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Implementation of miniaturized printed UWB antennas

Graduate School of Chosun University

Department of Information and Communication Engineering

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List of acronyms

FCC	Federal Communication Commission
UWB	Ultra-Wideband
HFSS	High Frequency Structure Simulator
VSWR	Voltage Standing Wave Ratio
GHz	Gigahertz
IR-UWB	Impulse Radio Ultra-Wideband
MPA	Microstrip Patch Antenna
PCB	Printed Circuit Board
RF	Radio Frequency
dB	decibel
dBi	dB (isotropic)
CPW	Coplanar Waveguide
FR4	Flame Retardant
3-D	3 Dimensional
DGS	Defective Ground Structure
SWR	Standing Wave Ratio

ABSTRACT

Implementation of miniaturized printed UWB antennas

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The increasing demand of wideband compact size, light weight and low cost antenna for many wireless communication applications in recent years has been topic of research. The performances of compact size antennas are same as large antenna with less manufacturing cost and easy to handle advantages. Hence reduction in antennas size became an important design parameter. Also wideband microstrip antennas have the advantages of enhancing the system capacity for transmission as well as for reception. The proposed work in this thesis is focusing on design of Ultra wideband (UWB) antenna with significant size reduction and unique feature. Various types of printed antennas along with several bandwidth enhancement techniques has been released for example slots or stub of some fixed wavelength in radiation patch, defective ground structures (DGS), and modified feed line. Mainly these methods focused on the surface current density with purpose of bandwidth and gain enhancement.

In present work, two different types of antenna have been discussed. The basic geometry of microstrip patch is modified by incorporating defective ground structures (DGS) technique and symmetrical and unsymmetrical slots in radiating patch. The proposed work is initiated with the design of simple patch antenna. The iterations of different lengths have been done in the radiating patch and ground structure is modified by inserting some slots intentionally to make size reduction and easy fabrication and full fill the desired requirement. Through the process of analysis and simulations, it was seen that patch antenna with U-slot in ground plane can resonate at higher frequency with suitable impedance matching fulfilling the UWB requirement.

Similarly, in the second proposed monopole antenna, modified feed line technique is applied along with backed conductor on bottom side. Three different width microstrip lines are used to feed the radiating patch which also acts as impedance matching network to match the 50 Ω

requirement. The top most layer consist of a feed line and radiating patch while bottom layer consist of a partial ground and unsymmetrical conductor backed plane slots.

The antennas are design using finite element method based High Frequency Structure Simulator (HFSS) and their performance are demonstrated in term of reflection coefficient , VSWR , radiation pattern , gain and group delay. The designed antennas are fabricated on FR4 substrate and Duroid ™ respectively. Very minor deviations observed among simulation and fabrication results due to environmental inaccuracies. Furthermore, designed antennas have bandwidth of (antenna 1 BW: 2.9 ~ 17.5 GHz), (antenna 2 BW: 4.3 ~ 13.4 GHz). Thus the antenna with small size, unique shape and wideband functionality are beneficial to cope with rapid growth of wireless communications systems applications. Especially, in the recent development of short/medium-range communication technologies, a multitude of services for indoor application scenario can be designed. Depending on the application scenarios, location information can be given with different level of accuracy by using antenna as transceivers. Both transmitters and receivers can be equipped with any types of directional antennas or adaptive array type antennas.

요약

소형화를 위한UWB 안테나의 구현

이람 나담

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최근 무선통신 시스템의 비약적인 발전으로 인하여 넓은 대역폭과 소형 및 저가 안테나에 대한 수요가 증가하고 있다. 소형 안테나의 성능은 기존 안테나와 동일해야 하며, 안테나의 크기는 중요한 설계 변수가 된다. 또한, 광 대역 마이크로스트립 안테나는 시스템 용량을 향상시키는 장점을 갖는다.

일반적으로 넓은 대역폭을 확보하기 위해 DGS (Defective Ground Structure), 슬롯 및 스터브가 삽입된 방사 패치, 변형된 급전 선로 방식 등의 다양한 유형의 안테나가 연구되고 있다. 이러한 방식은 대역폭 및 이득의 향상을 목적으로 하고 있다.

본 논문에서 제안한 UWB 안테나는 UWB 안테나의 설계조건을 만족하며 소형화하기 위하여 두 종류의 안테나를 제작하였다.

첫 번째 제안한 안테나의 경우는 패치 안테나 설계를 기반으로 하여 방사패치에 일정하게 반복되는 구조를 삽입하고 접지면에는 일정한 크기의 슬롯을 삽입하여 요구사항을 충족하였다. 시뮬레이션 분석을 통해, U-슬롯이 삽입된 패치 안테나는 UWB 시스템의 요구사항을 만족하였으며, 높은 주파수 대역에서 공진을 확인할 수 있었다.

두 번째는 제안한 안테나의 경우는 모노폴 안테나에 변형된 급전 선로와 하단에 추가로 삽입된 도체 구조와 함께 설계하였다. 서로 다른 마이크로스트립 라인의 폭은 패치에 연결되며, 임피던스 정합 네트워크로 작동하여 50 Ω의 요구사항을 만족한다. 상단에는 급전선과 방사 패치로 구성되며, 하단에는 부분 접지 및 비 대칭 도체 슬롯으로 구성된다.

제안한 안테나는 유한 요소법의 고주파 구조 시뮬레이션 툴(HFSS)을 사용하여 설계하였으며, 반사계수, VSWR, 방사 패턴, 이득 및 그룹지연 분석을 통해 성능을

검증하였다. 설계된 안테나는 FR4 및 Duroid^{TM}을 사용하여 제작하였으며, 시뮬레이션 결과와 측정 결과는 유사한 결과를 확인할 수 있었다.

1 INTRODUCTION

1.1 Overview

Modern communication demands the compact, availability of efficient and portable devices those can be operated at high data-rates with low signal power applications. Researchers are working towards the advancement and development of RF front ends to meet the latest requirements. Various novel approaches have been reported to improve the performance of microwave component. Ultra wideband (UWB) technology has been regarded as one of the most promising wireless technologies that have a capability of modernizing high data rate transmission. Since 2002, the report release by FCC (federal commission of communication, USA) on UWB wireless communication bandwidth of 7.5 GHz (3.1–10.6 GHz), a number of new techniques has been developed to support high data rate wireless communication for the next generation technologies. Basically, the capacity or maximum achievable data rate for the ideal band-limited case additive white gaussian noise (AWGN) channel is associated to the bandwidth and to the signal-to-noise (SNR) ratio by using shannon-nyquist criterion.

Microstrip patch antennas have various advantages such as conformal nature, low profile, economical to manufacturer and compatible with different integrated circuits. According to the commission defined rules and regulations regarding transmission power, frequency bands and bandwidths. UWB is known as any wireless scheme having fractional bandwidth ≥ 20% or 500 MHz of absolute bandwidth. Moreover, UWB has gain lots of attention because of the some attractive features involving high data rate, wide bandwidth, interference mitigation and low consumption of power with location and tracking. According to standards location tracking application for emergency services (LAES) 3.1 to 4.8 GHz has been reserved while for location tracking for automotive and transportation environment (LTT) 6 to 8.5 GHz is identified for person and object tracking and industrial applications. For tank level probing radar (4.5 to 7, 8.5 to 10.6) GHz, and for level probing radars (LPR) has 6 to 8.5 GHz acknowledged.

Hence antennas size are reduction became an important design parameter. Also wideband microstrip antennas have the advantages of enhancing the system capacity for transmission as well as for reception. The propose work in this thesis is focusing on design of ultra wideband (UWB) antenna with significant size reduction and unique feature. Various types of printed antennas along with several bandwidth enhancement techniques has been released for example slots or stub of some fixed wavelength in radiation patch , defective ground structures (DGS) and modified feed line. Mainly these methods focused on the surface current density distribution with purpose of gain and bandwidth enhancement.

1.2 Objective

The objective of the thesis is to study the antenna systems and design a microstrip patch antenna without affecting UWB predefined characteristics such as return loss, radiation pattern, efficiency and gain. The develop design can be used as transmitter / receiver or transducers to work for position location and tracking system design engineers.
Following are the main goals and ideas of this research work.

- Familiarization of the tools to be used HFSS (High Frequency Structure Simulator).
- Design of ultra wideband (UWB) antenna by DGS technique.
- Design of wideband antenna by feed line modification.

1.3 Organization of thesis

Rest of the thesis is organized into the following number of chapters.

Chapter 2 will be literature review which deals with a comprehensive study of printed antennas along with some basic types and principle of operation. Section 2.2 provides some advantages and disadvantages of printed antennas. Brief description of previously designed antennas by 3 – dimensional printing technology is also described in subsection 2.3.

Chapter 3 is about basic antenna elements and important factors used to describe its performance in real world applications.

Chapter 4 summarizes the two different techniques adopted previously to obtain ultra wide band functionality along with miniaturization in microstrip patch antenna.

Chapter 5 discuss in details the design of microstrip patch which is modified by incorporating defective ground structures (DGS) technique and symmetrical and unsymmetrical slots in radiating patch. Design specification is represented in section 5.1.1. The procedure adapted to design on the proposed work is explained in subsection 5.1.2. The demonstrations of simulated as well as the experimental results are described in subsection 5.1.3 in term of reflection coefficient , VSWR , radiation pattern and group delay characteristics.

Chapter 6 presents the work done and suggests direction for possible future work.

2 THEORATICAL REVIEW

2.1 Printed antennas

In telecommunications, a microstrip antenna (also called a printed antenna) refers to an antenna made using microstrip technology on a PCB. They are used primarily in microwave frequencies.

The individual microstrip antennas consist of metal patches of various shapes on the surface of the printed circuit board, with metal foil surfaces on the other side of the board which is known as ground plane. Most microstrip antennas consist of several patches in a two-dimensional array.

An antenna is typically connected to a transmitter or receiver using a microstrip transmission line of the foil. High frequency current is applied between the antenna and the ground plane (or the received signal is generated on the receiving antenna). Microstrip antennas have become very prevalent in recent decades due to the thinner planar profile that can be easily embedded in the surface of consumer products, aircraft and rockets [1]. Simplicity of manufacturing with use of printed-circuit boards; It is easy to integrate the antenna with the rest of the circuit on the same substrate, and it is possible to make an active antenna by adding to the antenna itself an active element, such as a microwave integrated circuit.

The printed antennas present several advantages compared with the conventional antennas. The main benefits are: low-profile, lightweight, small volume, compact, planar configuration, can be conformal in shape to the host surface, easy integrated with printed-circuit technology and with other MICs (microwave integrated circuits) on the same substrate, as well as allow both circular polarization and linear polarization. The tremendously short pulses in turn generate a very widespread bandwidth and offer several advantages, such as large throughput, robustness to jamming, lower power, and coexistence with current radio services [2].

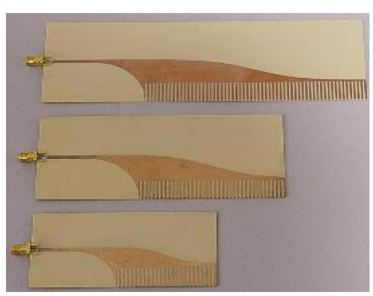


Figure 2.1: Printed antenna prototype [3]

2.1.1 Microstrip antenna

Microstrip antenna consists of a thin metallic radiating patch having fractional wavelength above a conducting ground plane on a low loss substrate. The ground plane and radiating patch is normally separated by a low loss dielectric. The substrates are usually nonmagnetic and have relative permittivity between 1 and 10 which enhances the fringing fields responsible for radiation pattern. But higher values substrate can be used in special circumstances. Whereas the patch conductor is normally copper and can be have any shape but simple geometries are used generally because of analysis and manufacturing simplification [4].

Microstrip antenna can be further divided into 3 categories: microstrip patch antenna (MPA), microstrip slot antenna (MSA) and microstrip travelling wave antenna.

2.1.1.1 Microstrip patch antenna

MPA (microstrip patch antenna) is a conducting component of any planer geometry which is photo-etched on one side of the board as well as backed conducting ground plane. It is fed by mostly coaxial connector which is soldered to the feed line. Circular disc, rectangular, square, triangle pentagon and ellipse are various shape of microstrip patch antenna made till now [5].

2.1.1.2 Microstrip slot antenna

MSA (microstrip slot antenna) involves various shape or multiple lengths slot in the ground plane [6].

2.1.1.3 Microstrip travelling wave antennas

Microstrip travelling wave antenna consists of chain shape periodic conductors or an ordinary TEM line which also supports a TE mode, on one side of the substrate while ground plane is on back side. Leaky wave antenna is its special form in which wave propagates through interior to a guiding structure rather than exterior [7]. The guided wave energy sets up a leaky wave exterior in the guiding structure and leaks away power in a controlled way as the mood propagates from the feed to termination. This antenna supports travelling waves; their structure design contains the main beam lies in any direction from broadside to corner fire (end points).

2.2 Dielectric resonator antenna

Materials with high losses and high dielectric permittivity can be used as originating electromagnetic energy and is known as dielectric resonator antenna. The radiating mechanism inside this antenna is due to displacement current circulating in the dielectric medium. DRA (dielectric resonator antenna) does not suffer from conduction losses and is characterized by high radiation efficiency with proper excitation. This antenna relies on a radiation resonator that can convert guided waves into unguided waves (radio frequency signal). In the past, these antennas were mainly realized by using ceramic materials with high dielectric permittivity along with a high Q factor (from 20 to 2000). At present, DRA is made of plastic material (Poly vinyl chloride PVC) [8].

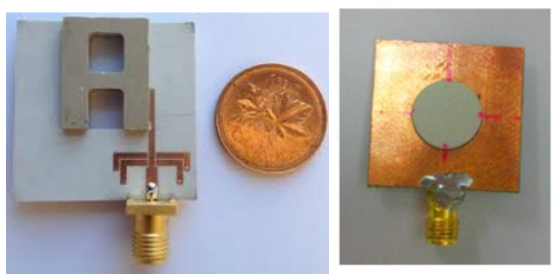


Figure 2.2: Bands notch and single feed aperture-coupled dielectric resonator antenna [9, 10]

2.3 Planer inverted cone antenna

PICA (planer inverted cone antenna) is fixed on a large ground plane and is similar to wide monopole disk antennas. The radiating part was carefully modeled to obtain higher modes. It is composed of a single flat element vertically mounted above a ground plane. The geometry of antenna is very simple and provides outstanding impedance and radiation pattern performance [11]. It is not the most suitable for portable communication systems.

Figure 2.3: Inverted biconical antenna prototype [12]

2.4 Fractal antenna

Fractal is known as fractious in latin language to mean broken or fractured geometry. Iterated function systems (IFS) represent a versatile technique for appropriately producing an extensive range of useful fractal structures. Fractal is basically rough or fragmented geometric shape that can be splitted into many subparts, each of which should be (at least approx.) a reduced-size replica of the complete structure [13]. The self-similarity and space filling property in fractal can achieve multiband and miniaturization characteristics in antennas.

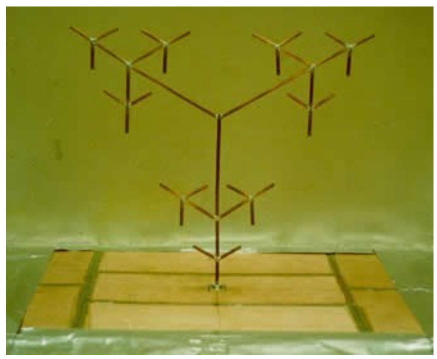


Figure 2.4: Fractal technology based antenna [14]

2.5 Advantages and disadvantages of printed antenna

Printed antennas for wireless communication provide a practical guide to the most advanced technologies used in wireless systems. Communications projects involves low gain patches for propagation studies at 2.5 and 5.8 GHz and medium gain arrays for communications links using radar transponders at 9.4 GHz (link to X-band antenna). Therefore; it turns to the practice of design engineers, graduate students and researchers in the field of telecommunications technology in commercial and governmental / military organizations [15].

Printed antennas are inexpensive and easy to fabricate by using modern printed circuit board (PCB) technology. It can enjoy almost all advantages of PCB with all of the matching networks, power dividers , phasing circuits and efficient radiator.

Some prominent advantages of the printed antennas are listed below:

- Light weight , compact in size and low profile
- Ease in fabrication and low manufacturing cost
- Simple feeding technique

- Easy to obtain dual frequency position
- Feed line and matching networks can be fabricated all together with antenna geometry
- Compatible with modular designs (solid state devices such as variable attenuators, amplifiers, switches, oscillators , mixers, phase and shifters, etc. can be added directly to the substrate board of antenna)

The main disadvantages of printed antenna include potentially low radiation efficiency compared with different technique antennas (although this depends expressively on the substrate material and thickness) and small bandwidth. Some of the disadvantages are:

- Poor isolation between feed line and radiating elements
- Limited efficiency by conductor and dielectric losses
- Low bandwidth

2.6 3-D printed antenna technology

3-D printing offers many advantages over traditional manufacturing techniques because 3-D printer has capabilities to deliver complex design very quickly with high accuracy from functional materials and almost zero labor cost [16]. It provides significant flexibility in the designs that combine the assembly of metal layers and dielectric material properties to achieve required performance characteristics such as radiation pattern and maximum gain.

Figure 2.5: 3 D printing utilization in antenna design systems [17, 18]

3 IMPORTANT PARAMETERS

3.1 VSWR

Voltage standing wave ratio (VSWR) is also known as standing wave ratio (SWR), which describes the ration between the maximum voltage and minimum voltage along transmission line.

$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|}. \tag{3.1}$$

where $|\Gamma|$ is return loss. This means that all power is transmitted to the antenna, and there is no reflection. For functional antenna VSWR value need to be between ≤ 2 when there is no Rf (radio frequency) signal sent to the antenna there will be no standing wave (SW) on the transmission line and VSWR has a value of one. However if there is mismatch between antenna and transmission line, the some fraction of the Rf signal sent to antenna is reflected back along the transmission line. In this case the VSWR value is less than one. It is easily measureable and value of 1.5 is considered excellent , while between 1.5 to 2 is also considered good but value above than 2 is unacceptable because of reasonable alignment mismatch.

3.2 Reflection coefficients (S_{11})

It is a logarithmic ratio measured in dB associates the power reflected by the antenna to the power fed into antenna from the transmission line. In other way, the reflection coefficient / return loss (S_{11}) is expression of mismatch, the impedance of the antenna must be matched with the transmission impedance for maximum power transfer.

$$S_{11}\ (\mathrm{dB}) = 10\log_{10}\frac{P_i}{P_r}. \tag{3.2}$$

$$S_{11}\ (\mathrm{dB}) = 20\log_{10}\frac{\mathrm{SWR}}{\mathrm{SWR}-1}. \tag{3.3}$$

The relationship between SWR and reflection coefficients is given by (3.3).

3.3 Bandwidth

The antenna bandwidth is referred as the range of frequencies for which the antenna can operate properly. It is the number of Hz / GHz / MHz for which the antenna can exhibit VSWR less than 2:1. Furthermore it can be defined in terms of percentage of radiation pattern.

$$\text{Bandwidth} = \frac{F_h - F_l}{F_c} \times 100 \,, \tag{3.4}$$

where F_h is the highest frequency in the band, F_l is the lowest frequency in the band while F_c is the central frequency in the band which can be measured as

$$F_c = \frac{F_h + F_l}{2} \,. \tag{3.5}$$

3.4 Gain

An antenna's gain is a key performance number. Basically it is the amount of energy radiated in the direction compared to the energy of an isotropic antenna radiating in the same direction when driven by the same input power source. It is the measure of overall antenna efficiency. For example if some antenna is 100 % efficient it means the gain is equal to its directivity. Furthermore, the isotropic antenna is hypothetical. There are many other factors which can affect and reduce overall efficiency [19]. The maximum gain is in the direction where maximum power has been radiated. The gain of an antenna is expressed in decibels (dB). Realized gain is slightly different in that it is reduced by losses due to mismatch of antenna input impedance to specified impedance. Realized gain will always be less than gain.

$$\mathrm{G} = \mathrm{E}_{\mathrm{antenna}} . \mathrm{D}, \tag{3.6}$$

where E is antenna efficiency and D is directivity.

$$\mathrm{G}_{\mathrm{dBi}} = 10\log_{10}(\mathrm{G}) . \tag{3.7}$$

A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern.

3.5 Radiation pattern

It is graphical representation of signal radiated from the antenna or defines the variation of the power radiated as a function of direction away from antenna at constant distance. This pattern is reception pattern as well since it can also defines the antenna receiving properties. In actual it is 3 dimensional , but usually the measured radiation pattern are a 2 dimensional slice of 3 dimensional patterns in vertical and horizontal plane. Normally the pattern is represented in polar format. The radiation pattern in the close region of antenna is different from the pattern at large distance. The term near field is known as the region near to antenna and far field is termed as field pattern far from antenna [20]. The far field is also called radiation field. Generally radiation pattern behavior of antenna leads us to classify it in two different types (1) Directional antenna (2) Omni directional antenna

Directional antenna: A directional antenna is the one that radiates its all energy in one direction more efficiently than others. Typically, these antennas have one main lobe and several minor lobes.

Omni-directional: It is an antenna that has a circular pattern (non- directional pattern) in a given plane.

3.6 Group delay

It is defined as rate of change of the transmission phase angle with respect to the frequency. It is expressed in time unit (angle is in radians and frequency is in radians per seconds). When it is extracted from S_{11}, unless the network is a perfect measurement of a transmission line, there will be variation over frequency. But for small bandwidth, group delay is usually near constant. If group delay is variable the pulse waveform is spread out in the time domain. In the time domain, a transient analysis can be performed which leads to the group delay. A pulse is generated whose frequency spectrum covers the bandwidth of the antenna applied input and its radiated pulse is detected. Both the pulse and its phase response are recorded. The group delay is obtained from the phase variation derivative with respect to angular frequency [21]. It is a critical parameter in designing antenna as the shape of the transmitted electrical pulse must not distort during transmission. Indeed for good pulse transmission and for verification of the antenna effectiveness the group delay must be very small. Mostly group delay variation more than 1 ns in considered as the phases are not linear in the far field and chances of pulse distortion is very high.

3.7 Radiation efficiency

It is known as the ratio of the total power radiated from the antenna to the amount of power accepted by the antenna at its own input terminal. Normally it is expressed in percentage but some people prefer to express in dB for example, an efficiency of 0.1 is 10% or -10 dB.

$$\eta = \frac{P_r}{P_a} . \tag{3.8}$$

where η is power symbol, P_r is radiated power and P_a is the accepted power. A highly efficient antenna has most of the power existent at the input which is radiated away but for low efficiency antenna most portion of the power is absorbed as losses inside the antenna or reflected away because of the mismatch [22]. The total efficiency of an antenna is the radiation efficiency multiplied by the mismatch impedance loss of the antenna, when connected to transmission line. Radiation efficiency loss is mainly due to conduction losses, dielectric losses and impedance mismatch loss.

3.8 Bandwidth dimension ratio

Bandwidth dimension ratio (BDR) is the most formal method to confirm the antenna compactness which includes corresponding electrical dimensions. Every UWB antenna published in the antenna design field shows uniqueness in shape and diverse bandwidth characteristics corresponding to different low end frequencies. UWB antenna that holds a standard operating frequency range starting from 3.1 GHz , so most of the authors has referred this frequency as the corresponding electrical dimensions of their antenna. The authors [23] have defined this index term that will allow antenna engineers to identify if their planner antenna is very much compact in size and wide in bandwidth. Hence, to see both the compactness and bandwidth characteristics of a planar antenna BDR index term can be used. This index term indicates considerable operating bandwidth (%) can be provided per electrical area unit which is equivalent to

$$\mathrm{BDR} = \frac{(\mathrm{BW})\%}{\lambda_{\mathrm{length}} \times \lambda_{\mathrm{width}}} . \tag{3.9}$$

where λ_{length} and λ_{width} represents the electrical length and width of antenna's substrate material used.

3.9 Effective bandwidth per unit volume

Effective bandwidth of interest per unit volume (EBIV) is used to proof antenna performance by authors in [24]. A higher figure of merit of EBIV index is considered good for antenna size as well as impedance bandwidth.

$$\text{EBIV}=\frac{\text{Total Bandwidth (GHz)}}{\text{Volume of entire structure (cm}^3\text{)}} \text{ x (BW) \% x Mean efficiency \% .} \tag{3.10}$$

4 MINIATURIZATION TECHNIQUES

4.1 Defective ground structure

Defected ground structure or DGS is a technology where the ground plane metal is intentionally modified to enhance the performance. As its name specifies “defect” simply means a small cut put by antenna system designers in ground plane of antenna, which is typically considered to be an estimate of an infinite, faultlessly conduction sink. A part of higher frequencies is removed from the idealized behavior of perfect uniform ground. In conclusion, these perturbations of DGS alter the antenna performance.

Microwave component with defected ground structure (DGS) has gained popularity among all the previous techniques due to its simple design structure and shapes. Etched slots, stubs or defects (of any shape) on the ground plane of microstrip circuits are referred to as defected ground structure. Number of defects on the ground plane can also be considered in same category. Initially, DGS was reported for filtering purpose beneath the microstrip line. It can be used beneath the microstrip line to attain band-stop characteristics by suppressing higher mode harmonics and mutual coupling. Because of successful implementation in the field of filters, these days DGS is in demand for countless communication systems applications. The basic working principles and equivalent models of different shapes defective ground structures are presented in [25]. As mentioned earlier the field of microstrip antennas for the purpose of enhancing the bandwidth, gain, mutual coupling between adjacent element and cross-polarization for improving the radiation characteristics DGS technique is recommended. Applications of this technique in term of microwave technology are focused in this paper [26] precisely in the field of antennas. The main advantages of DGS are that it introduces slow wave effect. This effect is mainly due to the defective ground structure’s equivalent L (inductor) and C (capacitor) components. The transmission line with DGS gives higher effective impedance and also introduces maximum slow wave effect, which can be applicable for rejection band in some frequency range. The DGS etched microstrip line contains large electrical length parameter as compared to conventional microstrip of the same physical length geometry. Thus, DGS helped us to lower resonance frequency as well as reduced the size of an antenna [27].

4.2 Modified feed line

Microstrip printed antennas are commonly feed by four different methods: co-planar feed, coaxial probe, microstrip line feed connected the patch edge (inset-fed), coupled microstrip patch through electromagnetic method. The transmission line characteristics impedance Z_o by using a quarter wavelength transmission line of characteristics impedance Z_1 and Z_A is shown

$$Z_{in} = Z_o = \frac{Z_1^2}{Z_A} . \tag{4.1}$$

By this relations Input impedance to the transmission line and antenna impedance can be calculated.

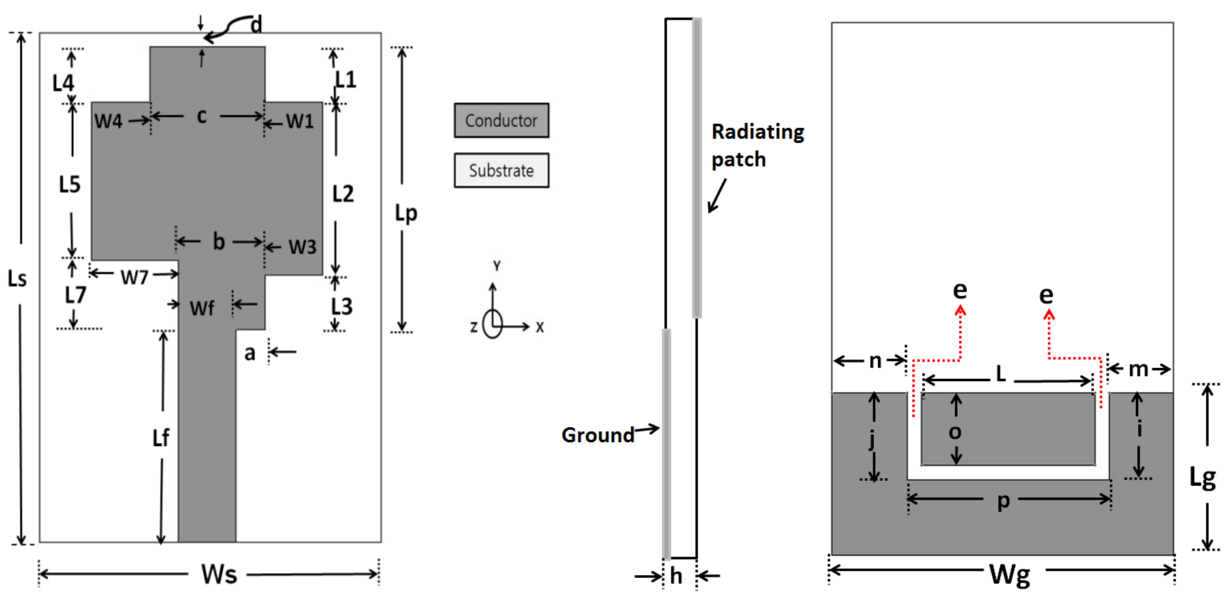
The basic configuration of the coaxial feed involves a central conductor of the coaxial cable connected to the radiating patch whereas the ground plane is connected to the outer conductor. Normally this type of fed has low bandwidth however for high bandwidth applications thick substrate with longer probe can be used. The simple excitation technique is microstrip line feed. This method involves direct connecting strip to the edge of a patch is highly convenient. However, the spurious radiation from the feed often creates problem. Electromagnetic proximity coupling consists of radiating patch etched on another substrate placed above the open ended feed line. Aperture coupling feeding involves microstrip line coupling through an aperture slot in the ground plane. The ground plane is placed between the patch, feed line and coupling between the two is provided by slot in the ground plane. The feeding arrangements primarily control the impedance matching and current distribution of the antenna. It can be explained as the incorporation of a symmetrical feed branch to a planar metal plate monopole antenna which can reinforce the vertical mode characteristics excitation and efficiently promote vertical current components on the radiating patch.

5 PROPOSED ANTENNA, SIMULATIONS AND RESULTS

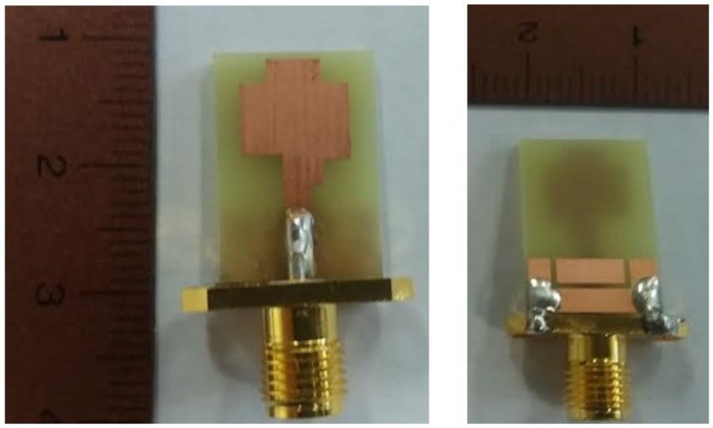
5.1 Patch antenna using U-slot in ground plane

5.1.1 Design specifications

The proposed small antenna fed by a microstrip line is shown in Figure 5.1(a), which is printed on an FR4 substrate of thickness of 1.6 mm , relative permittivity ε_r of 4.4 and loss tangent of 0.018. The basic patch antenna consists of a rectangular patch, feed line and ground plane. The rectangular radiation patch has width W_P (W1+ c +W4). The patch is connected to a feed line of width Wf , length Lf and Lg. The width of the microstrip feed line is fixed at 1.9 mm as shown in Figure 5.1(a). The corners of the rectangular radiating patch are truncated with three symmetrical lengths of L1, L3, L4 and one with variable length of L7. The length of the patch is Lp (L1+L2+L3) .On the other side of the substrate, a conducting ground plane with inside U-slot is placed as shown in Figure 5.1 (b). The prototype of proposed antenna is connected to 50 Ω SMA connector for the purpose of signal transmission is shown in Figure 5.1 (c).



(a) (b)



(c)

Figure 5.1: Proposed (a) Front view (b) Bottom view (c) Prototype of antenna

Table 5.1: Geometrical parameters of proposed antenna

Lengths	**Dimensions (mm)**	**Lengths**	**Dimensions (mm)**	**Lengths**	**Dimensions (mm)**
Ls	18	Ws	11.8	Lg	5.5
Wg	11.8	Lf	8	Lp	10
L1	2	L2	6	L3	2
L4	2	L5	5.5	L7	2.5
W1	2	W3	2	W4	2
W7	3	a	1.1	b	3
c	4	d	0.5	e	0.5
h	1.6	i	3	j	3
L	6	m	2.2	n	2.6
O	2.5	Wf	1.9	p	7

5.1.2 Design procedure

Designing of radiating patch elements include the estimation of its dimensions. The width of the patch Wp has small effect on resonance which can be obtained by using the mathematical modeling as shown below.

$$Wp = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}\,, \tag{5.1}$$

where c is the speed of light in free space and ε_r is the relative permittivity of the material used as substrate in the proposed antenna. The microstrip patch on top side of the substrate, therefore the electromagnetic wave has an effective permittivity (ε_{eff}) which is equal to

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w_p}\right]^{-\frac{1}{2}}\,. \tag{5.2}$$

The length of the radiating patch (Lp) also plays a crucial role in finding the resonant frequency and it is an important parameter to be considered while designing of patch antenna. The value of Lp can be determined by using the following formula:

$$Lp = L_{eff} - 2\Delta L\,, \tag{5.3}$$

where effective permittivity (ε_{eff}) of the substrate material can be determined by (5.2). Due to the fringing field effect the additional line length on ΔL both end of the patch length is given by

$$\Delta L = 0.412 \times h\,\frac{(\varepsilon_{eff} + 0.3)\times(\frac{wp}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)\times(\frac{wp}{h} + 0.813)}\,, \tag{5.4}$$

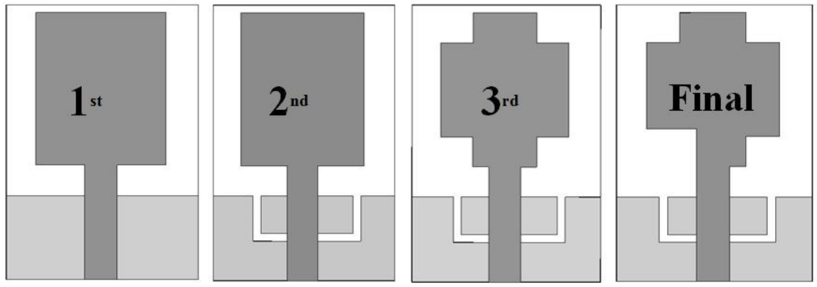
where effective patch length L_{eff} can be calculated by following formula

$$L_{eff} = \frac{C}{2f_r}\left[\frac{1}{\sqrt{\varepsilon_{eff}}}\right]\,, \tag{5.5}$$

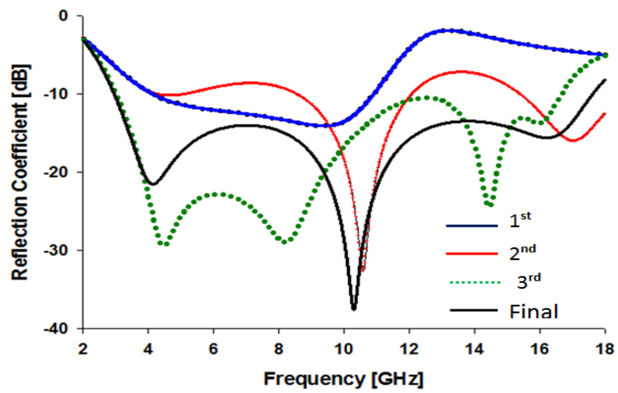
From (5.3) we can say that effective patch length is also equal to

$$L_{eff} = Lp + 2\Delta L\,. \tag{5.6}$$

Creating symmetrical and unsymmetrical slots in the main radiating plane and U- slot provides an additional current path. This changes the capacitance and inductance of the input impedance leads to bandwidth enhancement characteristics. The DGS applied to microstrip line causes resonant character in resonant frequency for the structure which can be controlled by varying the physical parameters of the slot and stub [28]. Therefore by inserting U-slot inside the ground plane and careful adjustment of parameters more enhanced impedance bandwidth can be attained. The important step in the design is to choose the lengths and position of the U-slot in the ground plane (which electromagnetically couples the whole ground plane) and placement of variable length slots in the radiating patch.



(a)

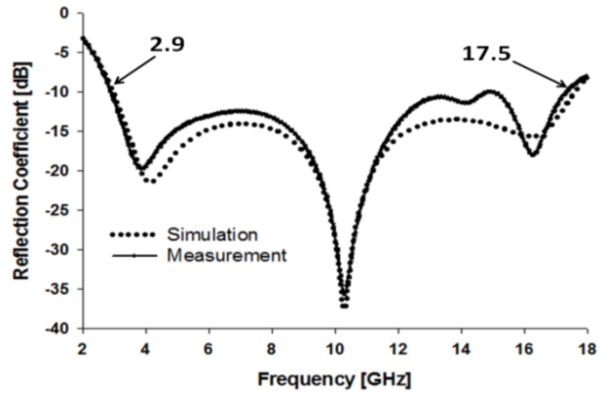


(b)

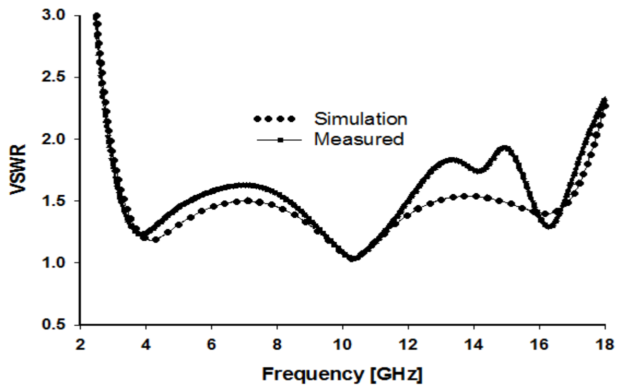
Figure 5.2: Simulated (a) Design iterations (b) Reflection coefficient

5.1.3 Simulated and experimental results

The measured and simulated reflection coefficient and VSWR (voltage to standing wave ratio) characteristics of the proposed antenna are shown in Figure 5.3 respectively. The fabricated antenna has frequency band of 2.9 GHz to over 17.5 GHz. A mismatch has been observed between the simulated and measured results of the proposed geometry because of two forms. First, pertaining to error during the manufacturing process. Second, to the loss between antenna and connector (SMA port). In physical network analyzer measurement, the feeding mechanism is composed of an SMA connector and microstrip feed line (microstrip feed line is excited by using SMA connector), while the simulated results are found by using HFSS*v*12. In software by default wave port is used for the antenna excitation, satisfying the full 50-Ω port impedance, therefore the discrepancy between simulated and measured results might be due to the effect of SMA port [29]. In order to avoid these mismatches for antenna designing it is recommended that manufacturing and measurement process need to perform very carefully. Hence, as the patch antenna has very small radiator so SMA connector can affects its impedance matching.



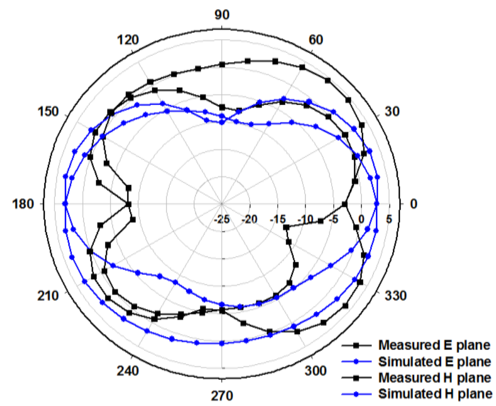
(a)



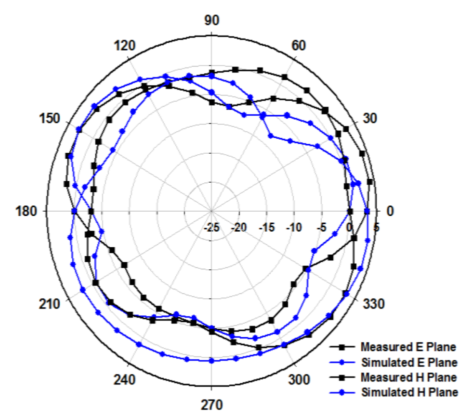
(b)

Figure 5.3: Measured and simulated results (a) Reflection coefficient (b) VSWR

Figure 5.4 presents the simulated and measured radiation pattern of the antenna in E-Plane or YZ-Plane (ϕ = 0°) and H-Plane or XZ-Plane (ϕ = 90°) at the resonance frequencies. The radiation patterns are measured by using far field anechoic chamber. It is seen that, the radiation pattern is omnidirectional in XZ-Plane, while monopole like pattern or somehow directional is observed in YZ-Plane. In Figure 5.4 (a) the YZ-Plane has two maxima directed along 60° and 270° respectively making a shape of "8". While the XZ-Plane has omni-directional characteristics. At 10.3 GHz two symmetrical dips are observed between 60° to 90° and 240° to 270° for YZ-Plane whereas the XZ-Plane behavior is same like before. The YZ-Plane radiation pattern at 16.8 has two shifted maxima's at 60° and 300° respectively, while XZ-Plane has some change in omni-directional pattern due to higher order mode radiation. In other words, radiation pattern is stable with some distortions at higher frequencies.



(a)



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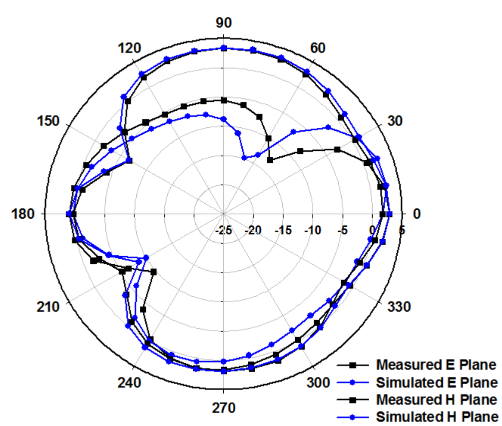


(c)

Figure 5.4: Measured radiation pattern at XZ-Plane , YZ-Plane of proposed antenna at (a) 4 GHz (b) 10.3 GHz (c) 16.8 GHz

The proposed antenna has a variable efficiency values in the whole radiating band, which is mainly due to the resonant properties. The measured results of peak gain and radiation efficiency is shown in Figure 5.5.It is observed that the proposed antenna features a good efficiency greater than 83 % to maximum value of 95 % across the entire radiating band, whereas the peak gain of the antenna varies from 2.5 to 5.48 dB.

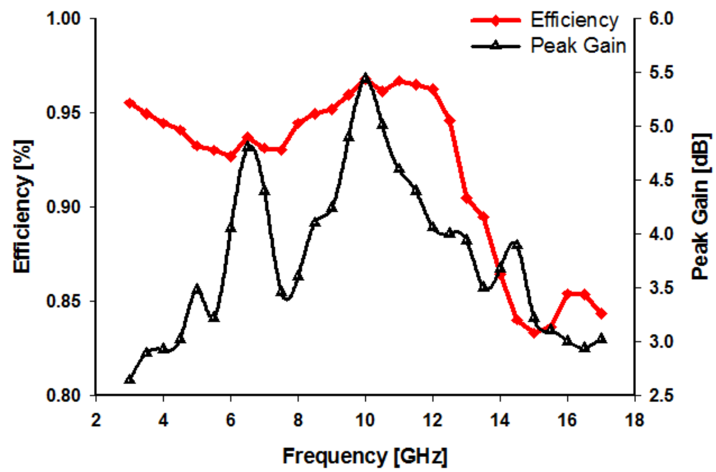


Figure 5.5: Measured peak gain and radiation efficiency of proposed antenna

Another critical parameter in designing antenna is group delay which represents the shape of the transmitted electrical pulse. It is the negative derivative of phase response with respect to frequency. For undistorted pulse transmission and to verify antenna effectiveness for time domain applications the group delay must be small and constant in entire covered bandwidth. Figure. 5.6 demonstrate the simulated group delay of the proposed antenna for 2.9 to 17.5 GHz. It is observed that group delay variation is less than 0.01 ns over entire bandwidth. The small variation signifies the good pulse transmission function characteristics of the proposed antenna to be used for wireless communication applications. Generally, if the group delay variation exceeds more than 1 ns, the phases are no longer linear in the far field region and there are more chances of existence of pulse distortion. This emphasize that the proposed antenna meets the group delay requirement.

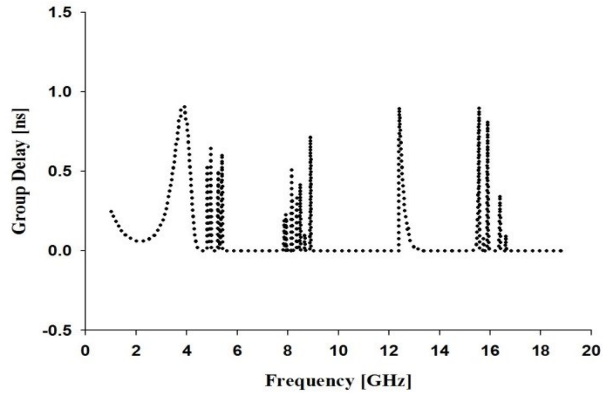


Figure 5.6: Simulated group delay vs. frequency of the proposed antenna

Table 5.2: Dimensions, bandwidths and EBIV comparison

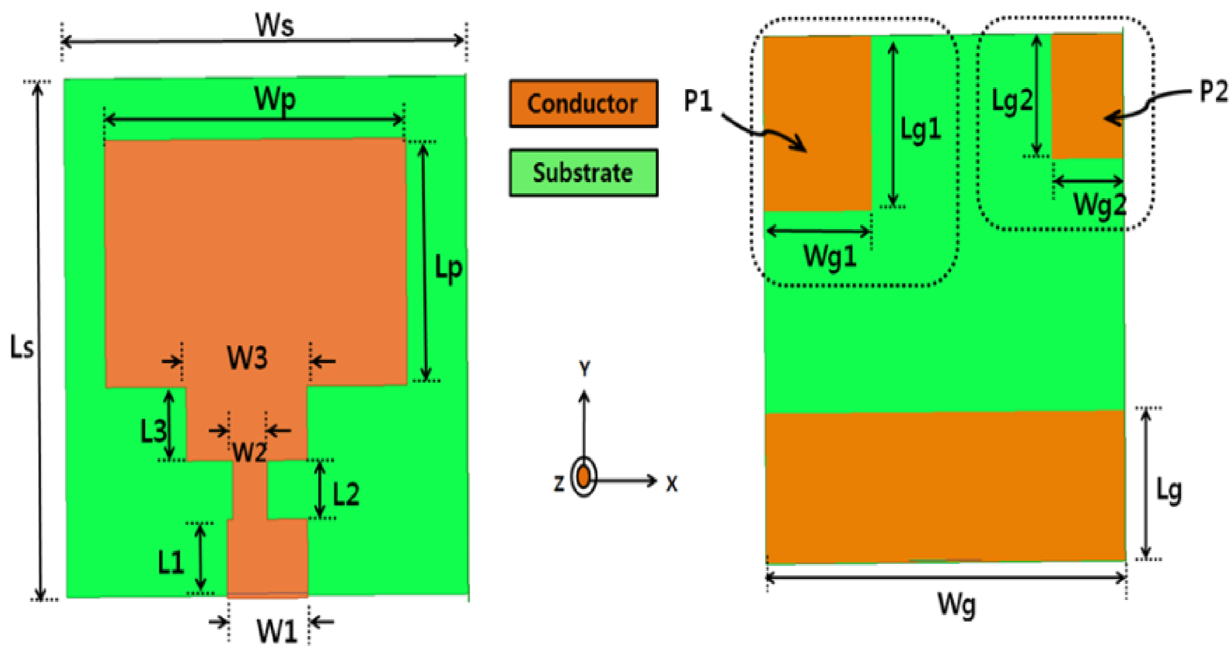
Antenna type	**Dimensions (mm)**	**Footprint (mm^2)**	**BW ($S_{11} \leq$ -10 dB)**	**BW Ratio**	**FBW (%)**	**EBIV**
[23]	40×25	1000	0.9 ~ 22.35	24.8 :1	184.5	24.75
[24]	28×29	812	5.73 ~ 10.8	1.88:1	61.3	2.40
[17]	16×20	320	4.9 ~ 22.1	4.51:1	127	32.85
[30]	52.25×42	2195	1.30 ~ 20	15.38:1	175.58	9.59
Proposed	18×11.8	212.4	2.9 ~ 17.5	6.03:1	143	58.71

Every UWB antenna published in the antenna design field has unique shape and their bandwidth characteristics below -10 dB return loss/reflection coefficient is diverse, corresponding to different low end frequencies. Calculation consideration is for comparison of compactness in the substrate relative permittivity which must be smaller. The volume occupied by the proposed antenna is 0.339 cm^3 when using the antenna dimensions stipulated in Figure 5.1. By adding the ideal case efficiency (100%) and the measured impedance bandwidth, the EBIV index is ~ 58.71. It is demonstrated that the proposed antenna provides compact size as well as simple design which radiates from 2.9 ~ 17.5 GHz, covering 14.6 GHz having fractional bandwidth of about 143 % , BWR 6.03:1and EBIV 58.71. Even though designs in reference [23] and [30] give higher bandwidth but the size of antenna is very large which are 2184 mm^2 and 1000 mm^2 respectively. This point emphasize that the proposed antenna can offer compact size, simple design and acceptable communication systems applications.

5.2 Monopole antenna with a modified feeding structure

5.2.1 Design specifications

The proposed antenna design is shown as Figure 5.7. The antenna is designed in XY-Plane with its normal direction parallel to Z axis. The top most layer consists of a feed line and radiating patch while bottom layer consist of a partial ground and unsymmetrical conductor backed plane slots (parasitic slot). Radiating patch consist of a rectangular patch as shown in Figure 5.7(a). Three different width microstrip lines are used to feed the radiating patch which also acts as impedance matching network to match the 50 Ω requirement. This feeding structure acts as impedance matching network and aides the wave spread from main radiating patch to space without bringing about noxious reflection. Figure 5.8 indicates the antenna prototype.



(a) **(b)**

Figure 5.7: Proposed antenna geometry (a) Top view (b) Bottom View

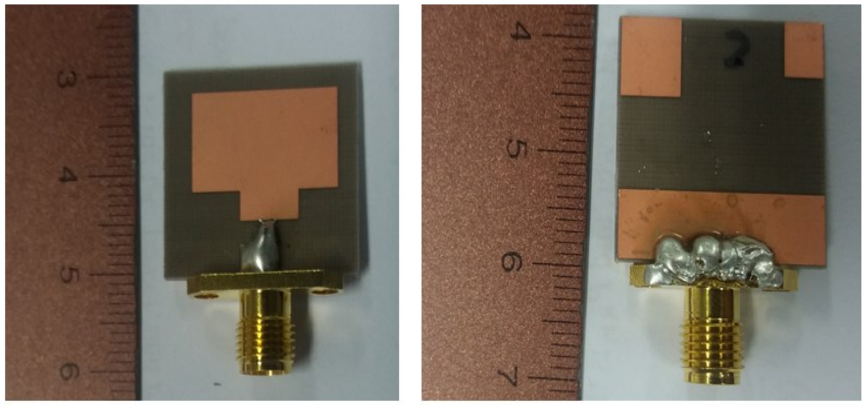


Figure 5.8: Antenna prototype front and back view

Table 5.3: Geometrical parameters of proposed monopole antenna

Parameters	Units (mm)	Parameters	Units (mm)
Ls	21	Ws	20
Lp	10	Wp	15
L1	3	W1	4
L2	2.5	W2	1.6
L3	3	W3	6
Lg	6	Wg	20
Lg1	7	Wg1	6
Lg2	5	Wg2	4

5.2.2 Design procedure

The details of the proposed parameters are shown in Table 5.3. The width of the radiating patch is calculated by

$$W_P = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \,. \tag{5.7}$$

Where f_r is resonant frequency of antenna which is chosen 7.9 GHz , ε_r = 2.2 (relative permittivity of substrate), $c = 3\mathrm{x}10^8$ m/sec (speed of light), the substrate uniform thickness is h = 1.2 mm respectively. The effective length of the patch is linked with the effective relative permittivity which is

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w_p}\right]^{-\frac{1}{2}}, \tag{5.8}$$

The normalized extension of the length of patch is calculated by

$$\Delta L = 0.41 \times h\frac{(\varepsilon_{eff}+0.3)\times(\frac{w_p}{h}+0.264)}{(\varepsilon_{eff}-0.258)\times(\frac{w_p}{h}+0.8)}, \tag{5.9}$$

Hence , the actual length of the patch is expressed as

$$L_p = L_{eff} - 2\Delta L . \qquad \therefore L_{eff} = \frac{C}{2f_r}\left[\frac{1}{\sqrt{\varepsilon_{eff}}}\right] \tag{5.10}$$

The relation between different widths of the feed line can be calculated by following equations

$$W1 = \frac{5}{2}(W2), \tag{5.11}$$

$$W3 = \frac{3}{2}(W1), \tag{5.12}$$

$$W_P = W1+W3+\Pi\times W2, \tag{5.13}$$

whereas

$$L_p = \sqrt{\frac{3}{2}}(L1+L2+L3). \tag{5.14}$$

The excited current distribution is indication in the square conductor backed plane. This can also be known as parasitic element because it provides additional current paths. Moreover, these structures can put significant changes in the capacitance as well as on the inductance of the input impedance. Based on electromagnetic coupling theory, by using pair of square backed plane above ground surface in air gap distance additional coupling is being introduced between ground plane and bottom edges of the radiating patch which in turn increased its impedance bandwidth without any cost of size or expense.

The three different lengths feeding structure acts as wide band impedance transformer and guides the wave propagation from radiating patch to space without any malicious reflection.

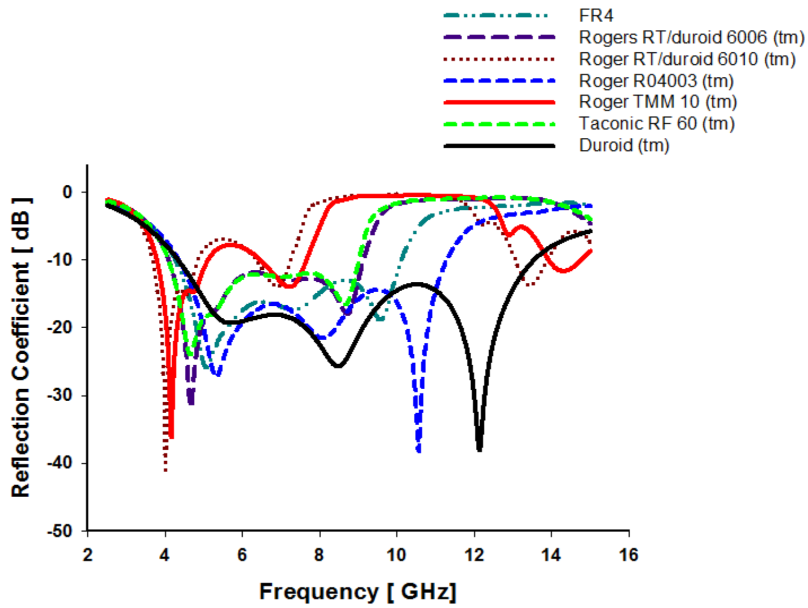


Figure 5.9: Substrate material effect on antenna reflection coefficient

The effect of substrate material on reflection coefficient is given while keeping all other antenna parameters same. In this simulation , FR4 (relative permittivity 4.4 , loss tangent 0.0013) , Roger 6006 (relative permittivity 6.15 , loss tangent 0.0019) , Roger 6010 (relative permittivity 10.2 , loss tangent 0.0023) , Roger R04003 (relative permittivity 3.55 , loss tangent 0.0027) , Roger TMM 10 (relative permittivity 9.2 , loss tangent 0.0022) , Taconic RF 60 (relative permittivity 6.15 , loss tangent 0.0028) and Duroid™ (relative permittivity 2.2 , loss tangent 0.0009) substrate have been considered. The first resonant at frequency 4 GHz is mostly prominent by antenna size and shape of patch and have less dependency on material of substrate. While higher resonant and frequencies are more dependent on material's relative permittivity. The material with highest relative permittivity is Roger 6010, which has extremely short bandwidth similar goes for Roger TMM 10 . This fact clarifies the bandwidth dependence on the substrate material chosen. Thus the maximum simulated reflection coefficient is obtained from Duroid™.

Figure 5.10 shows the simulated resistance and reactance behavior of the antenna as a frequency function. It is observed that the low S_{11} achieved from 4.3 to 13.4 GHz with input impedance is matched to 50 Ω. Which means the input resistance R is close to 50 ohms and reactance X is approximately zero and negative value producing proper impedance matching.

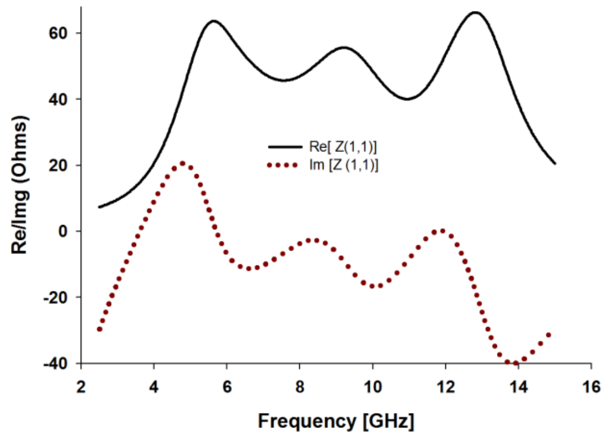


Figure 5.10: Simulated resistance and reactance of proposed antenna

5.2.3 Simulated and experimental results

The antenna parameters are optimized using the field solver software HFSS*v*12. The fabricated antenna is measured with Agilent N5230 network analyzer. Figure 5.11 shows the simulated and measured reflection coefficient (S_{11}) $\leq$ -10 dB. The measured result indicates that the antenna has achieved a wide bandwidth of 9.1 GHz ranging from 4.3 GHz to 13.4 GHz. Similarly, Figure 5.12 gives simulated and measured results at VSWR $\leq$ 2.

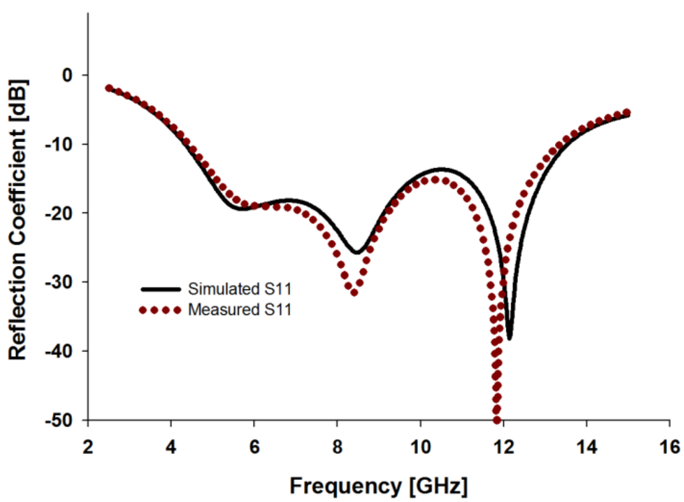


Figure 5.11: Measured and simulated reflection coefficient of the proposed antenna

A small mismatch has been observed between the simulated and measured results of the proposed antenna because of two reasons. First, pertaining to the error during the manufacturing process.

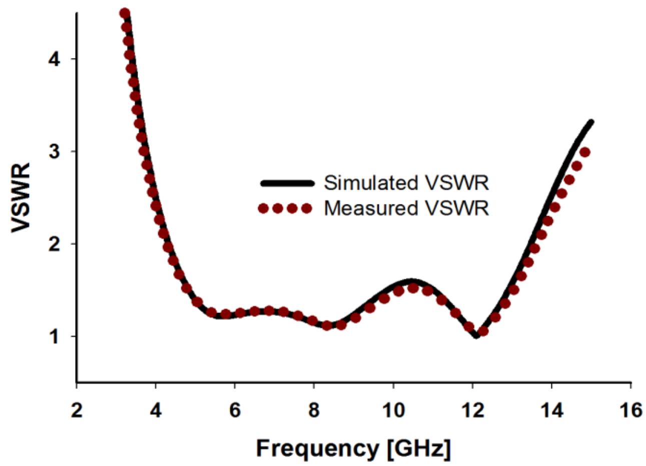


Figure 5.12: Measured and simulated VSWR of the proposed antenna

Second, the loss between antenna and SubMiniature version A (SMA) connector. Due to the fact that monopole antenna has steps in feed line and small radiator. Thus, SMA connector can affect its impedance matching. However, to avoid these mismatches it is recommended that manufacturing and measurement process need to perform very carefully. In Figure 5.13 the measured gain of the antenna varies from 0.68 dBi to 4.78 dBi for the frequency band of 4.3 to 13.4 GHz.

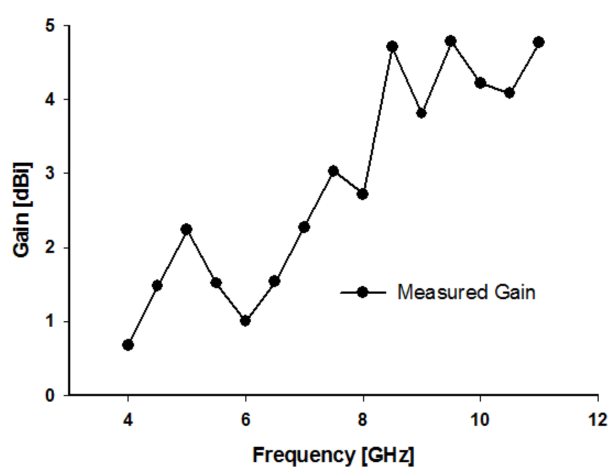


Figure 5.13: Measured gain of proposed antenna

The simulated AR (axial ratio) is been shown in Figure 5.14 along with numerical predictions. It can be seen that its simulated bandwidth is approximately 1 GHz (i.e. 11.5 GHz to 12.5 GHz).

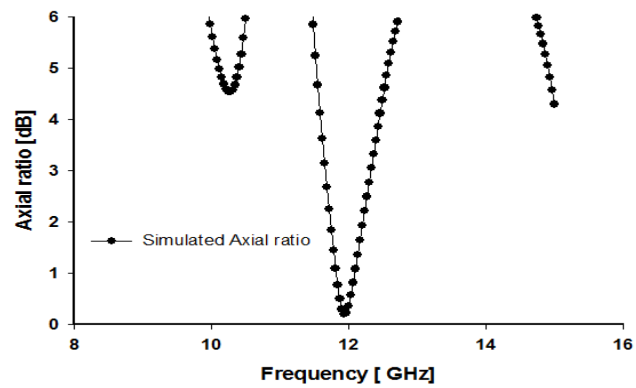
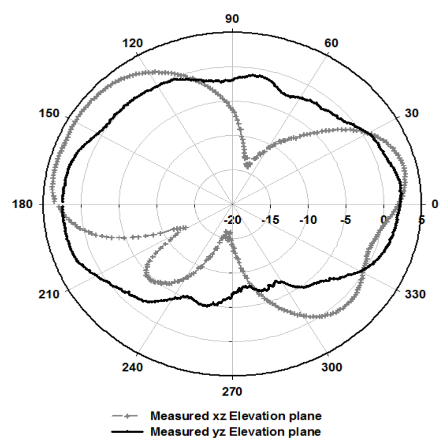
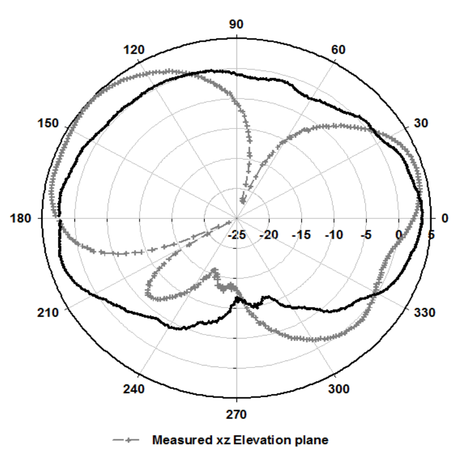


Figure 5.14: Simulated axial ratio of the proposed antenna

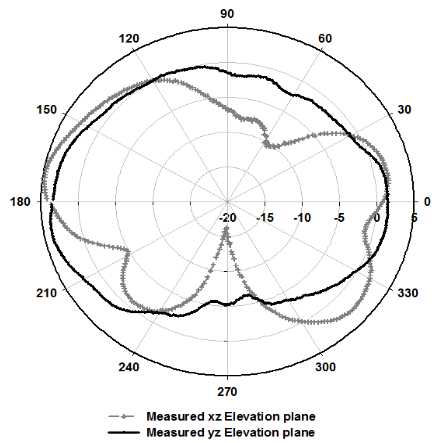
The RHCP and LHCP radiation pattern were measured in the Φ = 0 and 90 degree planes (antenna co-ordinates xz and yz respectively) at frequencies of 11.5 GHz , 12 GHz and 12.5 GHz.



(a)



(b)



(c)

Figure 5.15: Measured radiation pattern of proposed antenna (a) 11.5 GHz (b) 12 GHz (c) 12.5 GHz

Table 5.4: Fractional bandwidth and reflection coefficient comparison

Ref.	**Area (mm)**	**Footprint (mm^2)**	**S11≤ -10 dB (GHz)**	**BW Ratio**	**FBW (%)**	**EBIV**
[31]	35 × 25	875	3.1 ~16.3	5.25 : 1	136	34.85
[32]	39.1 × 34	1330	2.1 ~ 11	5.23 : 1	135	34.73
[33]	110 × 124	13640	1.02 ~ 24.1	23.6 : 1	180	20.75
Propose	21 × 20	420	4.3 ~ 13.4	3.11 : 1	103	21.95

In contrast with [31] and [33], the proposed antenna demonstrates better trade-off between size and bandwidth. Thus, the proposed antenna can offer compact size, simple design and acceptable wideband applications. The volume occupied by the proposed antenna is 0.504 cm^3 when using the antenna dimensions stipulated in Table 5.3. By adding the ideal case efficiency (100%) and the measured impedance bandwidth of 9.2 GHz, the EBIV index is ~ 21.95.

6 CONCLUSION & FUTURE WORK

6.1 Conclusion

The design of microstrip patch antenna modified by incorporating defective ground structure technique and number of symmetrical and unsymmetrical slots in radiating patch operating at 2.9 to 17.5 GHz is presented. The simulation process went through a series of iterations to obtain compact size high bandwidth antenna. Ground structure is modified by inserting some slots intentionally to make size reduction and easy fabrication and full fill the desired requirement. Eventually, it is verified that patch antenna with U-slot in ground plane can resonate at higher frequency with suitable impedance matching fulfilling the ultra wideband requirement.

Secondly, modified feed line technique along with backed copper conductor monopole antenna is also presented. Three different width microstrip lines are used to feed the radiating patch which also acts as impedance matching network to match the 50 Ω requirement. Bottom layer of the substrate consist of a partial ground and unsymmetrical conductor backed plane slots of width 1 mm.

The simulations of both proposed antennas are done in HFSS*v*12. The designed antennas have simulated reflection coefficient of -38 and -40 dB with good impedance matching in whole band of frequencies. Similarly, VSWR, radiation pattern, gain and group delays are also calculated through simulation and practical results. The substrate materials used in proposed models are FR4 and Duroid ™ respectively. The slight deviation has been observed between simulated and fabricated results because of the external environment and inaccuracies during the manufacturing process.

Taking all factors in consideration, it can be concluded that applying defective ground structure and variable length feed line techniques in patch antenna is a simple and effective methods to obtain UWB and wide band characteristics with minimal size. Furthermore, these antennas can be used on Novelda's Radar ICs (which is a low power and small size solution for impulse radar applications) to check its compatibility with indoor position location systems setup.

6.2 Future work

In future this research work can give in-depth knowledge of communication systems in which UWB location tracking technology by using antenna involves such as streamlining hospital process, strength management and tracking (finding accurate equipment and usage) safety (panic alarms containing position finding capability).High power spectral density or high signal power are basic key features through which it can easily penetrate through walls and hard surfaces transceivers, transmitters and receivers utilizing UWB technology, detection and location of objects with in structure and based on the physical parameters of material (building material analysis) is also possible. It also offers a solution that is efficient for every aspect of bandwidth, cost, size and power consumption.

The proposed design can be fabricated with other low relative permittivity material for higher gain value. It might also be helpful in array antenna structure or 3 dimensional antenna designs with higher bandwidth, moderate gain and circular polarization capabilities by applying above mentioned techniques. This antenna can be integrated with peripheral devices or elements for wireless communication device applications (such as mobile phones and laptops).

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CONTRIBUTIONS

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