Planar Antennas for Multiband and Ultra-Wideband Communications

by

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DECLARATION

It is declared that this is an original piece of my own work, except where otherwise acknowledged in text and references. This work has not been submitted in any form for another degree or diploma at any university or other institution for tertiary education and shall not be submitted by me in future for obtaining any degree.

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September 2017

Dedicated to my parents and my elder brother for their affectionate love, moral support and encouragement

CERTIFICATE OF APPROVAL

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ABSTRACT

This thesis focuses on planar monopole antenna designs and analysis. Extensive investigations are also carried out on two different planar antennas.

In the first part, a multiband planar monopole antenna is designed for GSM, DCS, WiMAX and WLAN communications. The proposed antenna consists of a G-shaped and inverted L-shaped radiators connected with each other. The G-shaped radiator is responsible to offer GSM (1800 MHz), WLAN (2.45 GHz) and WiMAX (3.5 GHz) frequency bands, while inverted L-shaped radiator is able to provide GSM (900 MHz) and WLAN (5.25 GHz) frequency bands. The proposed antenna is measured to validate simulated data. It is also observed that the proposed multiband antenna offered good radiation characteristics and gain for desired frequency bands.

In the second part of this thesis, the design of a compact planar monopole antenna is presented for UWB and two extra GSM frequency bands. A bevelled-shaped patch is used to achieve UWB response. Two Capacitive Loaded Resonators (CLRs) are employed with a ground plane to obtain resonance at 900 and 1800 MHz. Measurements are carried out to verify simulation results, and it is observed that the measured and simulated results are in agreement. Furthermore, good radiation characteristics and gain is obtained from the proposed design.

It is also observed that the proposed antennas are small in size. These features have demonstrated that the proposed antennas can be an excellent choice for various wireless communication systems.

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LIST OF ACRONYMS

CLRs	Capacitive Loaded Resonators
CLLRs	Capacitive Loaded Line Resonators
CPW	Coplanar Waveguide
DCS	Digital Cellular System
DGS	Defected Ground Structure
EM	Electromagnetic
EMC/EMI	Electromagnetic Compatibility/Interference
FCC	Federal Communication Commission
GPS	Global Positioning System
GSM	Global System for Mobile
HFSS	High Frequency Structure Simulator
ISM	Industrial Scientific and Medicine
MoM	Method of Moment
MIMO	Multiple-input Multiple-output
PIFA	Planar Inverted F-antenna
P	Peak
RF	Radio Frequency
RFID	Radio Frequency Identification
SRR	Split Ring Resonator
UWB	Ultra-wideband
VNA	Vector Network Analyser
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WCDMA	Wideband Code Division Multiple Access

LIST OF SYMBOLS

c	Speed of light
C_{PK}, C_{RK}	Capacitance of CLRs and radiators
ε_{eff}	Effective dielectric constant
f_r	Frequency
h	Thickness of substrate
L_{PK}, L_{RK}	Inductance of the CLRs and radiators
R_{PK}, R_{RK}	Resistance of CLRs and radiators
W_f	Width of the feed
Z_{in}	Input impedance
Z_0	Characteristics impedance
λ	Wavelength

Chapter 1

INTRODUCTION

According to IEEE definitions, "an antenna is a mean for radiating or receiving radio waves" or, in transmission mode, the antenna receives EM waves from a transmission line, and transmits them into free space, while in receiving mode, it receives the incident EM waves and converts them back into guided waves.

With the advancement in wireless technology, antenna is not going to be outdated because of its consistent use in communication systems. First generation (1G) mobile technology used small monopole antennas. Now-a-days, the industry manufacture and gives preference to compact internal antennas for mobile communication applications over long wire monopole antennas. Mobile communication antennas should be compact, light weight and able to provide omnidirectional characteristics. Also, the rapid increase mobile communication systems introduced different communication standards. Integrating these communication standards into a one unit, a compact wideband and multi-band antennas are required.

In this thesis, microstrip-fed planar monopole antennas are developed for multiband and ultra-wideband (UWB) applications, which can support existing wireless communication services, such as GSM, WiFi/WLAN, WiMAX and UWB frequency bands.

1.1 Motivation

Several factors that motivated this investigation on printed antenna are described below.

In the past two decades, wireless communication technology has influenced almost every field of human society. Following the rapid development of wireless terminals as well as the growing demands for new services, cell phones provide a freedom such that we can communicate with each other with ease, the technologies of

UWB, wireless local area network (WLAN) provides the facility and access to internet without the usage of expensive cables, and the third-generation (3G) and fourth-generation (4G) communication technologies have emerged.

Due to network capability and great stability, GSM system is widely used in mobile and portable devices. It consist of a frequency bands, such as GSM 850/900/1800/1900. Mostly, GSM-900 and 1800 are frequently used among them. GSM-1800 has the stronger piercing force and its power transmission is weaker, which makes it perfect candidate for remote and urban applications. GSM technique is inherited by WCDMA, which is selected as third generation (3G) of wireless communication system technique. WCDMA provides better and higher data rate for image, voice and video communication for mobile devices. Furthermore, WCDMA has become the main and regular 3G standard in the majority countries and areas, which has the richest terminal classes compared to other wireless communication systems. Apart from all this, WCDMA can be entirely compatible with GSM.

Since the allocation of UWB frequency spectrum by FCC, demand increased for miniature and less costly UWB antennas that can provide desirable and acceptable results. UWB systems should be small and low-profile so that they can be suitable with other portable wireless devices. That is why the size of antenna is considered a vital part while designing UWB systems. Planar designs are used to minimize the volume of such systems, i.e., replacing conventional radiators with their planar ones.

It is a common practice for single radio device to provide several services over a wide frequency range. For these types of devices, the ability to generate multiple frequency bands will eventually depend on their antennas performance. To achieve these requirements, multiple antennas are installed, and each one covers a specific frequency band. However, these antennas occupy much space in the device. Most importantly, such installations of multiple antennas generate electromagnetic compatibility/interference (EMC/EMI) problems and also increase the system complexity. Therefore, an antenna is required which provides wideband response to cover all the operating frequency bands of these wireless communication systems.

1.2 Research Objectives

The objective of this thesis is to design and fabricate antennas, which are compact, low profile, and can provide multiband and UWB frequency response. The desired bands are GSM (900/1800 MHz), WLAN (2.45/5.25 GHz), WiMAX (3.5 GHz) and UWB (3.1-10.6 GHz), respectively. Return loss of antennas should be $\leq$-10 dB and radiation pattern should be omnidirectional. Moreover, the gain of antennas should be greater than 5 dBi.

1.3 Thesis Organization

The thesis is organized in five chapters.

Chapter 1 is an introduction, providing basics about wireless systems and use of antenna in them. Key contribution and motivation is also included in the first chapter of this thesis.

Chapter 2 presents a brief history of planar antennas for multiband and wideband applications.

Chapter 3 and 4 present the proposed multiband planar antenna and UWB antenna with integrated cellular bands.

Chapter 5 provides the overall conclusion of the thesis, followed by a brief summary of all the designs and suggestions for future work.

1.4 Key Contributions

The main contributions of this thesis are given below.

Firstly, a printed antenna with inverted L and G-shaped strip is designed for GSM (900 MHz), DCS (1800 MHz), WLAN (2.45/5.25 GHz) and WiMAX (3.5

GHz) communication systems. The proposed antenna design occupies an overall dimension of 40×40×1.6 mm^3. Furthermore, it is observed that proposed antennas exhibits good radiation characteristics and acceptable gains.

Secondly, UWB planar monopole antenna is designed with an addition of GSM-900 and 1800 MHz frequency bands. UWB response is obtained by utilizing quarter wavelength transformer with bevelled shaped radiator. The additional GSM bands are obtained by adding capacitive loaded strips with a ground plane. The antenna occupies an overall size of 50×50×1.6 mm^3. From simulations, it is observed that the antenna resonates at 900 MHz, 1800 MHz and from 2.1 GHz to 10 GHz. It is further observed that the proposed antenna design offers a gain and radiation properties as desired.

Chapter 2

LITERATURE REVIEW

This chapter deals with a brief overview of the past development of microstrip antennas. The chapter starts with the initial development of a radiator. The different technologies and mechanisms so far adapted for the development of multiband antennas are discussed. Finally, the recent progress in multiband antenna research is presented.

2.1 Historical Background

Byron, in 1970's, designed the first microstrip radiator whose length consisted on several wavelengths and half-wavelength wide [1]. The ground plane was separated through a dielectric slab and it is fed using coaxial connectors at regular intervals. After that, Howell, in 1975, presented a radiator by using basic circular and rectangular shapes [2]. The designed antenna was low profile consisted of planar radiating element whose substrate thickness was very low as compared to the wavelength. From the study, author noted that the antenna bandwidth depends on the thickness and relative permittivity of substrate.

With the development, number of geometries of microstrip patch antennas was presented for space applications. The cylindrical array was constructed for S-band applications [3], conformal array was designed for KC-135 aircraft for L-band communication [4]. Some flush mounted antenna arrays were also presented for missile systems [5, 6].

2.2 Model History

Microstrip radiator was analyzed theoretically by using transmission line equivalent circuit model. In [7], author has applied transmission line theory to model a rectangular patch antenna. He separated the radiating edges by a half-wavelength, which was considered as narrow slots radiating into half space. A cavity model, which was more accurate than transmission line model was presented in [8, 9]. Different patch parameters were calculated by using the cavity model approach and different modes of excitation were also included in the calculation.

Important technique, which is used to formulate patch antenna is Method of Moment (MoM), and it is quite similar to cavity model which was formulated by Coffey et al [10]. In this model, the patch was assumed as a thin cavity. The radiated and stored energy in the walls were investigated in terms of complex wall admittances by applying specific boundary conditions. Wall admittances were calculated and given by Hammerstad [11] and more accurately by Alexopoulos et al [12]. The model expansion method is very much suitable for circular geometries. Mink [13] described that the wall admittance has to be known specifically for circular patch. He showed that the wall admittance has to be evaluated between 4% to predict the frequency change upto 0.5%.

Besides all the methods, MoM provides a numerical approximation of patch antenna [14, 15]. Some other methods which are used to analyze the patch antenna are Richmond's reaction method [16], Green function technique [17], finite element approach [18], etc.

2.3 Dual, Tri and Multiband Antennas

In the early literature, researchers presented some patch antenna and monopole antenna configurations for dual and tri-band frequency response. In [19], a dual-band monopole antenna was designed for WLAN applications. The antenna design was simple that it can be easily embedded on board for indoor wireless communication. The results show that the antenna was not able to operate well for 2.45 GHz frequency band. But, it provides good gain for both frequency bands. A defected ground structure with fractal patch geometry was presented for bandwidth enhancement for dual-band WiMAX communication [20]. According to the authors, defected ground structure (DGS) was able to increase the bandwidth of an antenna with relatively good gain. Veeravalli et al [21] proposed a meandered planar antenna design for dual-band GSM 900 MHz and 1800 MHz communication. The presented antenna design followed the design principle of Planar Inverted F-Antenna (PIFA). One of the reconfigurable antenna configurations was also presented in the literature for tri-band frequency response [22]. In this presented technique, slots were designed on rectangular patch which accommodates passive RF switches. The antenna somehow was not a good candidate for wireless communication because the passive RF switches needs a proper tuning to respond perfectly on the desired band.

Some planar monopole antenna designs are also presented in the literature. A T-shaped monopole having two inverted L-shaped strips, shown in Fig 2.1, was presented in [23]. The presented antenna was able to provide resonance for 2.55 GHz, 3.5 GHz and 6.19 GHz frequency bands, respectively. Another planar monopole antenna operating at GSM, DCS, WLAN and WiMAX applications was presented in [24]. The authors used T-shaped radiator with a rectangular loop structure was employed to achieve dual-band response. A G-shaped antenna was designed and presented in [25]. By using a simple structure, a dual-band response for RFID and WLAN applications was achieved. In [26], authors presented dual-band antenna design for WLAN/WiMAX communications. They employed a key-like slot in a rectangular patch to achieve dual-band response. It was also reported that the presented antenna exhibited omni-directional radiation characteristics for both frequency bands.

A compact CPW fed planar monopole antenna was presented for tri-band wireless applications [27]. The authors utilized two inverted L-strips, a circular parasitic element for tri-band characteristics. It was also described that the designed antenna offered good gain with stable radiation properties. In [28], a paw-shaped printed antenna was presented for WiMAX and WLAN communication systems, as shown in Fig 2.2. The presented antenna provided wideband bandwidth for the desired frequency bands. A simple and compact design for WLAN applications was presented in [29]. The presented antenna design consists of a L-shaped

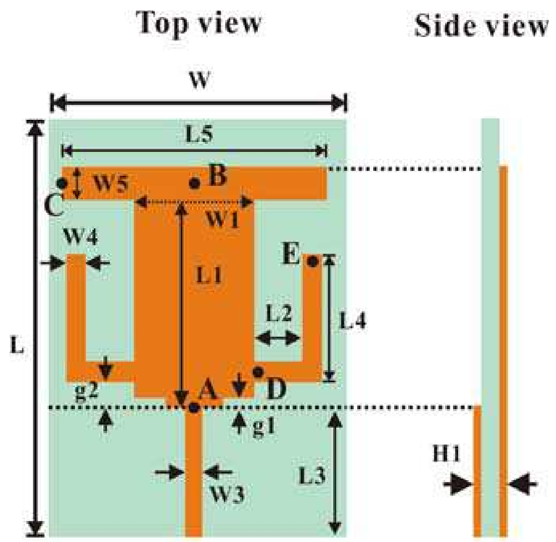


FIGURE 2.1: Design layout of the planar monopole antenna for tri-band characteristics [23].

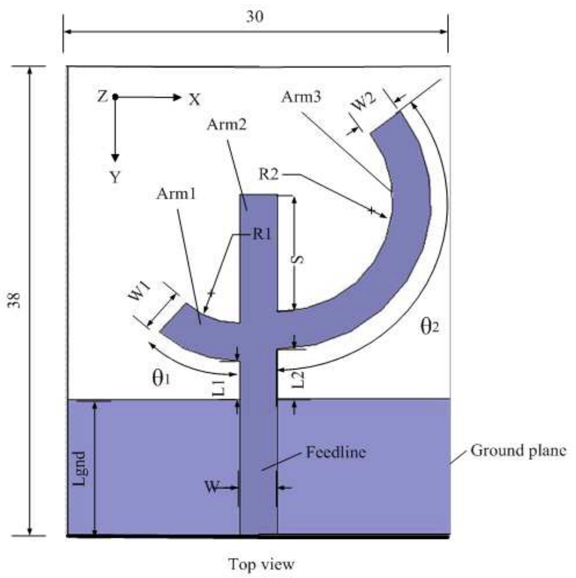


FIGURE 2.2: Geometry of the paw-shaped planar monopole antenna [28].

element and a meandered strip line. The L-shaped element was fed using 50Ω microstrip feed line. It is noted that the only L-element was resonating above 6 GHz. In order to tune the frequencies and to achieve dual-band response, authors employed meandered strip with a ground plane.

Recently, some compact and novel printed antenna designs are also presented for dual and triple-band wireless applications. In [30], a split ring resonator (SRR) based monopole antenna was presented for dual-band wireless communications. A compact U-slot based antenna was presented for tri-band wireless applications [31]. According to the authors, it was the first antenna of its kind, whose size was smaller than the antennas reported in literature. Another printed antenna was presented in [32] for triple band characteristics. This antenna was smaller than the antenna presented in [31]. The authors used crinkle structure to achieve resonance at 1.78 GHz, 3.5 GHz and 5.26 GHz. Inspite of its small size, the antenna offered good gain with a value of 2.7-dBi.

2.4 UWB Antennas with Extra Bands

In the 1980s, Federal Communication Commission (FCC) allocated Industrial Scientific and Medicine (ISM) bands for unlicensed wideband communications. In 2002, the amendments were made in Part 15 by FCC, which directed unlicensed radio devices to include the operation of UWB devices. For this purpose, a bandwidth of 7.5 GHz was also allocated, i.e., 3.1-10.6 GHz. According to the FCC rules, a signal having 500 MHz spectrum can be utilized in UWB systems. It means that UWB is no more restricted to impulse radio. This increasing demand in UWB systems stimulated researchers to design antennas for UWB communication systems.

For UWB systems, antenna designs faced many challenges, such as their impedance bandwidth, radiation characteristics and electromagnetic interference (EMI) problems. With these challenges, the antenna design should be compact for easy integration in portable devices. On the other hand, now-a-days, the demand on single antenna, which operates on multiple wireless frequency bands including UWB band is increased. For this purpose, some of the antennas have been highlited in the literature, which focused the integration of UWB frequency band with other available wireless communication bands.

In [33], a rhomboid structure based UWB antenna was presented for Bluetooth and UWB applications, as shown in Fig. 2.3. The resonance at added Bluetooth band was achieved by adding an L-shaped strip with the main patch. Zhan et al. [34]

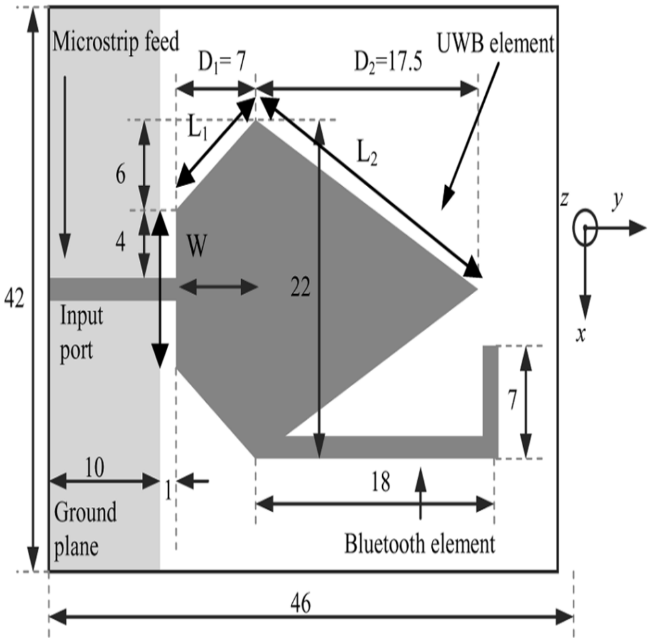


FIGURE 2.3: Design and geometry of UWB antenna with integrated Bluetooth band [33].

presented a novel antenna design for Bluetooth and UWB communication. They employed annular slot in the radiator to get resonance at 2.45 GHz. Furthermore, the authors realized omni-directional radiation properties by truncating the ground plane and by adding a branch at the top of antenna. Same technique was used in [35]. In [36, 37], a U-shaped monopole with longer arm and a fork-shaped patch with inverted L-shaped element were utilized to integrate 2.45 GHz frequency band with UWB operation. A hybrid antenna design for Bluetooth and UWB frequency operations was presented in [38]. UWB response was achieved by using elliptical monopole and resonance at extra bluetooth band was achieved by employing an electromagnetically coupled parasitic patch with arc-shaped strip on bottom of the substrate.

Some antenna designs are also presented in the literature to accommodate cellular, GPS, WiMAX and WLAN frequency bands with UWB band. In [39], a UWB slot antenna was presented for UWB frequency operation with integrated GPS band. The UWB response was taken through a semi-circular patch, and the added frequency response was achieved by employing inverted U-shaped strips with a

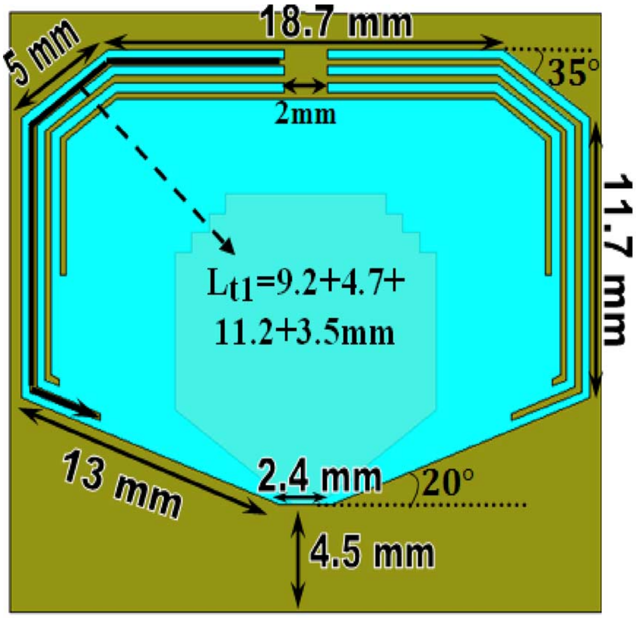


Figure 2.4: Slot antenna configuration for multiband and UWB applications [40].

defected ground structure. It was also described that by changing the length of the strips, one can optimize the design for other frequency bands. A novel and compact UWB slot antenna design was presented with extra cellular and wireless communication bands [40], as shown in Fig 2.4. The authors used the technique of [39] to accommodate extra bands with octagonal shaped UWB antenna.

In [41], a diamond-shaped monopole antenna with several narrow strips was designed. The diamond-shaped radiator was realized for UWB response and narrow strips were used for added GPS/GSM/WLAN bands. Li et al. [42] presented a compact UWB antenna integrated with GSM and wireless bands. A quarter wavelength transformer was utilized with conventional elliptical patch to achieve response in the frequency range of 3.1-10.6 GHz. The response at GSM 1800 MHz, WCDMA 2.15 GHz and WLAN 2.4 GHz frequency bands were obtained by adding three Capacitive Loaded Line Resonators (CLLRs) with a ground plane. Same technique was utilized in [43] but in this case, authors used CPW feed technique. In [44], a modified circular monopole antenna with a longer strip was designed for GSM, Bluetooth and UWB wireless applications. The authors used the technique presented in [33, 36, 37].

2.5 Summary

In this chapter, we have briefly described the past work regarding the origin and development of microstrip antennas. In the first part, basic printed antenna designs are discussed, which were proposed by the researchers. The chapter has discussed how antennas become an interesting field in wireless communication. After that, different designs and configurations are discussed for dual-band, tri-band and multiband antennas.

Chapter 3

MULTIBAND PLANAR MONOPOLE ANTENNA

In this chapter, design of a printed antenna is presented for multiband cellular, WiMAX and WLAN applications. The design procedure and results are also discussed.

3.1 Proposed Antenna Design

The design of the proposed planar multiband monopole antenna is shown in Fig. 3.1. The proposed antenna is designed on FR4 substrate with thickness, $h = 1.6$ mm and relative permittivity, $\varepsilon_r = 4.4$, respectively. It is shown in Fig. 3.1 that the proposed antenna consists of a G-shaped and inverted L-shaped strips. Both strips are connected to each other to realize multiband response. First of all, a G-shaped radiator is designed and simulated in Ansys HFSS and its return loss result is shown in Fig. 3.2. It is observed from the figure that the G-shaped radiator is responsible to provide resonance at 1800 MHz, 2.45 GHz, 3.5 GHz and 5 GHz frequency bands, respectively. After that, an inverted L-shaped strip is designed with a G-shaped radiator to achieve resonance at 900 MHz and to shift 5 GHz frequency band to the desired frequency, which is 5.25 GHz. The combined effect of both the radiators is also provided in Fig 3.2. The length of both the radiators is equal to $\lambda_g/4$, where λ_g is the guided wavelength and can be calculated as:

$$\lambda_g = \frac{c}{f_r\sqrt{\varepsilon_{eff}}} \qquad \textit{Eq (3.1)}$$

It is observed from the figure that the addition of inverted L-shaped strip shifts 5 GHz frequency band to 5.16 GHz and also provides resonance at 900 MHz. Therefore, a final multiband antenna design is realized, as shown in Fig. 3.1. A

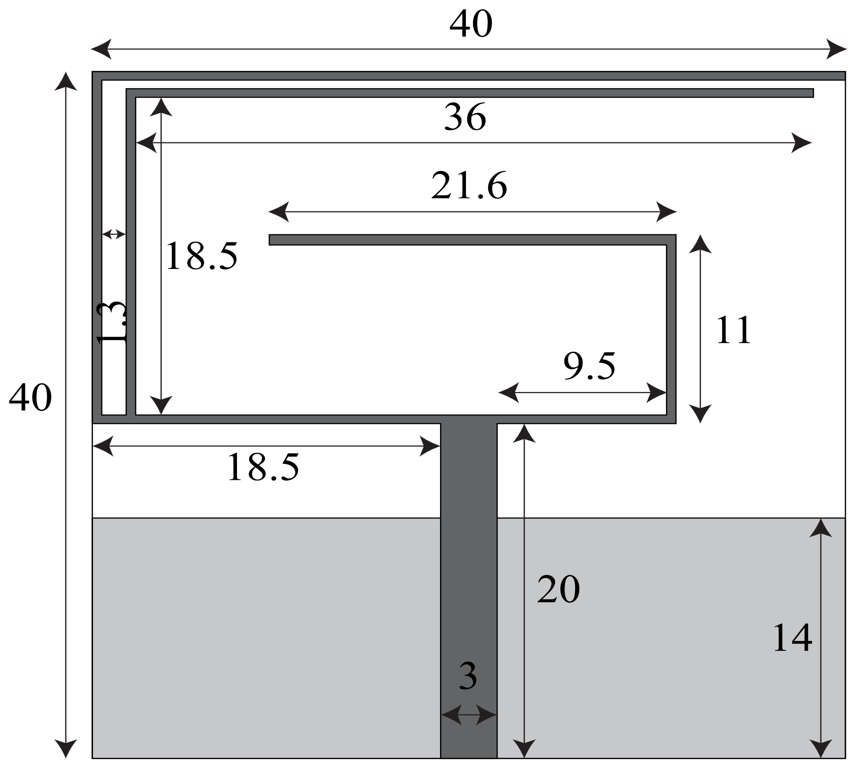


FIGURE 3.1: Geometry of the proposed multiband planar monopole antenna and it's parameters (in mm).

50Ω microstrip feed line is used to feed the proposed antenna. The width of the feed line is calculated as:

$$W_f = \left[\frac{8e^A}{e^{2A} - 2}\right] h \qquad \textit{Eq (3.2)}$$

$$A = \frac{Z_0}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{1/2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \qquad \textit{Eq (3.3)}$$

where W_f is the width of microstrip feed line, h is the thickness of the substrate, Z_0 represents impedance of the feed line and ε_r denotes relative permittivity of the substrate. The width of G-shaped and inverted L-shaped strips is 0.5mm. The rest of the optimized design parameters of the proposed multiband antenna are shown in Fig. 3.1.

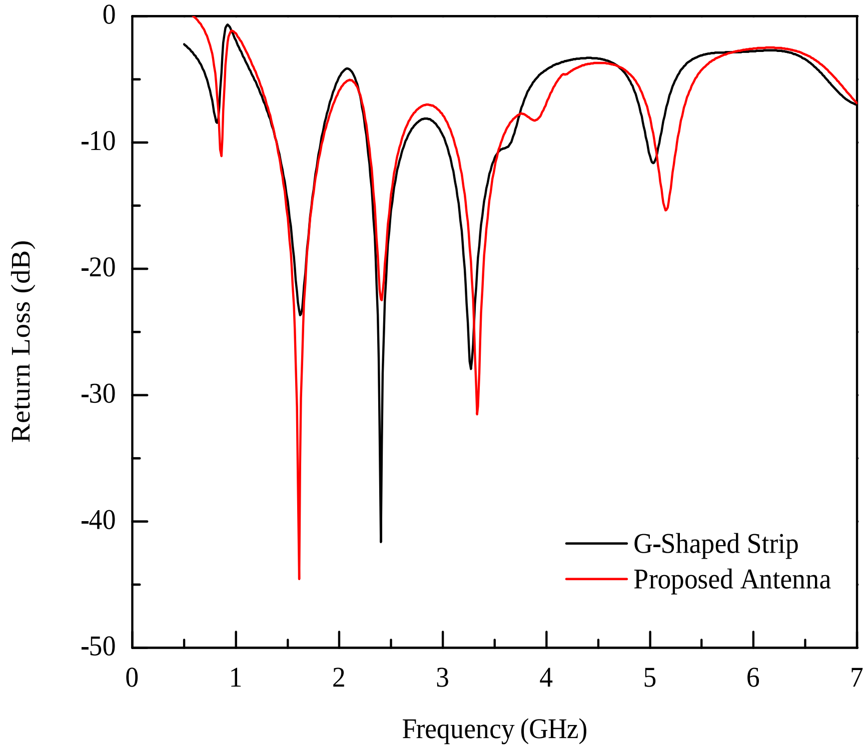


FIGURE 3.2: Return loss results of the two designed antennas.

3.2 Results and Discussion

The proposed antenna is simulated in Ansys HFSS, a commercially available electromagnetic software. After simulations, the proposed antenna is fabricated to validate the simulation results and the prototype is shown in Fig 3.3. The return loss is measured by using Agilent Technologies Vector Network Analyzer (VNA) N5242A. The simulated and measured return loss results are shown in Fig 3.4. It is observed from Fig. 3.4 that the proposed antenna is resonant at 900 MHz, 1800 MHz, 2.45/5.16 GHz and 3.5 GHz, respectively. The discrepancies between both results are due to fabrication tolerance, connector losses and imperfect soldering of SMA connector.

The simulated gain of the proposed multiband antenna is depicted in Fig. 3.5. It is observed from the figure that for GSM 900 MHz, the gain is high as compared to rest of the bands. The gain values noted for resonant frequency 900 MHz, 1800

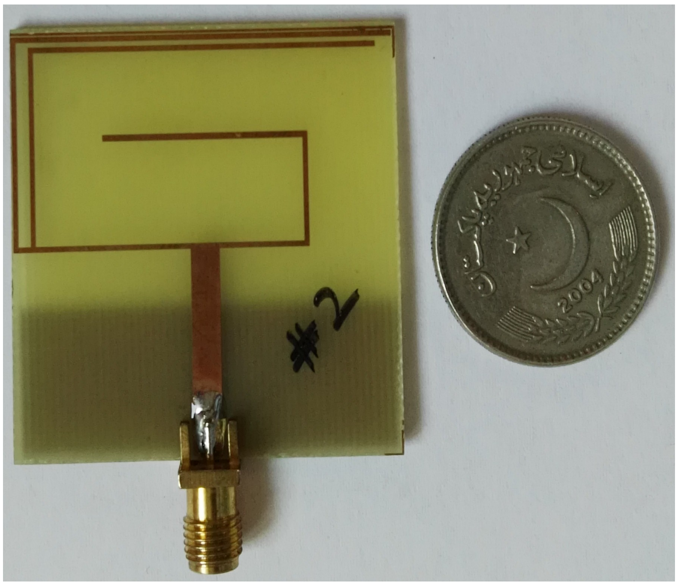


FIGURE 3.3: Prototype of the proposed multiband planar monopole antenna.

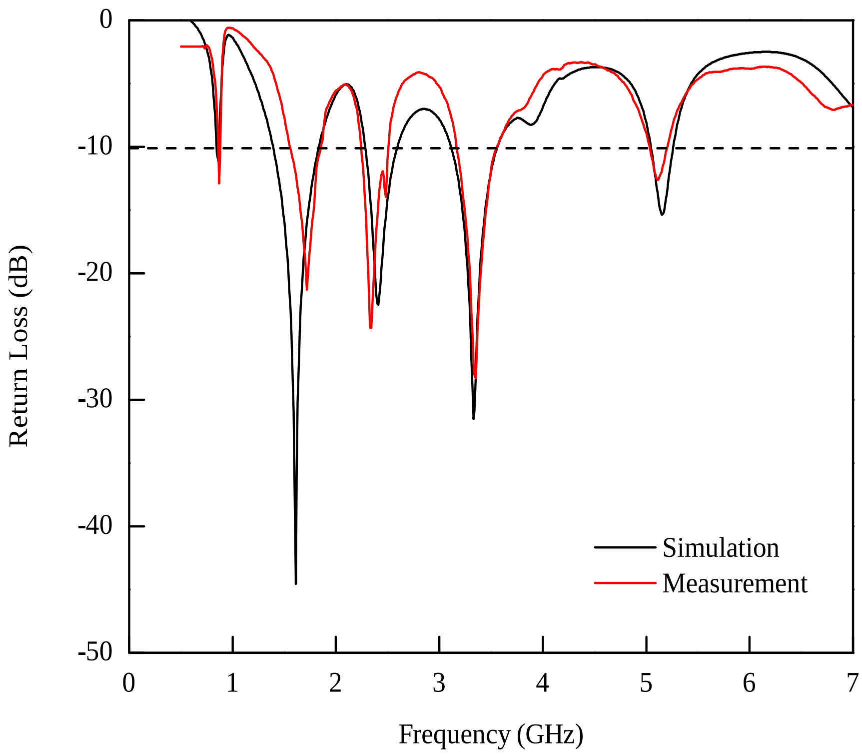


FIGURE 3.4: Simulated and measured return loss of the proposed multiband planar monopole antenna.

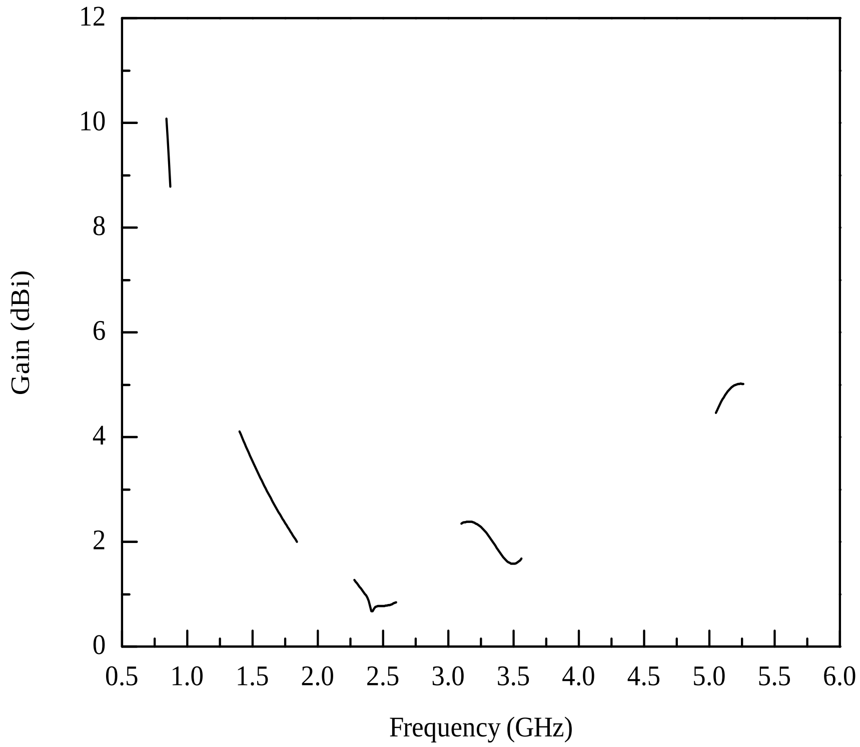


FIGURE 3.5: Simulated gain of the proposed multiband planar monopole antenna.

MHz, 2.45 GHz, 3.5 GHz and 5.25 GHz are 9.67-dBi, 2.15-dBi, 1-dBi, 2-dBi and 5-dBi, respectively.

The simulated E-plane ($\phi = 0^0$) and H-plane ($\phi = 90^0$) radiation patterns of proposed antenna at different frequencies are shown in Fig. 3.6. For 900 and 1800 MHz, shown in Fig. 3.6(a, b), omni-directional radiation patterns are observed for E plane and typical monopole like patterns are observed for H-plane. For 2.45 GHz, directional pattern is observed for E-plane, while omni-directional characteristics are noted for H-plane, as shown in Fig. 3.6(c). For resonant frequency 3.5 GHz, shown in Fig. 3.6(d), bi-directional radiation properties are observed for E-plane and omni-directional pattern is observed for H-plane. For last resonant frequency, which is 5.16 GHz, directional radiation pattern is realized for both E and H-plane, as shown in Fig. 3.6(e).

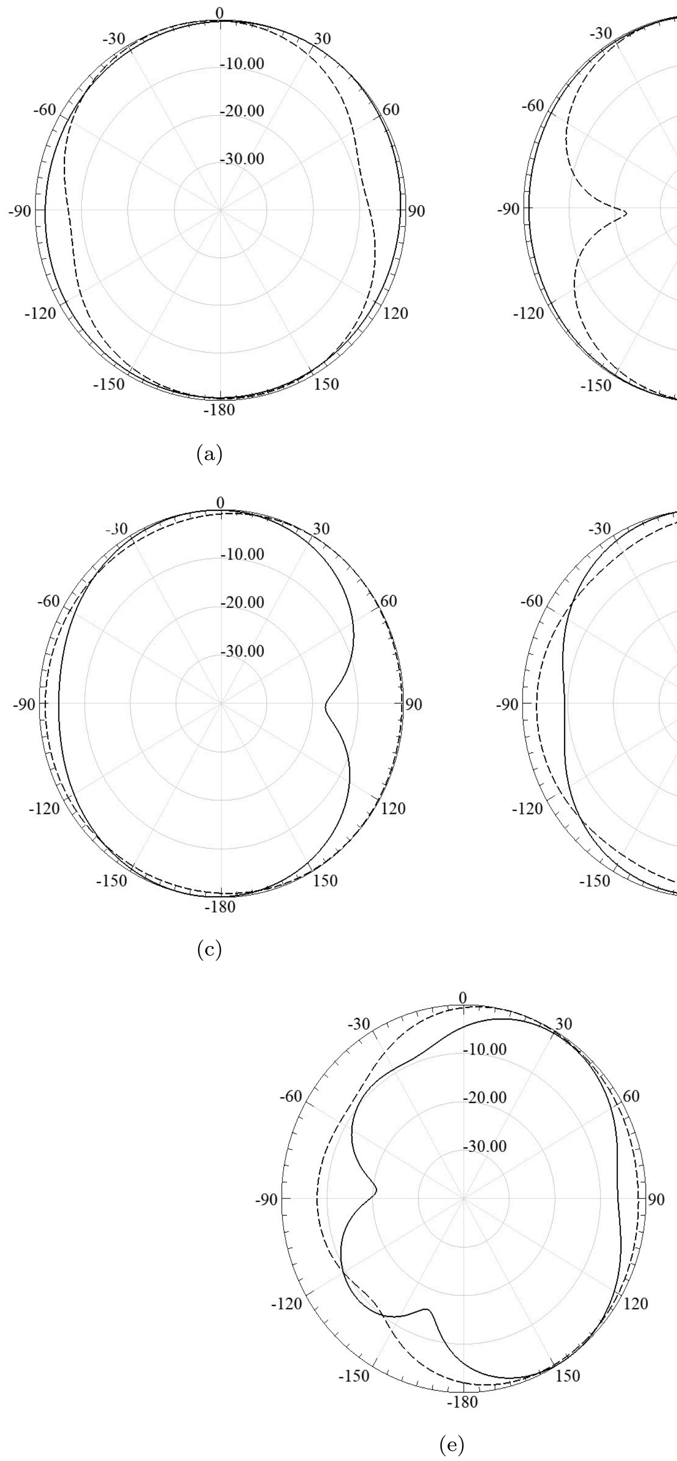


Figure 3.6: Simulated radiation pattern of the proposed planar monopole antenna at (a) 900 MHz, (b) 1800 MHz, (c) 2.45 GHz, (d) 3.5 GHz and (e) 5.16 GHz (Solid line: E-plane, Dashed line: H-plane).

3.3 Comparative Analysis

A comparison between previously presented [21, 24, 25, 26, 27, 28, 30, 31, 32] and proposed planar antennas is done in terms of frequency of operation, peak gain and physical dimensions. Although, previously presented antennas were small in size but they are either dual-band or tri-band, as shown in Table 3.1. On the other hand, the proposed antenna operates on multiple bands on the expense of size. It is also observed from Table 3.1 that the proposed antennas offered high gain than previously presented designs. Therefore, multiband characteristics and high peak gain of the proposed antenna makes it suitable for many communication applications.

TABLE 3.1: Comparison of the proposed antenna with previously presented antennas.

Authors	**Antenna Type**	**Dimensions (mm^2)**	**Resonant Freqs. (GHz)**	**P. Gain (dBi)**
Veeravalli [21]	PIFA	35×10	0.8-0.96, 1.7-1.8, 1.6-1.7	4.8
Jang [24]	Patch	40×60	0.9, 1.9,3.96	2.7
Panda [25]	Printed	38×30	2.43, 5.24	2.5
Ku [26]	Slot	30×35	2.39-2.51, 4.57-5.99	5.6
Dong [27]	Printed	29.5×32	2.4/5.2/5.8, 2.5/3.5/5.5	3.06
Song [28]	Printed monopole	38×30	2.3-2.8, 3.3-4.3, 5.1-5.9	4.7
Imaculate [30]	Printed monopole	24×22.5	2.4, 5.2, 5.8	5.6
Kunwar [31]	Patch	10×26	2.4/5.2/5.8, 2.5/3.5/5.5)	5.10
Beigi [32]	Fractal structure	14×14	1.780, 3.520, 5.260	2.7
Proposed	Printed	40×40	0.9, 1.8, 2.45, 3.5, 5.25	9.67

3.4 Summary

In this chapter, a planar monopole antenna is designed and fabricated for multi-band GSM, DCS, WiMAX and WLAN communication applications. A G-shaped radiator with inverted L-shaped strip is realized to achieve resonance at desired frequency bands. It is observed from both simulations and measurements that the proposed monopole antenna is resonating at 900 MHz, 1800 MHz, 2.45 GHz, 3.5 GHz and 5.16 GHz, respectively. It is also observed that the proposed antenna design exhibits good radiation properties and provides gain averaged 3.964 dBi on desired frequencies and having peak gain at 9.67 dBi. A table is drawn at the end to compare previously presented planar antennas and proposed antenna.

Chapter 4

PLANAR ANTENNA FOR CELLULAR AND ULTRA-WIDEBAND COMMUNICATIONS

This chapter presents the design of a planar monopole antenna for cellular and ultra-wideband (UWB) communications systems. The overall design process and results are also discussed in this chapter.

4.1 Antenna Design

Figure 4.1 shows the geometry of the proposed UWB planar antenna with added bands. The proposed antenna is designed on FR4 substrate with thickness, $h =$ (1.6) mm and relative permittivity, $\varepsilon_r = 4.4$, respectively. This design configuration is inspired by the one presented in [42]. First of all, a bevelled-shaped monopole antenna is designed to realize UWB response. An impedance transformer of 70Ω having a width of (2.65) mm is utilized with 50Ω microstrip feed line (3 mm) and partial ground plane to achieve a response in frequency range of 3.1-10.6 GHz. Figure 4.2 shows the response of the designed UWB antenna. It is observed from the figure that the antenna is able to resonate in the frequency range of 2.1 to 10 GHz.

After that, to achieve resonance at 900 and 1800 MHz, two Capacitive Loaded Resonators (CLRs) are designed, which are connected with the ground plane. For GSM (900 MHz) frequency band, the length of CLR1 is 75.5 mm, while for GSM(1800 MHz) frequency band, the length is 25 mm, respectively. The CLR1 has a meandered shape, which is utilized to fit the CLR1 in the required space. Furthermore, to reduce mutual coupling effect between monopole and CLRs, the length of CLR1 is designed larger than $\lambda_g/4$. Also, to provide space for CLRs and to obtain compact size, the hexagonal patch shifts 7 mm apart from the center. The width of CLRs and gap between them is 0.5 mm. Therefore, the proposed

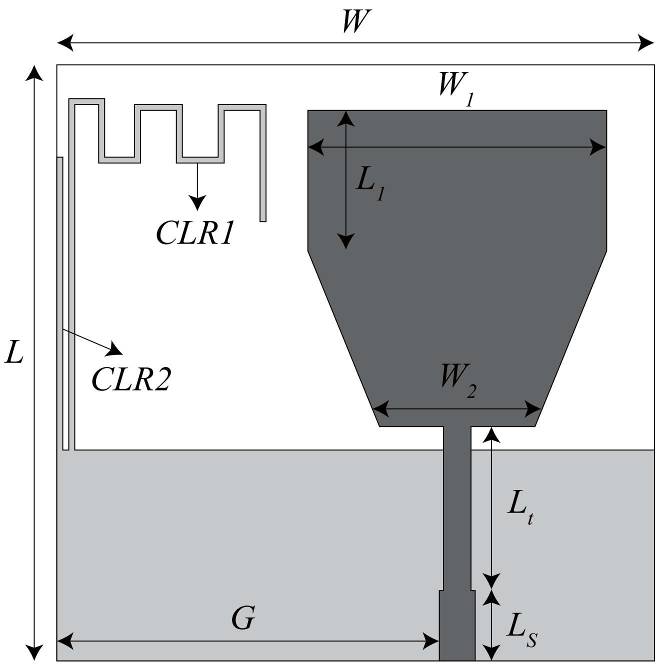


FIGURE 4.1: Geometry of the proposed planar monopole antenna.

TABLE 4.1: Design parameters of the proposed planar monopole antenna [in mm].

Parameters	L	W	L_1	W_1	W_2	L_S	L_t	G
Values (mm)	50	50	12	25	13	6	14	32

antenna realizes an overall size of 50×50 mm^2. The effect of CLRs on the designed antenna is also shown in Fig. 4.2. It is observed from the graph that the designed CLRs with UWB antenna are resonating at 900 MHz and 1800 MHz, respectively. The lengths of the CLRs are calculated by using Eq. (3.1).

Rest of the optimized design parameters are given in Table 4.1.

4.2 Results and Discussion

The proposed antenna design is simulated in Ansys HFSS, and the simulated return loss result is shown in Fig. 4.3. It is observed from the figure that the antenna is able to provide tri-band response at 900 MHz, 1800 MHz and from 2.1 GHz to 10 GHz (UWB frequency response), respectively. The proposed antenna is fabricated on a low cost FR-4 substrate, prototype is shown in Fig. 4.4(a, b). For

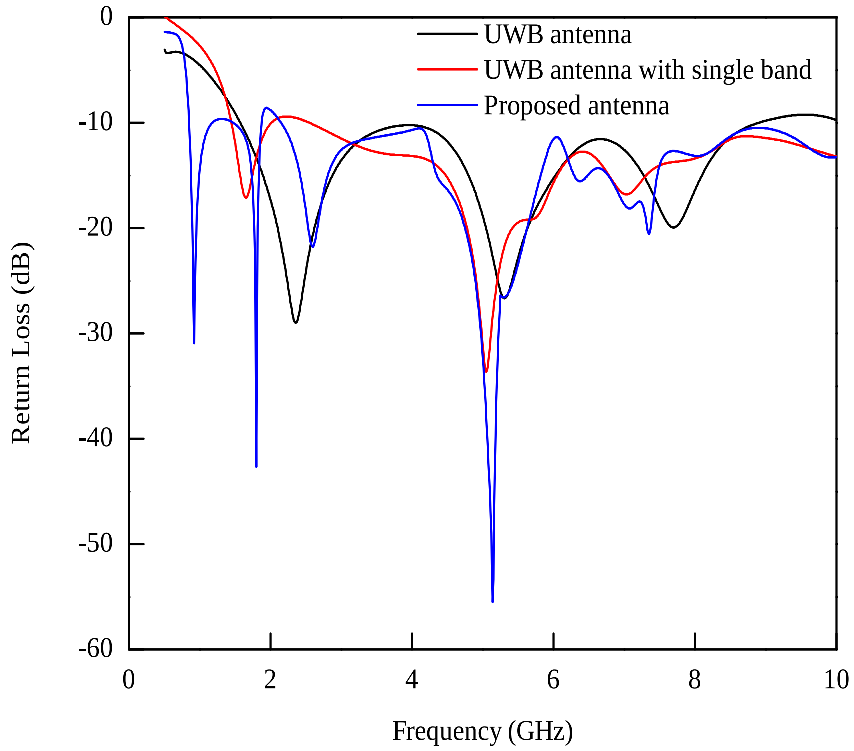


FIGURE 4.2: Return loss results for the UWB antenna with added single and dual-bands.

validation of simulated result, the measurement of fabricated antenna is carried out by using Agilent Technologies Vector Network Analyzer (VNA) N5242A. The measured return loss result is also shown in Fig. 4.3. It is observed from the Fig. 4.3 that the simulated and measured results are in good agreement. Some discrepancies are observed, which are due to fabrication tolerances and connector losses.

The surface current distribution for 900 MHz and 1800 MHz frequency bands is shown in Fig. 4.5(a, b). In case of 900 MHz, a dense current is distributed on the feed line and meandered CLR, shown in Fig. 4.5(a), while for 1800 MHz, maximum current is distributed on feed line and CLR2. Therefore, it is clear from Fig.4.5 that the designed CLRs are able to resonate on desired GSM frequency bands.

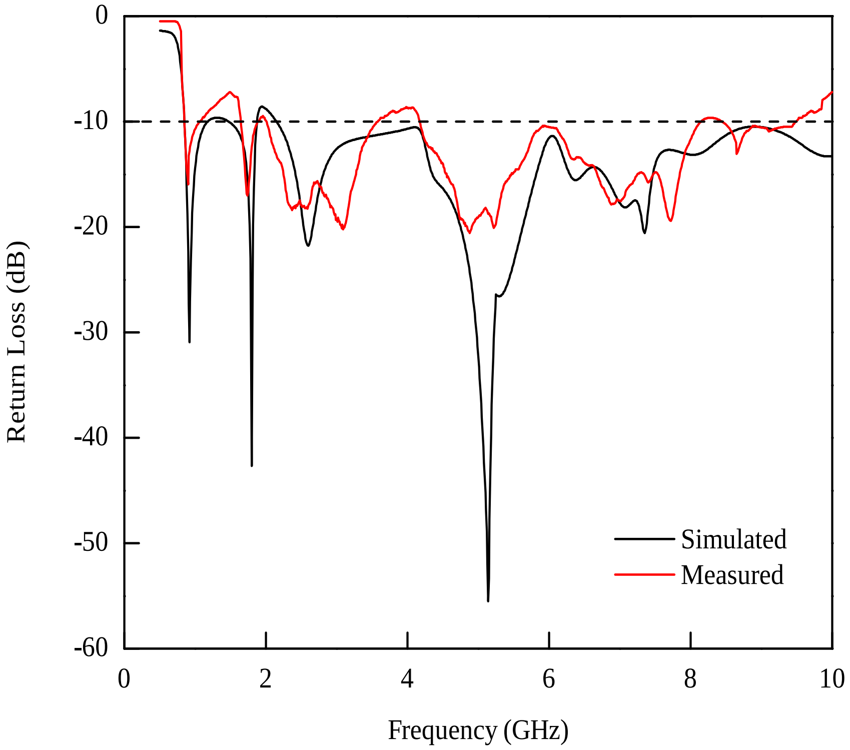
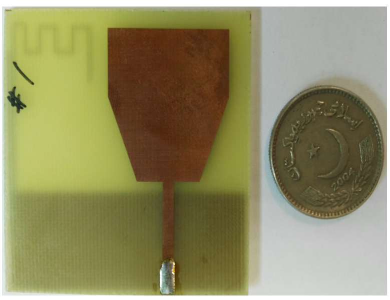
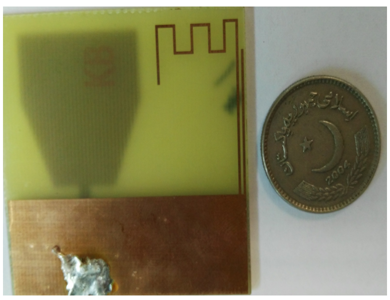


FIGURE 4.3: Simulated and measured return loss of the proposed planar monopole antenna.

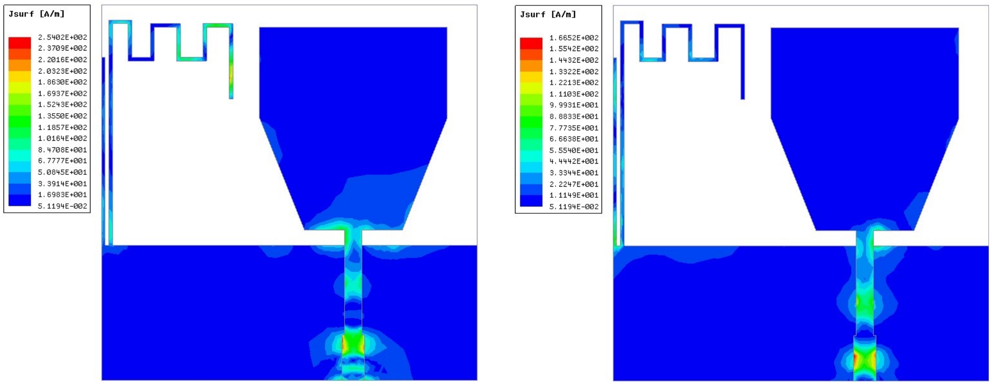


(a)



(b)

FIGURE 4.4: Prototype of the proposed planar monopole antenna (a) Front view (b) Back view.



(a) (b)

FIGURE 4.5: Surface current distribution at (a) 900 MHz (b) 1800 MHz.

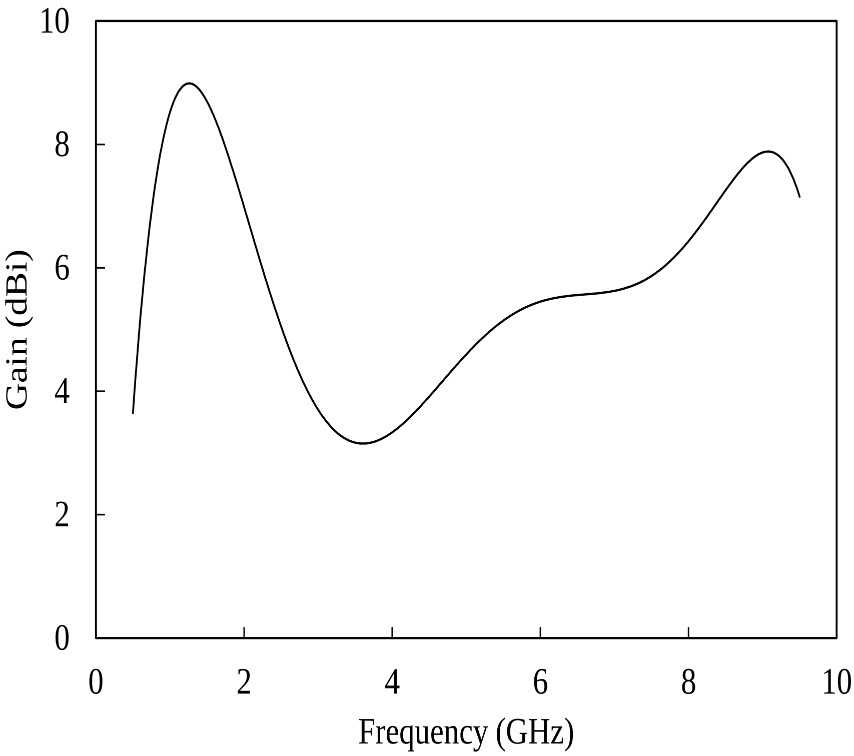


FIGURE 4.6: Simulated gain of the proposed planar monopole antenna.

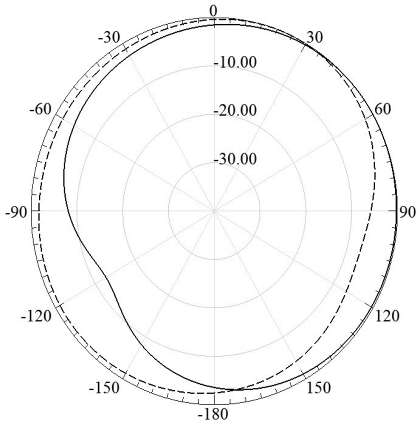
The simulated gain of the proposed monopole antenna is depicted in Fig 4.6. It is observed from the result that for GSM frequency bands, the gain is high as compared to the UWB frequency range. The gain values noted at GSM 900 and 1800 MHz bands are 7.7 dBi and 6.94 dBi, respectively. For UWB frequency range, the average gain value is 5.3 dBi.

The simulated E-plane ($\phi = 0^0$) and H-plane ($\phi = 90^0$) radiation patterns of proposed antenna at different frequencies are shown in Fig. 4.7. For 900 MHz, shown in Fig. 4.7(a), directional characteristics are observed for both E plane and omni-directional pattern is observed for H-plane. For resonant frequency 1800 MHz, and 3 GHz, bi-directional radiation properties are observed for E-plane, while omni-directional characteristics are noted for H-plane, as shown in Fig. 4.7(b, c). For resonant frequency 6 GHz, shown in Fig. 4.7(d), directional pattern is observed for E and H-plane. For 9.5 GHz, omni-directional pattern is realized for both E and H-plane with some ripples, as shown in Fig. 4.7(e).

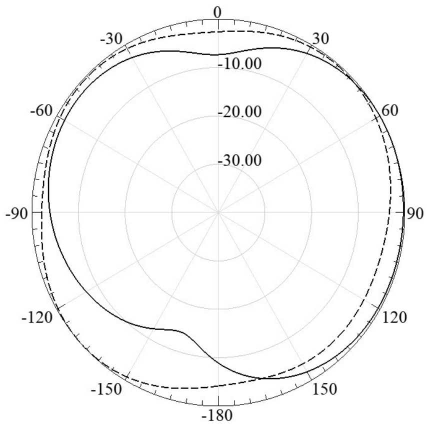
From the above presented results it is clear that the proposed antenna design is a suitable candidate for GSM and UWB communications. Also, the proposed antenna is simple profile, so that it can be easily integrated or installed with portable communication devices.

4.3 Comparative Analysis

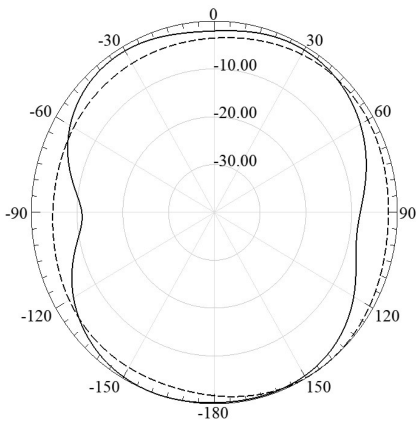
Table 4.2 shows the comparison between previously presented [33, 34, 35, 36, 37, 38, 39, 41, 43, 44] and proposed planar antennas. Comparison is done on the basis of operating frequencies, dimensions and peak gain. Although, the dimensions of the previously presented antennas were slightly less but they offer very low peak gain as compared to the proposed antenna.



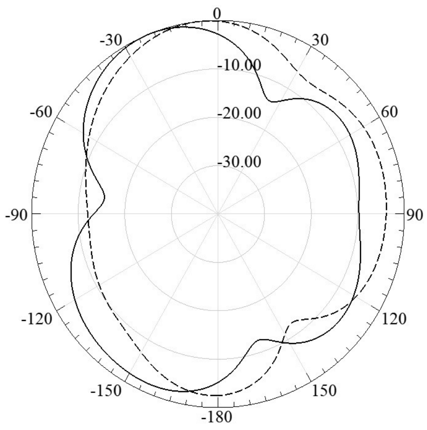
(a)



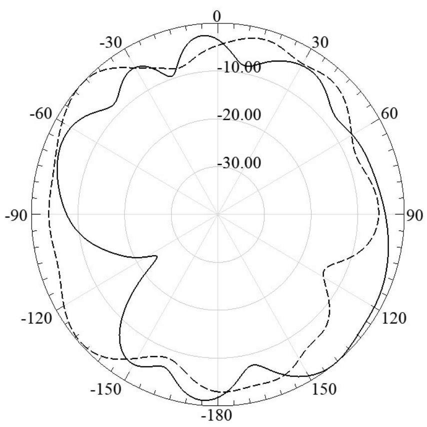
(b)



(c)



(d)



(e)

FIGURE 4.7: Simulated radiation pattern of the proposed planar monopole antenna at (a) 900 MHz, (b) 1800 MHz, (c) 3 GHz, (d) 6 GHz and (e) 9.5 GHz (Solid line: E-plane, Dashed line: H-plane).

Table 4.2: Comparison between proposed and previous antennas.

Authors	**Antenna Type**	**Dimensions (mm^2)**	**Resonant Freqs. (GHz)**	**P. Gain (dBi)**
Yildirim [33]	Printed	42×46	2.4, 1-1.06	6.5
Zhan [34]	Printed	45×32	2.4-2.5, 3.1-10.6	3.9
Mahamine [35]	Printed circular	38×30	1.7-1.8,2.4-2.48,3.1-10.6	5.9
Mishra [36]	Printed	42×24	2.4-2.484, 3.1-10.6	4.7
Labade [37]	Patch	38×30	2.4-2.5, 3.1-13, 5.15-5.9	4.55
Ren [38]	Printed	35×30	3.5, 5.2	3.8
Bod [39]	Slot	23×29	1.5-2.4, 3.1-10.6	3
Foudazi [41]	Planar monopole	16×22	1.8, 2.4, 3.1-10.6	4
Chuang [43]	Mobile antenna	44.5×17.65	0.9, 1.8, 2.2	3.46
Mahamine [44]	Printed	38×30	1.78-1.82, 2.4-2.48, 3.1-10.6	5.9
Proposed	Planar monopole	50×50	0.9, 1.8, 2.1-10.6	7.7

4.4 Summary

In this chapter, a planar monopole antenna is designed and fabricated for GSM as well as UWB communication applications. A bevelled patch radiator, and CLRs with ground plane are utilized to achieve resonance at 900 MHz, 1800 MHz and UWB (2.1-10 GHz) frequency band. It is also observed that the proposed antenna design exhibits good radiation properties and provides gain averaging more than 5dBi. At the end of the chapter a comparison table is drawn which shows the peak gain of the proposed antenna is 7.7 dBi.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

With the rapid advancements in wireless communication systems, a number of multiband antennas have been proposed. Selection of an appropriate antenna is a crucial task in order to meet the stringent performance requirements of a particular application. Owing to this, planar antennas remained a research subject for considerable period of time because they have some advantages such as, low cost, light weight and easy integration with hand-held devices.

In the first part of this thesis, a compact planar antenna is designed and presented for multiband cellular and wireless communication systems. The proposed antenna design consists of a G-shaped and inverted L-shaped strips, which are connected to a 50Ω microstrip feed line. It is observed from both simulated and measured results that the proposed monopole antenna is able to provide resonance at 900 MHz, 1800 MHz, 2.45 GHz, 3.5 GHz and 5.3 GHz frequency bands. Furthermore, the designed antenna provides good gain and stable radiation properties for desired bands. As well as, the antenna occupies an overall size of 40×40 mm^2 so that it can easily be integrated with hand-held devices.

In the second part of this thesis, a printed antenna is designed for ultra-wideband (UWB) communication with added GSM frequency bands. Bevelled-shaped radiator with a quarter wavelength transformer is realized to achieve UWB frequency range. The resonance at GSM frequency bands is achieved by adding Capacitive Loaded Resonators (CLRs) with a partial ground plane. The simulation results show that the proposed antenna is resonating at 900 MHz, 1800 MHz and in the UWB range (2.1-10 GHz). The proposed antenna is fabricated to validate the simulated data, and good agreement is observed between simulated and measured results. Furthermore, the designed antenna provides good gain at GSM frequency bands than UWB frequency band.

5.2 Future work

Based on the conclusion drawn above and the limitations of the presented work, future work can be carried out in the following area:

1. For mobile and other compact portable devices, the size of an antenna should be small. Therefore, future research should focus on further size reduction of antennas by finding out new methods.
2. MIMO and massive MIMO communication systems have gained a lot of attention to provide enhanced channel capacity and high data rate. Therefore, an array of antennas with reduced mutual coupling can be developed.
3. It is observed the the proposed antenna designs are not properly providing omni-directional radiation properties. So, a solution can be proposed to overcome this problem.

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