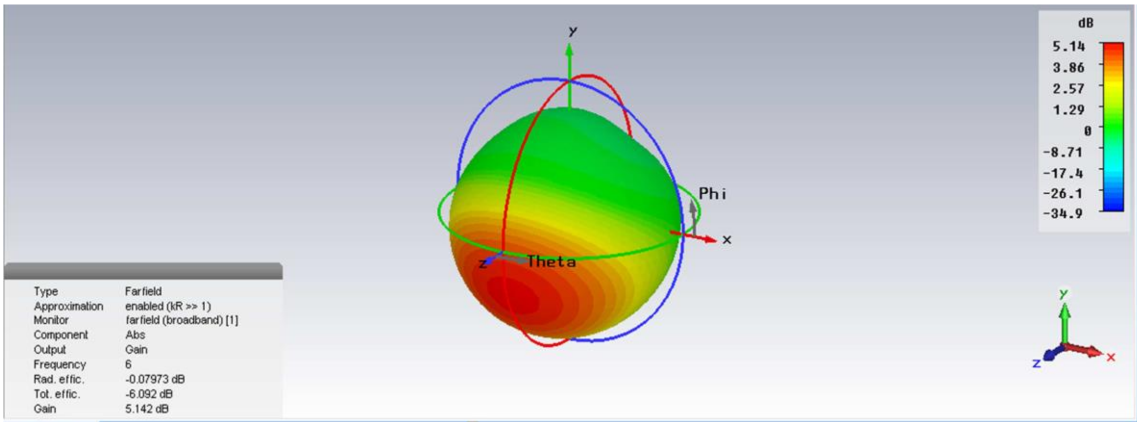


Figure 4.5 Graph of peak gain of proposed antenna with gain enhanced structure

4.3.3 Voltage Standing Wave Ratio (VSWR)

Another parameter which is essential to analyze the performance of an proposed antenna is VSWR. When the VSWR value lies between1 to 2, it means maximum of the power is radiated and minimum amount of power is reflected back. If the value of VSWR is more than 2 it means the maximum amount of power is radiated back and antenna is not properly working. The figure 4.6 shows that at resonant frequency of the proposed antenna the value of VSWR is 1.08 dB which means antenna radiates properly.

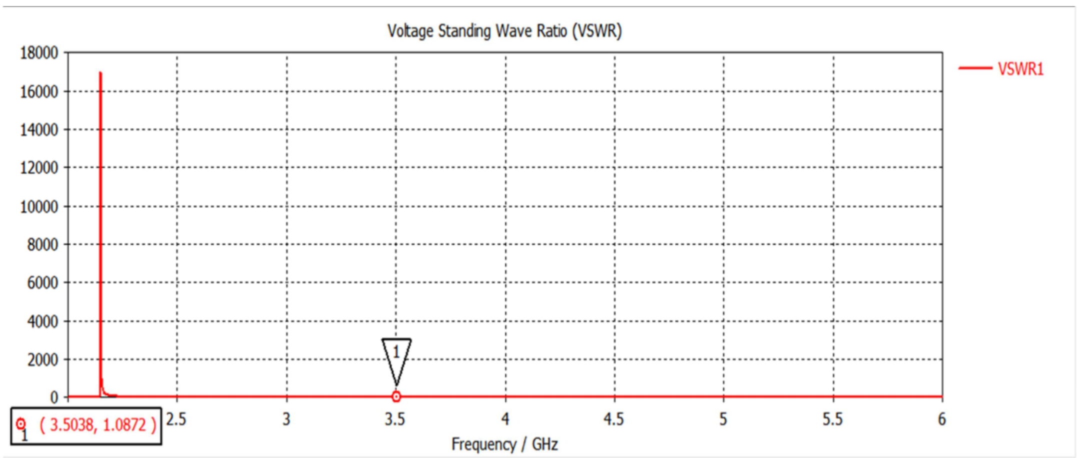


Figure 4.6 Simulated results of VSWR of proposed antenna with gain enhanced structure

Table 4.2 Difference between the Results of Two proposed PIFA Structures

Parameter	**Edge truncated planar inverted PIFA**	**Proposed antenna with gain enhancement structure**
Resonant frequency	3.4 GHz	3.5 GHz
Gain	3.5 dB	3.8 dB
Peak gain	4.34 dB	5.14 dB
VSWR	1.07 dB	1.08 dB

4.4 Conclusion

In this chapter a design of new antenna is proposed which works on LTE band. In this proposed structure four slots are cut from the ground plane to enhance the bandwidth. The simulated results of the proposed antenna is also shown.

CHAPTER 5

FABRICATING AND TESTING OF EDGE TRUNCATED PLANAR INVERTED F ANTENNA

5.1Fabricating and Testing of Planar Inverted-F Antenna for High Band LTE

The fabrication of planar inverted F antenna for high band LTE is done by using FR4 substrate. For the fabrication of proposed antenna Photolithography technique with wet etching facility was used. The top view of the proposed planar inverted F antenna is shown in figure 5.1.

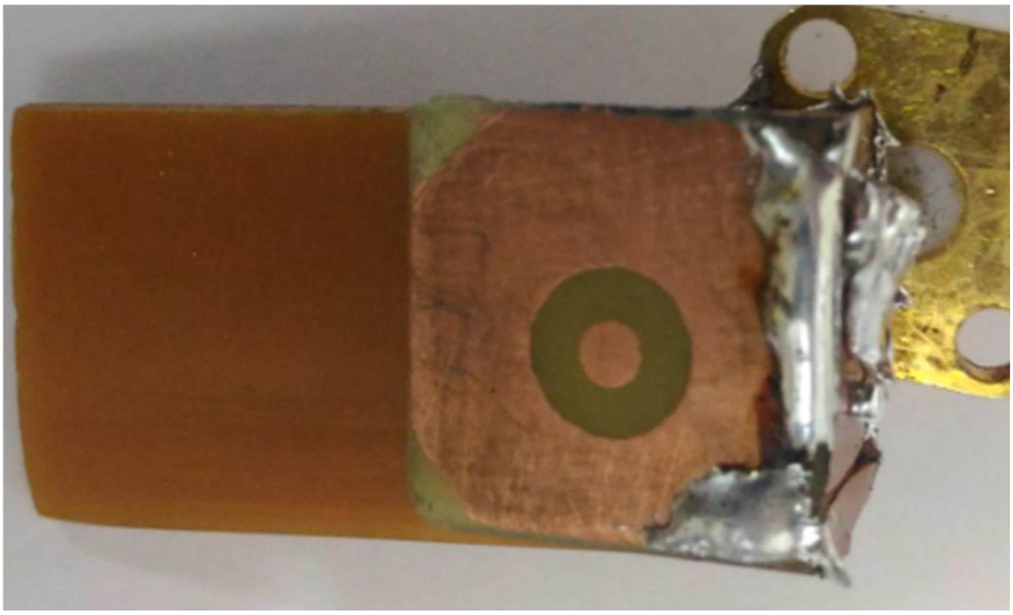


Figure 5.1 Top view of the proposed antenna

The return loss of the planar inverted F antenna for high band LTE was measured with the help of Agilent E5071C vector network analyzer at Antenna Research Laboratory, Thapar University, Patiala. The measured return loss plot is shown figure 5.2.

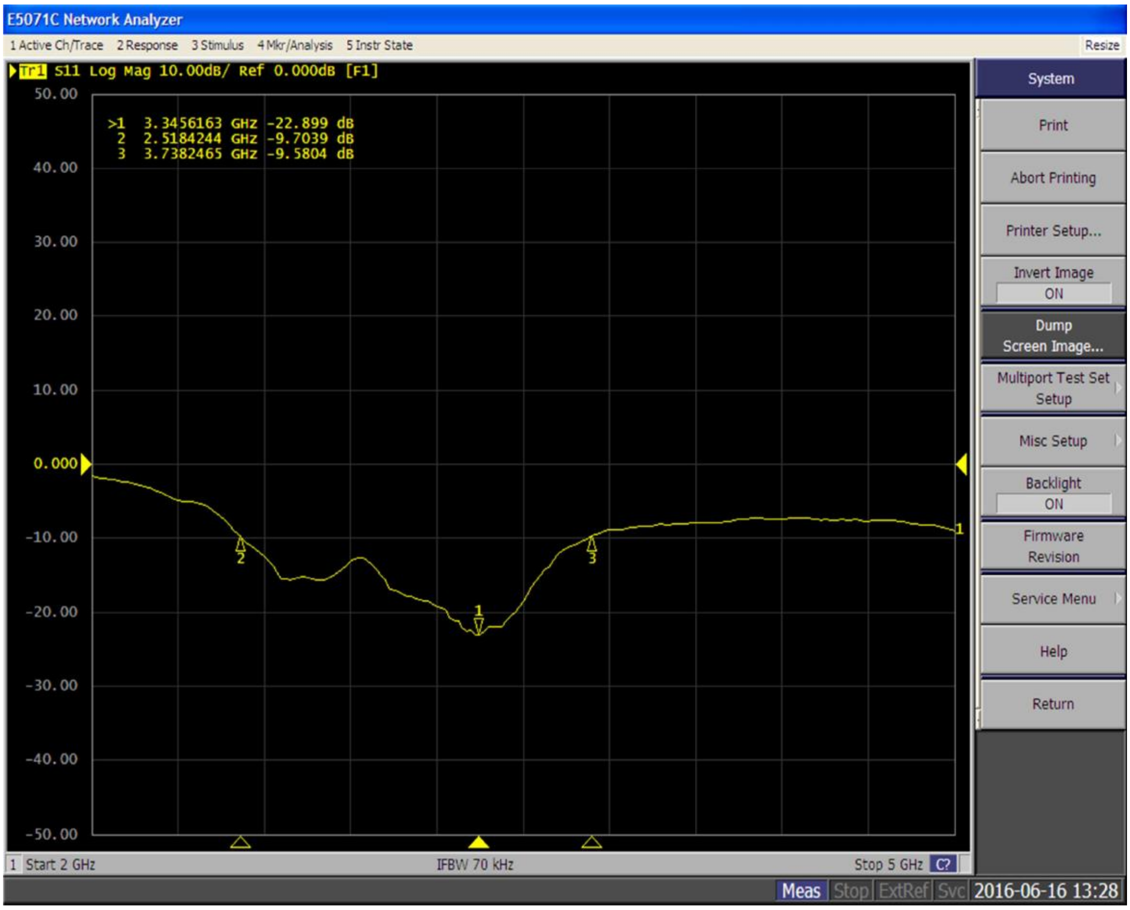


Figure 5.2 Measured return loss of the planar inverted f antenna for high band LTE

The measured return loss plot shows that planar inverted F antenna resonate at3.34 GHz and value is -22.8dB.

5.2 Comparison between Measured and Simulated Results

Because of connector loss and fabrication process there is a slightly difference occur between measured and simulated results. In table 5.1 comparison between measured and simulated results are presented, which shows that some difference occurs between measured and simulated results in terms of return loss, bandwidth and resonant frequency of the proposed antenna.

Table 5.1 Comparison between Measured and Simulated Results

Parameter	**Measured**	**Simulated**
Resonant frequency	3.34 GHz	3.4 GHz
Return loss	-22.8 dB	-28.7 dB
Bandwidth	1.2 GHz	1.5GHz

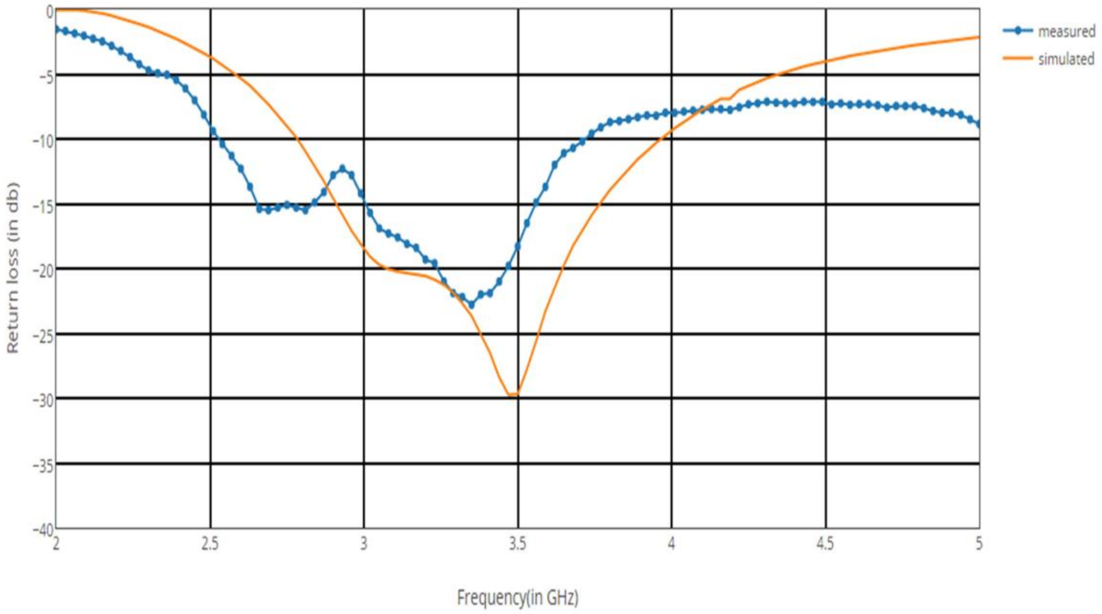


Figure 5.11 Difference between measured and simulated results

5.3 Conclusion

In this chapter the simulation results and measured results of edge truncated PIFA for high band LTE applications is shown and the simulation result of proposed antenna with gain enhancement structure is shown.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The main aim of this thesis work was to design the PIFA antenna for LTE high band applications. To find the optimized results parametric studies have been done on different parts of the antenna. With the help of parametric studies the optimized dimensions of the proposed antenna were obtained. It has been observed that the dimensions of shorting plate and the feeding plate decide the bandwidth and the resonant frequency of the structure respectively. The width of the antenna patch also decides the bandwidth of the structure. The length of antenna defines resonance frequency and breadth of an antenna helps to get proper impedance matching.

In chapter 3 edge truncated planar inverted F antenna for high band LTE is designed.

In chapter 4 the simulation results along with parametric studies have been shown, which show that:

- At resonant frequency that is 3.455 GHz, -28.76 dB return loss is obtained.
- The value of VSWR lies between1 and 2, the exact value of the VSWR is 1.0757, at resonant frequency which shows that the antenna radiates very well.
- The value of gain at resonant frequency is 3.5 dB and the value of peak gain over entire bandwidth is 4.34dB.

There is another design shown in chapter 4 in which slots have been cut on the ground plane. The dimensions of the antenna is similar to the previous one. The dimensions of this structure with slots is shown in chapter 4 and the measured results of this proposed structure have been shown in chapter 5.

The result of PIFA with gain enhancement structure shows that:

- At resonant frequency that is 3.5 GHz, -29.096 dB return loss is obtained.
- The value of VSWR is lies between1 to 2, the exact value of the VSWR is 1.08, which shows that the antenna radiates very well.
- The value of gain at resonant frequency is 3.8 dB and the value of peak gain over entire bandwidth is 5.14dB.

6.2 Future Scope

- The proposed PIFA antenna has good enough bandwidth, but it not working on multiband. So the proposed work can be extended to support multiple bands.
- This PIFA has a very small size, means it covers very small volume but its gain is not constant over entire bandwidth, which can be optimized further.
- It can be extended to MIMO structure.

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Communicated

- Dr. Rajesh khanna, Atipriya Sharma, "A Novel Edge Truncated Planar Inverted F Antenna (PIFA) for LTE High Band Applications", communicated to ***Indian Journal of science and technology.***
- Atipriya Sharma, Dr. Rajesh khanna, Naveen Kumar, "A Novel Edge Fed Planar Inverted F Antenna (PIFA) for LTE High Band Applications", communicated to***International Conference on Intelligent Circuits and Systems***.

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