Compact UWB Antenna Design

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Certificate

I, **Sukhdeep Kaur** hereby certify that the thesis entitled "**Compact UWB Antenna Design for Personal Area Network Wireless Applications**" which is being submitted by me to **Department of Electronics & Communication Engineering, Thapar University, Patiala** in fulfillment of the requirements for the award of degree of "Doctor of Philosophy" is a record of bonafide research work carried out under the guidance and supervision of **Prof. (Dr.) Rajesh Khanna**. The matter presented in this thesis does not incorporate without acknowledgment any material previously published or written by any other person except where due reference is made in the text.

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ABSTRACT

Now a days Wireless communications have been rising with an astounding rate. Device size is reducing day by day with the development of wireless systems. Recent wireless devices provide various Wireless Personal Area Network Applications (WPAN) such as home for entertainment purpose such as digital video disc(DVD), LCD High-Definition TV(HDTV)and , multimedia applications like video conferencing, and online gaming etc. WPAN give the freedom to interconnect various devices in a home or office without wires. Additionally fast data rate is the prime requirement for such type of devices. The high data rate can be obtained by enhancing the bandwidth. Ultra wideband Antenna is the most promising way to achieve large bandwidth due to very large frequency spectrum ranging from 3.1 GHz to 10.6 GHz .It is very challenging task to design a UWB antenna because it should be competent enough to provide the wide band according to Federal Communications Commission (FCC) norms.

This thesis work focus on compact size UWB antenna proposed to cover the wide band for WPAN applications. Analytical model is used to design the UWB antenna for target frequency without using mathematical values. After theoretically designing the proposed UWB antennas, they are analyses and simulated with the help of HFSS and CST software's. The wet etching and photolithography process is used for the fabrication of antenna and the results are measured using vector network analyzer (VNA). The different parameters of proposed antennas such as reflection coefficient, 2D and 3D radiation pattern and current distribution have been observed. Finally one of the proposed UWB antenna is also optimized using neural network.

In this thesis mainly three UWB antennas are discussed for various WPAN applications. The first type of compact UWB antenna with Hexagonal patch shape has been studied. In the second type a staircase patch antenna has been discussed. This antenna is modified using Defected ground structure. Flower type DGS is introduced to reduce the size of antenna as well as improve the impendence bandwidth. In the third design a rectangular shaped antenna with different step size is used to achieve wider bandwidth .This antenna is further optimized using artificial neural network (ANN).All the proposed antennas achieve UWB frequency range with compact size hence can be applicable for various WPAN applications.

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ACRONYMS AND ABBREVIATIONS

AMPS	Advanced Mobile Phone System
ANN	Artificial Neural Network
BBO	Biogeography Based Optimization
BW	Bandwidth
CAD	Computer Aided Design
CE	Communication Equipment
CMOS	Complementary Metal Oxide Semiconductor
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
DAA	Detect and Avoid
DC	Direct Current
DCS	Digital Communication Systems
DGS	Defected Ground Structure
DS-CDMA	Direct Sequence Code Divison Multiple Access
DS-UWB	Direct Sequence Ultra Wideband
DVD	Digital video Disc
EM	Electromagnetic
EPMSA	Elliptical Patch Micro-strip Antenna
ETRI	Electronics and Telecommunications Research Institute
EBG	Electro Magnetic bandgap
FBW	Fractional Bandwidth
FCC	Federal Communications Commission
FDM	Frequency Divison Multiplexing
FDTD	Frequency Domain Time Domain
FFBP	Feed Forward Back Propagation
FIT	Finite Integration Technique
FR4	Flame Retardant 4
HDTV	High Defintion Television
HFSS	High Frequency Structural Simulator
GA	Genetic Algorithm

GHz	Giga Hertz
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineering
IFFT	Inverse Fast Fourier transform
IMT	International Mobile Telecommunication
IP	Internet Protocol
ISI	Intersymbol Interference
ISM	Industrial Scientific and Medicine
ITU	International Telecommunication Union
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LNA	Low Noise Amplifier
LTCC	Low Temperature Co-fired Ceramic
MAI	Multiple Access Interference
MB-OFDM	MultiBand Orthogonal Frequency Division
MAV	Micro Air Vehicles
MIC	Ministry of Internal Affairs & Communications
MLP	Multi Layer Perception
MPCS	Multi Protocol Communication Subsystem
MSA	Microstrip Antenna
MSE	Mean Squared Error
OFDM	Orthogonal Frequency Divison Multiplexing
PC	Personal Computer
PCB	Printed Circuit Board
PCN	Personal Communication Network
PDA	Personal Digital Assistant
PG	Processing Gain
PR	Photo Resist
PSD	Power Spectral Density
PSO	Particle Swarm Optimization
PVP	Personal Video Player

PVRs	Personal Video Recorders
QS	Quasi Network
RBF	Radial Basis function
RF	Radio Frequency
RL	Return Loss
RSA	Rectangular Shaped Antenna
RTLS	Real-Time Location System
SMINLP	Sequential Mixed Integer Non Linear Programming
SNLP	Sequential Non Linear Programming
SNR	Signal-to-Noise Ratio
STB	Set Top Box
TH-IR	Time Hopping Impulse Radio
USB	Universal Serial Bus
UWB	Ultra Wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
WBAN	Wireless Body Area Network
WPAN	Wireless personal area network
Wi-Fi	Wireless Fidelity
Wi -MAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WUSB	Wireless Universal Serial Bus

Chapter 1
Introduction to Ultra Wideband Systems

Wireless technology has become an essential part of life of each and every person all over the world.Wireless communication has influenced the globe in many significant ways. At each and every stage of life people need to communicate with each other hence the demand of wireless communication is increased.There are several examples available in literature which brief the importance of wireless communication. The power of instant communication over long distance has transformed society and made the world a smaller place for example, making a phone call from high speed train or using a tab in own vehicle..For such type of applications a stable wireless communication network is required to compete with engineering challenges. Wireless communication also captures the immense market share in the communication sector. Media and public seek attention to this area because of its popularity. It is one of the greatest achievement in the well-being of humanity [1]. In this the information is transmitted through wireless signals without the use of cables, conductors or any other transmission lines. Wireless signals could propagate from a few meters (for example, DVD's remote control system) to several thousand of kilometers (for example, mobile communication). The examples of wireless communication devices consist of mobiles, GPS units, tablets, computer and satellite television. Furthermore,attention has been rewarded into wireless personal area network (WPAN) technology due to its continous link between wireless transportable devices for example PDAs (personal digital assistants), cellular phones, digicams (digital camera) and other end user electronics in homes and offices. A wideband is required for such type of multimedia applications which, otherwise, is not possible with conservative wireless technologies having fixed operating frequencies and bandwidth [2]. So, to achieve high speed, large signal power is required. Now a days, every portable device is battery operated and merely increasing signal power is not an optimum solution.

In this era of technology the prime objective is derived by need of small, high speed devices and higher data rates. There is a requirement of supporting more users in a wireless system and to transmit data with high speed. To meet the demand of higher data rates, ultra wide band (UWB) technology is used. For designing ultra wideband system, the operating frequency band has also to be shifted to higher frequency range. The dimensions of the component, inthe device are inversely proportional to the frequency, i.e. higher the frequency, smaller the size. Thus the miniaturization of devices is well supported by the shift in the operating frequency band of wireless technology to higher range [3].The larger bandwidth of ultra wideband technology meets the objective of higher data rates for various wireless applications.

1.1 UWB Definition

The Federal Communication Commission (FCC) in February 2002 allocated 3.1 - 10.6 GHz of the frequency spectrum for commercial UWB communications and applications [4]. Also, rulings of FCC define the UWB signal as a signal whose fractional bandwidth(B_f) is above 500 MHz (25%) and is defined as

$$B_f = 2\frac{f_H - f_L}{f_H + f_L} \qquad \text{...........(1.1)}$$

wheref_L and f_H are considered as lower and higher cut off (-10dB) frequencies, respectively. The centre frequency f_c is defined as the average of these cut off points.In another way UWB is defined as radio technology used for transmitting large amount of data over a wide frequency band over short distance by using very less power.Fig. 1.1 shows the fractional bandwidth a UWB system.

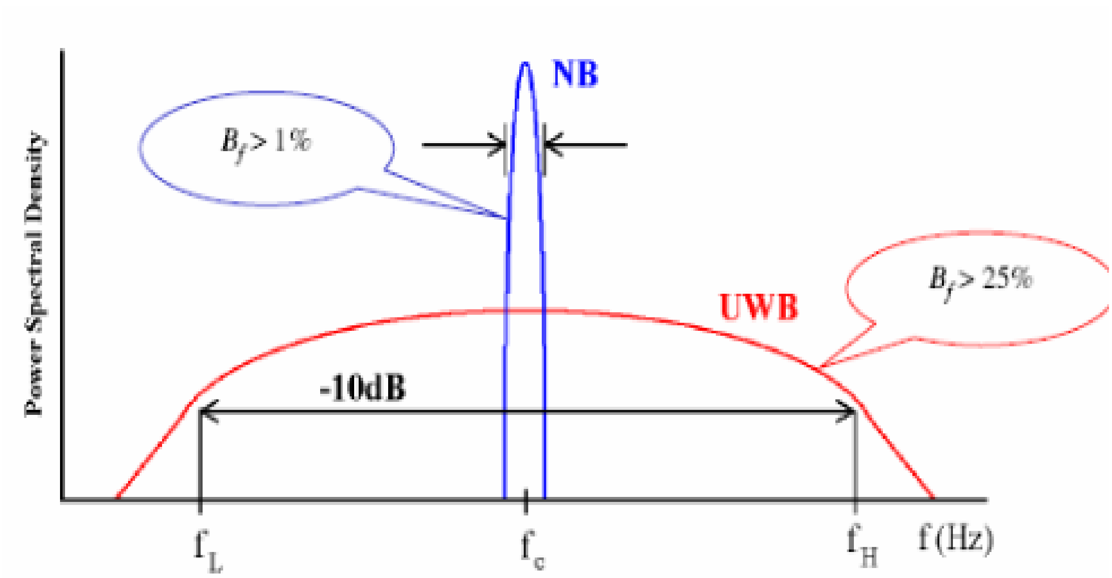


Fig.1.1: Spectrum of a UWB system[5]

1.2 History of UWB

UWB technology has become an emerging technology since the year 2000. Its popularity can be guessed by tagline ‘one of ten technologies that will change your world’. In late 1800s, spark generator generates a short pulse that was used as a electromagnetic signal [5]. Also, transfer of electromagnetic radiation from one place to another started with the evolution of UWB. The transmission using pulse radio dates back to late 1800's, when a pulse-based spark-gap radio system was developed by Marconi. This radio system induced pulsed signals which had very wide bandwidth. Further, the theoretical research of UWB systems started more than a century ago. Sommerfold, a theoretician, invented the diffraction of a short pulse by half plane that is considered as a more fundamental problem of UWB whereas the researchers' interest shifted to narrowband technology in 1910. The reason of shifting is that the signals generated by spark gap transmitters had low spectral efficiency, low bit rate and large bandwidth. On the other side, frequency division multiplexing (FDM) is used in narrowband communications in which number of signals can be sent using small bandwidth. Further UWB technology was revived in 1960 for military and radar applications where spectralefficiency is not much considered. However, spatial resolution is of more concern. A generator having short pulses and high power was invented by USA and Soviet Union for military applications [2,6].

In 1970, UWB again attracted the interest of researchers. This time it was known as carrier free communication. Three years later in 1973, it was found that short pulses having large spread spectrum were not influenced by existing interferers. However, the issue of multiple access interference (MAI) by unsynchornised users remained and was resolved by the insertion of Time hopping impulse radio(TH-IR) technique in 1990. In this technique, pseudo-random transmission times are assigned to the signals from a number of users and hence is able to carry a large no. of individuals [7, 8].

UWB cannot be commercially used in many countries because of the problems that were political in nature [4,8]. Throughout the world, narrow frequency bands were assigned to operators and particular services by the frequency regulators. UWB emits signals over a wide frequency band also including those bands which have already been assigned to other applications hence, violates the frequency assignments. FCC, frequency regulator in the USA, was convinced by the UWB proponents that the emission from UWB devices would not interfere with other devices. After solving all these problems of MAI, the FCC finally issued guidelines in 2002 [4]. According to these guidelines, the deliberate UWB emissions will be in the frequency band of 3.1 GHz-10.6 GHz with certain limitations imposed on the power spectrum. With a very short span of time more than 300 companies were working on this technology. A working group was established by the IEEE to standardize the physical layers based on UWB. They didn't use the impulse radio technology rather used the technologies like OFDM and DS-CDMA. Using the impulse radio technique, UWB can also be used to transmit data at low data rates [9].

1.3 Motivation

Ultra wideband (UWB), a leading candidate for short-range, wireless personal area networks, or WPANs, has been drawing substantial awareness and experiencing speedy growth worldwide. This technology helps people to share information, music, video and voice among networked consumer electronics, PCs and mobile devices throughout the home and even remotely without wires. This requires a data rate which is considerably greater than what has been attained in presently surviving wireless technologies [2,10]. The UWB technology has practiced several improvements in last few years. Still, there are many challenges that must be overcome. One major assignment is to design UWB antennas that can fulfill the necessities of this technology. UWB has a significant effect on antenna design. Extensive work has been has been done to improve the performance of UWB antenna since last decade and still work in progress [2,11]

UWB has engrossed a great interest in antenna design by giving novel research and prospects for antenna inventors. Many variations of UWB antennas have been proposed in past few years with nearly omni-directional radiation patterns [12]. UWB systems need an antenna that achieve UWB bandwidth and is proficient of getting on to related frequencies at the same time [2]. Therefore, UWB antenna. should be able to cover an ultra-wide range of operating frequency bands and its performance has to be reliable through the complete band.The firmest task in designing UWB antenna is achieving the wide-ranging impedance bandwidth while sustaining high radiation efficiency [2,12].

Further, the recent wireless communication systems, are required to built on small, low-profile integrated circuits in order to be well-matched with the portable electronic devices containing UWB based systems. Thus, size of the antenna for portable devices is one of the serious issue in UWB system design. Planar design helps in reducing the size of UWB antennas by substituting three-dimensional radiators with two-dimensional (2D) geometry. It also makes the farication of antenna easier by printing it on a PCB **[2,13]. Hence UWB** antenna must be compact and yet robust enough to be mounted in settings that range from satellites to the human body. Therefore, UWB antennas miniaturisation is a motivating research topic. In this thesis, three different designs are applied to reduce the size of UWB as well as to achive the enhanced impedance bandwidth in whole UWB band.

1.4 Frequency Regulation

Frequency range plays a major role while designing a UWB system. The transmit signal must have followed the frequency rule in which the device operates. There is great interference between the broadband and narrowband systems. To avoid this, UWB system are allowed by the FCC in 2002 for minimizing the interference by increasing the power over a wide bandwidth [4]. The environmental condition and application decides the frequency mask. A power spectral density of −41. 3 dBm/MHz between frequency 3.1 and 10.6 GHz is permissible for indoor communication. Similarly, outdoor communications are also following the same frequency range (i.e. 3.1–10.6 GHz) between mobile devices, but with different spurious emission mask as shown in Fig.1.2.

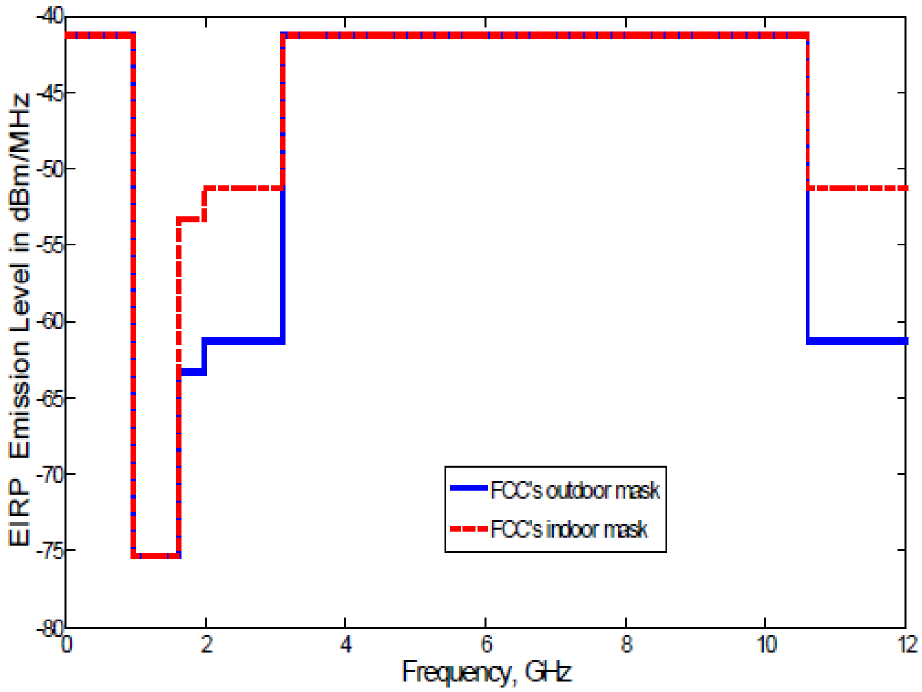


Fig.1.2: Indoor and outdoor emission masks of FCC's [14].

Frequency range of 3.1 GHz to 11 GHz, or less than 960 MHz is admissible for wall-imaging systems and ground-penetrating radar, however, the frequency ranges from 1.99–

10.6 GHz, and less than 960 MHz is allowed for through-wall and surveillance systems[16]. Apart from this various military applications also use the UWB systems in mentioned range. Vehicular radar systems use 24 to 29 GHz frequency band. Japanese and European drafted another rule in 2005 for UWB system as mentioned in Table 1.1. The frequency range between 3.1– 4.8 GHz and 6–10 GHz is admissible for lower and upper UWB band, respectively[14].

Table 1.1: Different values assigned to UWB band in different regions.

Region	Frequency range of UWB band
United States	3.1GHz to 10.6GHz for Single band
Europe	3.1 to 4.8GHz for Lower UWB band 6.0 GHz to 8.5GHz for Upper UWB band
JAPAN	3.4GHz to 4.8GHz for Lower UWB band 7.25GHz to 10.25GHz for Upper UWB band

1.5 Applications of Ultra-wide Band Antenna

Ultra wide band is an emerging technology which offers many advantages that can be used for a variety of applications. UWB is capable of high datarates, hence well suited for wireless personal area networks (WPAN)[16,17].

This technology has wide scope of WPAN applications.

- Substituting IEEE1394 cableand providing connection between CE devices likecamcorders, digital cameras, and portableMP3 players, with wireless connectivity.
- Providing wireless universal serial bus (WUSB) connectivity for PC peripherals, including scanners and other external storage devices.
- Substituting cables in Bluetooth Devices,IP-based CE/mobile devices and3G cell phones
- Providing high speed wireless connectivity for mobile applications, CE and PC devices

1.5.1 Wireless connectivity of peripheral devices

UWB technology is used for connecting various PC peripheral devices nowadays. Wired USB has a significant market segment share as the cable interconnect of choice for the PC platform. Bluetooth has solved the problem to some extent, but it was not that successful due to interoperability problems. The wireless USB has solved this problem and widely used in the market. This device provides a speed upto 480 Mbps, equivalent to wired USB 2.0 in 10 meters range. With the help of WUSB it is very easy to connect a mobile with portable media player or with a PC, LED and a laptop.

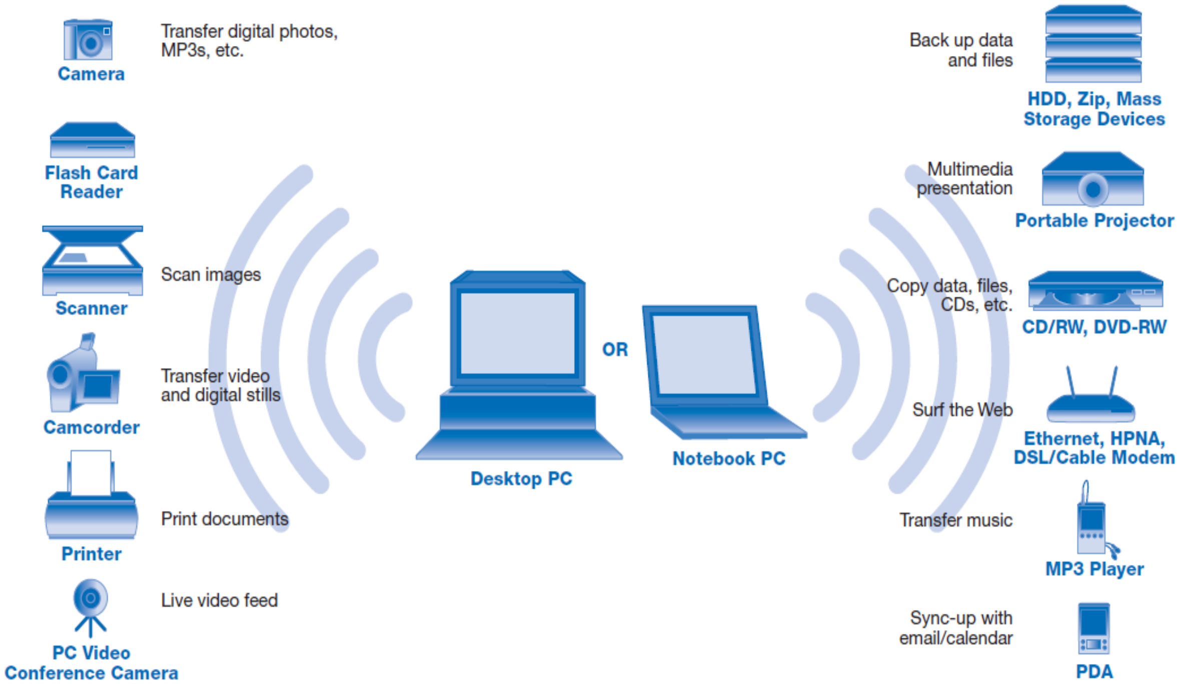


Fig1.3: Different cluster interconnected through USB [8].

1.5.2 Wireless multimedia Application

The ease of use is the key advantage of wireless multimedia applications. This type of devices have wide entertainment area that is, in HDTVs, personal video recorders (PVRs), stereos, STBs, digital video disc players (DVDs), digital camcorders, CE devices, MP3 players and many other communication devices used in daily life. For example, at home wall mounted plasma and HDTVs are connected without using the cables by using the USB technology. With a LED or plasma TV it is very easy to watch and listen movies and songs. By using a digicam or Laptop we can send images and multimedia messages or post pictures to our relatives from anywhere. This is known as the UWB Wireless local area network (WLAN) and wireless personal area network (WPAN) applications. Several WPANs within proximity of each other connected with UWB technology picked out each other and streaming get started when a user presses the play button [18].

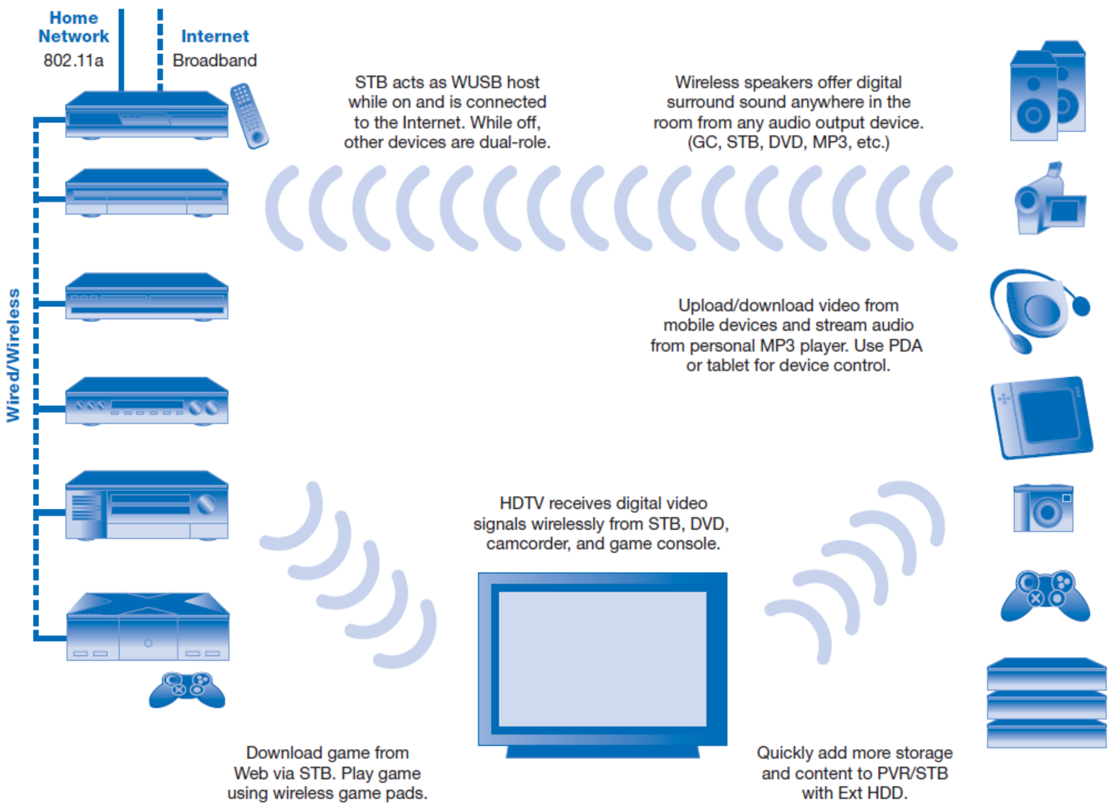


Fig 1.4: Various entertainment clusters [8].

1.5.3 Radar

Radars employ non-sinusoidal UWB systems with extremely short pulses of less than 1ns and having bandwidth in the range of GHz. For information spread over a large operating band width UWB refers to a transmission technology[8]. It is used for high data rate communication, high accuracy in radars and imaging systems such as, enhanced target recognition, higher range measurement accuracy and range resolution and detection of slowly moving targets and stationary targets. Also, UWB is an emerging technology for micro air vehicles (MAV) applications. As UWB systems can generate millions of pulses per second so they are able to penetrate through the variety of materials such as concrete blocks, building materials, wood and plastic [19].

1.5.4 Target Postion and Tracking

Target position and tracking have wide advantages in todays modern world. These include locating patient in case of critical condition, managing a variety of commodities in a big shopping mall, chasing cars and hikers injured in remote countries[8].In a precision time of flight measurement, UWB short pulse techniques are advantageous. Human space intervention is supported to identify the objects, persons and target task of the user. If we get the location of a person then we can estimate near to who and what this person is and can construct a hypothetical thought of user's target. In WBAN, human space intervention could make the life better. Patient's data are collected using a large number of smart sensors which is first forwarded to PDA then finally to remote server. In the event of critical condition such as arrhythmic disturbances, the correct identification of the patient's location could assist medical experts in the handling[8].

1.6Advantages of UWB communication

The UWB technology has various advantages over narrowband communications systems.

1.6.1 Sharing of frequency spectrum

The power requirement of indoor communication is 41.3dBm/MHz, as approved by the FCC (Federal Communications Commission). Due to this, UWB systems are put in the class of unintentional radiators like computer monitor and TVs. By imposing the power restriction on UWB systems, there is a possibility of coexistence of UWB signals with other RF signals with very small interference. Modulation technique used to transfer data is also a key factor in UWB systems. Some modulation techniques generate unwanted discrete spectral lines in power spectral density, which act as interference problems to UWB systems from other radio services [14].

1.6.2 Large channel capacity

UWB signals have very large bandwidth. The advantage of this large bandwidth is in the improvement of channel capacity. The Channel capacity of a system is defined as the maximum amount of data per second that can be handled by a communication channel. It also increases linearly with bandwidth B of the system. UWB systems generate the signals of several gigahertz resulting inimproved channel capacity. For UWB transmission, the FCC has imposed some limitations on current power so only for short distances, say for 10 meters, high data rate is available. So,UWB has a wide range of application forhigh data rate and wireless system applications, i.e. for wireless personal area networks (WPANs), UWB has proven to be the best option. The tradeoff between data rate and the range makes UWB best suited for a diversity of applications in medical, military and commercial sectors[6].

1.6.3 Low SNR requirement

According to Hartley-Shannon formula for maximum capacity, The channel capacity is a logarithmic function of SNR (signal-to-noise ratio) for maximum capacity according toShannon's formula. Therefore, UWB communications systems can workfor worst communication channels having low value ofS/N ratio. Due to its wide bandwidth it offers a large channel capacity[14].

1.6.4 Minimize complexity and cost

In UWB systems the signal transmitted is of baseband nature, hence they have a low price and complexity. The pulses generated by UWB transmitter are of very short time, hence additional RF mixing stage is not required for the propagation of these pulses because it is not easy to detect picosecond pulses without knowing their arrival time[19].

1.6.5 Low probability of intercept and detection

UWB technology is joined up with the lower average transmission power which makes UWB systems immune to detection and interception. To detect the transmitted data and information eavesdroppers needs to be in the range of about 1 meter or less of theUWB low power transmitter. Besides, each transmitter/receiver pair is designated with unique codes and UWB pulses are time modulated with these codes[6].In UWB communications, narrowband pulses are time modulated which provide extra protection to transmission.Therefore, UWB systems are highly secure and have a low probability of detection and interception. This makes UWB systems suitable for military applications [20].

1.6.6 Resistance to multipath fading and jamming

Narrowband frequency signals have very low bandwidth, unlike UWB signals. A wide range of frequencies from 3.1 to 10.6 GHz is covered by the UWB spectrum. UWB signals have a high processing gain and therefore it has resistance to multipath fading as well as jamming.The large bandwidth of UWB system offers frequency diversity, which along with discontinous transmission makes the UWB signal resistant to multipath propagation and jamming. In a narrowband system the signal strength fluctuates due to additional large number of mutlipath componets at receiver. While in UWB system all these components can be resolved easily due to large bandwidth [21].

1.7 UWB Antennas

Antennas are a really important component of the communication system. Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. Waveguide, transmission line) and the free space[9]. The antenna can also be thought of as an impedance transformer, coupling between the impedance of free space and line impedance. Due to thelarge bandwidth of UWB antenna the impedance transformation is the key area of interest.Initially from dipoles and then converting into the entire whole UWB band[10].

1.7.1 Requirements for a UWB Antenna

UWB antenna is necessary to radiate signals in UWB band. The requirements are explained as below:

1.7.1.1 Bandwidth and efficiency

In UWB, pulses of short duration, typically in picoseconds, are generated and as it is well known that the length of the pulse and bandwidth have an inverse relationto each other so, the spectra of these signals is very broad. Broadband antenna can be characterized as if an antenna having stable radiation pattern and impedance i.e. it will remain constant for at least one octave [8].As already mentioned that if a system's bandwidth is more than 500 MHz and a relative bandwidth of more than 20%,then it is known as UWB system.The spectral efficiency defines the quality of a system matching over the whole frequency range. The major advantage of UWB antenna is their higher efficiency over narrowband antenna.

1.7.1.2 Signal distortion and dispersion

The transmitted signal is deformed in UWB antenna. The antenna response to very short duration pulse is seen as a ripple in UWB and is known as ringing effect. This effect is associated with the dimensions of the antenna and is treated as a time delay or frequency dispersion, due to which transmission speed is reduced[5]. With the help of self-similar antennas, this effect are compensated. Furthermore, the planar monopole antennas and other UWB antennas have the same area of radiating element and constant phase at all frequencies, which is helpful in illuminating the ringing effect [21]

1.7.1.3 Stable transmission-reception transfer function

Antenna's matching, the gain and polarization should be static over the given frequency in the direction of the link, presuming that the conditions of the channel remain constant through the time. The antenna transfer function is another important factor with all these factors. It compares the transmitted pulse to the antenna and the radiated pulse by the antenna. By using these the spectra of radiated signals can be effectively shaped [21].

1.7.1.4 Constant transfer function

In this method UWB Pulses are selected directly from the source with the help of suitable circuit, so that the radiating systemmeets the requirement of the whole spectrum. For the smooth functioning of pulse the antenna transfer function should remain constant. Rayleigh pulses are wide

1.7.2 Different types of UWB antennas

The different types of UWB antennas are presented next. They can be classified as follows:

1.7.2.1 Cylindrical Monopole Antennas

The straight monopole antenna exhibits a very simple structure i.e directly wire adjacent to a ground plane, as shown in Fig. 1.5.

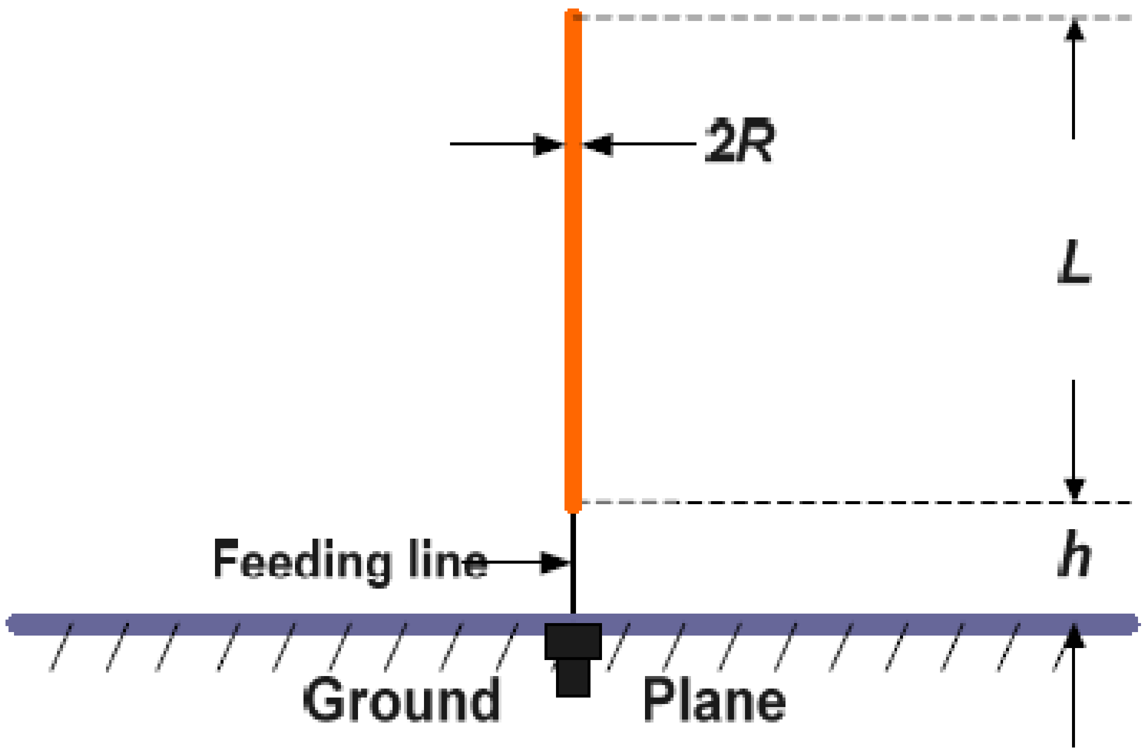


Fig 1.5: Straight wire monopole antenna [10].

This is one of the most commonnly used antennas in wireless devices.The main reason is its simplicity in designing and fabrication, omni-directional in nature, low price and easy impedence matching. However the bandwith of -10dB return loss is approximately 10% to 20% depending upon the ratio of radius to length. It is mentioned in the literature of monopole antenna that its bandwidth is directly proportional to ratio of radius to length of the monopole [10]. It is worthwhile to mention that a thicker/fatter structure will improve the bandwidth due to increase in current area and the radiation resistance. However variance or mismatch will occur if the radius is too large with respect to feeding line. So the bandwidth is not further enhanced in this case.Another way to improve bandwidth is to use more broader/flatter shapes [10].

1.7.2.2 Planar Monopole Antennas

The planar monopole antenna has more consideration in the latest UWB literature due to its simple design process. The fundamental plan is to build a"fat" structure, which reduces the Q due to which it is easy to tune the antenna at lower frequencies. For a broad response the shape of the patch near the feed becomes important such as circle, triangle, square etc. as shown in Fig. 1.6.

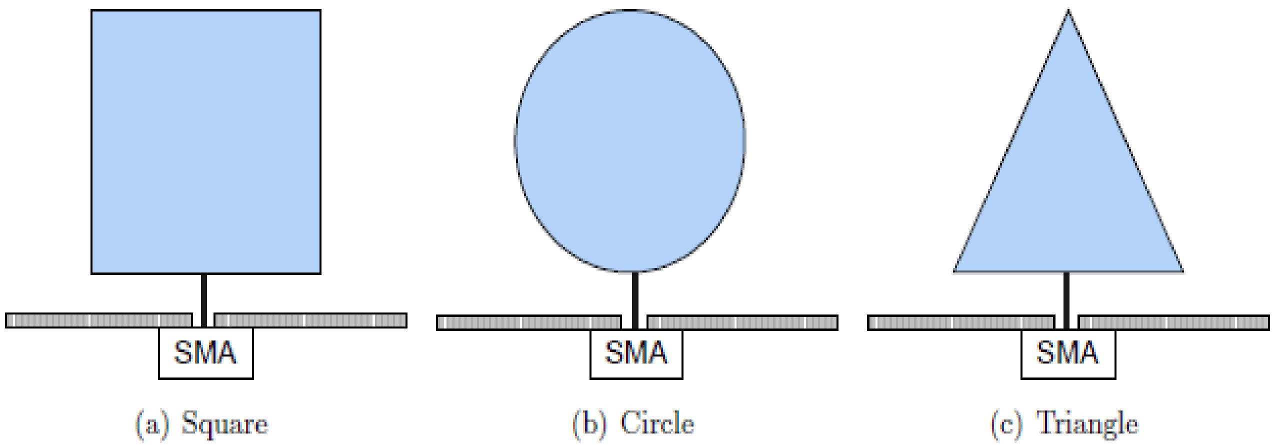


Fig. 1.6: Monopole antenna with broader structure.[10].

1.7.2.3 Planar Monopole Antennas with a Band-Notch Characteristic

UWB devices are compatible with present narrowband services in terms of frequency allocation.The IEEE 802.11 standard whose operating frequency lies between 5.15 - 5.825 GHz is one of the best example [10]. UWB signals having low –power spectral density as compared to the narrowband signal . So, in order to prevent interference band-stop filters are required.Due to this antennas are designed with a band-notch characteristic to reject the narrowband signal.Above mentioned planar monopoles can be customized by the accumulation of internal\external slot as shown in Fig.1.7 [10].

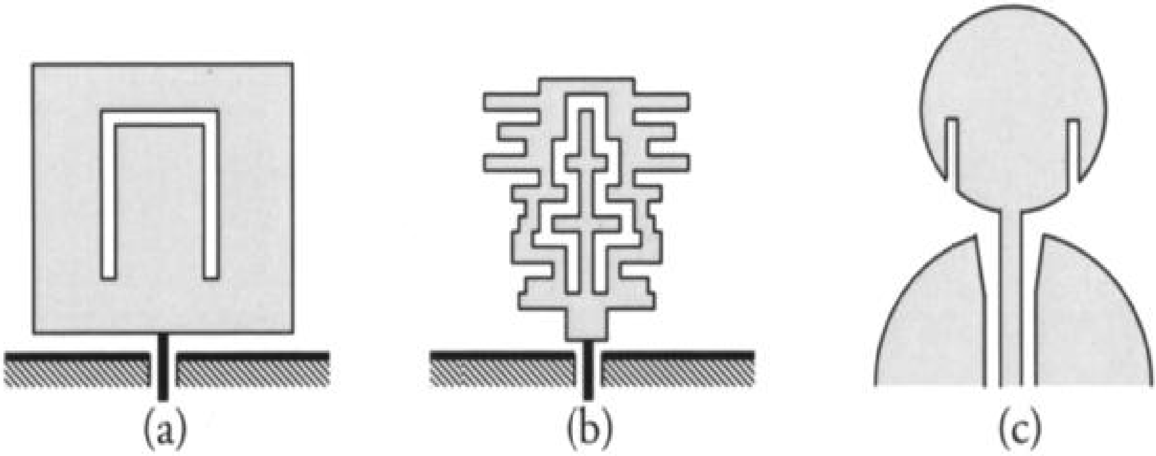


Fig. 1.7: Monopole antenna with band-notch characteristic[10].

1.7.2.4 Bowtie and Biconical Antennas

The bowtie and biconical antennas shown in Fig.1.8 are well known to demonstrate commendable broadband performance. Authors in [10] described that two octaves of impedance bandwidth are accessible with a biconical antenna. Impedance characteristics can be improved by tapering of the biconical antenna instead of linear dipole. That's why biconical dipole(in its canonical form) is a good example of UWB antenna.It also achieves the two octaves of impedance bandwidth and VSWR ratio 2:1 using a 60° cone[5],[10].The bowtie antenna is also a UWB antenna but its performance is some what less than the biconical antenna. The primary advantage of the bowtie antenna is its flatness due to which it can be used in a planar medium for example printed circuit. Such cost-savings frequently far outweigh any performance degradation for massed-produced applications.

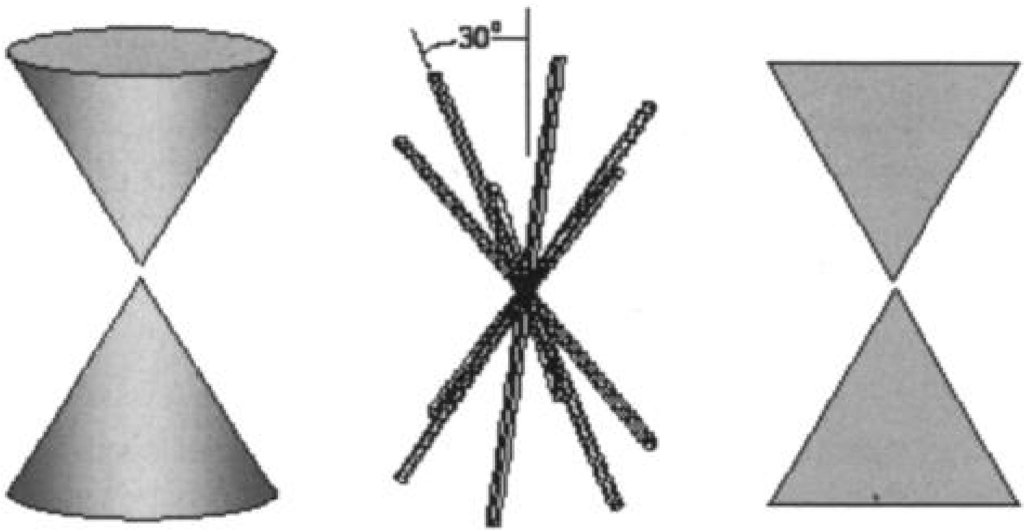


Fig 1.8: Bowtie and biconical antennas[10].

1.7.2.5 UWB antenna with defected ground structures

Compact size, high performance, and low cost are the necessities of modern communication systems. There have been many structures for example Substrate integrate wave-guide (SIW),Defected ground structures (DGS), Photonic band gap (PBG), etc.to improve quality of system[22]. PBG implodes and utilizes metallic ground plane and breaks conventional antenna or microwave circuit design to surface components. It is a cyclic structure which is used to provide rejection of certain frequency band. In the similar way, there is one more technique GPA (ground plane aperture) which basically incorporates the microstrip line with a centered slot at the ground plane.The GPA has striking applications for spurious band suppression in band pass filters and improved coupling It is complicated to use a PBG structure for the design of the antenna due to the difficulties of modeling. In addition, if GPA is introduced below the strip, characteristic impedance varies with the width of the GPA due to which line properties are changed drastically. So to improve over these problems DGS is introduced which provides more liberty in antenna/microwave circuit design and give a wide range of application. Many novel DGSs were proposed in the subsequent years and they had become main areas of research due to their extensive applicability in antenna and microwave circuits[22]. It (DGS) is an engraved periodic or non-periodic cascaded pattern defect in ground of a planar transmission line for example coplanar, microstrip and conductor backed coplanar wave guide which disturbs the shield current distribution in the ground plane.Transmission line characteristics such as line capacitance and inductance are changed due to this disturbance. In another way there will be rise in increasing effective capacitance and inductance due to defect in theground plane. A variety of DGS shapes such as spiral head, arrowhead-slot and "H" shape slots have been introduced as shown in Fig 1.9 (a),(b),and(c).Furthermore some composite DGSs also mentioned to improve the circuit performance for example a square open-loop with a slot in middle section, open-loop dumbbell and interdigital DGS (Fig1.9(d),(e),(f)).

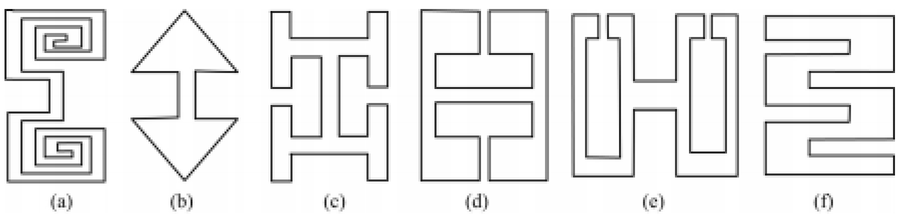


Fig 1.9: Shapes of defected ground structure [22]

DGS has many advatanges such as providing rejection of certain frequency band,suppress the unwanted surface waves, suppressing higher harmonic and achieving broader stopband response. Furthermore,most significant advantages of DGS is the slow-wave effect (caused by the equivalent LC components).Because impedance of transmission lines with DGS have higher values and hence improved slow-wave factor than conventional lines. This property helps in size reduction [22].

1.8 Objectives of the thesis

1. To propose a new design for UWB Antenna for Wireless Personal Area Network applications.
2. To evaluate the performance of proposed antenna in terms of impedance bandwidth, gain and return loss.
3. To study and analyze the effects of ground plane on the proposed antenna design.

1.9 Organization of Thesis

Based on the above proposed objectives, the prime focus of this thesis is the performance analysis of compact ultra wide band antenna design for wireless personal area network. First step is to design and simulate various UWB antennas for next generation wireless and mobile communication.. This is followed by fabrication and testing of proposed antennas The defected ground structure has been used to miniaturize the size of antenna.. The thesis has been organized into six chapters. The contents of each chapter are briefly described as under:-

The **first Chapter** 'Introduction' provides a brief description about the evolution and need of Ultrawideband Antenna. Under the heading,'origin and history of the Ultrawideband antennas (UWB)', the suitability of various microstrip antennas with different shapes and different structures have been studied Further, motivation of thesis, methodology adopted for the present work and thesis organization has also been briefly explained.

Chapter 2 covers a comprehensive literature survey which includes the effect of using different substrate, variation in ground structure as well as defected ground structure (DGS) to miniaturize the size of the antenna and effect of cutting a notch or strip from microstrip patch antenna to improve the electric field.

In chapter 3, the brief overview of the principles, pre-processing fabrication process and operation of various patch antenna has been given. The first objective of this research work, i.e. 'To propose a new design for UWB an Antenna for Wireless Personal Area Network applications' has been covered in this chapter. A Hexagonal shaped ultra-wideband (UWB) antenna for WPAN application with reduced ground plane size has been introduced.

The proposed antenna exhibit return loss below -10dB at different frequencies, i.e. VSWR<2 and efficiency is (ή) =89%. The gain of proposed antenna is around 5dBi with little variation at different frequencies. The experimental results show good agreement with theoretical results and demonstrate that the an omnidirectional antenna is simply obtained through the proposed methods.

Chapter 4 discusses the second objective of this dissertation, i.e. 'To evaluate the. Performance of proposed antenna based on impedance bandwidth, gain and return loss. To achieve this staircase shaped Ultra wide band antenna is designed. A new compact flowery defected ground structure and staircase patch have been introduced to increase the bandwidth of the antenna and to minimize its shape. To create a multi-band antenna, several notches are cut from patch (rectangular, circular, single and double stripe) acting as resonance paths, can be integrated with the antenna. The designed antenna dimensions are 30×30 mm^2 and covering the frequency bands 4.96-5.93GHz and 6.70-7.78GHz , 5.18-10.91GHz,3.19-4.60GHz and 4.66-10.02GHz band for various wireless applications.

Chapter 5 considers the various artificial neural network (ANN) based optimization methods related to optimize the return loss and antenna gain. There are many methods to train ANN, such as Quasi-Newton (QN), simulating annealing (SA) algorithm, particle swarm optimization (PSO) etc. This chapter deals with third objective to study and analyze the effects of ground plane on the proposed antenna design. A Neural Network model is used for the optimization of microstrip patch antenna for a desired frequency range. The results which are obtained from ANN when compared with experimental and simulated results are found to be satisfactory.

Finally the **Chapter 6** covers the summary of conclusions drawn in all the three objective areas. The new novel ultrawideband antennas with reduced ground size were fabricated and tested. From industrial application point of view, the proposed compact ultrawideband antenna covers present as well as future wireless and mobile communication bands. The experimental results obtained by proposed methods matched very well with simulated results.

1.10 Summary of the Chapter

This chapter comprises the scope of the presented research work. An introduction about the advancement and need of the UWB Antenna for Wireless Personal Area Network has been presented. This chapter also describes the history, frequency regulation,advantage and application of UWB antenna.Further designing of new improved UWB antennas with reduced ground size,with and without DGS and optimization techniques for antenna as well fabrication of proposed antennas are identified the major research objective of the thesis. In chapter-2, a comprehensive literature review about UWB antenna is given that has assisted the author throughout the investigations.

Chapter 2

Survey: Advancement in UWB antenna

In the modern era of wireless communication ultra-wideband (UWB) systems have been widely used for commercial applications and has resulted in increased interest of researchers in the field of ultra-wideband antennas. From decades UWB antenna are in commercial use. Even the venerable AM broad cast antenna is also UWB which covers a band from 535-1705 kHz for excess of 100% fractional band width [23]. UWB systems are non-sinusoidal system with extremely short pulses of less than 1ns and having bandwidth in the range of GHz [8].Thus in UWB systems the transmitted information is spread over a large operating band width. Hence UWB refers to a transmission technology used for high data rate communication, for high accuracy in radars and imaging systems. From decades UWB technology was developed and employed in military applications. Attention and efforts are paid on the use of UWB systems for commercial systems. On February 14, 2002, Federal Communications Commission (FCC) allowed the unlicensed use of UWB that met the emission mask [4]. Two types of UWB systems that are traditional pulse based system and carrier based system are used. The pulse based system transmits each pulse which covers the UWB bandwidth and the carrier based system is based on frequency-division multiplexing (MB-OFDM) [15]. Both academia and industry widely study the antenna design as it is the one of the important elements of the UWB systems. This design mainly depend on modulation technique used by UWB systems and its applications.UWB antenna faces more difficulty in designing than narrow band systems because large banwidth is the prime need to design these antennas.The antennas having wide band response in terms of return loss, gain and polarization are the requirements of the UWB wireless communication systems. These requirements are same as of conventional broadband wireless systems but broad bandwidth of 50% to 100% with consistent gain response is the main requirement.The main requirement of UWB antenna apart from bandwidth is compact size for portable devices,consistent performance across the UWB band and omnidiectional as well as direction radiation pattern depending upon the application.So,to meet the aforementioned requirements it is important to study the chracterstics of UWB antenna mentioned by different authors based on their research.

2.1 Categorization of Literature survey

The literature survey has been divided into following categories

- Developments in UWB antenna
- Bandwidth enhanced UWB antennas
- UWB antenna with band notch chracterstics for wireless applications
- Advancement in UWB antenna with Defected Ground Structure(DGS)
- Recent optimization techniques used for UWB antenna

2.1.1 Developments in UWB antenna

The FCC in 2002 issued the first report and order that allowed the UWB band for commercial applications. FCC allocated the spectrum from 3.1 to 10.6 GHz for unlicensed UWB communication applications with EIRP less than 41.3 dB/MHz. Since then, UWB has been considered as one of the most promising wireless technologies to revolutionize high data transmission [23]. In [24], various types of planar antennas for UWB systems with band-notched designs are studied. UWB printed slot antennas and UWB printed monopole antennas are compared by the authors for the proposed design. The author claimed dimensions of UWB antenna can be reduced by use ofUWB printed monopole antennas and comparatively higher gain can be achieved by UWB printed slot antennas. Also the progress in planar UWB antennas is studied

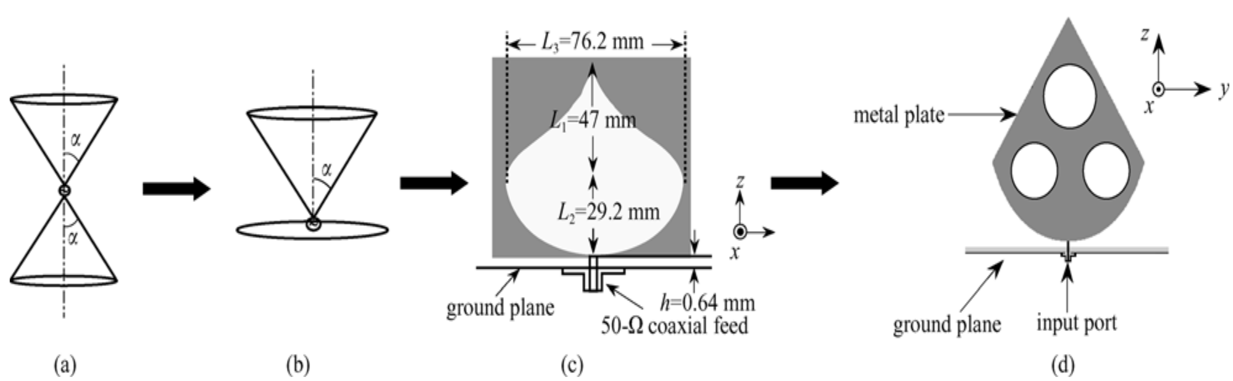


Fig 2.1: Structure of bi conical antenna and metal plate monopole antenna [24].

In [25] advancement of ultra wide band and super wide band is discussed. Authors have presented the discussion on band notched UWB antenna and on SWB antenna having band width ratio greater than 10:1 for the advancement. This paper provides the comparison of the printed monopole antenna and printed slot antenna.

In [26] author present the two disc monopoles with same radiator (a circular disc with radius of R=12.5mm), but feeding techniques used for optimization are different for both of them i.e. coplanar waveguide (CPW) feeding technique and coaxial feeding technique. Both antennas cover the whole UWB frequency band (3.1 to10.6GHz). In addition, by using inductive loading the size of UWB disc antennas can be reduced.

Nader Behdad et. al. in [27] have proposed a compact sectorial loop antenna. This antenna is designed for UWB applications using magnetic coupling of two adjacent sectorial loop antennas. The proposed antenna has an impedance bandwidth of 8.5:1 and consistent radiation parameters over frequency range of 4.5:1.

Foudazi [28], introduced a diamond-shaped-patch (DSP) monopole antenna. The size of the substrate used for the proposed antenna is 16×22 mm^2 which provides the frequency bands of GPS (1.26–1.3 GHz), GSM (1.71–1.88 GHz), WLAN (2.4–2.48 GHz), and UWB (3.1-10.6 GHz). With the help of different narrow strips, which act as resonance paths, multiband antenna is designed. The antenna achieves dual-, triple- and quad-bands with stable radiation patterns over the required frequency bands.

In [29] different shapes of radiator is discussed by the authors. To achieve a wider bandwidth and to reduce the size of the antenna the radiator is covered with dielectric superstrate. So a small printed UWB antenna is proposed for obtaining maximum band width and reduced size suitable for portable RF device. This paper described that the elliptical edges of radiator can be used to increase the bandwidth of an UWB antenna more than 50%.

In [30] author suggested that by cutting a rectangular notch from printed radiator majority of the electric current is concentrated on the radiator, which reduces the effect of the ground plane and size of antenna.In this paper the size is reduced up to 25 mm x 25 mm x 1.5 mm but the result are good in lower UWB band only however author claimed to cover the whole UWB band.

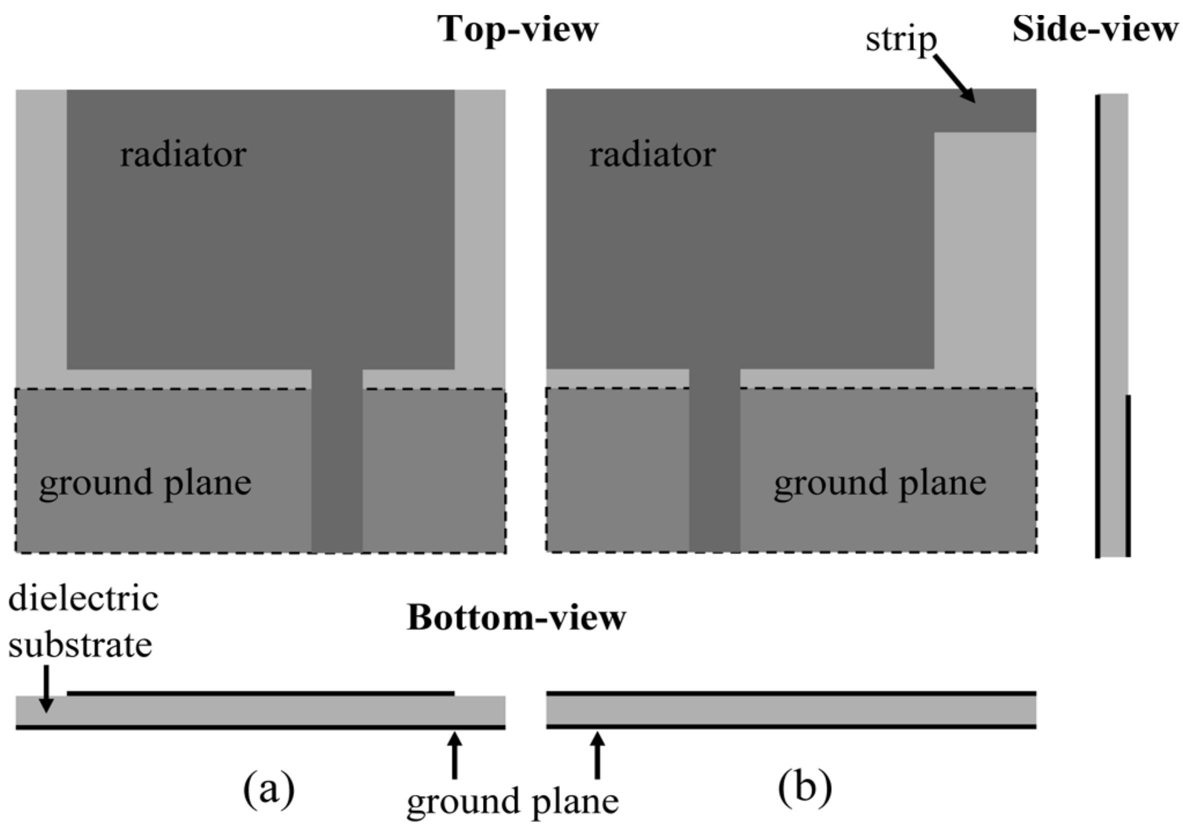


Fig.2.2: Rectangular patch antenna with stripline [30].

Srifi,M.N.et.al.in [31] have proposed a monopole antenna with circular disc for ultrawideband (UWB) applications. In this paper, the transitions are introduced between micro strip line and the printed disc to improve the impedance matching of the proposed antenna By using a dual and single microstrip transition based simple antenna matching technique, impedance bandwidths from 2.5 to 11.7 GHz and 3.5 to 31.9 GHz are obtained respectively.

In [32] a circular patch printed monopole antenna is proposed by the authors. The proposed antenna has improved the band width ratio which is not achievable by conventional UWB antenna or simple square planar antenna. Authors have used a trapezium ground plane and tapered CPW feed in the middle for the construction and feeding of the antenna respectively. In the result 9.2:1 band width ratio for VSWR 2:1 is achieved as well as Omni directional radiational pattern is also exhibited by the antenna.

In [33] the authors have designed a butterfly shaped monopole antenna for UWB applications. The antenna has good impedance matching across 3.1-10.6GHz. Further in this paper, the effect of the ground plane is also discussed. The authors claimed an increase in back lobe radiation and decrease in peak gain for small ground planes.The antenna has a good impedance matching and covered the whole UWB range from 3.1-10.6 GHz. The authors have studied the co and cross polarization performance and claimed that the antenna has stable radiation patterns and high gain.

Zhi Ning Chen in [34] has proposed an antenna, consisting of two semi-elliptical-ended arms connected by a shorting bridge, for UWB applications. This is a compact antenna having size of 13mm ×16mm. A planar monopole is wrapped to construct the rolled monopole. The antenna is evaluated in both time and frequency domains. The results show that the proposed antenna has omnidirectional radiation pattern and has a feature of broadband in the UWB wireless band from 2.8-10.9 GHz.

In [35] authors have presented a microstrip fed compact planar monopole antenna for UWB applications.Two quarter circles are used at each side of the lower corners of the a rectangular patch to form a smooth connection between the microstrip line and the radiation patch.The impedance band width (3.0–14.7 GHz) S11< - 10 dB is improved and achieved by introducing a notch in the truncated ground.

A novel hexagonal shaped slot cut out from asquare patch antenna is presented in [36]. The antenna is designed for UWB application which also provides the operation of dual band notching and it is fed by a micro strip feed line of 50Ω. In this paper author claims the size reduction (up to (45% and 36%) for two different frequencies compared to a normal rectangular patch.

With the features of broad impedance and improved gain performance, a planar dipole antenna is introduced in [37]. This antenna,that solves the problem of compact size having broad impedance bandwidth and suitable gain,consists of two semi-elliptical-ended arms and a shorting bridge to connect them.

In [38] Xeu Ni Low et. al. proposed a suspended plate antenna having two layers. Top four radiating plates are attached to the common bottom plate with vertical strips. This paper claimed that the antenna has achieved the bandwidth of 72.7% (2.8-6GHz) for VSWR 2:1. The antenna has good radiation performances like bandwidth, gain in the range of 3.1-4.8 GHz which covers the lower band UWB. To minimize the effects of interference, frequency notched UWB antennas are desirable.

2.1.2 Bandwidth enhanced UWB antennas

Cheng Yong et. al. in [39] introduced a compact planar UWB antenna. In this paper a symmetric polygon wide slot has been introduced in the ground plane,. A tapered fork like microstrip line is used to feed the proposed antenna. In this paper, the transient pulse signal fidelity is investigated by finite-difference time domain (FDTD) method. The antenna provides the unidirectional radiation pattern and gain is almost flat over the frequency range of UWB. UWB antennas are widely used in military and civilian systems. It replaces the narrowband antenna and reduces complexity.

In [40] author presented a CPW-fed monopole-like slot antenna with a T-shaped feeding stub for UWB applications. The proposed antenna is compact with an overall size of 5 mm × 25 mm × 0.8128 mm and has flat gain over desired frequency range.The antenna has good impedance matching, stable radiation patterns, and wide operating frequency band from 3.0–14.3 GHz (130.6%). The radiation characteristics and impedance matching of the proposed antenna can be controlled by changing the dimensions of ground plane,slot and the feeding stubs.

Ryu and Kishk in [41] describes characteristics of two antennas for single band notched and double band notch to achieve three different frequency bands.Single band-notch antenna which has a single separated strip covers the 5.15–5.825 GHz band while dual band-notches antenna which uses the two separated strips covers the 5.15–5.35 GHz band and 5.725–5.825 GHz band.The author claims to suppress interference in Ultrawideband (UWB) system from other communication systems by designing this type of antenna.

In [42] an antenna with reduced height is suggested by slotting ground plane because most of the wireless system hardware is getting compact day by day. In this paper the cancellation of the current on the ground plane and radiator has been reduced to reduce the size of an antenna. The authors suggested that the vertical slot can be cut in the vertical ground plane under an inverted F antenna to reduce the cancellation of current. By doing this the height of the antenna is reduced to half.

A new S-shaped printed slot patch antenna is presented in [43]. The proposed antenna is circularly polarized and CPW feeding is used to feed the antenna. The main radiating patch is comprised of L shape. Author claims that the antenna shows a good impedance matching in the frequency range of 1.78-5.64 GHz with an impedance bandwidth of 104% and also has 3 dB axial ratio bandwidth of 58.6% from 2.85-5.21 GHz.

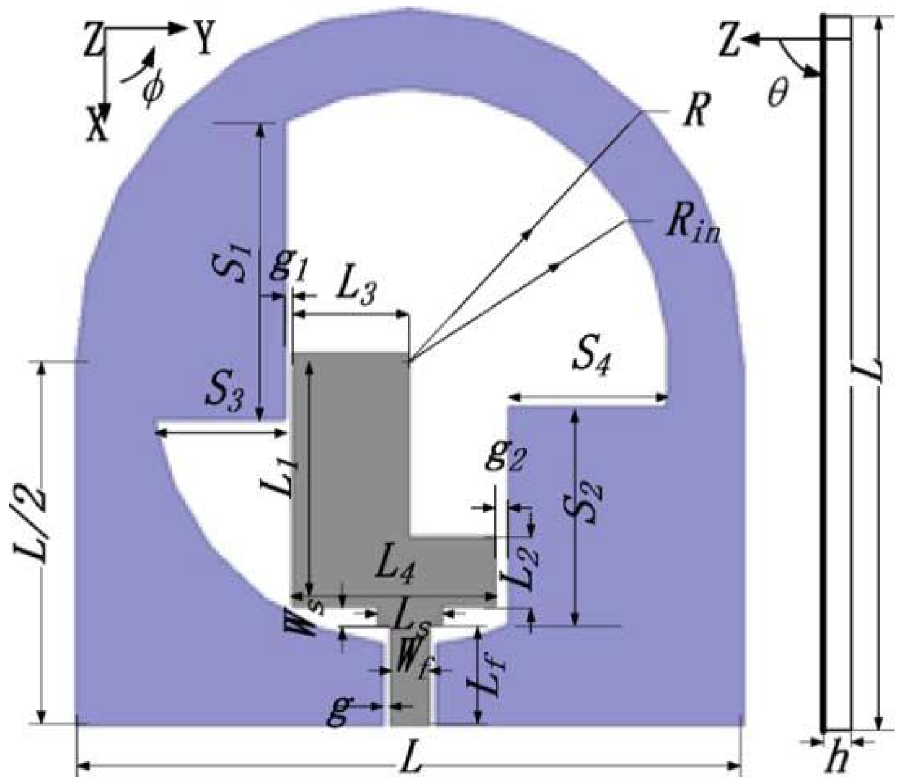


Fig 2.3: Structure of S-shaped printed slot patch antenna[43].

In [44] dual band, triple band and broad band antenna using stepped impedance resonators (SIRs) fed with CPW feeding, is presented. The substrate material used for the proposed antenna is FR4. Dual band antenna is designed at center frequencies of 1.5 GHz, 3.5 GHz and triple band antenna is designed for 1.5 GHz, 3.5 GHz,5.5GHz and the ultra wide band antenna are designed allocating the three frequencies close enough to achieve return loss of 6 dB in 1.5-4.4 GHz. Further to achieve omnidirectional radiation pattern 1st and 2nd antenna's slots are added near the main radiating element.

A compact step shape slot antenna with rotating patch is introduced in [45] for UWB applications. A compact antenna with wide band characteristics with low profile, low cost, ease of fabrication is the requirement of UWB communication system. So this paper has presented a new approach for this requirement. The step slot and rotated patch used for the proposed antenna is helpful in obtaining bandwidth enhancement for UWB operation. 117.5% from 2.88-11.08 GHz is achieved for the proposed antenna. This bandwidth is also useful for portable devices of size 25×25 mm^2.

In [46] a compact patch antenna with a half-U and half-E slots isproposed by the authors. The impedance bandwidth in the range of 20-30% is achievable by U-shape wide band antenna.In this paper it is shown that the same characteristics can be obtained using half U shape slot.Further the, technique of shorting pin is used for the reduction of the size of the U slot antenna which shows the bandwidth of 28.6% and radiation efficiency exceeding 90%. Half E-shaped slot also provide the wide band behavior. Further, the bandwidth of 20% and 25.2% and stable radiation pattern are achieved in the results.

In [47] authors have discussed a noval band dual dipole composite unidirectional antenna for wireless applications. The parametric study of the surface current distribution, radiational pattern and impedance is analyzed for the operational principle of the antenna. The radiation pattern, gain and reflection co efficient are provided in the results of the proposed antenna which are given as two pass band from 1.54-3.24 and 4.88-6.87 GHz, reflection co efficient less than -10dB and average gain 6.7 dbi at lower frequency and 6.5dbi at higher frequency.Monopole printed antenna has the advantages of low profile, low cost etc. Many structures are designed for the printed monopole antenna like circle, rectangle and many more.

In [48] a pentagon shape micro strip antenna is presented by the authors for the wireless applications. The ground plane of 50 mm×80 mm resembling to wireless portable cards is used. 25% of the ground plane is used by the antenna and the remaining area is used for RF circuitry. Slot and stub of pentagon shape and feed line are used to obtain 124% impedance bandwidth. The effect of the several variations of the antenna designed is discussed and these variations are using rotating and the straight feed line for two substrates and using a reflecting plate on the backside of the radiator. The directional radiation pattern is obtained by using this reflecting plate.

2.1.3 UWB antennas with band notch characteristics for wireless applications

Qing-Xin Chu and Ying-Ying Yang in [49]proposed a compact planar ultrawideband (UWB)antenna with 3.4/5.5 GHz dual band-notched characteristics. Author claims to achieve band-rejected filtering properties for Wi-MAX/WLAN bands by cutting two slots of C- shape in the patch as well as consistent radiation patterns and gain is also obtained.

In [50] the author has presented the same for ultra-wideband/2.4GHz band WLAN applications. A meandered- slotted stub and cross wide slot has been introduced to achieve compact size and frequency notched function. The return loss lower than -10 dB is achieved in the frequency range of 2.39- 11.25 GHz with a frequency notched band ranging from 4.75-5.85 GHz.

Quasi Haru Yoshioka et.al.in [51] have presented small sized monopole antenna with dual band for WLAN/UWB applications. Authors have used four stubs, radiating patch and the truncated ground for the designing of the specified antenna in this paper. Authors have claimed the dual band of 0.45 GHz (2.20-2.65GHz) and 5.23GHz(6.52-11.75GHz) for -10 dB return loss in these bands. A good impedance matching, group delay and gain are also provided in the results of the proposed antenna.

S.Oudayacoumaret. al. has prescribed a monopole antenna in [52] operating at 2.4GHz, 3.9GHz and 5.3GHz band used for WLAN and Wimax applications. The size of this compact antenna is 30 mm × 40 mm × 1.6mm and fed by a 50ohm microstrip line. In this paper author introduced two branches and two stubs in the radiating patch which is responsible to make the circuit to radiate at 2.3GHz, 3.9GHz and 5.3GHz respectively. The operating bandwidth of the proposed antenna is (2.2-2.4) GHz, (3.7-3.92) GHz and (5.2-5.4) GHz with VSWR values of 1.2, 1.9 and 1.1. Further, return loss of -19dB, -25dB and -38dB at proposed frequencies respectively. The proposed antenna has a unidirectional pattern of radiation in E plane and bidirectional pattern in H-plane.

2.1.4 UWB Antennas with defected ground structure

As the use of smart phones, tablets, notebooks, laptops is increased, the demand for compact printed antennas has also been increased hence antenna is gaining the researchers attention.Patch antennas have usually low bandwidth. So to this contest, researchers use the technique of defected ground to enhance the bandwidth of the antenna. Defective ground structure (DGS) made a considerable break-through in the development of UWB antennas. It is the latest technology to improve the quality and properties of antenna. This technique is also useful in enhancing the impedence bandwidth as well as reducing the size of antenna. DGS is introduced by engraving the ground plane of microstrip antenna, this disturbs the current distribution in the ground plane which influences the change in transmission line characteristics such as line capacitance and inductance.Various shapes of DGS slot have been discussed for microstrip antenna such as circle, dumbbells and spiral.Authors of [53] have presented a UWB band pass filter (BPF) with frequency notch characteristics. This frequency notch function is achieved by 2U-DGS. Inner U-DGS is integrated with capacitors and outer U-DGS is integrated with RF PIN. To show the effect on the center frequency of the notched band which is decreased by 56.7% ,the curve fitting formula is used. Quality factor improvement and filter size reduction of 72% is achieved by capacitors whereas band notched rising by 27% is achieved in the outer U-DGSby RF PIN diode switch.Further, the proposed antenna shows the advantage of reduced size, low insertion loss, high rejection and higher band attenuation.

In [54] the author has discussed the application of DGS to branch line couplers. A doubled layer substrate is employed to reduce the ground contact problem.

In [55] CPW fed horse shoe shaped slot antenna with DGS for WiMax/WLAN applications is proposed. The antenna is designed on FR4 substrate with dimensions of 30mm × 43mm × 1.6mm. The proposed antenna operates in the frequency range of 2.5-2.69 GHz, 3.4-3.69 GHz and 5.25-5.85 GHz having impedance bandwidth of 85.13%. Also the author has compared the performance of the proposed antenna (with DGS) to a conventional antenna (without DGS) and concluded that designed antenna has significant gain improvement and consistent radiation pattern as compared to conventional antennas.

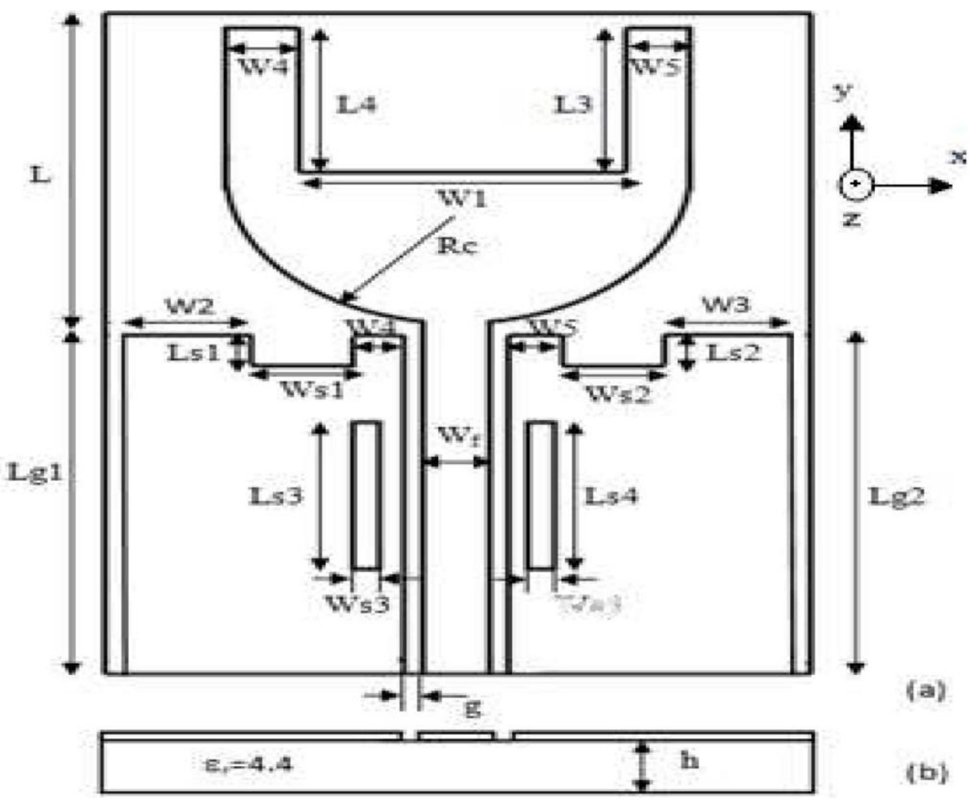


Fig 2.4: Defected ground structure antenna[55].

In [56] the author has tried to reduce the electromagnetic interferences using planar inverted E shaped antenna (PIEA) using defected ground structure having size of 10mm×5mm×4mm. The antenna has a good impedance matching at the frequency of 2.4 GHz and 5.5 GHz and efficiency of 49.33% and 55.23%, respectively.

In [57] a dual inverted L shaped strip rectangular microstrip patch antenna has been discussed. The defects are introduced in the ground structure of the antenna. Cross shaped microstrip line is used to feed the antenna. The designed antenna operates over a frequency range of 2.396 GHz to 3.678 GHz covering WLAN and WiMAX bands.

A novel monopole patch antenna with defected ground structure covering PCS-1900/ UMTS-2100 and WLAN standards is discussed in [58]. This antenna is designed on a substrate of FR4 epoxy material which having a dielectric constant of 4.2. The ground plane of proposed antenna consists of three protruding strips which improve the excitation and increase the bandwidth of the antenna. Results explained that the antenna has good peak gain and directivity in all the three operating bands.

Parmod kumar et.al.have proposed a compact micro strip antenna operating at 4.8 GHz in [59] by using technique of size reduction. Proportional formula of defect is used in three steps for the reduction of the antenna size. Symmetrical defected micro strip (DMS) like structures are etched along the patch surface for reducing the size. The DMS is inserted along the length to avoid cross polarization.The DMS/DGS used disturbs the current distribution by introducing discontinuities in the signal plane.The achieved compact size antenna claimed the higher impedance bandwidth of 23.1GHz w.r.t conventional patch. The size reduction of 40% is also claimed at 4.8GHz by the authors. The results of the designed antenna show that the performance of the antenna varies with the shape, size and position of the DMS inserted.

2.1.5 UWB antennas using neural networks

Compact size antenna with multiband operation and omni directional radiational pattern are the requirement of the antenna's in the modern communication system.The microstrip antenna is always an attractive option because of the small dimension, simplicity, etc. The calculation of the designing parameters of the antenna is quite difficult. Now a days, the optimization of design parameters is most important consideration in order to obtaining efficient computational results. Many methods for the optimization of design are proposed in literature, which include Genetic Algorithm(GA), Particle Swarm Optimization(PSO), Neural Network (NN) etc.

The neural network is used in [60] to optimize various parameters of a RFID antenna structure. These parameters are difficult to optimizeby mathematical modelling. Further, a swarm algorithm is used to train a neural network and PSO is used for optimization in this paper. The result of the defined antenna shows that the convergence rate is faster and errors are small with PSO optimization. Also the improvement in the computer simulation baseddesign of microstrip antenna is achieved by the neural network.

In [61] author studies microstrip patch antenna design optimized by PSO (Particle Swarm Optimization) algorithm using artificial neural network.A neural network based designed antenna results are compared with measured antenna values. The results obtained using NN accurately match with measured results, are very less time consuming and donot suffer from intensive computations. The neural network models can be used as alternative technique for antenna design to avoid complex and long lasting computations.

Authors of [62] have again used the neural network, but in the designing of elliptical micro strip patch antenna (EPMSA) for the desired frequency in the L band. The main advantages of the designed antenna is the easy extraction of the design parameters of EPMSA at particular frequencies and gain of interest. But the synthesis of EPMSA is avoided by including the gain at resonance frequency, as this become difficult. The advantage of the proposed antenna explained in this paper is that the parameters required for the EPMSA can be easily extracted out without using time consuming and iterative design procedures. The errors claimed for the proposed antenna by the authors is less than 2%.

In [63] authors presented an antenna array synthesis based on the concept of human brain and using radial basis function neural network. The proposed array uses a large number of neurons and radial basis neural network with exact solution. A regular antenna array with uniform amplitude distribution is synthesized initially and then the results are extended to linear amplitude distribution. Authors have used different values of the training samples and antenna elements for investigation of the antenna.Authors have shown the ability of the network to perform the synthesis by obtaininga small mean error of the amplitude and phase at the output of the network.

Neuro spectral method is presented in [64] for designing of the rectangular patch antenna. The antenna dimensions are derived using ANN. The simulated results are found to be in close agreement with ANN results. In [65] for the designing of multi antenna and fast analysis of the antenna, an artificial neural network modeling technique is proposed by the authors. The designing of multi antenna is discussed in this paper because of the increasing demand of higher data transmission rate and low bit error probability characteristics for the mobile phones. Multi antenna technique is the best solution for achieving these characteristics. Ground plane effects are also considered in this paper for the designing of the antenna. Further, Authors have shownthat the ANN has the advantage of being very fast both in simulation and designing of the antenna.

Artificial neural network (ANN) is again used by the authors in [66] but for calculation of the parameters of a rectangular patch antenna. In this paper dielectric constant, thickness of the substrate and resonant frequency which contain the data are transformed into the antenna parameters that are the length and width of the rectangle. Authors have used IE3D simulator for the simulation of the antenna in this paper.

In [67] a new approach using cellular automata and fuzzy ARTMAP neural network is used for designing multi patch antenna**.** Authors have used different slot configurations for the designing of the antenna based on cellular automata. The fuzzy ARTMAP neural network is used to link the design to the return loss.The calculation of the resonant frequency is done by using neural network and Neuro-fuzzy system in this paper.

2.2 Summary of the chapter

In this chapter we had studied various advancements in UWB antennas.To widen the antenna operating bandwidth, several methods have been studied. For resonant antennas, the bandwidth enhancement can be accomplished by lowering the antenna quality factor.However, this (low quality factor) will provide low gain and low efficiency.Broadband performances can be achieved by increasing the surface area of antenna. Numerous monopoles and dipoles have been studied to exhibit UWB characteristics. Various techniques have been also reviewed to reduce the size of UWB antennas in this chapter. In this context, researchers have used the technique of defected ground structure (DGS) to enhance the bandwidth as well as to reduce the size of antenna. The optimization of design parameters is most important consideration in order to obtain efficient computational results. Many methods for this are proposed that include genetic algorithm (GA), particle swarm optimization (PSO), neural network etc. In the next chapter,Hexagonal shaped UWB antenna is taken as a first research problem for miniaturised UWB antenna.

Chapter 3

Hexagon Shape Ultrawideband Antenna

3.1 Introduction

In recent years, UWB proved as a good candidate for wireless communication because of its characteristics of high data rate, high data resolution, robustness to multi path fading and very low interference which are the requirements of the next generation wireless personal area network systems. Hence more research is going on in the development of WPAN as the demand of WPAN is growing more in recent technology[68].This research in development of WPAN is to provide reliable wireless connections between computers, portable devices and consumer electronics in the short range. Sharing of photos, videos and even networked printer attached with different computers in home/office network is done with the help of UWB technology [3]. UWB supports high data rate multimedia applications because of its ultra wide frequency band width.To achieve the requirement for different applications various UWB antennas are proposed recently. In year 2002, the federal communications commission (FCC) has allocated the frequency spectrum from 3.1-10.6GHz forUWB[4]. Since then technology has witnessed immense growth and applicability in real time applications. Various microstripantennas have recently been introduced for obtaining considerably larger impedance bandwidth by using different patch shapes such as rectangular, circular, and elliptical. In this chapter a Hexagon shaped UWB antenna is introduced which achieves high impedance bandwidth and gain performance across operatingUWBbandwidth of 3.1–11GHz with reduced ground size.

Hexagonal shape radiator is printed on one side of UWB antenna and reduced ground is on the bottom side.In this chapterthe effect of reduced ground planeon the impedance performanceis studied by considering different sizes and shapes of the antenna at different frequencies.The effect of rectangular antenna with notch is also taken at ground plane, which shows that the effective current path is extended by the notch and majority of the current is concentrated on the radiator instead of the system ground plane.

3.2Antenna Design

The frequency band of operation, input impedance, polarization, radiation beam width, gain and total bandwidth are main designing parameters for UWB antenna.The proposed antenna is designed using double sided PCB with one side having radiator and other side having the ground plane. We can design the hexagonal micro strip antenna (HMA) from a circular micro strip antenna (CMA). HMA also has straight edge which can be used to feed the antenna.These two antennas are closely related to each other [69, 70]. The frequency of a circular patch antenna is given by

$$f_r = \frac{X_{mn}}{2\pi r_e \sqrt{\varepsilon_r}} c \qquad \text{.....................(3.1)}$$

Wheref_r represents the resonant frequency of the patch,
For the dominant mode TM_{11} value of Xmn = 1.8411, c =3×10^8 (velocity of light in free space) and ε_r is the relative permittivity of the substrate.
r_e denotes the effective radius of the circular patch and given by equation mentioned below

$$r_e = r\{1 - \frac{2h}{\pi r \varepsilon_r}(\ln\frac{\pi r}{2h} + 1.7726)\}^{0.5} \qquad \text{...................(3.2)}$$

Where ‘r’ is the actual radius of the circular patchand h is the height of the substrate.

For the proposed antenna the radius of the circular patch is taken as 7.5mm. The effective radius using equation (3.2) is found to be r_e =7.17 mm

Equation 3.3can be applied for designing a hexagonal microstrip patch antenna [69] by relating the areas of the circular and hexagonal patches as shown in Equation 3.3

$$\pi r_e^2 = \frac{3\sqrt{3}}{2} a^2 \qquad \text{............................(3.3)}$$

Whereais the side length of the hexagonal patch.Using (3.3) and r_e=7.17 mm the side of hexagon is found to be a=7.96

A simple hexagonal microstrip patch antenna is designed on a FR-4 substrate having dielectric constant ε_r= 4.4, with height of 1.6 mm. The shape of the radiating patch is taken as hexagon with a side length ‘a’ of the hexagonal patch antenna has been calculated using Equations3.1 - 3.3 and it is found to be 7.96 mm.

The proposed antenna is printed as a patch having dimensions of 17 mm × 17 mm × 1.6mm on one side of substrate. The feed line length is about3mm and the width is about 3.1mm. The antenna is designed with a finite size ground of length 5mm and width 17 mm. Fig. 3.1(a), (b) illustrates the geometry and dimensions of the proposed antenna.

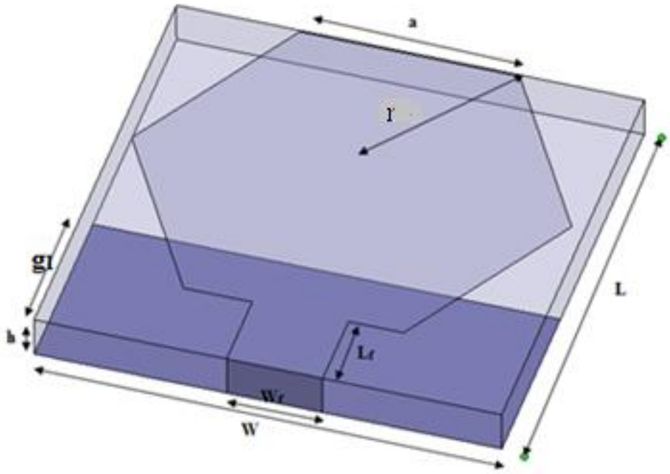


Fig 3.1(a): Proposed structure of the hexagonal antenna

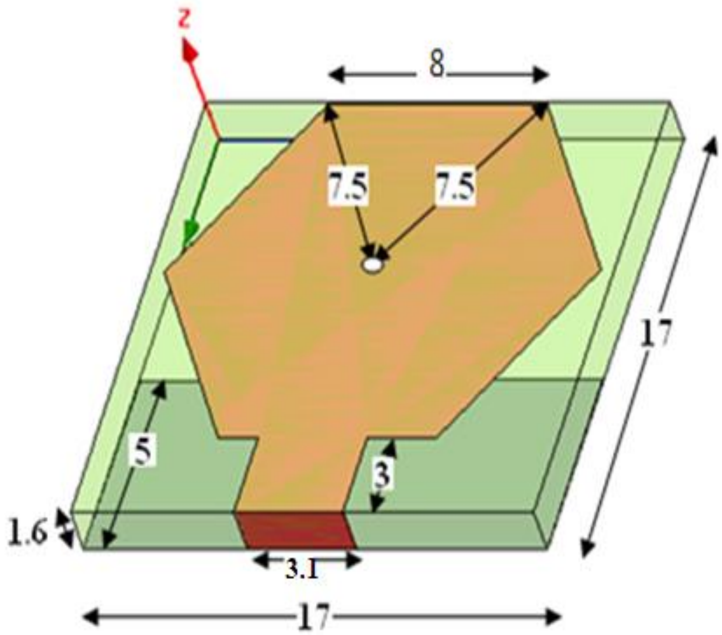


Fig 3.1(b):Proposed structure of the hexagonal antennawith dimensions

The parameters are selected according to the -10 dB return loss, bandwidth in the range 3.0 to 11 GHz.

3.3Parametric study

To optimize the antenna, parametric study of the antenna is done. The aforementioned proposedhexagonalantenna is examined for different values of ground plane, substrate thicknessandby captivating the different value of dielectric constant. Thevariation of parameters has been studied with objective to investigate effect on bandwidth of the antenna. These are discussed in next section.

3.3.1 Effect of change of substrate and patch dimension

In this design the substrate dimension are considered 14×14 mm.with side length a=7.5 mm to optimize the size of hexagonal patch.Simulated results (Fig.3.2) show that the antenna with afore mentioneddimensionsdoes not behave as a UWB antenna

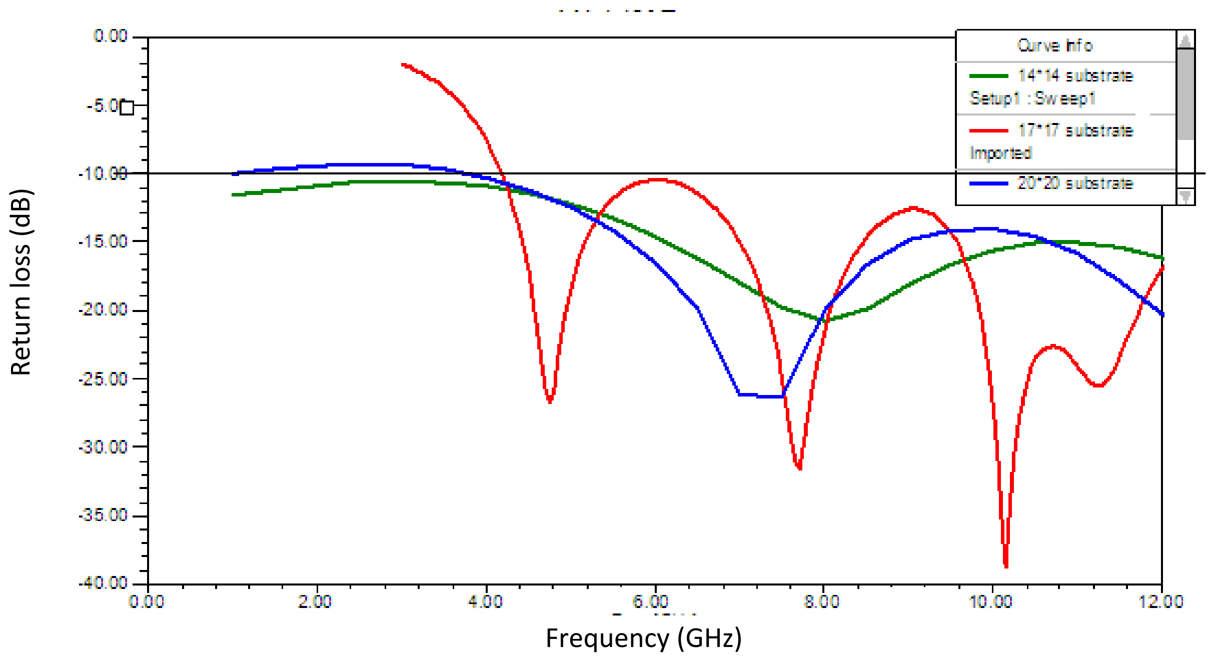


Fig. 3.2: Effect of change in substrate dimension

In next step the hexagonal patch antenna is modified with substrate dimension 17mm ×17 mmwith side length (a) of hexagonal patch is 8 mm.It is seen from the Fig.3.2 that the bandwidth is achieved in lower as well as upper UWB band.The proposed hexagonal patch antenna is further modified with substrate dimension 20×20 mm with side length(a) of hexagonal patch is 8 mm .It has been observed that the bandwidth is shifted to 7.5GHz and again not covering the lower UWB band.It has been observed that with decrease or increase in the substrate dimension beyond 17×17 mm, bandwidth range slightly shifts towards the upper side of UWB band and return loss gets reduced.

3.3.2 Effect of radius (r)

The proposed hexagonal antenna(with substrate dimension 17mm ×17mm) is examined for different value of **r i.e**. distance from the center. At first step the value of r is taken 7mm the frequency band achieved at 5.5 to 6.2 GHz and9 to12 GHz. As the r is increased from 7mm to 7.5mm the bandwidth of antenna increases and it cover the frequency band from 4.2 to 12GHz.By further increasing the value of r from 7.5 mm to 8 mm the results remain same at the higher frequency however it is degraded at lower frequency band as shown in Fig 3.3.

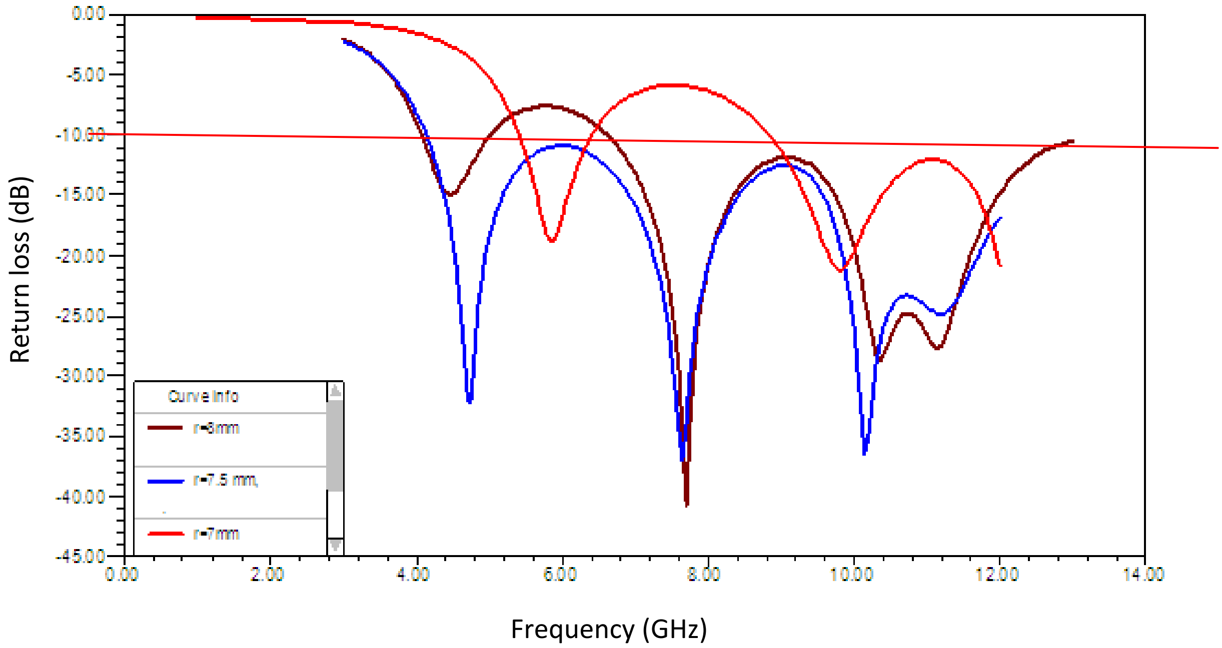


Fig. 3.3:Effect of change in radius(r)

3.3.3 Effect of ground length (g_l)

The proposed hexagonal antenna is examined for different ground length variation Fig. 3.4 depicts the comparison of return loss for different ground sizes of 3mm,5mm,7mm and 10mm. Simulated results show that the antenna having ground size of 3mm does not behave as a UWB antenna. It has better return losses only in one band from 8.1-10.5 GHz only. As the ground length is increased from 3mm to 5mm the bandwidth of antenna increases. The antennas resonate from 4.2GHz to 12GHz. There is no significant change in bandwidth as the length of ground plane is further increased to 7mm and 10mm. As the bandwidth of antenna does not change significantly when the ground plane length increases from 5mm to 10mm.So, the optimum value of ground length is chosen 5mm for proposed antenna as we preferthe reduced ground plane for compact antenna.

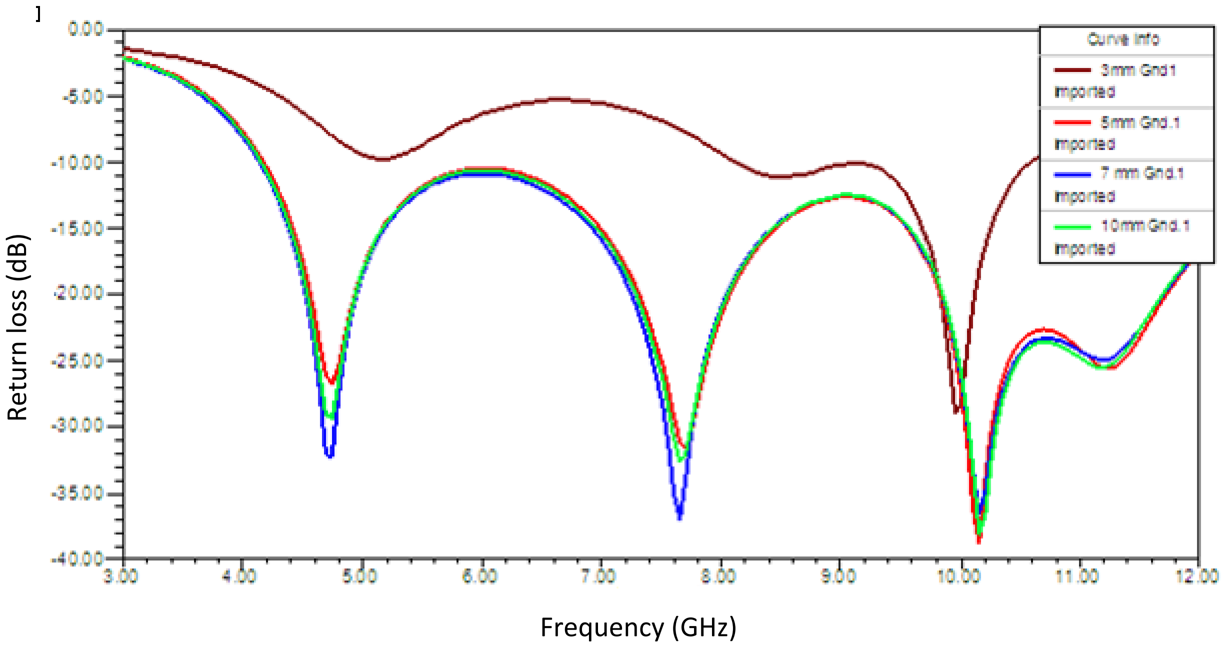


Fig. 3.4:Effect of change in ground length (g_l)

3.3.4 Effect of different value of dielectric constant/different substrate material

The performance of proposed antenna is analyzed for the different value of dielectric constant or types of substrate materials as shown in Table 3.1.

Table 3.1: Dielectric constant of different substrate materials

Different substrate materials	Permittivity
FR4	4.4
Rogers (4003)	3.5
Quartz	3.7

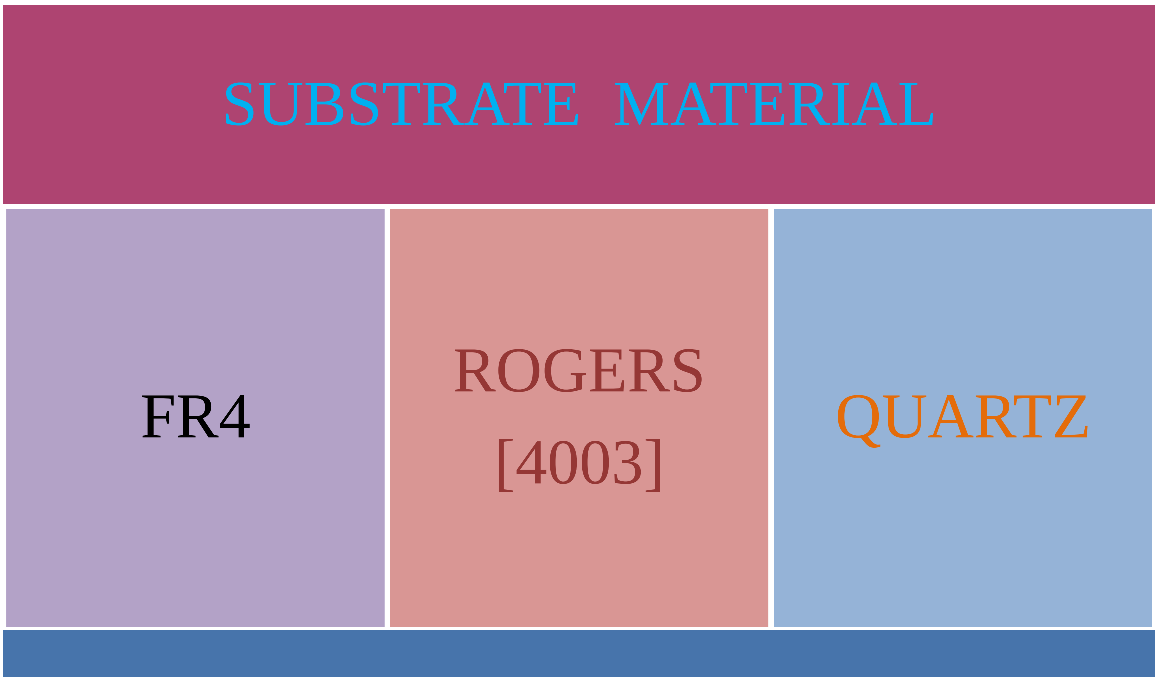


Fig.3.5:Different substrate materials

The return loss provided by the FR4 material is –26.5dB at 4.7GHz, -30 dB at 7.7GHz and -40 dB at 10.2GHz as shown in Fig.3.6. Further the return loss obtained by Rogers's material with dielectric constant 3.5 is better than the return loss obtained by quartz material. Rogers mainly improves the result in higher band as comparison to other two materials. The return loss in higher band of Roger material is -34.5dB and of quartz it is -31dB.Roger substrate having less dielectric constant among three substrate considered in present work. In terms of return loss, FR4 plot shows better result and bandwidth increases with decrease in dielectric constant of substrate i.e. in case of Rogers substrate (ε_r = 3.5).

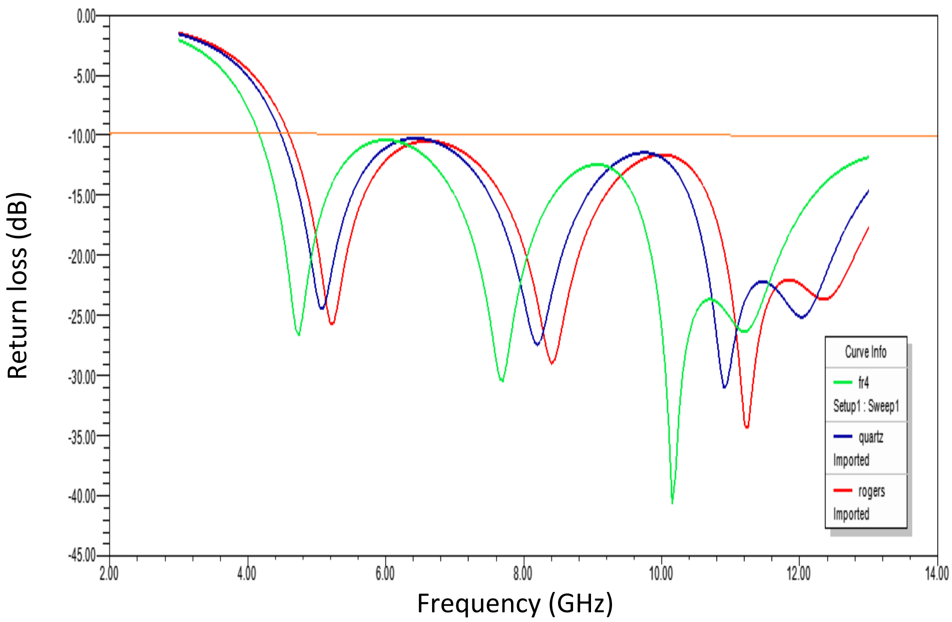


Fig.3.6:Effect of variation in dielectric constant on substrate material

The parameters of proposed antenna design are adjusted vigilantly by running several parameter sweeps and lastly the best possible parameters for proposed design are mentioned in Table 3.1 in tabular form.

Table 3.2: Parametric value of the proposed antenna

Parameters	Size in mm
Length of substrate(L)	**17**
Width of substrate(W)	**17**
Thickness of substrate(h)	**1.6**
Length of ground(g_l)	**5**
Length of feedline(L_f)	**3**
Width of feedline(W_f)	**3.1**
Dimension of single side of patch(a)	**8**
Distance from a center(r or d/2)	**7.5**

3.4 Current distribution

Thecurrent distributionplots describe the relation between desired (co-polarization) and undesired components (cross polarization) of the UWB hexagonal shape patch antenna.Furthermore, it explains about the nature of the fields propagating through the patch antenna.As shown in Fig. 3.7 the surface current is concentrated along the boundary edges at frequency7.75GHz (resonant frequencies).

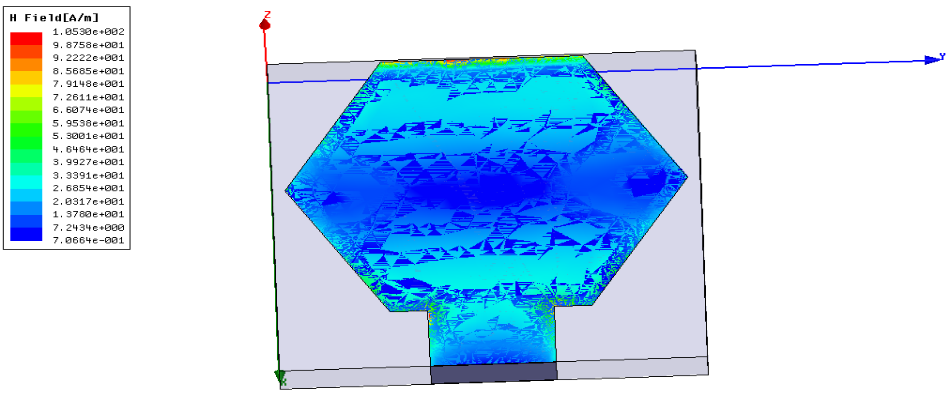


Fig.3.7: Current distribution in patch at 7.75GHz.

3.5 Radiation pattern

Representing the radiation properties of the antenna as a function to space coordinates forms the radiation pattern of the antenna. The properties which come under the radiation properties are intensity of radiation, strength of field, directivityetc.The performance of the linearly polarized antenna is mostly described in the E plane, which has electric field and H plane which has a magnetic field. Both planes provide the maximum radiation direction [12, 71].3D polar plot of proposed antenna is shown in Fig 3.8at resonance frequency. Different colors on the surface of antenna describe the average current density and it has been observed from the Fig. 3.8 that the proposed antenna is achieving directionalproperties. The radiation pattern of the proposed antenna attributed good gain for short range communication which makes it suitable for WPAN applications.

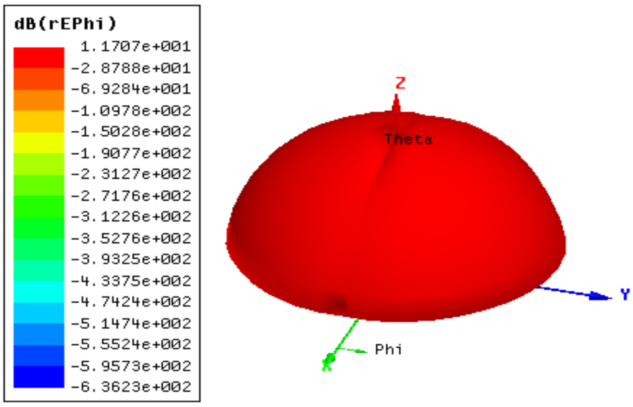


Fig.3.8: 3D radiation patternat 7.75 GHz

The radiated power is varies with radial distance and the angular position from the circuit. The variation of power density with angular position can be graphically defined as radiation pattern.On the spherical coordinate system,the azimuth plane is indicated by the x-y plane (ϕ measurement and θ=90°) whereas the x-z planeindicatesthe elevation plane (θ measurement and ϕ=0).Normally, the E-plane (elevation plane) will contain the electric-field vector and theH-Plane (azimuth plane) will contain the magnetic-field vector.

Simulated relative power patterns, at two principle plane, azimuth and elevation, were taken at various frequencies, i.e.at 4.5 GHz, 5.0 GHz, 7.75 GHz and 10.2 GHz and shown in Figs. 3.9 to 3.13 respectively. The simulated results are obtained from the HFSS software and measured results are taken in an anechoic chamber.The plot of Fig. 3.9 (a),(b) to 3.13(a),(b) are showing elevation plane i.e. E-theta component, which correspond to, co-polarization (y-z plane, phi=90) and cross polarization (x-z plane, phi=0) cut planes and the plot of Fig. 3.9 (c) to 3.13 (c) are showing azimuth plane i.e. H-phi component in co polarization (plane, theta=0) cut planes. It has been observed that a figure-eight pattern in x-y plane at theta=0signifies a dipole type of radiation pattern at different frequencies. On the other side the antenna as expected achieving a fairly Omni-directional and normalized patterns in elevation plane supported by the simulated 3D realized gain radiation patterns shown in Fig. 3.8.The measured and simulated radiation patterns also agree very well at different frequencies.

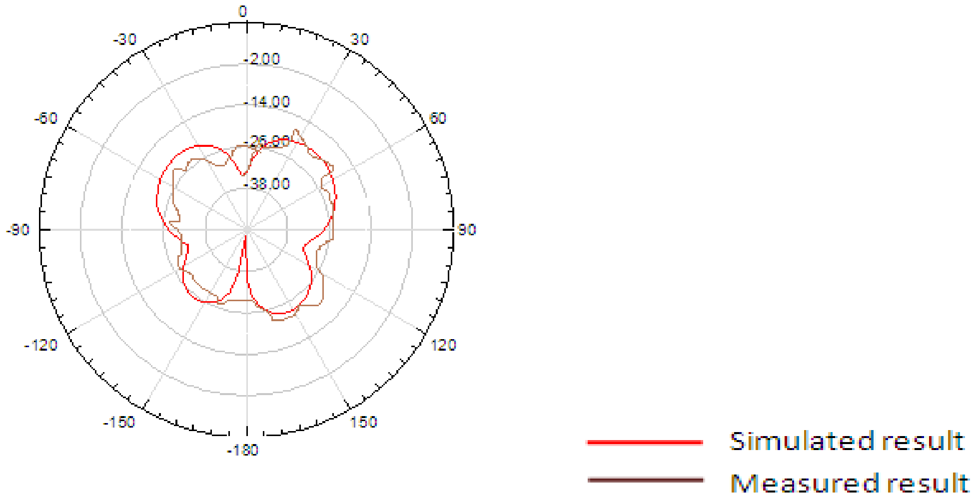
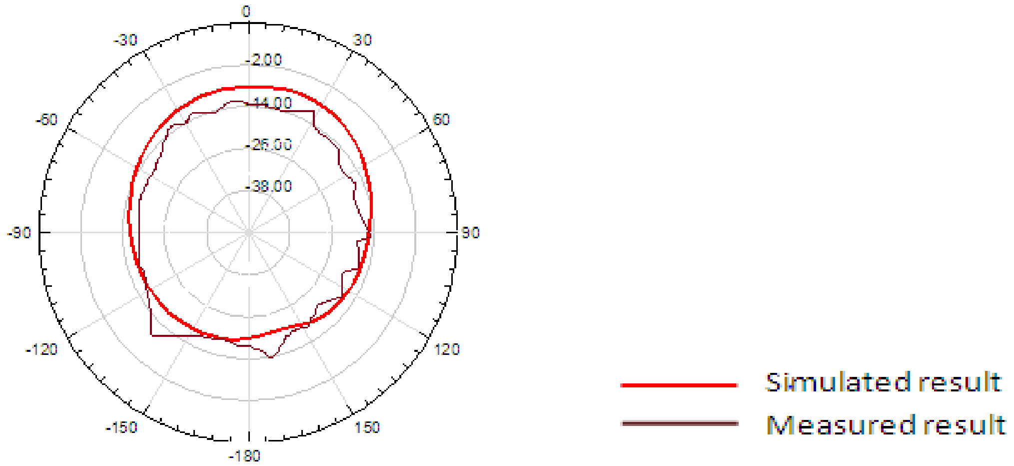
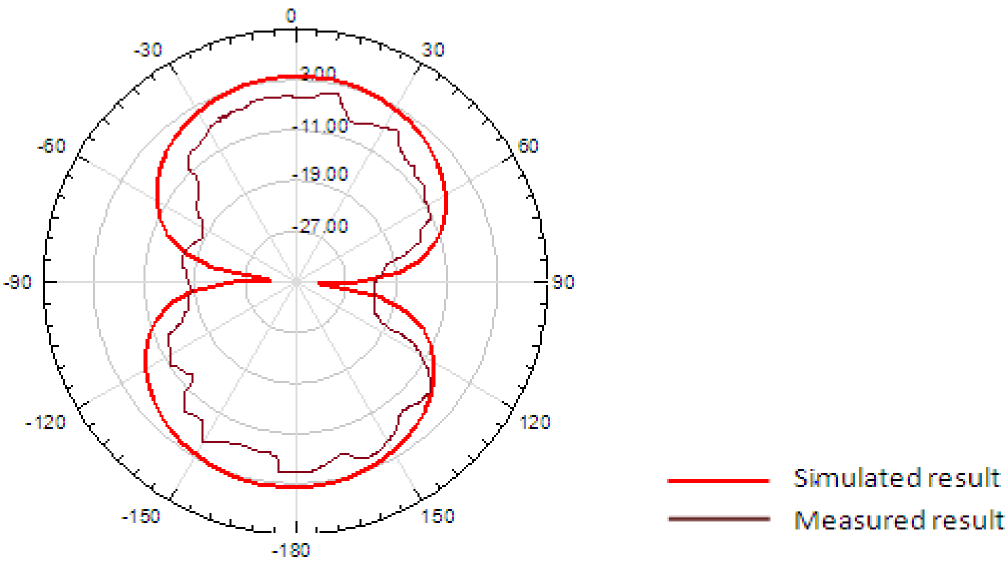


Fig. 3.9(a):Radiation pattern at 4.5 GHz at(Phi=0 degree)



(b)

Fig. 3.9(b):Radiation pattern at 4.5 GHz at(Phi=90 degree)



(c)

Fig. 3.9(c): Radiation pattern at 4.5 GHz at(Theta=0 degree)

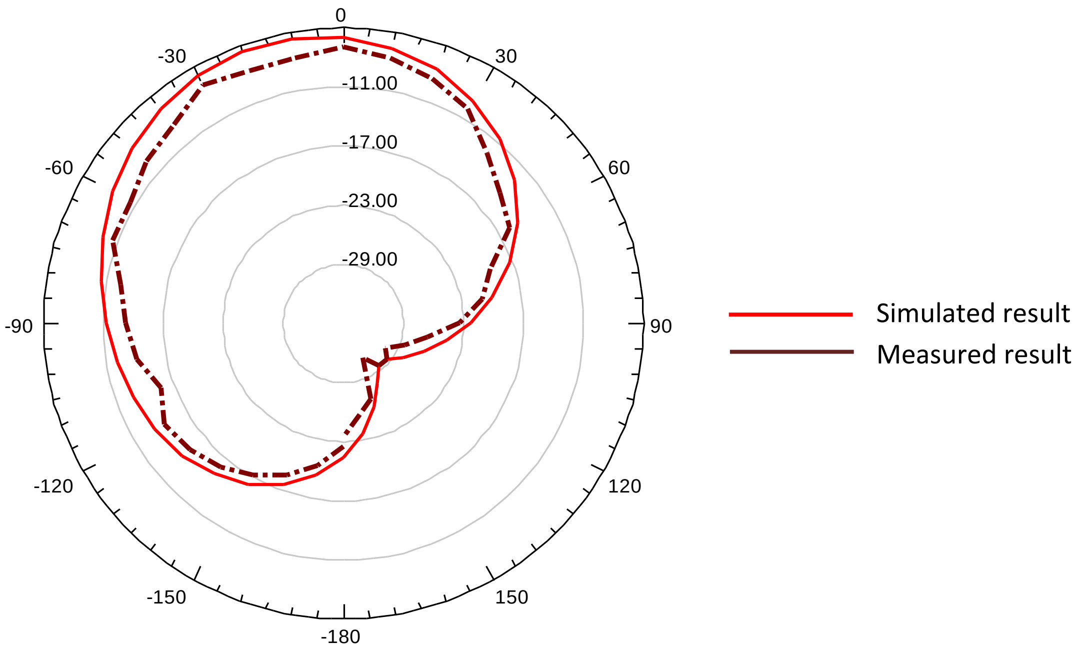


Fig. 3.10(a):Radiation pattern at 5.0 GHz at(Phi=0 degree)

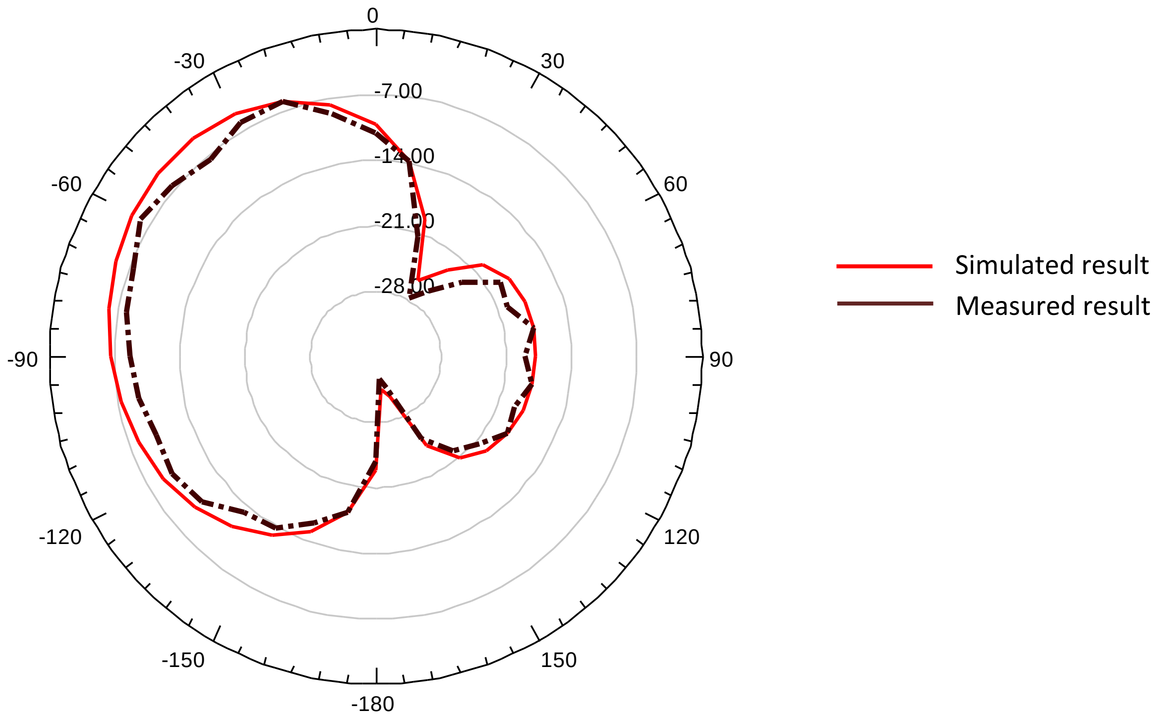


Fig. 3.11(a):Radiation pattern at 7.0 GHz at(Phi=0 degree)

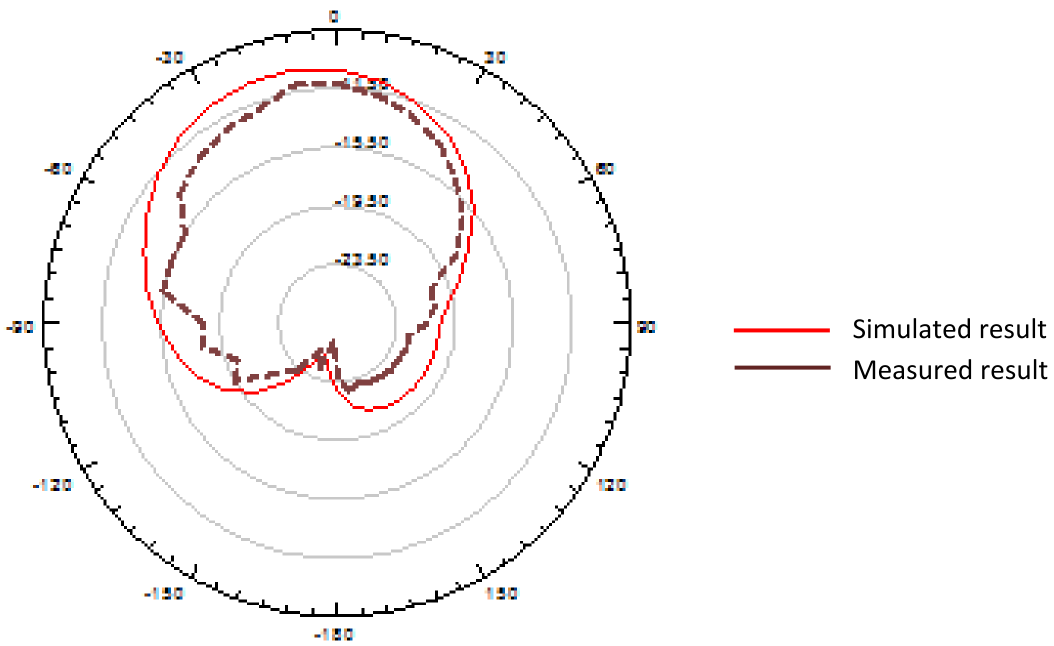


Fig. 3.11(b):Radiation pattern at 7.0 GHz at(Phi=90 degree)

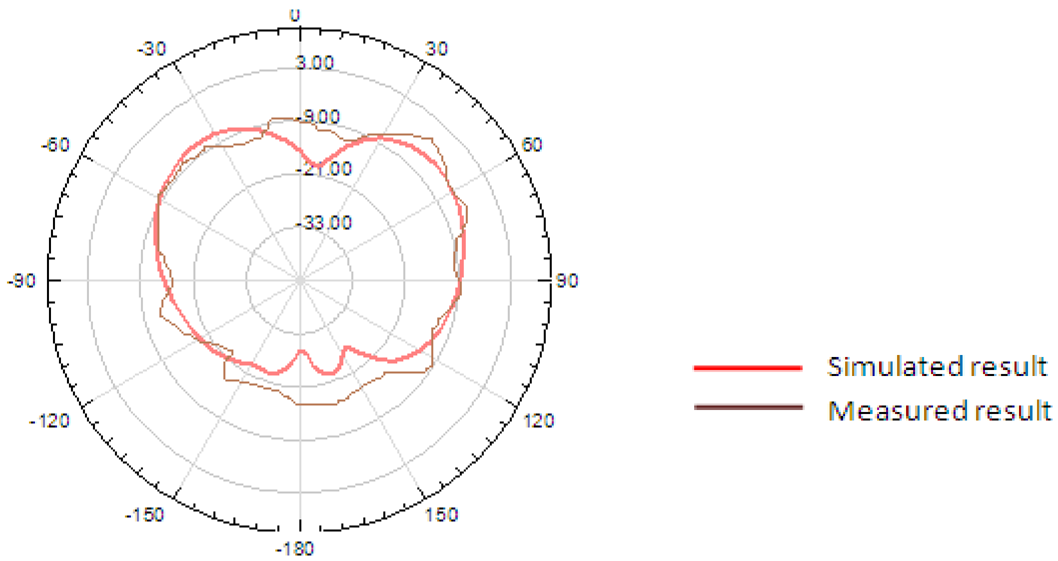


Fig. 3.12(a): Radiation pattern at 7.75 GHz at(Phi=0 degree)

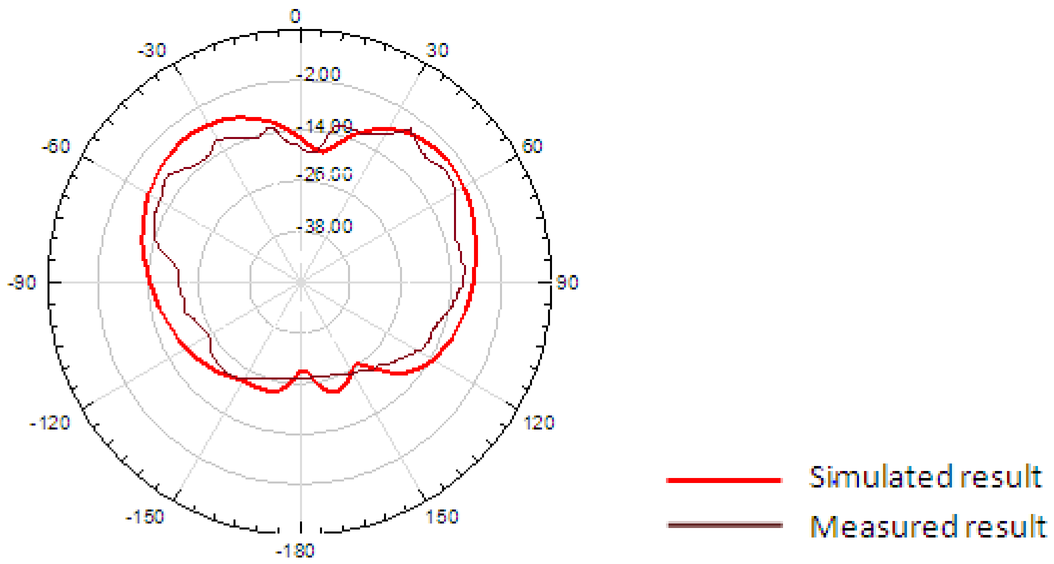


Fig. 3.12(b): Radiation pattern at 7.75 GHz at(Phi=90 degree)

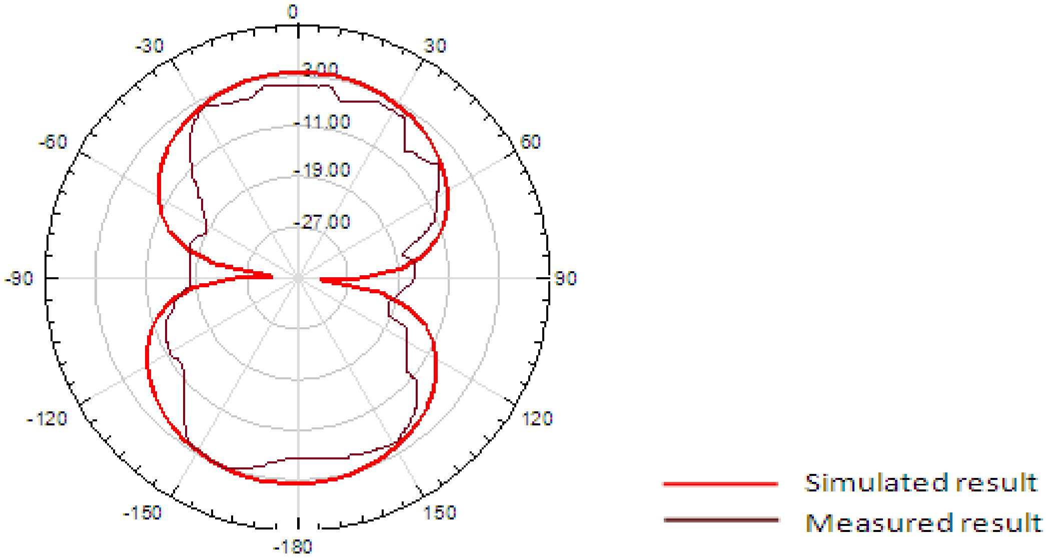


Fig. 3.12(c): Radiation pattern at 7.75 GHz at(Theta=0 degree)

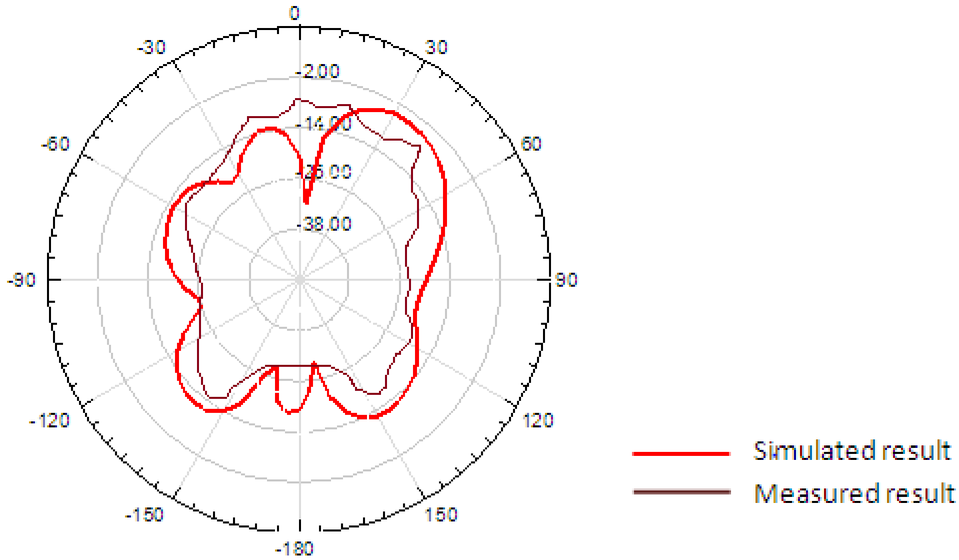


Fig. 3.13(a): Radiation pattern at 10.2 GHz at(Phi=0 degree)

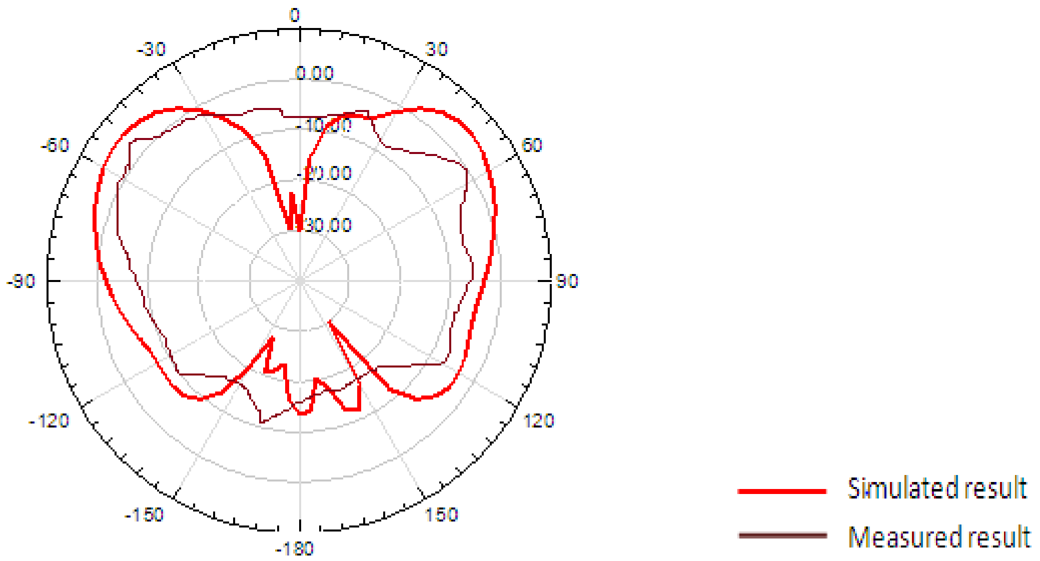


Fig. 3.13(b): Radiation pattern at 10.2 GHz at(Phi=90 degree)

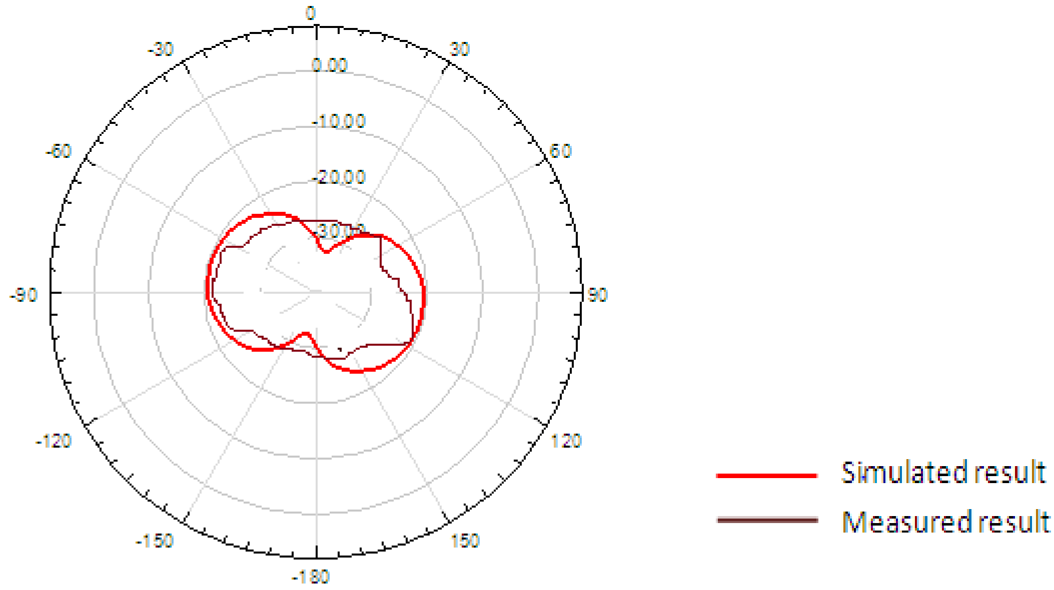
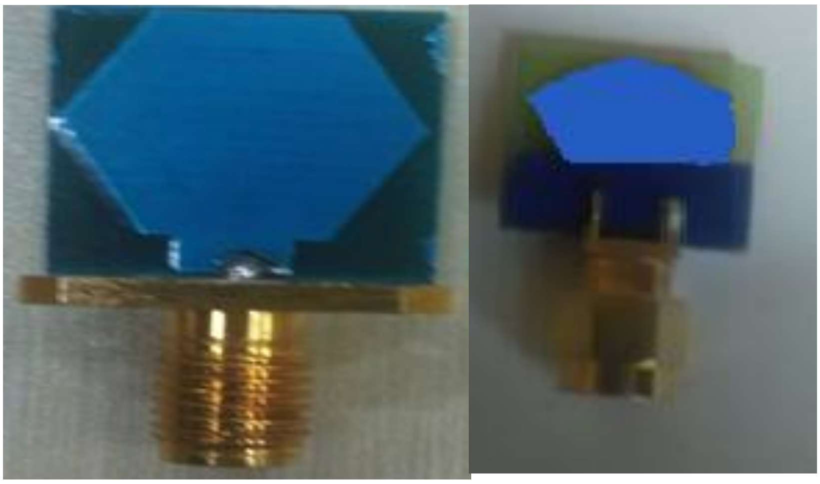


Fig. 3.13(c): Radiation pattern at 10.2 GHz at(Theta=0 degree)

3.6 Fabrication and Measurement Results

The simulated antenna after parametric study and simulation was fabricated on a dielectric substrate material FR4 (ε_r= 4.4, tanδ = 0.002, h = 1.6 mm).The photograph of fabricated hexagonal patch antenna with plane rectangular ground is shown in Fig. 3.14 (a),(b). After fabrication, the return loss of the antenna with respect to frequency is tested using vector network analyzer at Antenna Laboratory, UIET, Kurukshetra.



(a) **(b)**

Fig 3.14: Prototype of fabricated hexagonal antenna (a) front view (b) Rear view

In Fig. 3.15 comparisons of simulated and measured results are presented and found very proximate to each other. Return loss property with good gain is achieved by the proposed antenna as per the requirement of the specified application of the UWBantenna**.**

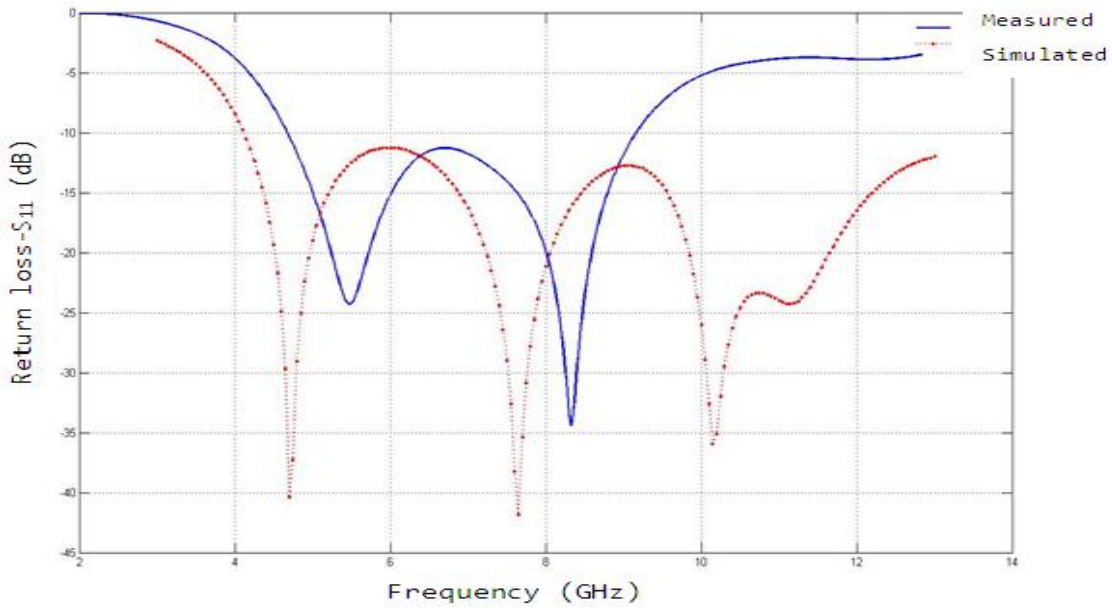


Fig. 3.15: Comparison of the simulated and measured return loss.

3.7 Modification in ground plane shape of Hexagonal UWB antenna

In this section proposed antenna is modified by changing the shape of ground plane and to studythe effect of this modification on bandwidth of UWB antenna. The ground plane mainly consists of metal which is helpful in confining the field between patch and ground plane.The variation in the ground shape has been done in the form of rectangular plane with notches, circular and semi circular ground plane.

3.7.1 Hexagonal patch antenna with notch in (rectangular ground plane)

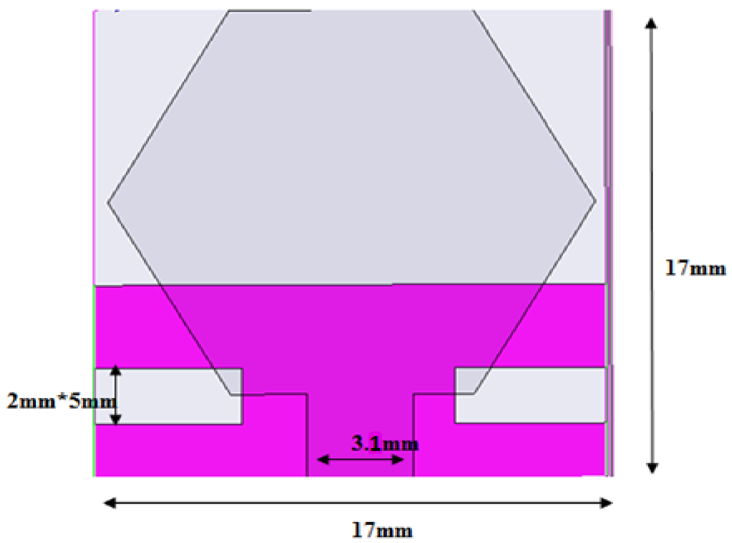


Fig 3.16: Hexagonal patch antenna with notch (rectangular ground plane)

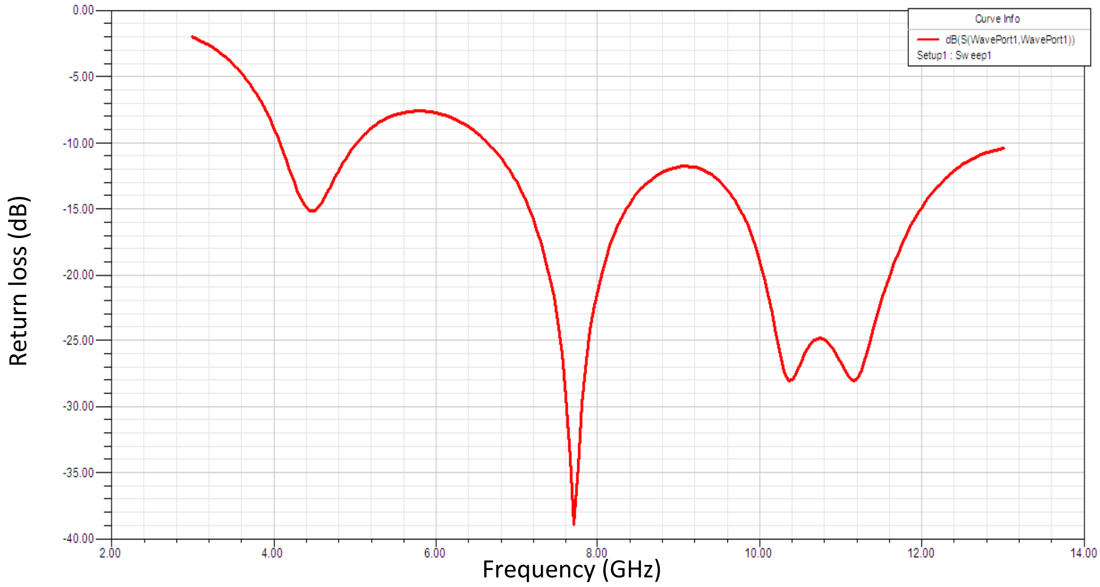


Fig. 3.17: Results of the hexagonal patch antenna with notch cut in the ground plane

The antenna designed with two rectangular notches cut in the ground plane is shown in the Fig. 3.16. Notches are used to extend the effective current path. Rectangular notches provides two frequency band one from 4 - 5 GHz which covers the C- band and another is wide band of 6.8-12.4GHz which covers the C as well as X band. The performance of the antenna is best in the middle band as shown in the Fig. 3.17.Simulated relative power patterns, i.e., Y-Z and X-Y cut patterns are shownFig.3.18 (a) and Fig. 3.18(b)ofhexagonal patch antenna with rectangular ground plane containing notchat resonance frequency 7.6 GHz.The radiation pattern atat 7.6 GHz at(Phi=90 degree) represents the omnidirectional properties.

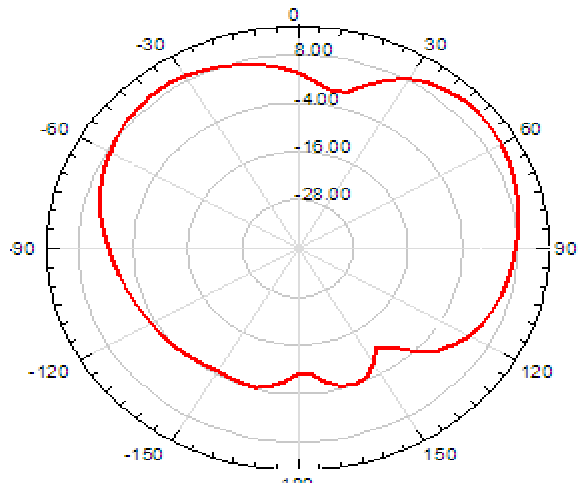


Fig. 3.18(a): Radiation pattern at 7.6 GHz at(Phi=90 degree)

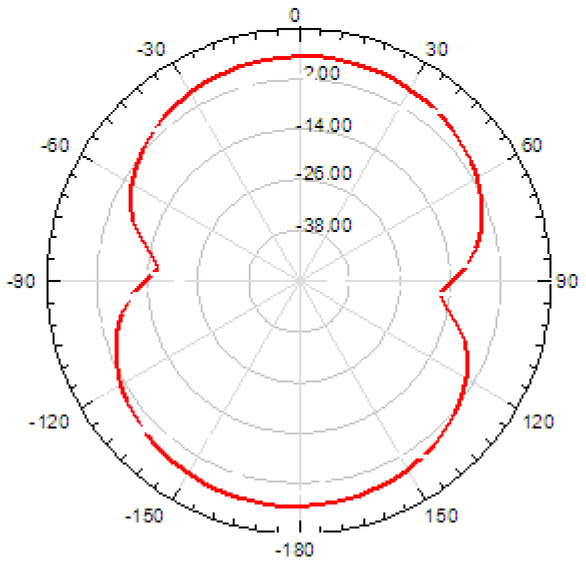


Fig. 3.18(b): Radiation pattern at 10.2 GHz at(Theta=0 degree)

3.7.2 Hexagonal patch antennawithsemicircular ground plane

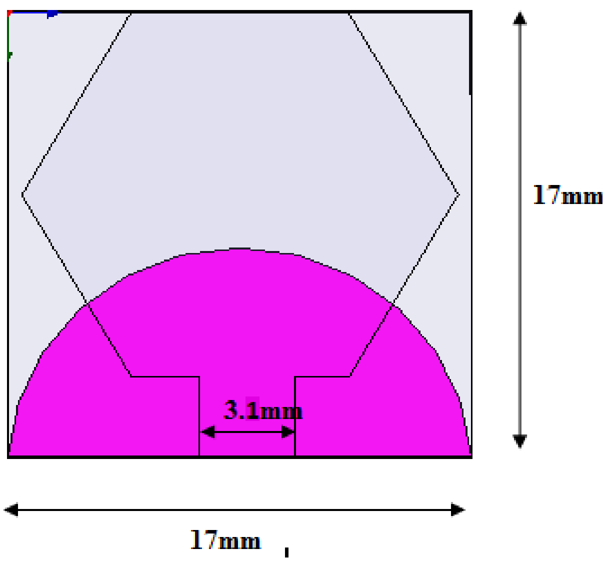


Fig. 3.19: Hexagonal patch antenna with semi circle ground.

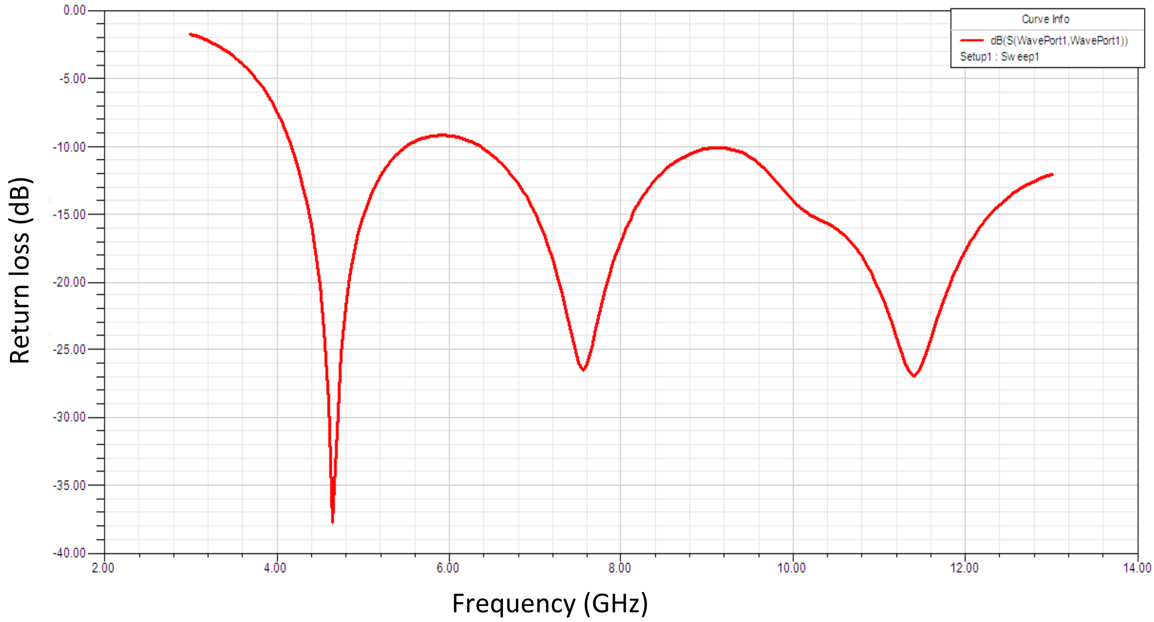


Fig. 3.20: Simulation results of the hexagonal patch antenna with semi-circle ground.

The ground plane of Hexagonal shaped antenna is modified in the form of semi-circle as shown in Fig. 3.19. This improves the result in the lower UWB bandi.e.return loss achieved is -36.0 dB at 4.3 GHz asshown with the help of Fig. 3.20.The radiation pattern of hexagonal patch antennawith semicircular ground plane at resonance frequency 4.8 GHzis shown in Fig.3.21(a) and Fig. 3.21(b).

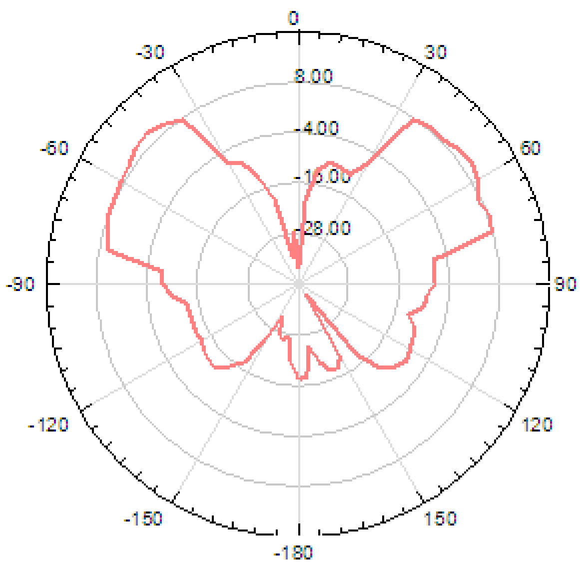


Fig. 3.21(a): Radiation pattern at 4.8 GHz at(Phi=90 degree)

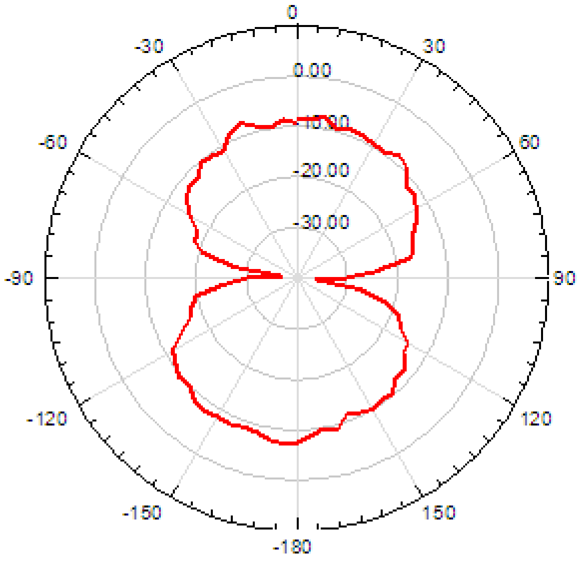


Fig. 3.21(b): Radiation pattern at 4.8GHz at(Theta=0 degree)

3.7.3Hexagonal patch antenna with circular ground

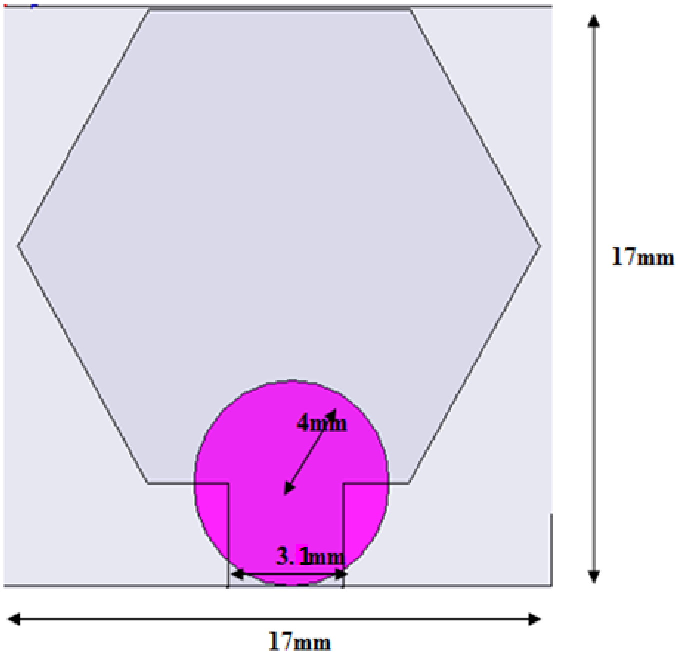


Fig.3.22: Hexagonal patch antenna with circular ground.

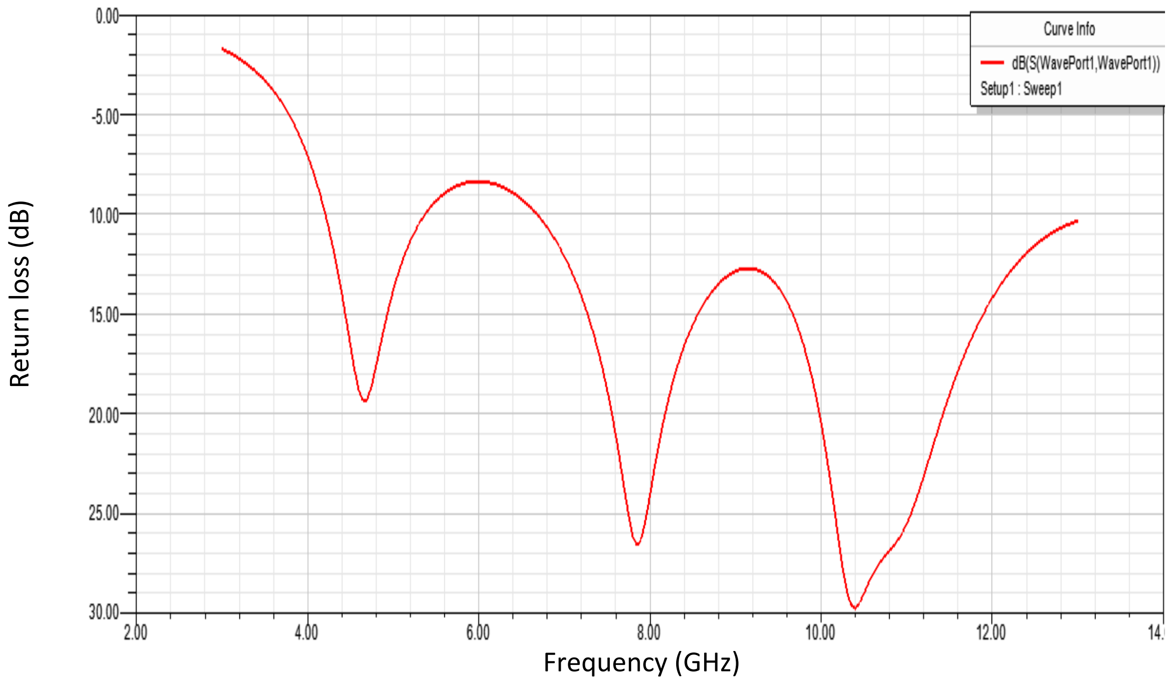


Fig.3.23: Simulation results of the hexagonal patch antenna with circular ground.

The hexagonal patch antenna with circular ground (Fig 3.22)provides good return loss in upper UWB range. The return losses of -19dB,-27 dB and -30 dB is achieved at 4.3GHz, 7.8GHz and 10.2GHz, respectively as shown in the Fig. 3.23.This antenna achieve good results in frequency range 7.8GHz to 11.5GHzthat is useful for X band applications.Theradiation pattern of hexagonal patch antennawith circular ground plane at resonance frequency 7.9 GHz inelevation plane and azimuth plane is shown in Fig.3.24(a) and Fig.3.24(b) respectively.

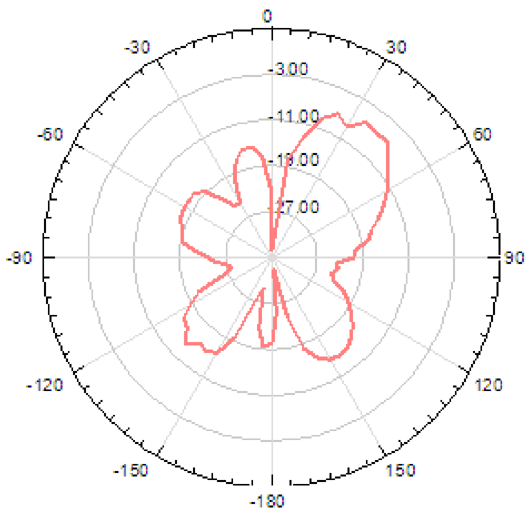


Fig. 3.24(a): Radiation pattern at 7.9 GHz at(Phi=90degree)

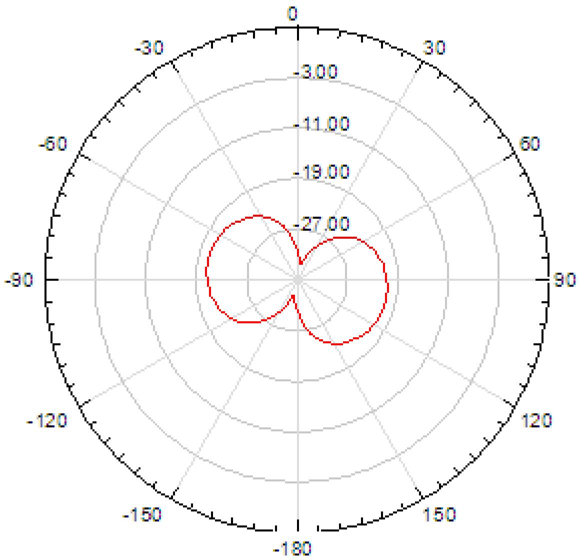


Fig. 3.24(b): Radiation pattern at 7.9 GHz at(Theta=0 degree)

3.8Summary of the chapter

Hexagonal shaped patch antenna having dimension 17mm×17mmis proposed in this chapter. The current density distribution and radiation pattern of hexagonal patch with parametric variation has been discussed. Simulation of the antenna is done with the help of HFSS ver. 11, and the measurement is done by using Vector Network Analyzer (VNA). There is a lot of similarity between the measured and simulated results of the designed antenna. Further the variation in the ground plane in the form of rectangular, circular and semicircular ground has been observed. These variations in ground plane results in resonating at 4.3GHz, 7.9GHz, 10.2GHz and 11.2GHz. The proposed antenna radiationcharacteristics including return loss indicate that the proposed antenna can be used for WLAN, X band, PCSandUWB WPAN applications.In next chapter, the design of novel printed staircase monopole antenna is discussed for UWB frequency range.

Chapter 4

StaircaseUltrawideband Antenna With Flowery DGS

4.1 Introduction

Tremendous growth has been noticed in Ultra-wideband (UWB) technology since FCC released the frequency range of 3.1–10.6 GHz for commercial use purpose. This chapter,proposes the design ofanew printed monopole antenna for UWB applications.The shape of rectangular radiator is cut into stairs like structure to form a printed monopole antenna that radiate in UWB frequency range.Single vertical stripline and double vertical stripline slot are cut from stairshape antenna to resonate the antenna for multiband operation such as Wi-Fi/IMT/WiMAX applications. Defective ground structure (DGS) made a considerable improvement in the development of UWB antenna. It is the latest technology to improve the quality and properties of antenna[22]. This technique is also useful in enhancing the impedence bandwidth as well as reducing the size of antenna.DGS is introduced by etching the defects in the backside ground plane lying under the microstrip feedline.This causes the shield current distribution to get disturbed hence alters the characteristics of transmission line such as inductance and capacitance[73,74]. Various structures of DGS slots have been discussed for microstrip antenna such as spirals, circle and dumbbells [22]. In this chapter the DGS is designed with a flower like shape to increase the bandwidth of the antenna. Finally, the proposed antenna is fabricated and performance parameters like return loss, current distribution and radiaition pattern are measured to approve against simulation results.

4.2 Antenna Design

The proposed antenna was derived from a plane rectangular patch which is designed by using the following equations(Equation 4.1-4.4) for length and width [9],[72].The dielectric material selected for this design is FR4 which has a dielectric constant of (ε_{rel}=4.4), the height of the dielectric substrate is (h = 1.6) mm. the resonant frequency of the antenna must be selected properly. The UWB antenna use the frequency range from (3.1-10.6) GHZ, so the f_c selected for this design is 3.4 GHz.

Width of rectangular microstrip patch is given by

$$\boldsymbol{w} = \frac{v_0}{2f_c}\sqrt{\frac{2}{\epsilon_{rel}+1}} \qquad \text{……….(4.1)}$$

Where fc = 3.4 GHz

Where v_o is the velocity of the light

$\epsilon_{rel=}$ 4.4 the dielectric constant of the dielectric material

So w = 26.8 mm

Effective refractive index: The radiations traveling from the patch towards the ground pass through air and some through the substrate (called as fringing). Both the air and the substrates have different dielectric values, so the value of effective dielectric constant($\epsilon_{rel(eff)}$) is calculated using the following equation

$$\epsilon_{rel(eff)} = \frac{\epsilon_{rel}+1}{2} + \frac{\epsilon_{rel}-1}{2}[1+12\frac{h}{w}]^{-1/2} \qquad \text{…………(4.2)}$$

Where 'w = 26.8 mm

h=1.6 mm 'is the height of the substrate.

$\epsilon_{rel(eff)}$=3.25

Due to fringing effects there is extension in length by an amount of (ΔL).Therefore, ΔL (increase in length) of the patch can be calculated using the following equation

$$\frac{\Delta l}{h} = 0.412\frac{(\epsilon_{rel(eff)}+0.3)\{\frac{w}{h}+0.264\}}{(\epsilon_{rel(eff)}+0.258)\{\frac{w}{h}+0.8\}} \qquad \text{…………(4.3)}$$

$$\Delta l = 0.757 \text{ mm}$$

So, the effective length l_{eff} of rectangular microstrip patch is given by

$$l_{eff} = \frac{v_0}{2f_c\sqrt{\epsilon_{rel(eff)}}} \qquad \text{…………..(4.4)}$$

Where $\epsilon_{rel(eff)}$=3.25

Hence actual length of antenna is given by

$l = l_{eff} - 2\Delta l$

$l = 24.1 - 1.5 = 22.6$ mm

Using the above mentioned equations, the antenna is designed with a rectangular patch having dimension 26.8 mm (w) x 22.6 mm (l) as shown in Fig.4.1.

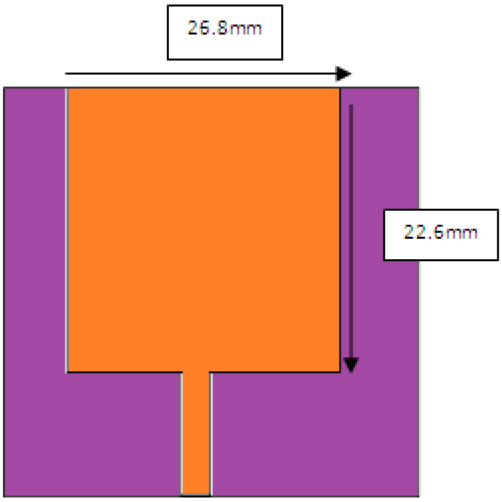


Fig. 4.1: Rectangular patch Antenna

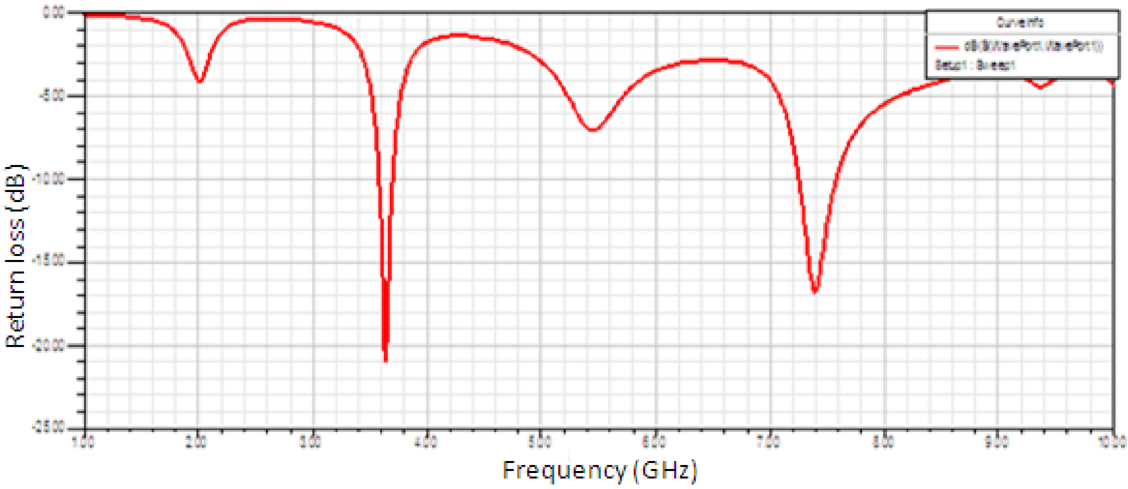


Fig. 4.2:Simulated return loss for rectangular patch Antenna

Intially antenna is designed to work on lower UWB frequency. The dimensions of patch is selected to work on 3.4 GHz by using standard desiging equations. In next step the dimensions of patch is reduced to achieve middle UWB frequencies. Further, in order to achieve higher UWB frequency band as well as overall UWB, steps are introduced in patch in iterative manners. The parametric study is also performed to achieve desired UWB bands (3.2 to 10.6 GHz).

In this step the dimensions of patch is reduced to achieve wide bandwidth.After going through the optimization process, the optimum parameters for the rectangular microstrip patch antenna were taken as 20 mm (width) and 26 mm (length) as shown in fig.4.3. It has been observed that modified rectangular patch antenna achieve frequency band from 6.4 to 7.8 GHz shown in fig 4.4.

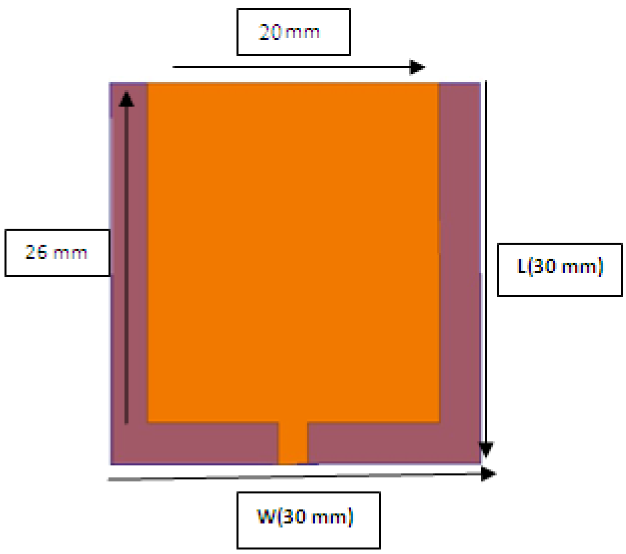


Fig. 4.3: Rectangular patch Antenna with modified dimension

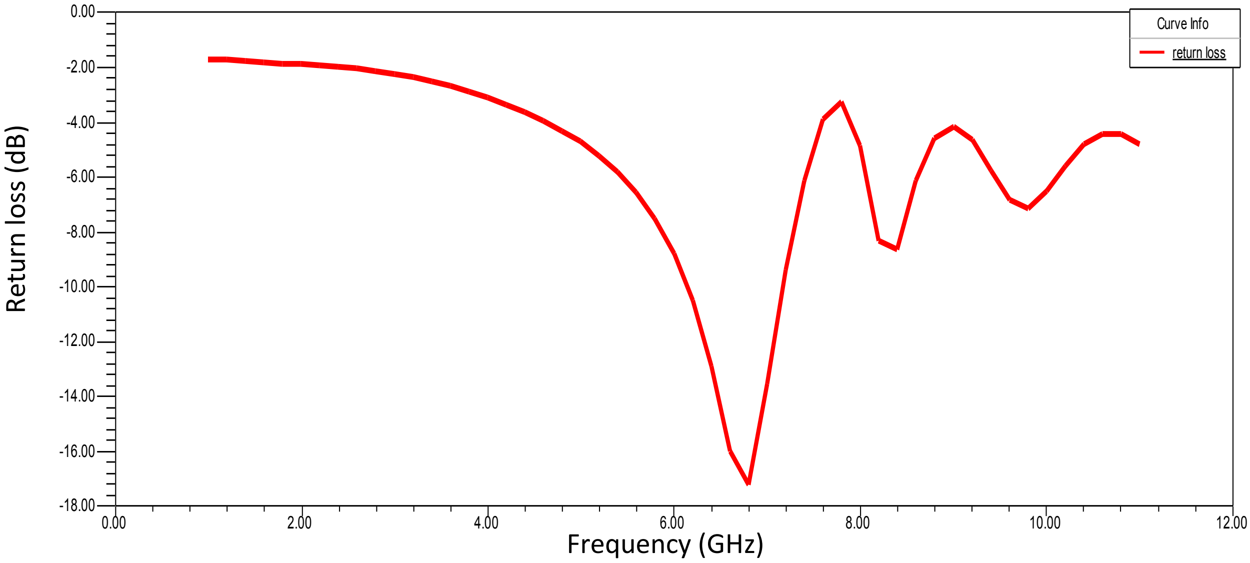


Fig. 4.4:Simulated return loss for modified rectangular patchAntenna

To achieve the wide band the rectangular patch antenna was modified by cutting steps along the width as shown in figure 4.5 .One step was cut along the lower side and the upper side of the patch[75],[76]. It has been observed from the return loss graph shown in Fig. 4.6 that the antenna with single stair is now resonant at dual frequency bands from 5.9 to 6.4 GHz and 9.2 to 9.6 GHz.

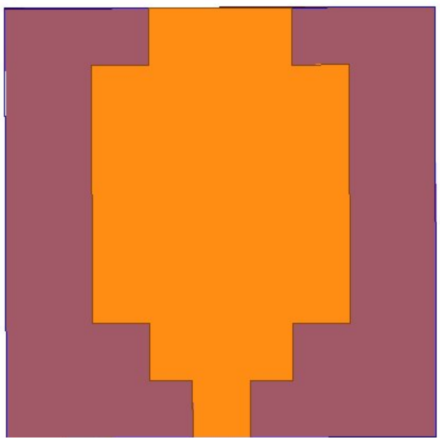


Fig 4.5:Rectangular patchAntenna with single Step.

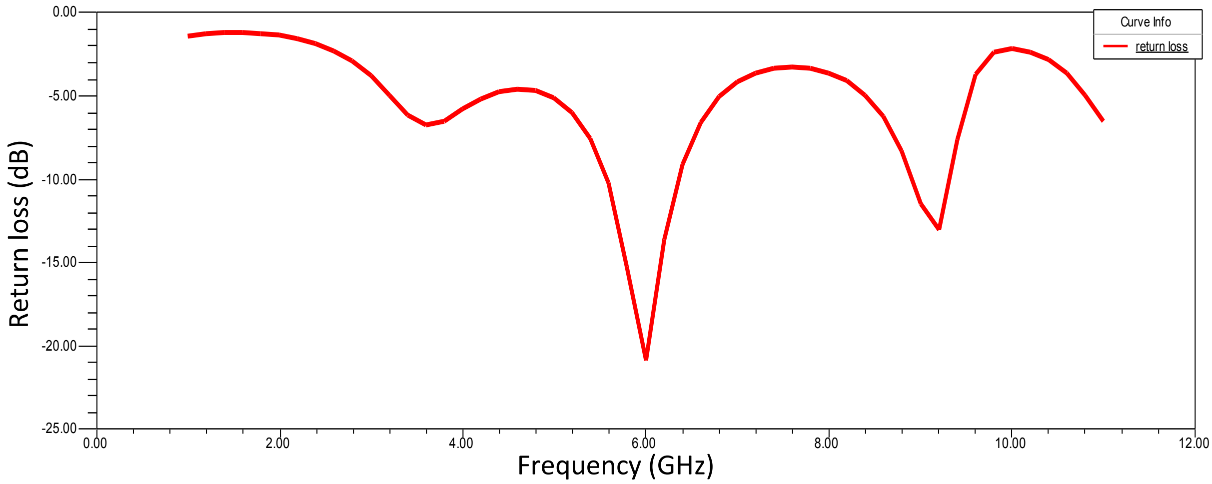


Fig. 4.6: Simulated return loss for rectangular patchAntenna with single step.

In next step the antenna was further modified by cutting one more step[76] as shown in Fig.4.7.This modification improves the bandwidth and antenna now covers the frequency range between 3.4 to 9 GHz and 10.2 to 10.6 GHz as shown in Fig.4.8 there by making it a ultra wideband structure.

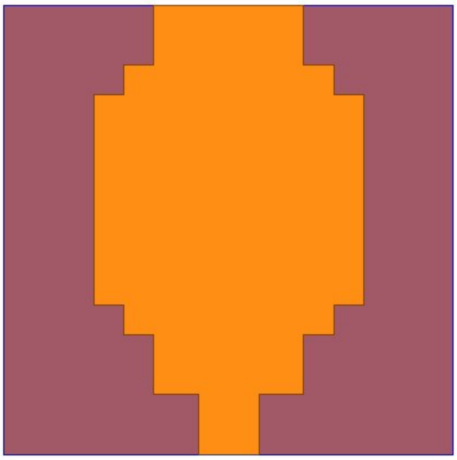


Fig. 4.7:Rectangular patchAntenna with double step.

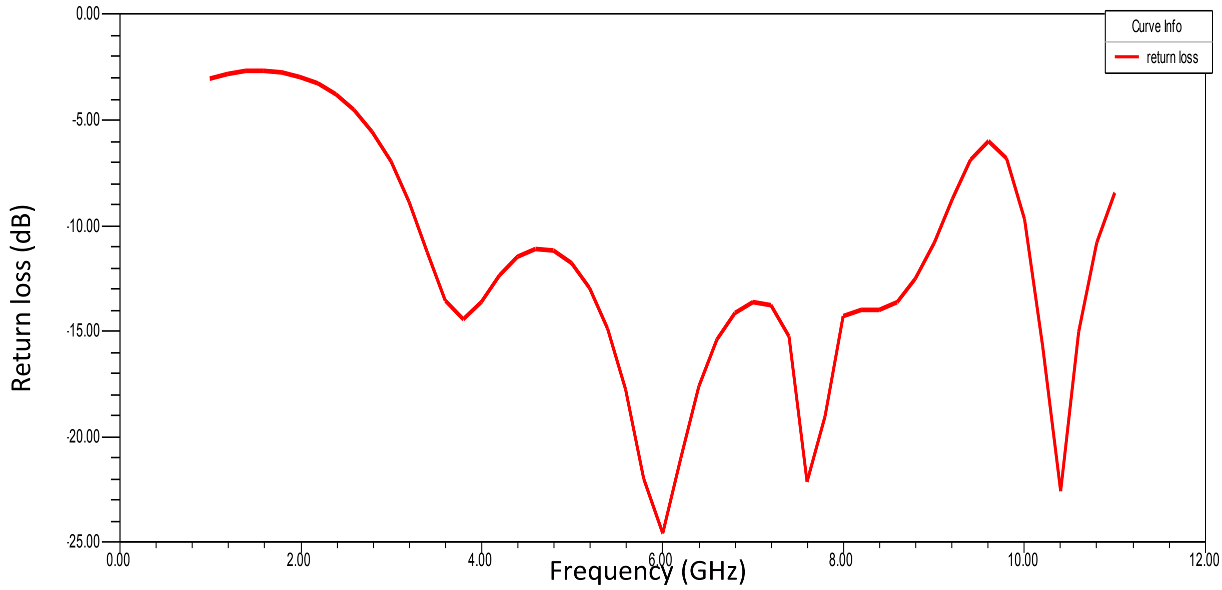


Fig. 4.8:Simulated return loss for rectangular patchAntennawith double step

4.3 Parametric study

This chapter describes a novel staircase ultra-wide band antenna (UWB). The design also includes defected ground structure (flowery DGS) to improve the bandwidth and to reduce the harmonic and surface wave effect. The proposed antenna is further modified using single strip and double strip notch to finds its applications inmilitary services (7.2/8.3GHz),IMT services (5.8/6.7 GHz),WLAN(5.2/5.8 GHz)and WiMAX (3.5/5.5 GHz)

4.3.1 Effect of varying steps length and width on return loss

The proposed UWB antenna is considered and parameterized by selecting the best values of different parameters mentioned in Fig.4.9. In this parametric study the optimal value of each parameter was selected and left over(remaining) parameters were optimized by fixing it. In this parametric study the simulation results were obtained using ANSYS SOFT HFSS simulator to simulate the antenna parameters .The proposed antenna isinvestigatedfor step width(a,bandc) and step length (s1,s2,s4 and,s5) of this structure for best results.

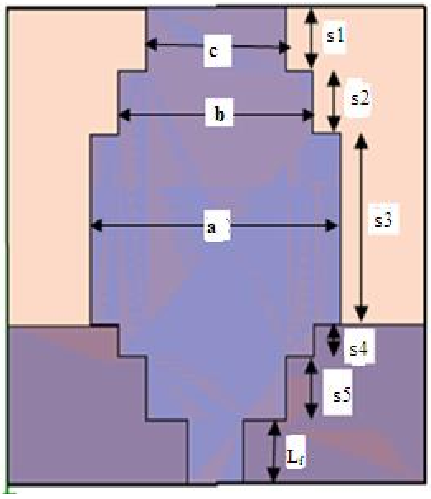


Fig 4.9: Geometry of proposed antenna

4.3.1.1 Variaiton of parameter 'a'

At first the value of 'a' is varied from 17mm to 19mm with a step of 1mm with fixed values of parametres b and c. It is observed that the variation in parameter has great impact on bandwidth as well as on return loss of proposed antenna. As the value of 'a' is increased the bandwidth gets improved initially and on further increase the bandwidth is decreased.Peak of the return loss curve is sensitive to the variation of this parameter. The optimal value of a is 17mm. as shown in Fig.4.10.

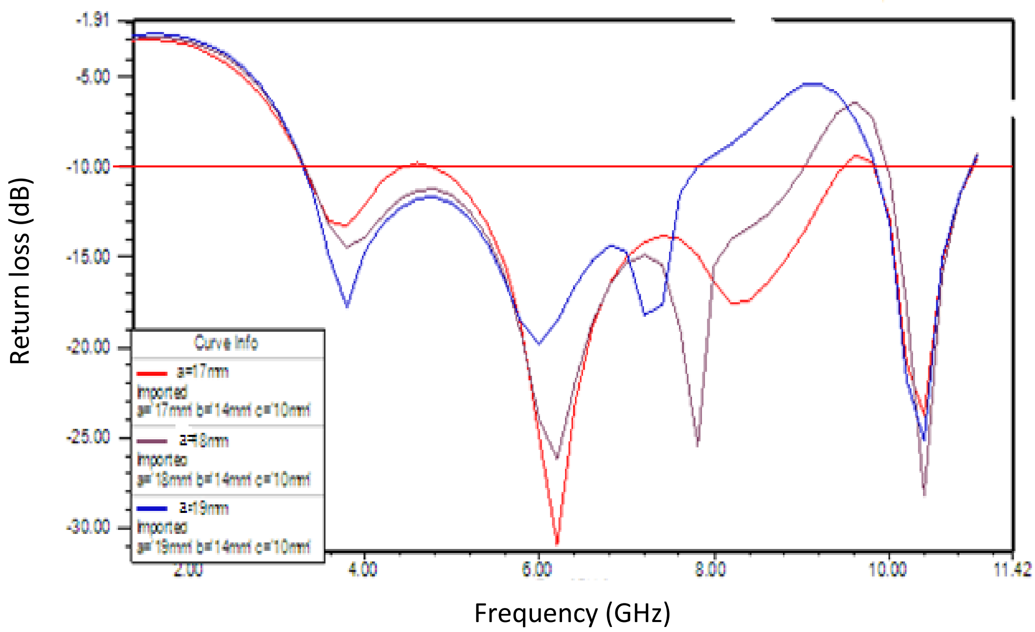


Fig.4.10:Parameteric variation of a(width)of stair.

4.3.1.2 Variaiton of parameter 'b'

In next step value of 'b' is varied from 13 to 15 mm with a step of 1mm with fixed values of parameters a and c.The bandwidth obtained at 14mm and 15 mm is very proximate to each other as shown in Fig 4.11 . Peak of the return loss curve is also sensitive to the variation of this parameter so,15mm is considered as optimum value for parameter 'b'.

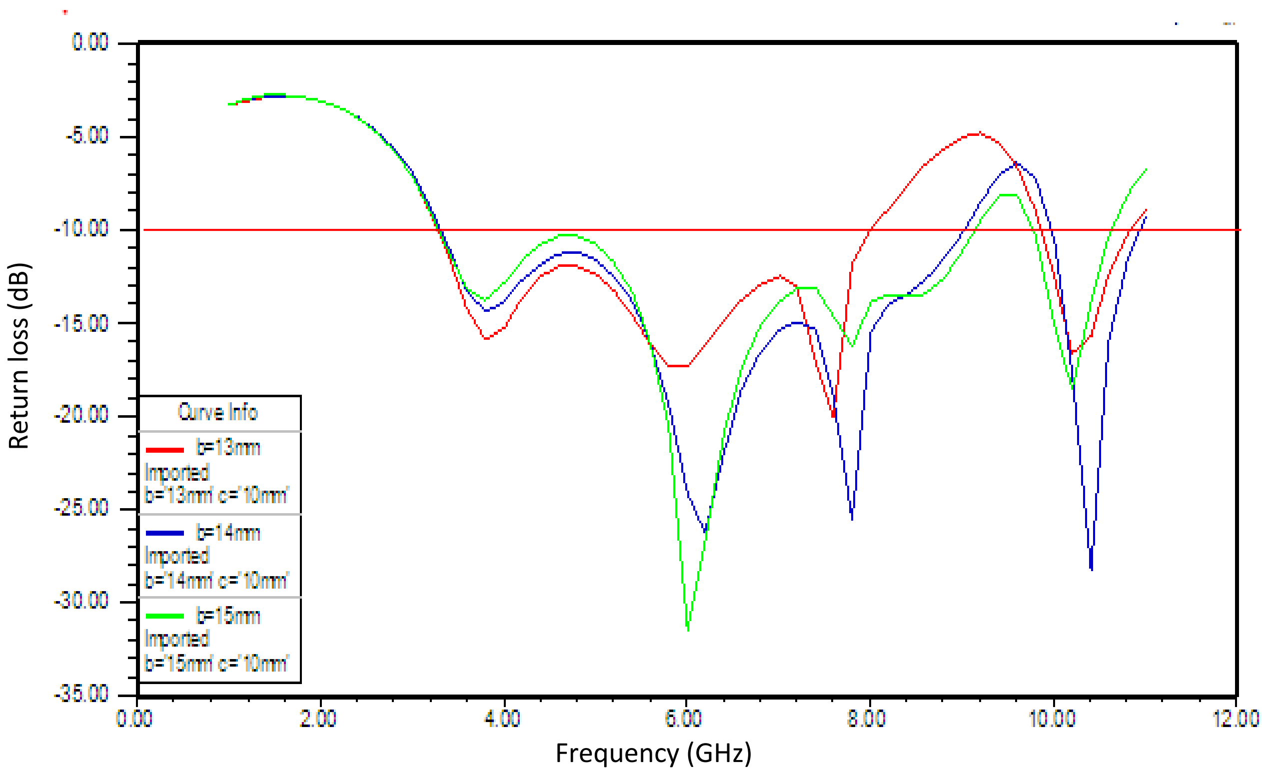


Fig.4.11:Parameteric variation of b (width) of step.

4.3.1.3 Variaiton of parameter 'c'

Further,the value of 'c' is parametrized by varing it from 9 to 11mm with fixed values of parametres a and b. At c=9mm bandwidth achieved in lower UWB band is better then the upper UWB band. As the value of 'c' is increased the bandwidth gets improved however on further increase the bandwidth is decreased. Finally the optimum value of c is 10mm as shown in Fig.4.12.

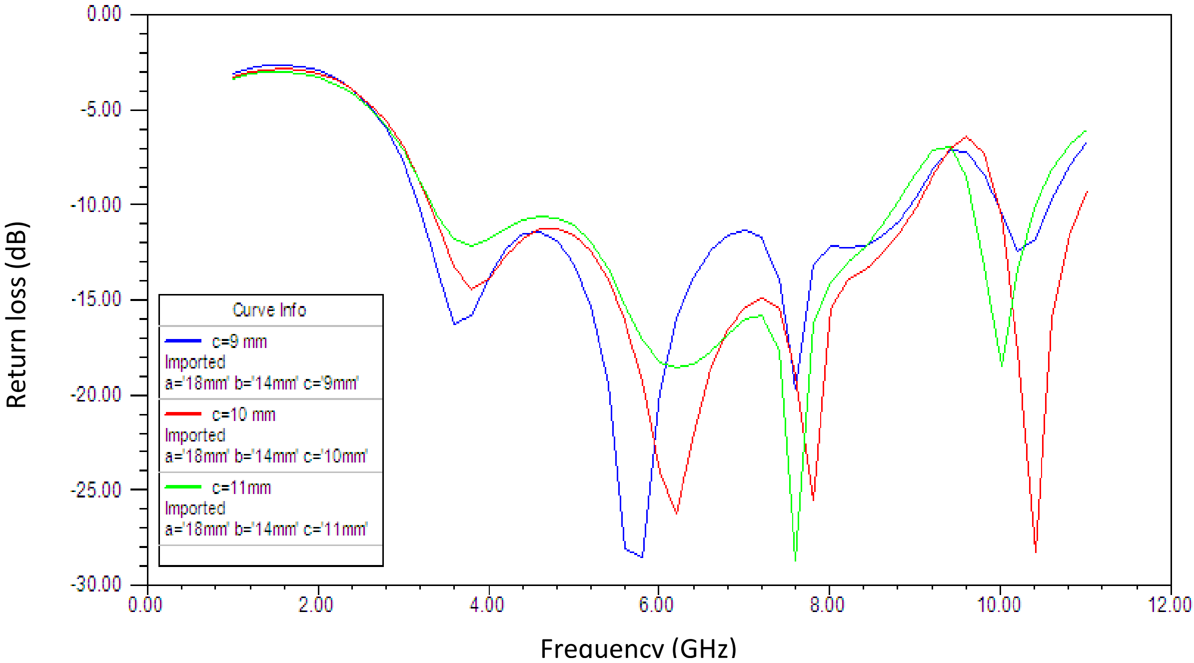


Fig.4.12:Parameteric variation of c(width) of step.

4.3.2.Variaiton in length of steps

After fixing the widths of various steps, the optimization of the proposed antenna is done in terms of length of the staircase(s1,s2,s4,s5) to attain the ultra wideband characteristics. In this section the proposed antenna is investigated for five different step sizes of staircase antenna. The return loss graph w.r.t. frequency for various step sizes has been observed and from Fig. 4.13 it is evident that step size 5,5,3,5 (black trace) gives better bandwidth which is necessary for wideband/UWB antennas.

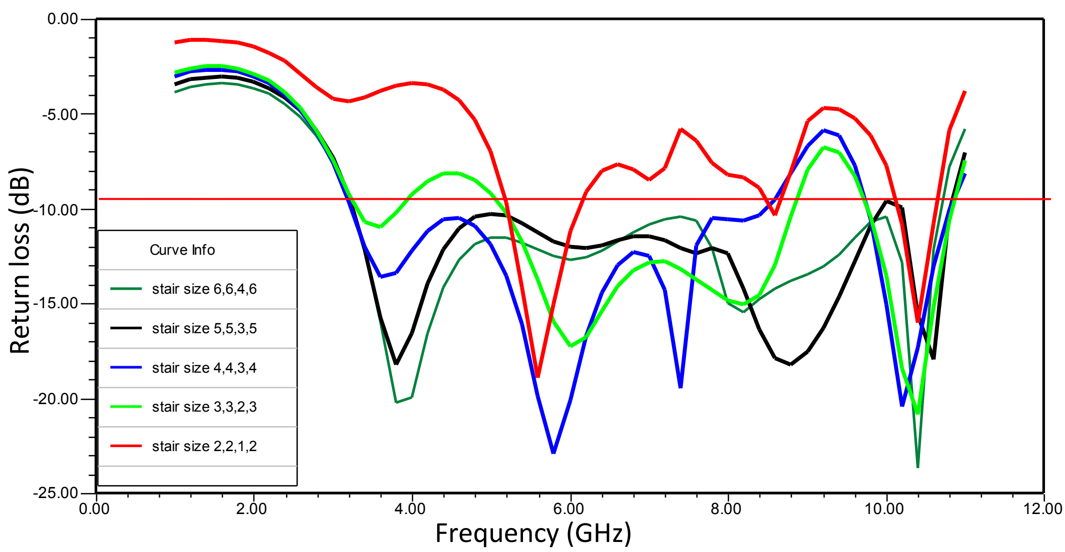


Fig. 4.13: Effect of step length variation on proposed antenna

The configuration of UWB antenna with dimension is demonstrated in Fig. 4.14 and given in table 4.1. The radiating patch has stairs like structure. FR4 epoxy substrate is used to design the antenna with a dielectric constant of 4.4 and loss tangent value of 0.02. The size of substrate is 30 × 30 sq. mm with thickness of 1.2 mm. A microstrip feed line of 50 ohm is used to excite the antenna. The width of feed line is 2.3 mm and ground length is of 10 mm.

Table 4.1: Parametric Study of Staircase antenna

Parameters	**Size in mm**
Width of first step(a)	**17**
Width of second step(b)	**15**
Width of third step(c)	**10**
Length of step1(S1)	**5**
Length of step2(S2)	**5**
Length of step3(S3)	**8**
Length of step4(S4)	**3**
Length of step5(S5)	**5**
Length of feedline(L_f)	**4**
Width of feedline(W_f)	**2.3**

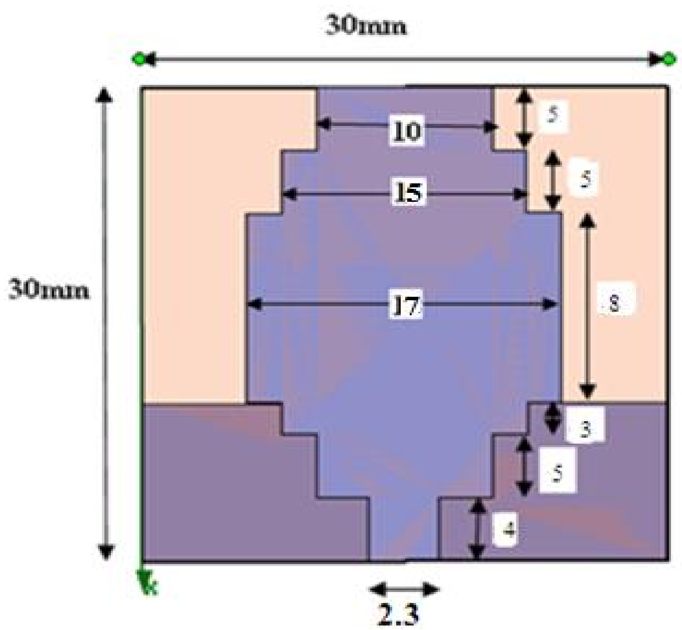


Fig. 4.14: Dimensional structure of proposed antenna

The performance of the proposed antenna is described by the reflection coefficient curve in Fig.4.15. It has been observed that the proposed staircase antenna achieve the wideband from 3.8 to 9.8 GHz and 10.2 to 10.6 GHz which covers nearly the complete UWB band and suitable for UWB application.

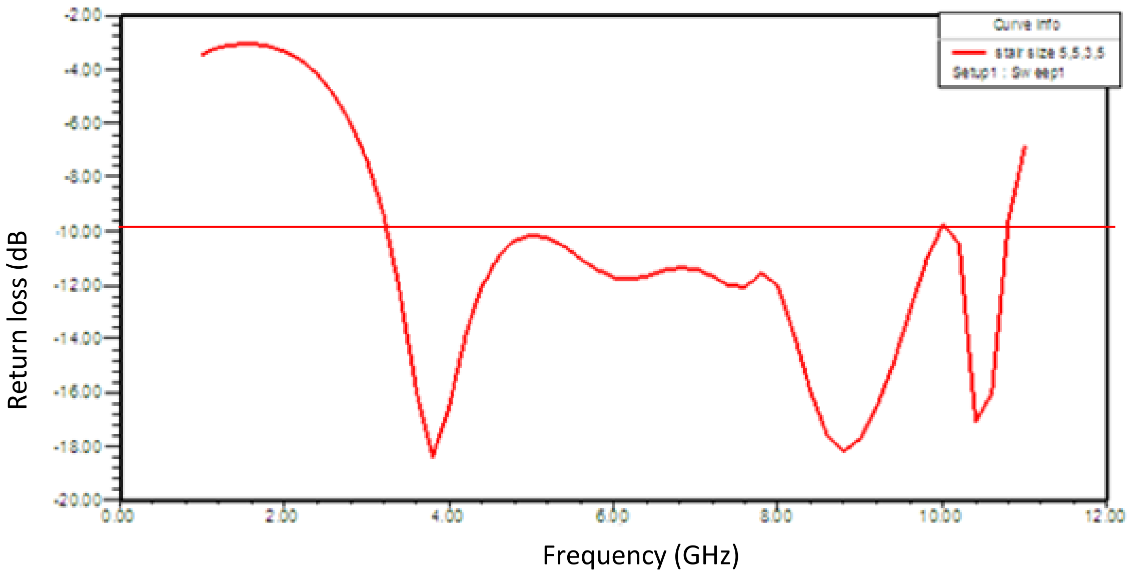


Fig. 4.15: Simulation results of proposed antenna with rectangular ground

4.4 Design of defected ground structure ultra wide band antenna

In reference to UWB antenna, defected ground structure technique is employed to design an ultra wideband antenna.The major disadvantage of microstrip antenna is its narrow bandwidth compared to other microwave antennas. So, to overcome the bandwidth problem or to enhance the bandwidth DGS has been introduced in regular antenna.Secondly the surface wave that occurs at the substrate layer is undesired. Because when the antenna radiates some of the radiated power is confined along the surface of the substrate due to which antenna efficiency and bandwidth is reduced [22]. By adding the DGS, the effect of surface wave can be suppressed resulting into enhancement in impedance bandwidth by achieving the same radiation pattern and gain[52]. DGS may be introducing by cutting shape from ground plane and it can be simple or complex. The different cuts used in patch of antenna, is used to change the direction of antenna which finally resonate the antenna at different bands. It is observed different DGS helps in achieving different resonant frequencies and different bandwidth [73,74]. This chapter influence the staircase patch to define the boundary and flowery shape DGS (Fig 4.16) is introduced to improve the bandwidth and current flow. The flower petals are configured by using the circles having same radius from the center.The length and width of defected ground is 16mm each and radius r is of 3mm. The value of central radius denoted by R is 3.16mm. These dimensions and position of DGS has been obtained in this case as to fully fit inside the staircase shape.

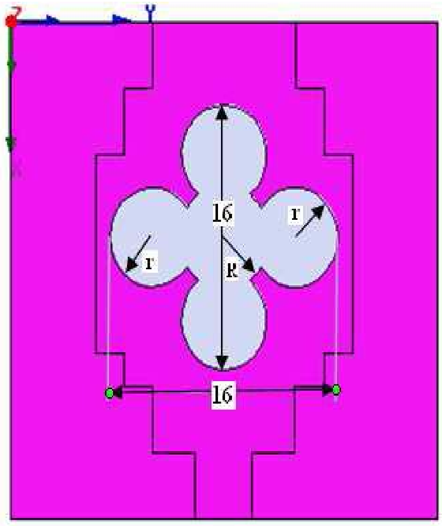


Fig.4.16:Defected ground structure design of the proposed antenna

The return losses for the Staircase antenna with DGS is shown in Fig. 4.17. The realized antenna achieved high bandwidth within the range of 3.2 GHz to 10.6 GHz covering almost the entire UWB band.Improved return loss in complete band is observed from 3.2 to 10.6 GHz instead of 3.6 to 10.2GHz in normal ground.Peak of return loss curve is also improved from -18dB to -22dB and new operating resonant frequency 5.8 GHz is also observed after introduction of DGS. As specified in previous section that DGS helps in achieving different bandwidth and different resonant frequencies.

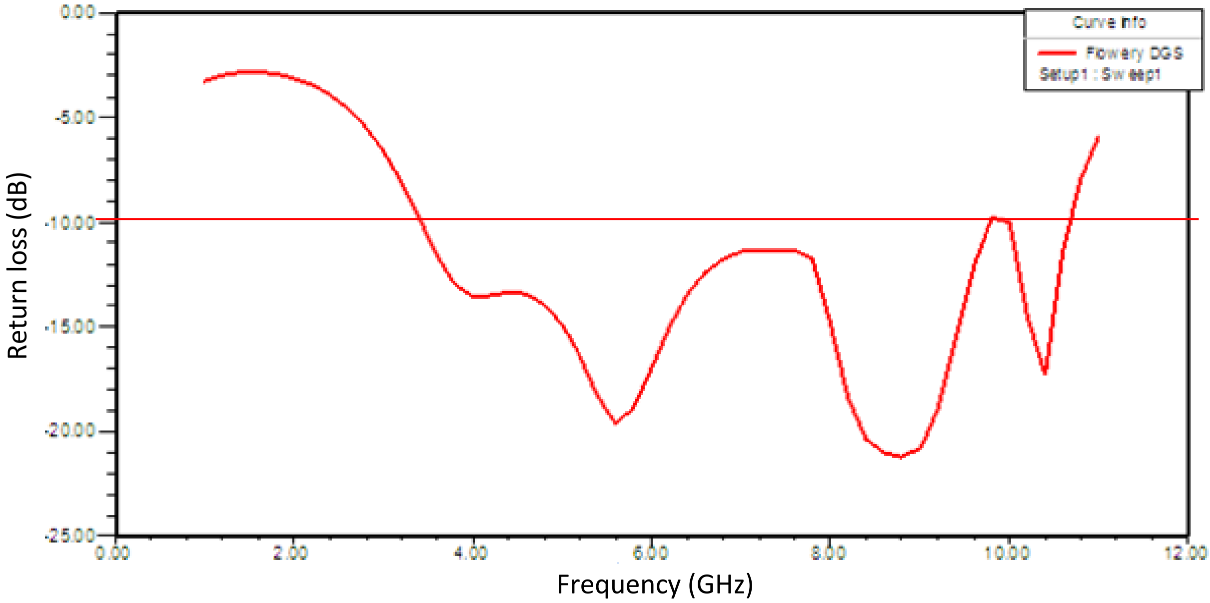


Fig. 4.17:Simulated return loss for the proposed UWB antenna with flowery DGS.

4.5 Electric field distribution and VSWR for the proposed antenna

The electric field distribution of both antennas (rectangular patch and rectangular patch with staircase) are demonstrated in Fig.4.18 and Fig. 4.19 respectively.

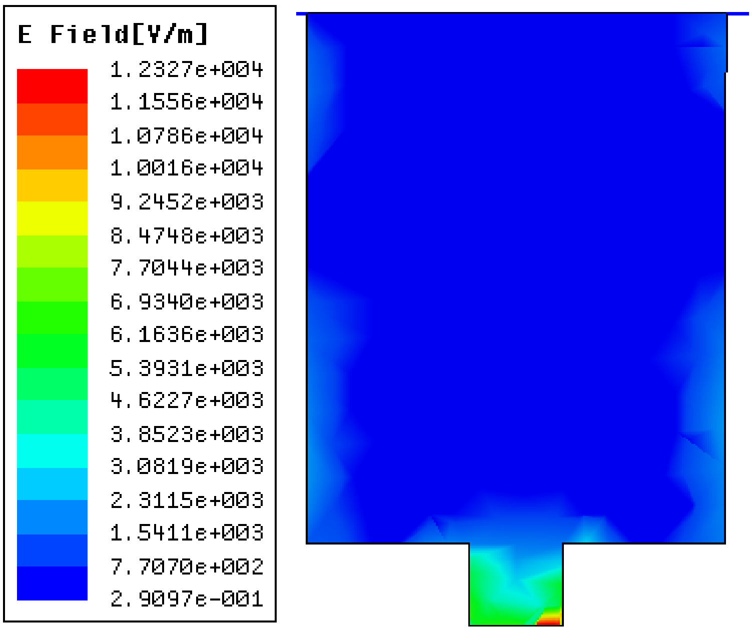


Fig.4.18:Simulated results of the electric field distribution for the rectangular patch antenna(without staircase)

Fig.4.19 shows that the E-field is more at the staircase rectangular antenna instead of plane rectangular patch antenna (Fig.4.18) which justifies the broadband performance of staircase antenna .

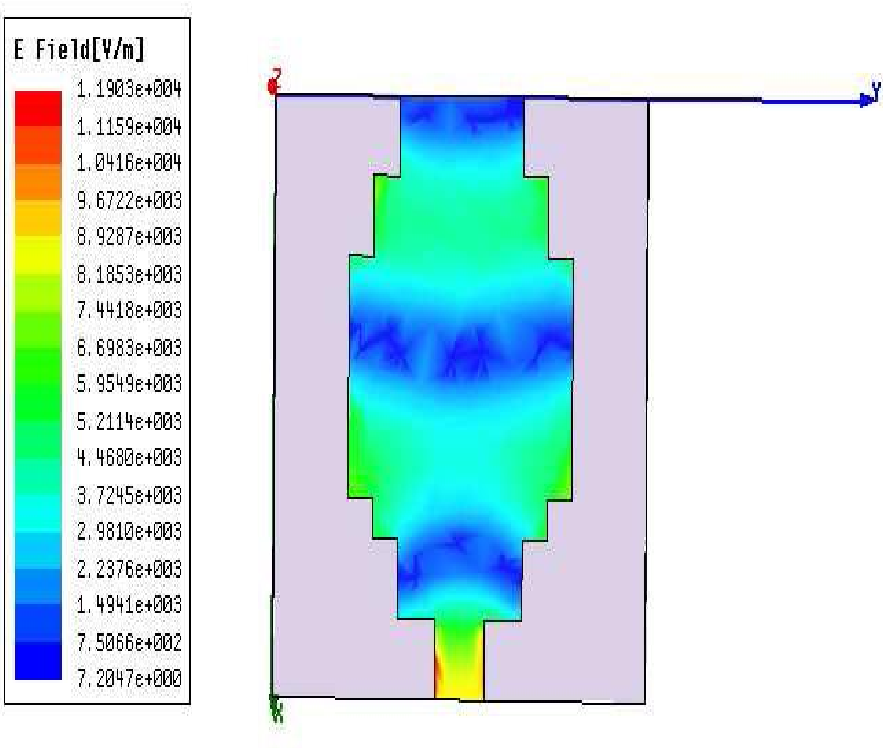


Fig.4.19:Simulated results of the electric field distribution for the proposed antenna.

It is desireable that for efficient working of antenna VSWR should be less than 2:1.As clear from the Fig.4.20 that VSWR is less than two for frequency range 3.3 to 10.6 GHz for staircase antenna.

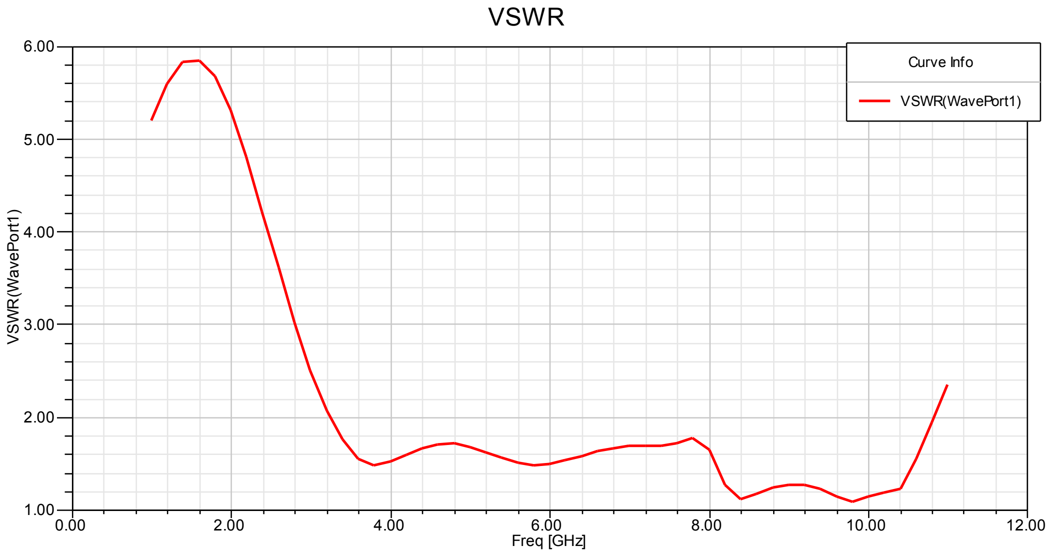


Fig.4.20: VSWR for the proposed antenna.

4.6 Radiation patterns of the proposed antenna

A radiation pattern describes the behaviour of antenna's radiation in the surrounding space. The pattern is usually measured at a sufficient distance from the antenna known as far field. Considering spherical coordinates, an H- plane indicates rotation in the x-y plane with rotating the antenna in the phi direction while theta measurement held constant. Similarliy an E- plane measurement indicates rotation through the x-y plane withrotating the antenna in the theta direction while keeping the phi measurement constant.The 2D far field radiation patterns for Elevation plane and Azimuth plane of the proposed antenna(simulated and measured) at different frequencies are discussed in this section.From Fig.4.21 (a),(b) to Fig.4.24 (a),(b),Co- and cross-polar radiation patterns of proposed antenna are taken at various frequencies i.e at 6.0 GHz, 7.8 GHz,9.0 GHz and 10.4 GHz respectively in H-plane (Y-Z plane, phi=90, phi=0). It has been observed that antenna has omni-directional radiation patterns at operating frequency of 6 GHz, 7.8 GHz and 10.4 GHz(Fig 4.21(a) to (b),Fig 4.22 (a) to (b)and4.24 (a) to (b)).However radiation pattern in E-plane (X-Y plane, theta=0) at 6.0 GHz, 7.8 GHz, 9.0 GHz and 10.4 GHz respectively is shown in Fig. 4.21(c) to 4.24 (c) indicates a figure like eight for elevation plane representing dipole pattern characteristics.

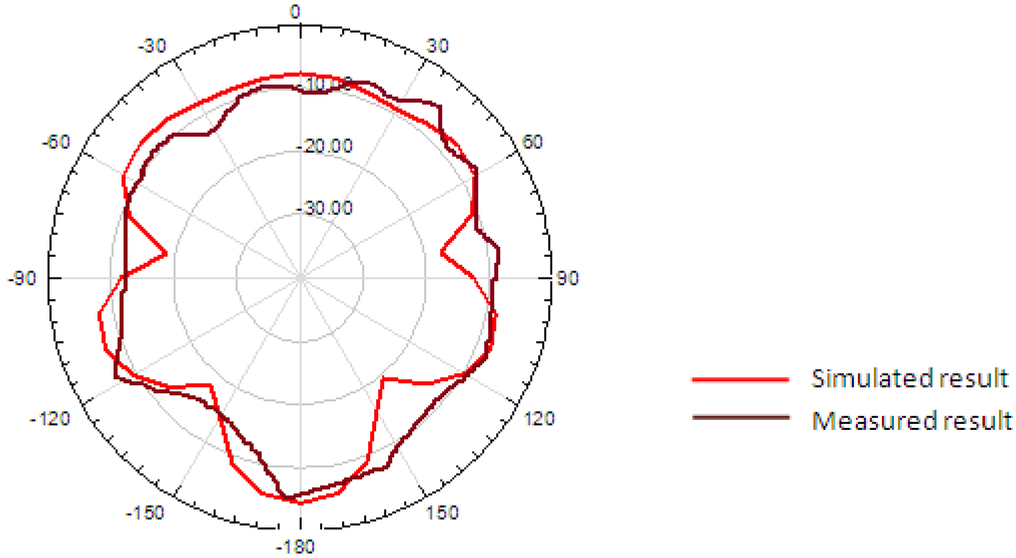


Fig. 4.21(a):Radiation pattern at 6.0GHz at(Phi=0 degree)

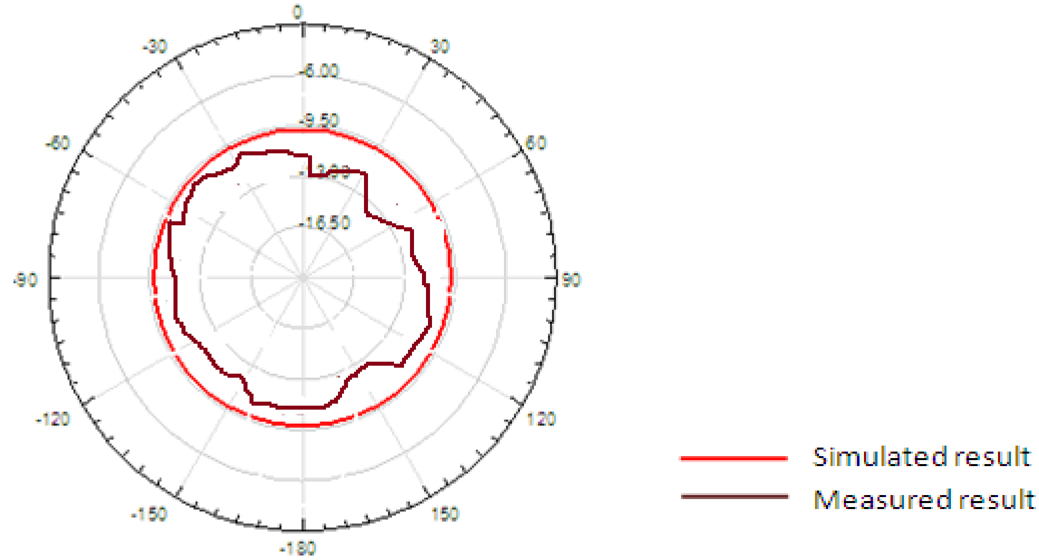


Fig. 4.21(b):Radiation pattern at 6.0GHz at(Phi=90 degree)

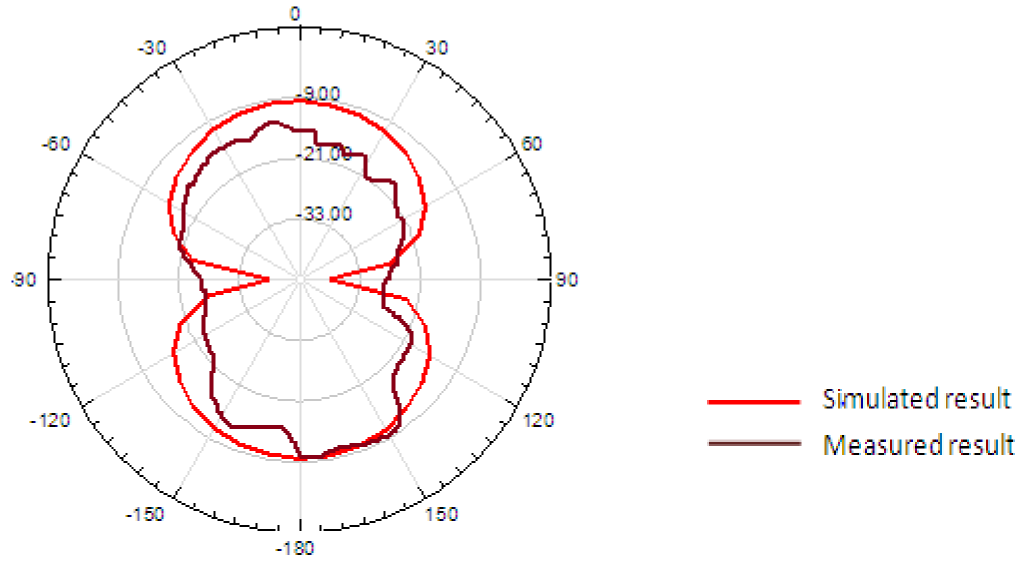


Fig. 4.21(c):Radiation pattern at 6.0GHz at(Theta=0 degree)

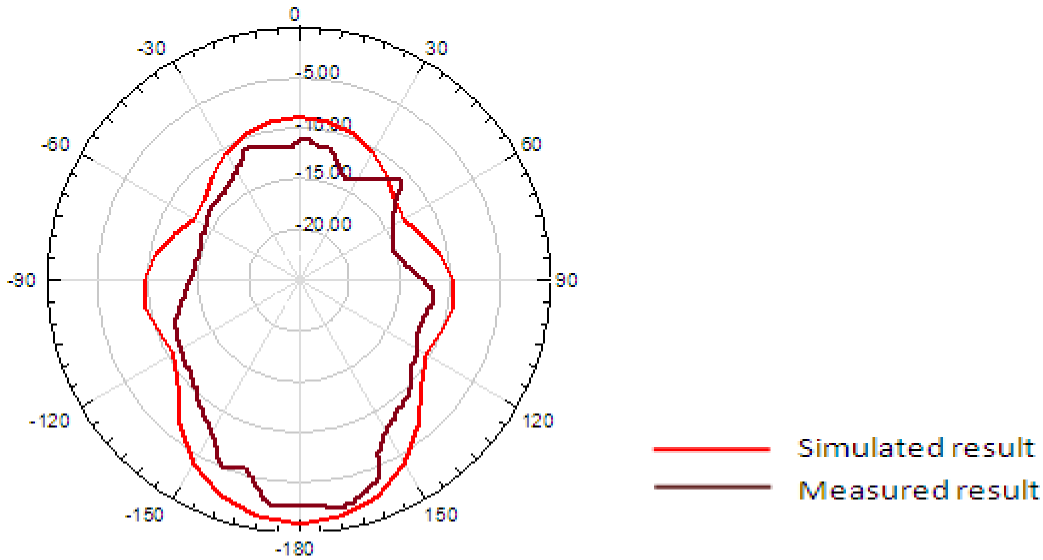


Fig. 4.22(a):Radiation pattern at 7.8GHz at(Phi=0 degree)

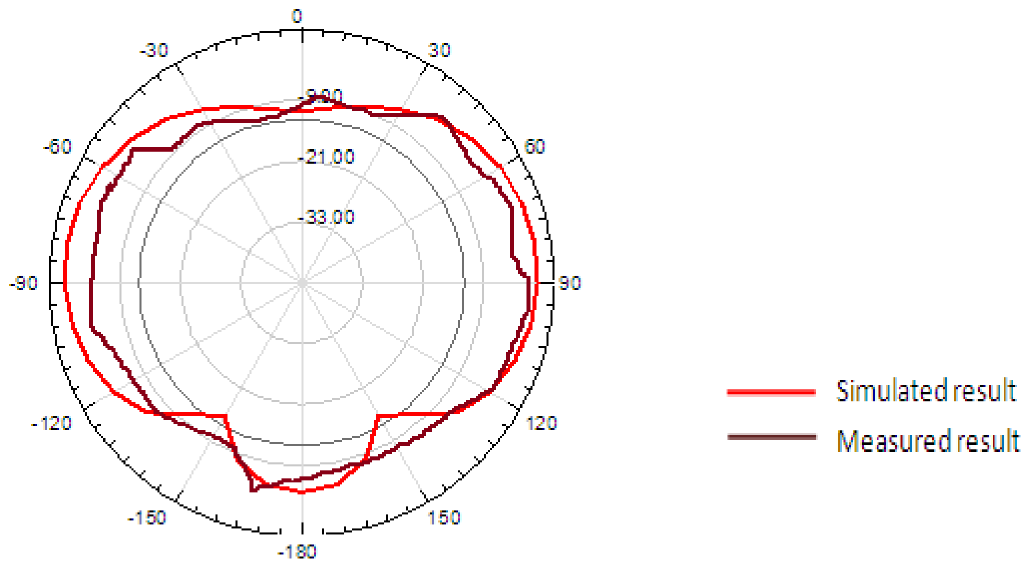


Fig. 4.22(b):Radiation pattern at 7.8GHz at(Phi=90 degree)

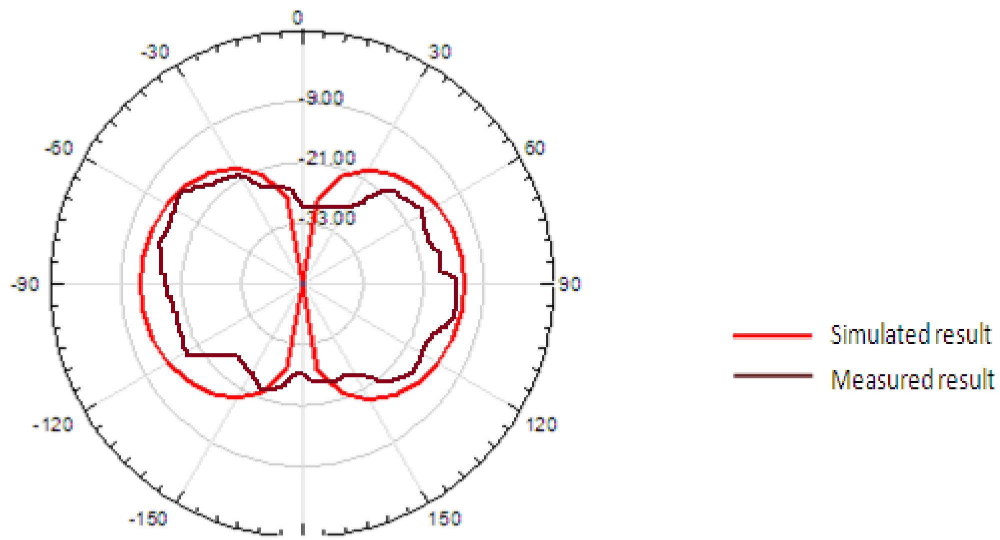


Fig. 4.22(c):Radiation pattern at 7.8GHz at(Theta=0 degree)

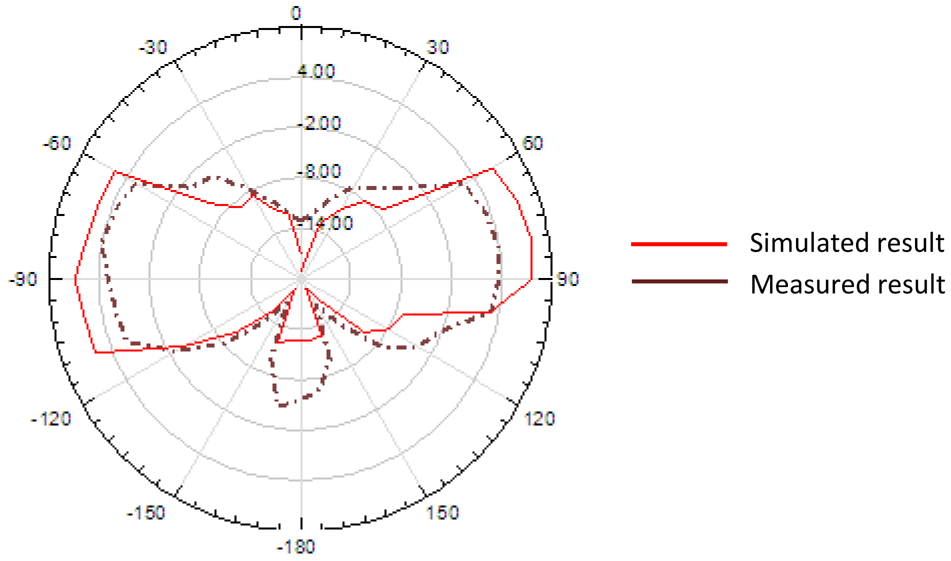


Fig. 4.23(a):Radiation pattern at 9.0 GHz at(Phi=0 degree)

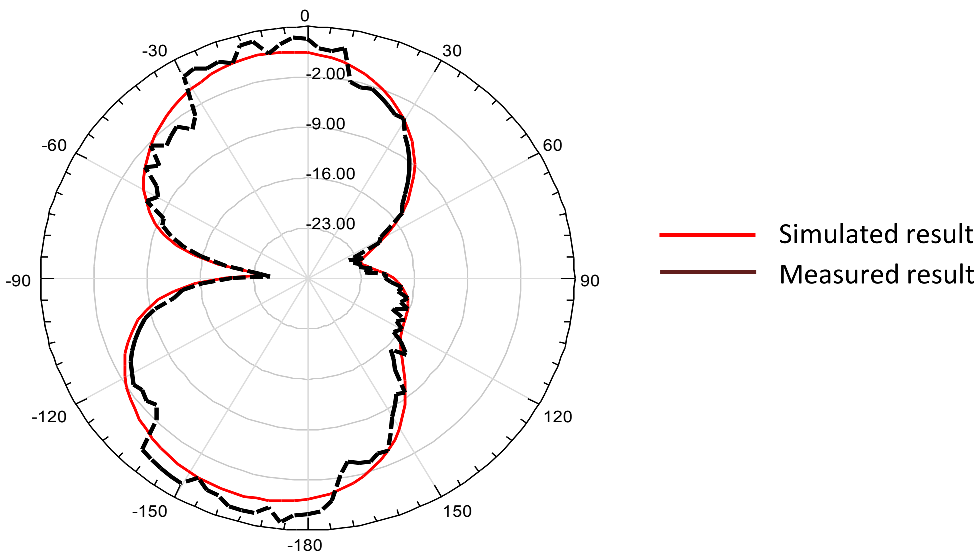


Fig. 4.23(b):Radiation pattern at 9.0 GHz at(Theta=0 degree)

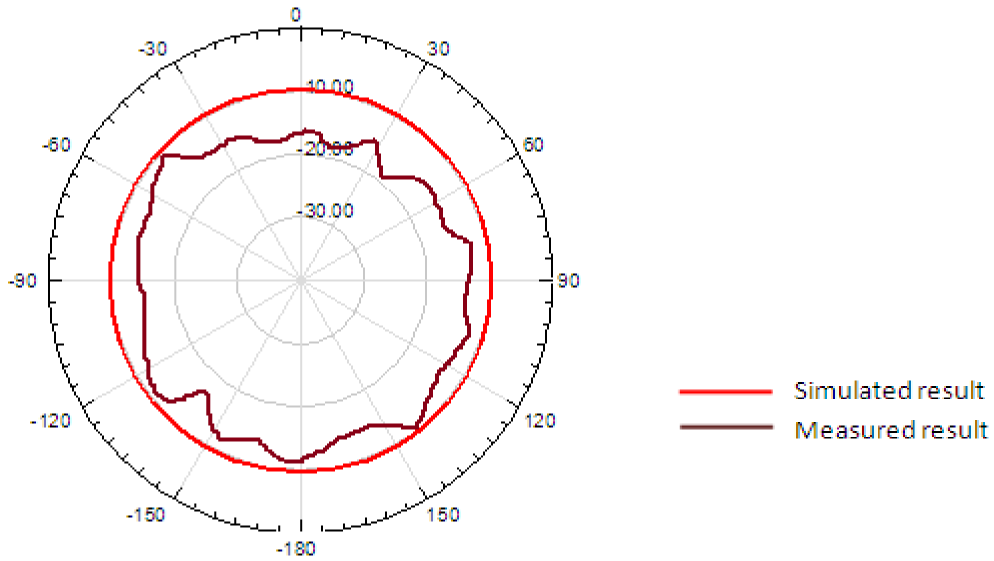


Fig. 4.24(a):Radiation pattern at 10.4GHz at(Phi=0 degree)

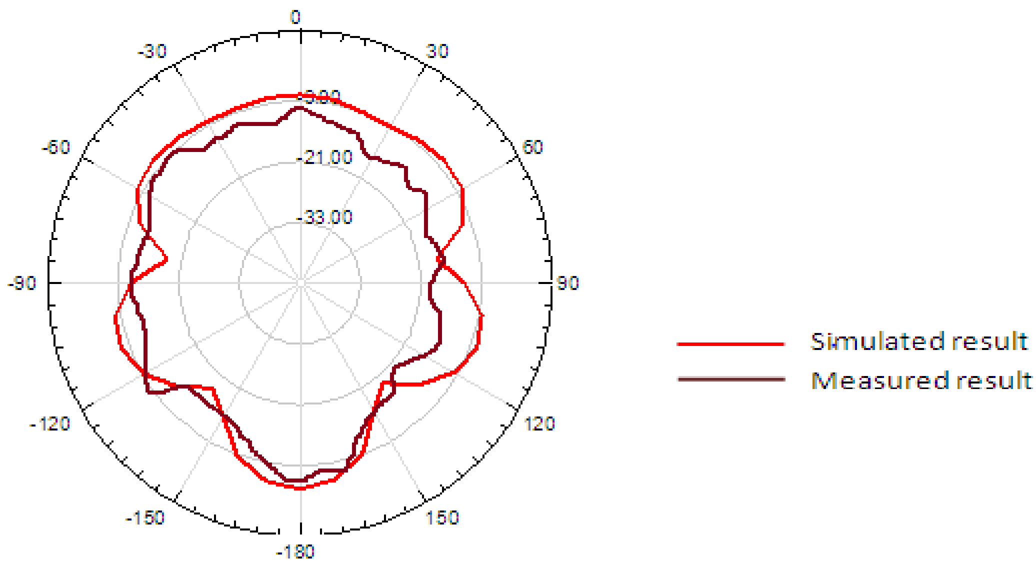


Fig. 4.24(b):Radiation pattern at 10.4GHz at(Phi=90 degree)

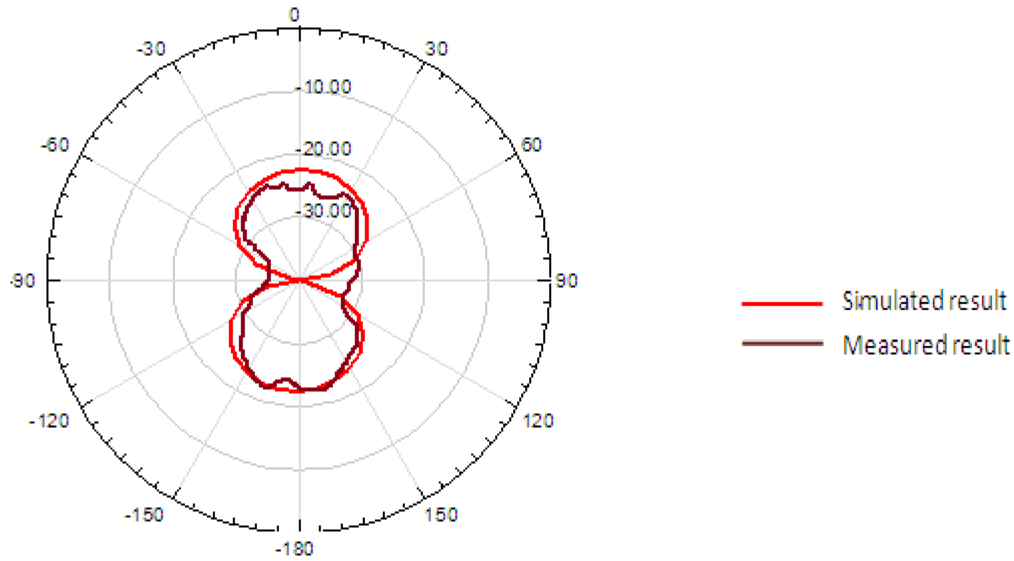


Fig. 4.24(c):Radiation pattern at 10.4 GHz at(Theta=0 degree)

4.7 Effect of different notches in patch on antenna performance

To improve the return loss and bandwidth of the antenna of planar monopole antenna,different notches are introduced. The notches would be of various shapes such as, toothbrush ,double bend , cross,rectangular ,L-shape or U-shape etc[75,76].These notches can be designed not only for broadband applications but also for dual- and triple-band as well as for circular polarization operation however the conventional antenna cannot be applied for various applications if they resonant at single frequency band.The various notches cut in the staircase structure antenna have a great influence on the antenna performance. UWB systems share various frequency bands such as Wi-Max, WLAN and HIPERLAN etc[77,78]. So to avoid interference from nearby communication systems different types of slots are introduced in microstrip antennas. Furthermore to reduce the size of patch and increase the bandwidth as well as to obtain the frequency band at specific frequency it is the appropriate method to insert the slot. The parameters that affect the broadband performance of the patch antennaare the slot length and width and the position of the slot. These parameter can be calculated by using the following expression

$$L_{slot} = \frac{0.45c}{f_{notch}\sqrt{\varepsilon_{eff}}} \dots \dots \dots \dots (4.5)$$

Where c is the velocity of the light in free space

$w_{slot}=[c/(f_{notch}\sqrt{\varepsilon_{eff}})] - 2(L+2\Delta L - E)$............(4.6)

WhereE=λ/60

ΔL denotes the extension in length due to fringing effects and ε_{eff} repersents effective dielectric constant

It is noted that the slot width should be small relative to the slot length.Unfortunately with the help of mathematical formulas and by using equation 4.5 and 4.6 donot meet the condition of required bandwidth.Hence the length,width and the position of the slot are adjusted by iterative trials or potentially by taking an evolutionary technique of prediction and optimization. Thus the Single strip and double strip notch are cut from staircase antenna and optimize for different slot length and width.

4.7.1 Effect of slot length (L1)

The staircase patch antenna that is further optimized for slot length and width[75],[76].A vertical strip is cut from staircase radiator patch as shown in Fig.4.25.At first the value of 'L1' is varied from 19 mm to 24mm with a step of 1mm.The width of slot is fixed at 2 mm. The antenna resonate at a single frequency at the intial value of L1=19 mm and 20 mm. If we further increase the value of L1 the bandwidth is improved and cover the wideband at 23 mm.On further increasing the length to 24mm the bandwidth starts reducing. Hence,the examined optimum value for slot length L1 is 23 mm. It is clear from the Fig.4.26 that the results are not optimum if the value of slot length is increased or decreased beyond this range.

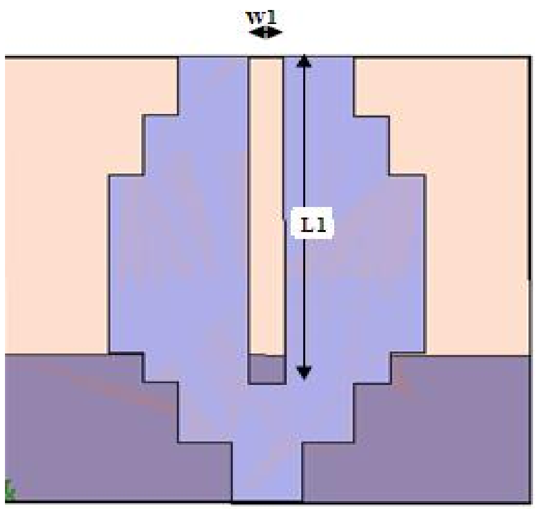


Fig. 4.25:Staircase patch with single strip notch

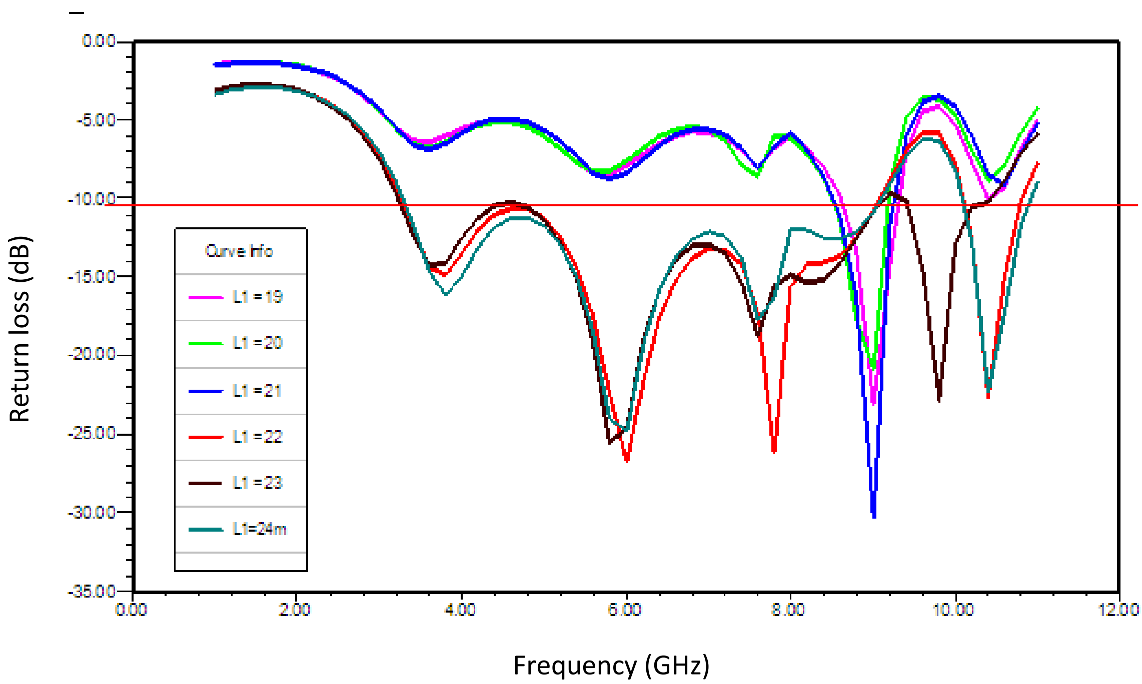


Fig. 4.26:Effect of slot length on patch antenna

4.7.2 Effect of slot width W1

The proposed antenna is also examined for the width of strip line slot. At W1=0.5 mm and 1mm the bandwidth achieved in the Upper UWB band only.By further increasing the value of W1 bandwidth gets improved upto 2mm and on further increase (2.5mm) the bandwidth is decreased.So,from different variation of slot width the optimum value of 2 mm is observed as shown in Fig.4.27.

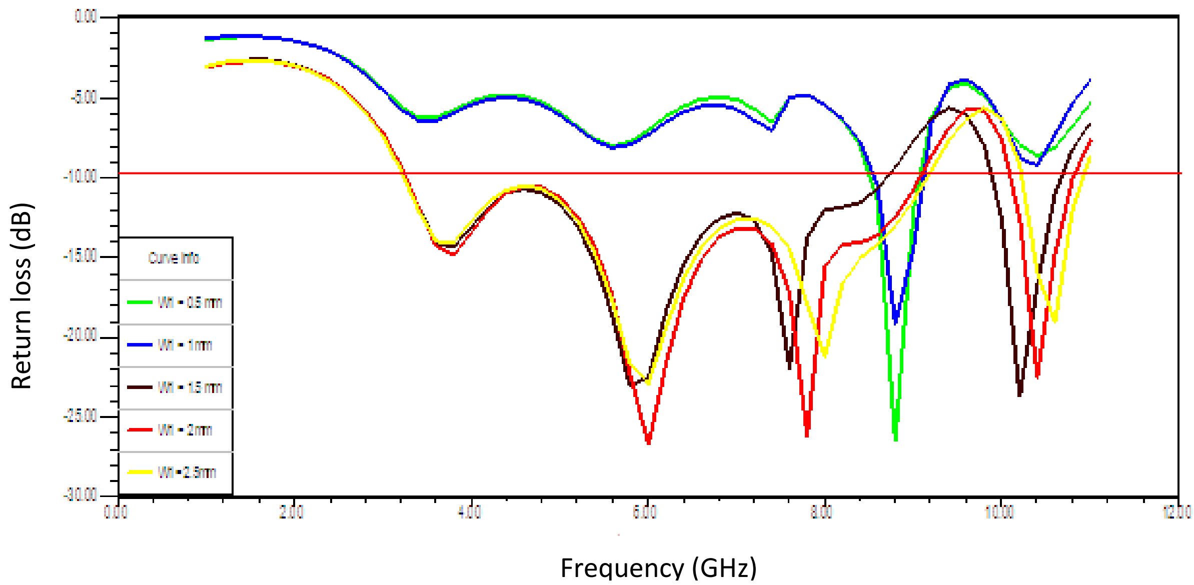


Fig. 4.27:Effect of slot width on patch antenna

Finally Fig.4.28 describes the optimum value of length (23 mm) and width (2 mm) of single vertical stripline slot for staircase antenna.reflection cofficent are illustrated in Fig. 4.29.

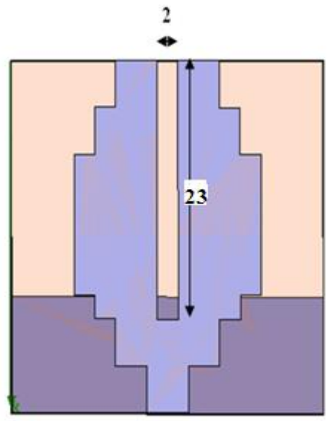


Fig.4.28:Stair shape antenna with single strip notch cut into the patch

Fig. 4.29 illustrates that thiis antenna resonate at two additional frequencies at 6.0GHz and 7.8GHz which is useful .

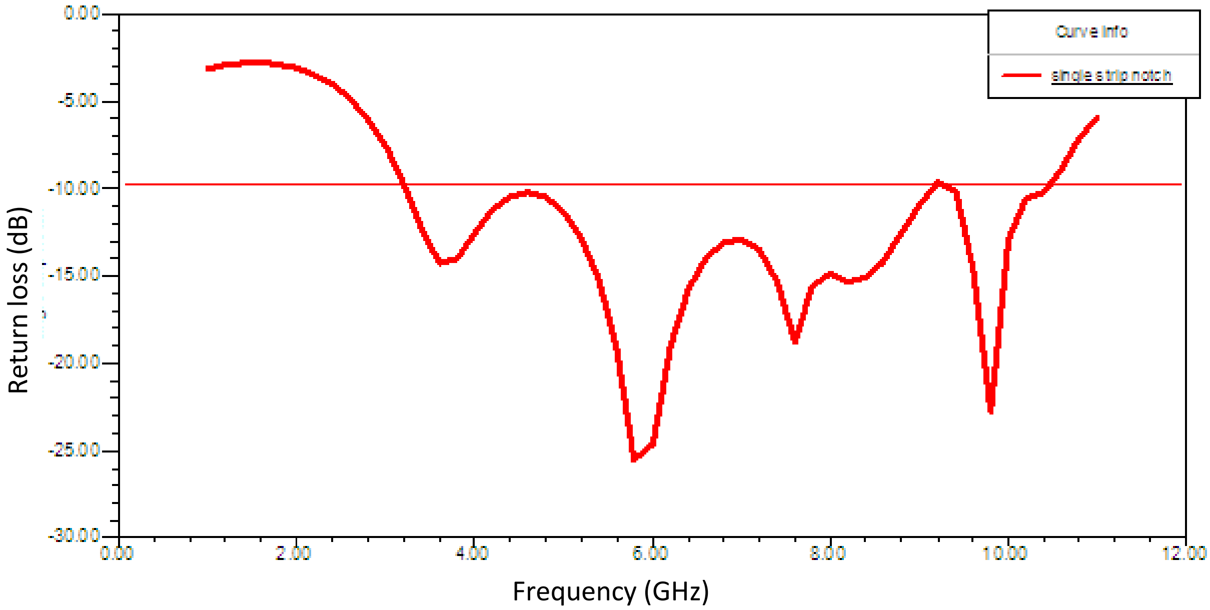


Fig.4.29:Simulated return losses for single strip notch stair shape patch antenna

In second modification the proposed staircase patch is optimized for double vertical stripline[75],[76] as shown in Fig.4.30 .After examined different value of slot length as discussed in(Fig 4.26) and width (Fig 4.31)the L1,L2=23mm and W1,W2= 1.5 mm is found the optimum value for double stripline shown with the help of Fig.4.32.

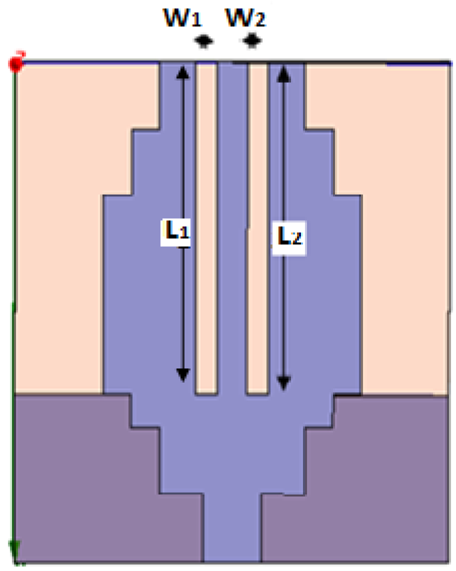


Fig.4.30: Stair shape antenna with double strip notch cut into the patch

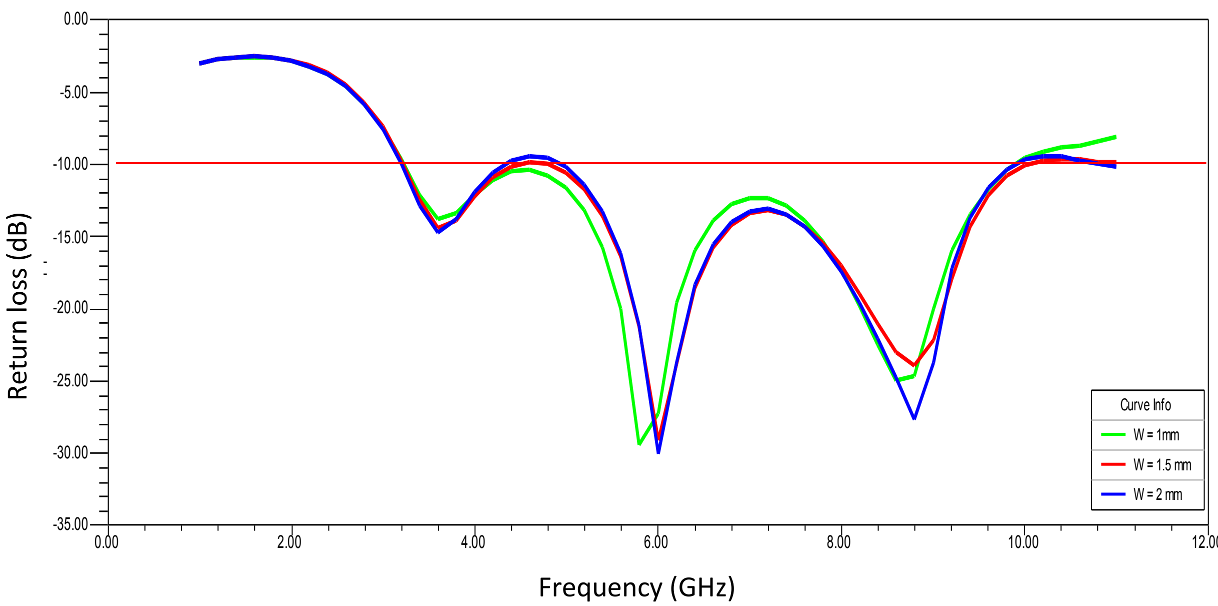


Fig. 4.31:Effect of slot width on patch antenna

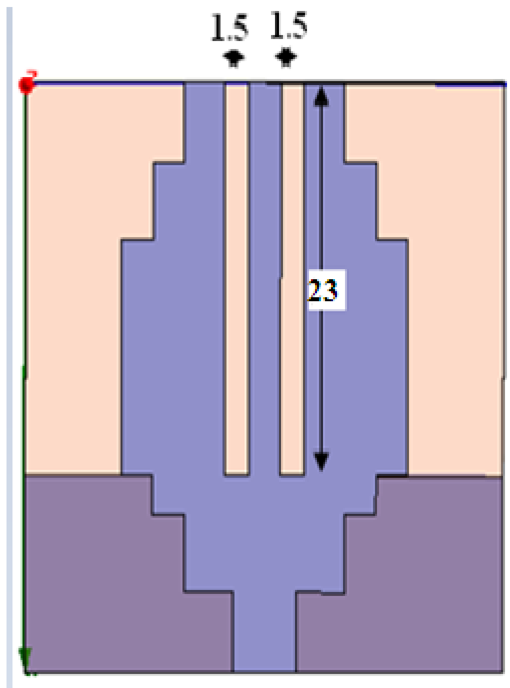


Fig.4.32: Stair shape antenna with double strip notch cut into the patch

Staircase antenna with double strip notch operates in 3.19GHz - 10.2 GHz band and also improves the bandwidth in as shown in Fig 4.33.

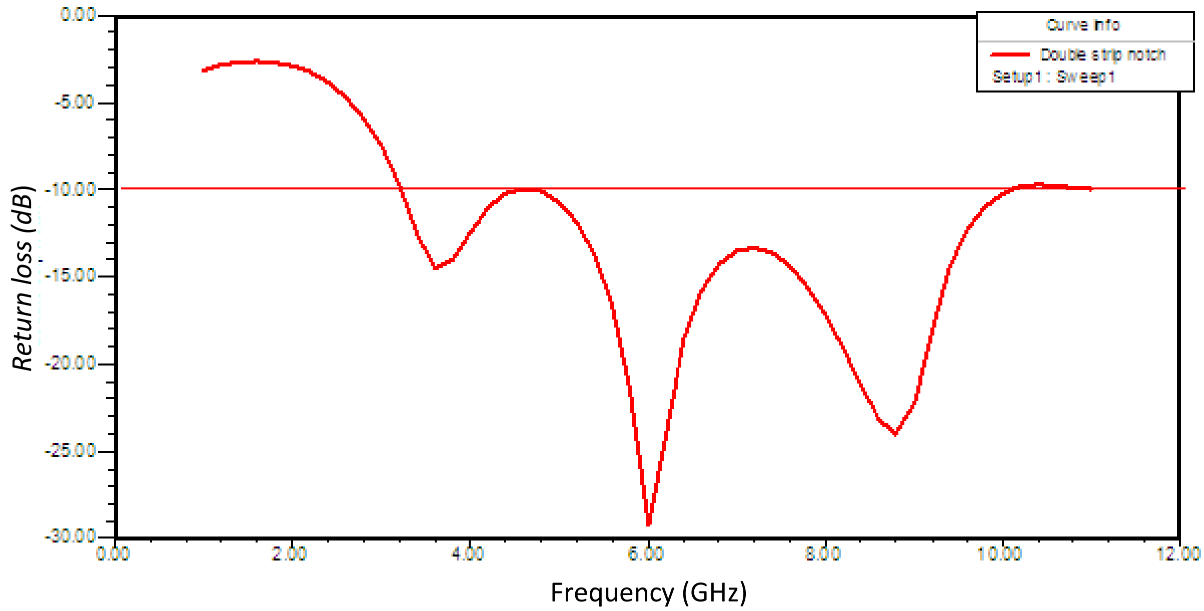


Fig.4.33:Simulated return losses for double strip notch stair shape patch antenna

The characteristics of the given antenna for different notches cut from the radiator are shown in table with frequency range obtained for the respected structures.

TABLE 4.2: Performance of the proposed antenna in terms of frequency bands having different notches

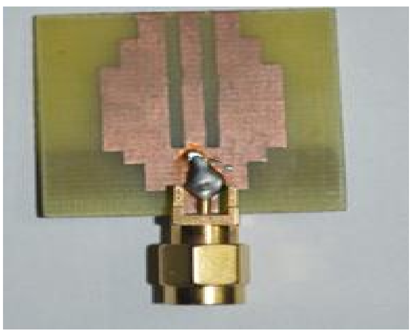
Type of the antenna	Frequency range obtained
Single stripnotch	3.22-9.01GHz,9.6 to 10.2 GHz
Double strip notch	3.19-10.02GHz

4.8 Measured Reflection coefficient

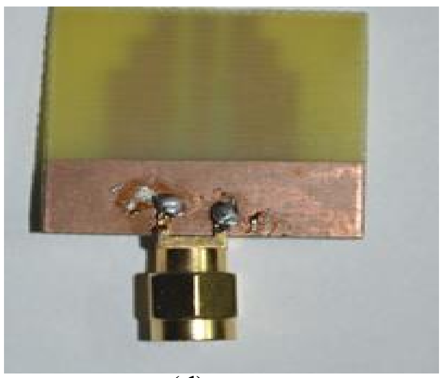
The proposed antenna is fabricated using FR4 substrate by using Wet etching(photolithography)process.The front and back view of fabricated antenna with and without DGS as well as with double strip notch are shown in Fig.4.34. The reflection coefficient of antenna are measured using Vector Network Analyzer at UIET Kurukshetra.The simulated and measured result of fabricated antennas are shown in Fig 4.35 ,Fig 4.36 and and Fig 4.37 found in very good agreement .There is some shift in frequency, which may be due to mismatching between the antenna feeder and the connector, as well as due to dimensional error in fabrication process.

(a)

(b)



(c)

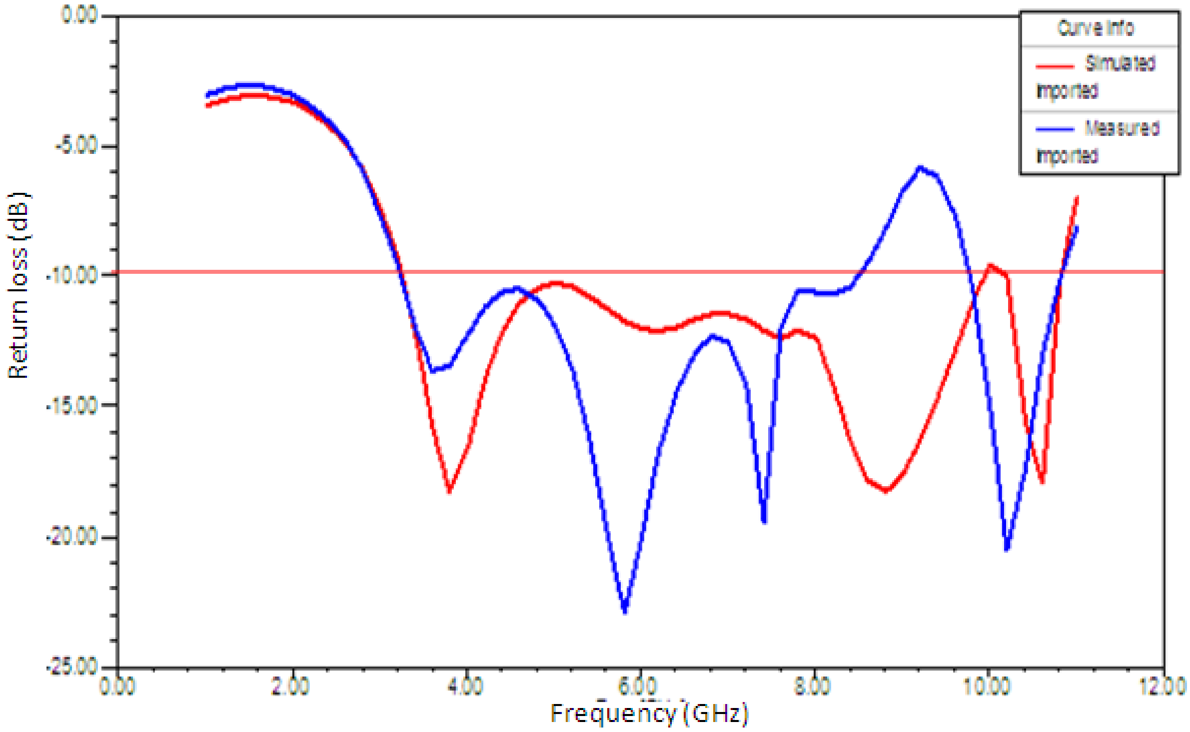


(d)

(e)

(f)

Fig. 4.34:Fabricated antennas (a),(b): front and back view of staircade antenna,(c),(d): front and back view of staircade antenna with double strip notch,(e),(f): frontand back view of staircade antenna with DGS



Frequency (GHz)

Fig. 4.35:Simulated and measured results of proposed antenna without DGS

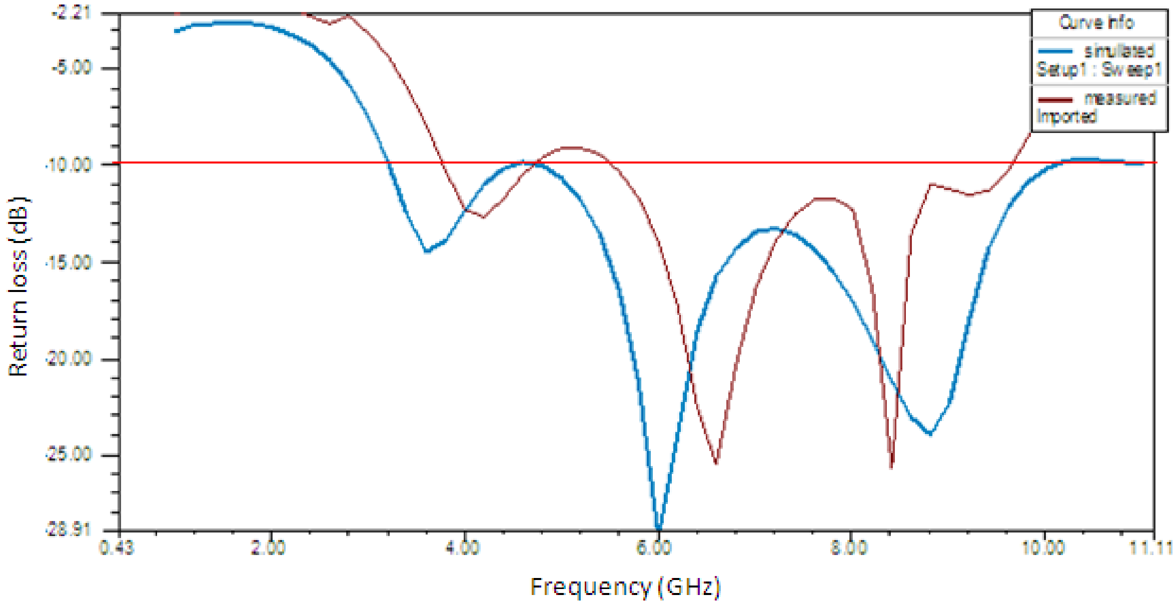


Fig.4.36:Simulated and measured results of staircase patch with double strip notch

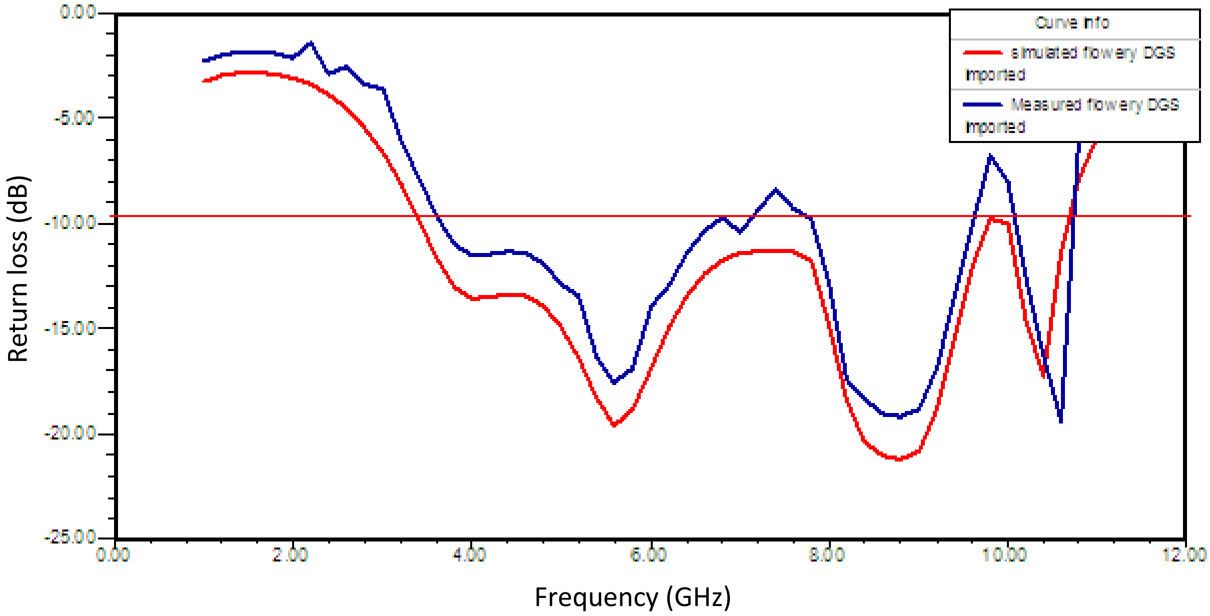


Fig. 4.37:Simulated and measured results of proposed antenna with DGS

4.9 Conclusion

A printed stair shape monopole antenna using DGS for ultra wideband applications is presented in this chapter. The proposed antenna was characterized for reflection coefficient, radiation pattern and current distribution. The simulation and Measured result of the antenna prove that it has a good impedance matching over the UWB frequency range from 3.5 - 10.4GHz. The effect of different parameters on antenna performance has also been studied. Further, the effect of single strip and double stripline slot has been discussed for the antenna and it is claimed that by using these slots antenna can work for various wireless bands such as Wi-Max and Wi-Fi without interference. It has been also concluded that DGS in designing of antenna provides significant advantages of improving the bandwidth, miniaturizing of antenna size and good impedance matching. The configuration of the proposed antenna is really simple making its fabrication at low cost. The proposed antenna is the best candidate for UWB systems as it follows all the characteristics of the UWB systems and can be used in various WPAN aaplications. In next chapter, a new optimization approach i.e. artifical neural network (ANN) is used to design the UWB antenna is presented.

Chapter 5

ANN Optimization Technique for UWB Antenna

This chapter proposes a novel monopole antenna for UWB applications. The aim of this chapter is to optimize the proposed antenna design to attain UWB with significant impedance bandwidth for various wireless applications. The antenna is initially designed using CST Microwave studio. The proposed antenna is then optimized with ANN, fabricated and tested to validate against simulation results. The design process, parametric study, simulation results beside with ANN results are presented for UWB applications.

5.1 Introduction

Now a days, the optimization of design parameters is most important consideration in order to obtain efficient computational results. Many methods for the optimization of design are proposed in literature, which includes genetic algorithm (GA), particle swarm optimization (PSO),Biogeography based optimization (BBO),neural network and many more[79].Optimization technique is the method of detecting the minimal/maximal of an operator defined in the form of cost function. Optimizers adapt the variable calculations until the lowest gets hold of it with satisfactory precision. The optimizers are distinguished by either error function (EF) or search methods (SM) formulations. Most of the aforementioned optimization algorithms available in the market are compatible with simulation software's. To propose a wide choice of capability, HFSS and CST electromagnetic simulation software's incorporates either of the subsequent kinds of mathematical optimizers like ANN (compatible with matlab software), Quasi Newton, Sequential Non-linear Programming (SNLP), Sequential Mixed Integer Non-linear Programming (SMINLP), and GA [80].

ANN algorithm is used in this chapter to optimize the proposed UWB antenna. Feed forward Network with radial basis function (RBF) is preferred. ANNs are dispensation procedure (algorithms) that are freely modeled subsequently the neuronal formation of the cerebral mammalian cortex on the other hand on a reduced scale. A big ANN model might have few hundred or few thousands of processing units, while a brain of mammalian has billions amount of neurons using a consequent enhance in magnitude value of their in general interaction and growing behavior. Collective behavior of the neurons in a network provides the power of the neurons where all the neurons are unified. The neural network starts growing: by considering the inputs, the neurons evaluate their output, weighted sum are calculated and compared to threshold to choose if they should work. This parallel process is very complex whose complexity can't be reduced by considering individual neurons [81]. ANNs are best option for the optimization of microwave circuit statistical design. The computational efficiency of neuro models are much more than EM models. Once learning data obtained from a "fine" model trained the neuro models by either EM simulation or measurement, the efficient and accurate optimization can be obtained by neuro models and also the design can be obtained in the region of training. For the microwave modeling, simulation and optimization ANN proved as fast and accurate models [82, 83].

Further, in this chapter, the capability of the ANN has been utilize for the computation of resonant frequency of proposed microstrip patch antenna. The NN considered as a computational tool in optimizing the structure of antennas. To minimize the error and to get the geometric dimensions with great accuracy for bands of selective frequencies, the NN training algorithms are preferred.

5.2 Antenna Design

The patch antenna is designed and optimized with the objective to achieve UWB and at the same time to work for multiband resonant frequencies. In this chapter a rectangular patch antenna with different step size widths (W) and lengths (S) comprising of four steps with dimensions of W1×S1, W2×S2, W3×S3, and W4×S4 to enhance the bandwidth of UWB antenna is proposed. Following steps are used to design the patch.

Step1: Initially a rectangular patch antenna is designed whose length and the width [9] [72] are calculated by the given relationships (5.1), (5.2), (5.3) and (5.4)-

Calculation of the width (*w*):

$$w = \frac{v_0}{2f_c}\sqrt{\frac{2}{\epsilon_{rel} \ +1}} \qquad \text{……….(5.1)}$$

Where v_o is the free space velocity of the light

fc = 3.2GHz

ϵ_{rel} = 4.4 the dielectric constant of the FR4(dielectric material)

So W = 28 mm

Calculation of effective dielectric constant ($\epsilon_{rel(eff)}$)

$$\epsilon_{rel\,(eff\,)} = \frac{\epsilon_{rel}+1}{2} + \frac{\epsilon_{rel}-1}{2}[1+12\frac{h}{w}]^{-1/2} \qquad \text{…………(5.2)}$$

Where ‘w = 28 mm

h=1.6 mm ’is the height of the substrate.

Therefore $\epsilon_{rel\,(eff\,)}$=3.38

Calculation of the effective length (l_{eff}) as: for

$$l_{eff} = \frac{v_0}{2f_c\sqrt{\epsilon_{rel\,(eff\,)}}} \qquad \text{…………(5.3)}$$

Where fc = 3.2GHz *and* $\epsilon_{rel\,(eff\,)}$=3.38 it gives

l_{eff} = 25.5

Calculation of the length extension (Δl)

$$\frac{\Delta l}{h} = 0.412\frac{(\epsilon_{rel\,(eff\,)}+0.3)\{\frac{w}{h}+0.264\}}{(\epsilon_{rel\,(eff\,)}+0.258)\{\frac{w}{h}+0.8\}} \qquad \text{…………(5.4)}$$

$$\Delta l = 0.770 \text{ mm}$$

Where Δl is extension in length due to fringing effects.

Calculation of actual Length of patch (l)

$$l = \frac{v_0}{2f_c\sqrt{\epsilon_{rel\,(eff\,)}}} - 2\Delta l$$

l= 24mm

The antenna is designed on FR4 substrate with dielectric constant of 4.4 and height of 1.6 mm.Initially the dimensions of patch are taken (by using above equations) 28mm× 24mm with ground plane and substrate having dimensions 32 mm x 40mm (Fig.5.1). The CST software has been used to simulate the antenna and study the electromagnetic characteristics. The return loss for the plane rectangular design is shown in Fig.5.2

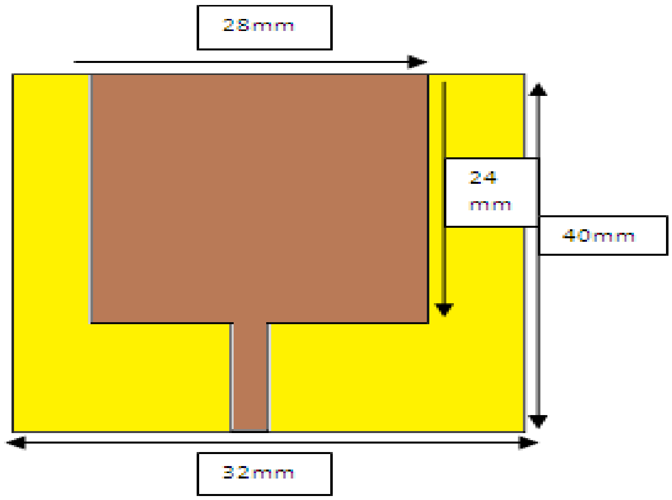


Fig. 5.1: Rectangular patch Antenna

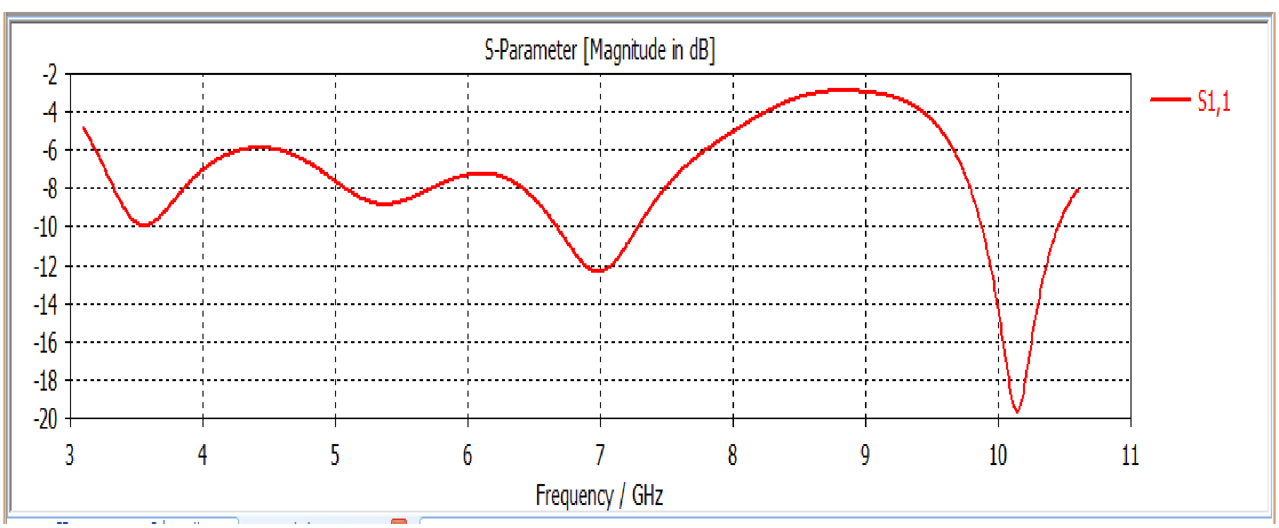


Fig .5.2: Simulation result of rectangular patch antenna

The dimensions of rectangular patch antenna are further modified to improve the bandwidth below -10db and considered as 28mm× 28.75mm. The return loss curve in fig.5.3 shows that the bandwidth improve in the middle band and resonance at 5.77 GHz.

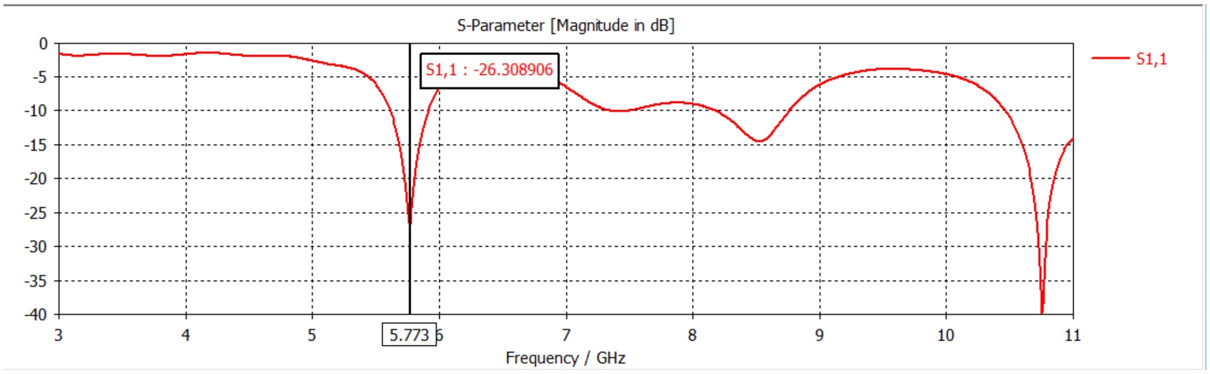


Fig .5.3: Simulation result of modified rectangular patch antenna

Step2: A step is cut out from the above rectangular antenna [76] as shown in figure 5.4.The return loss for the proposed single step design is shown in Fig. 5.5. The return loss curve shows the resonance at 9.776 GHz.

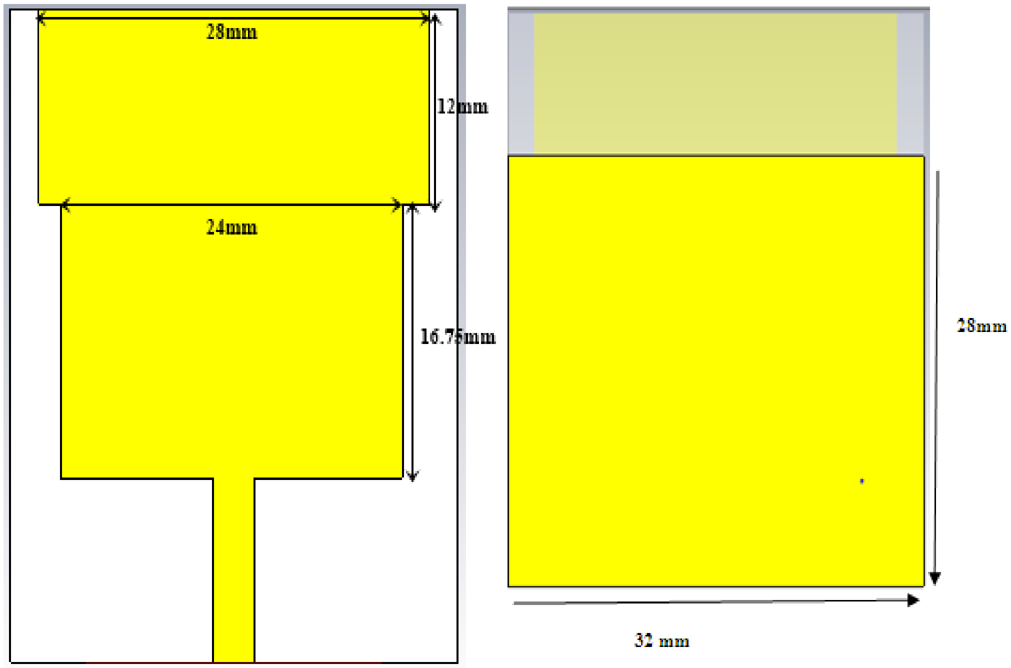


Fig. 5.4: Antenna with double step size.

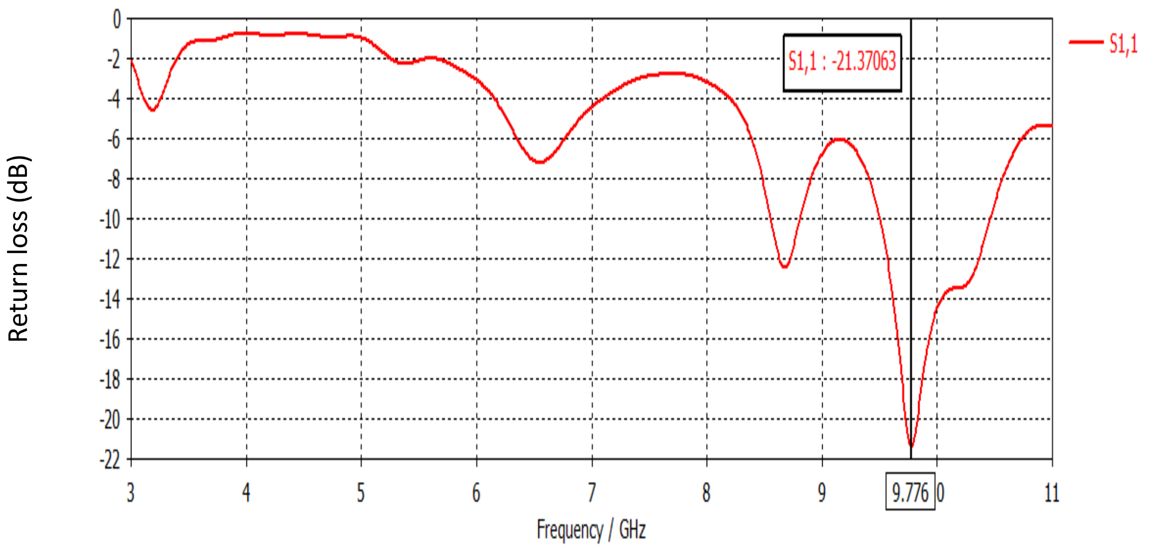
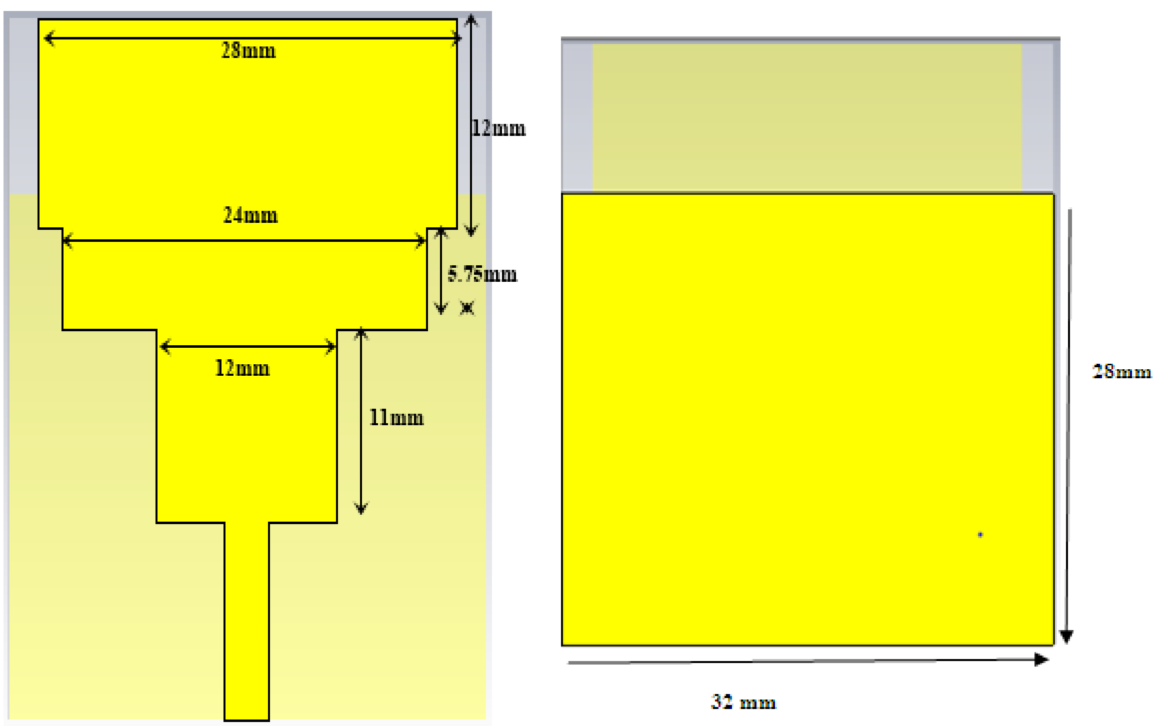


Fig. 5.5: Simulation result of antenna with double step size

Step 3: Another step is cut out from the previously carved out step as shown in Fig.5.6. The



return loss curve for the design of Fig. 5.6 is shown in Fig. 5.7. The resonant frequency gets shifted to 7.376 GHz.

Fig. 5.6: Antenna with triple step size

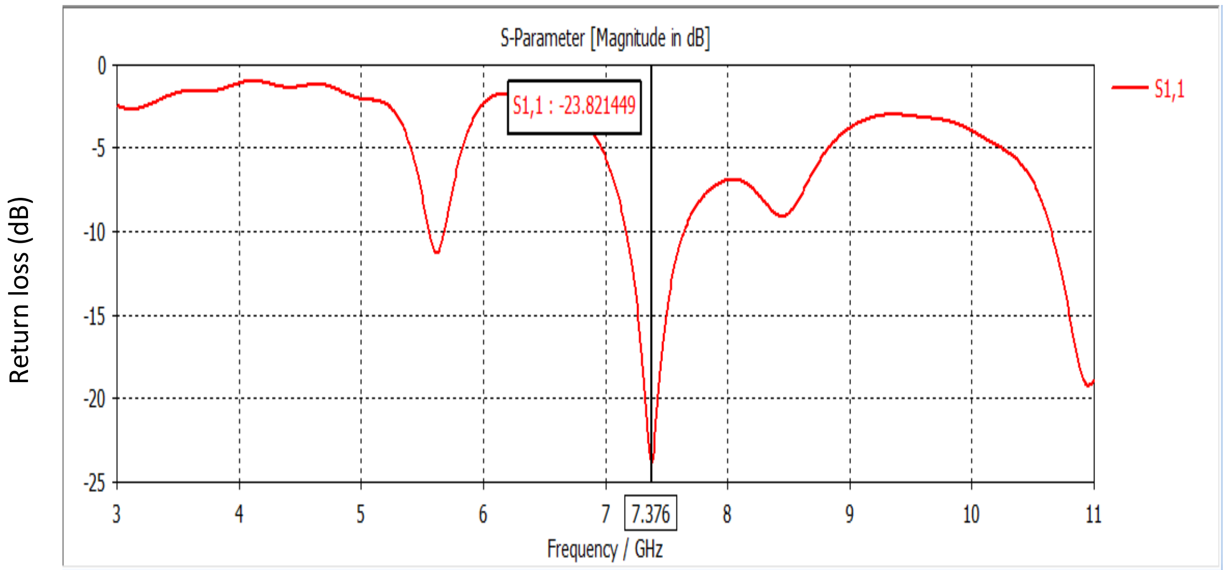


Fig.5.7: Simulation result of antenna with triple step size

Step 4: One more step is cut out from the step of carved out in step 3[76].The final geometry and dimension of proposed antenna is shown in the Fig. 5.8 and Fig. 5.9 (a), (b), respectively. The reflection coefficient of proposed antenna achieves the wide frequency spectrum from 4.2 GHz to 11 GHz as shown in Fig. 5.10.

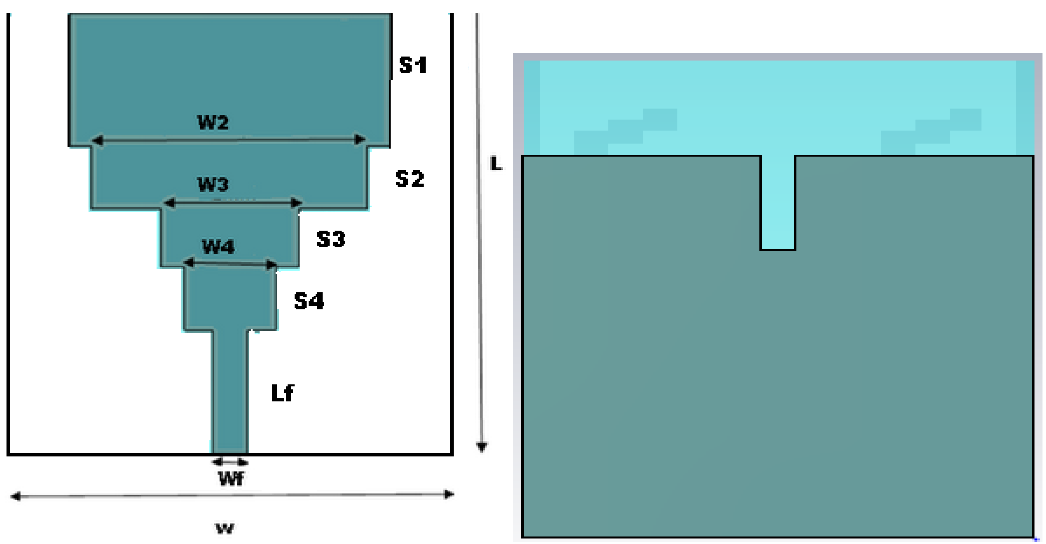
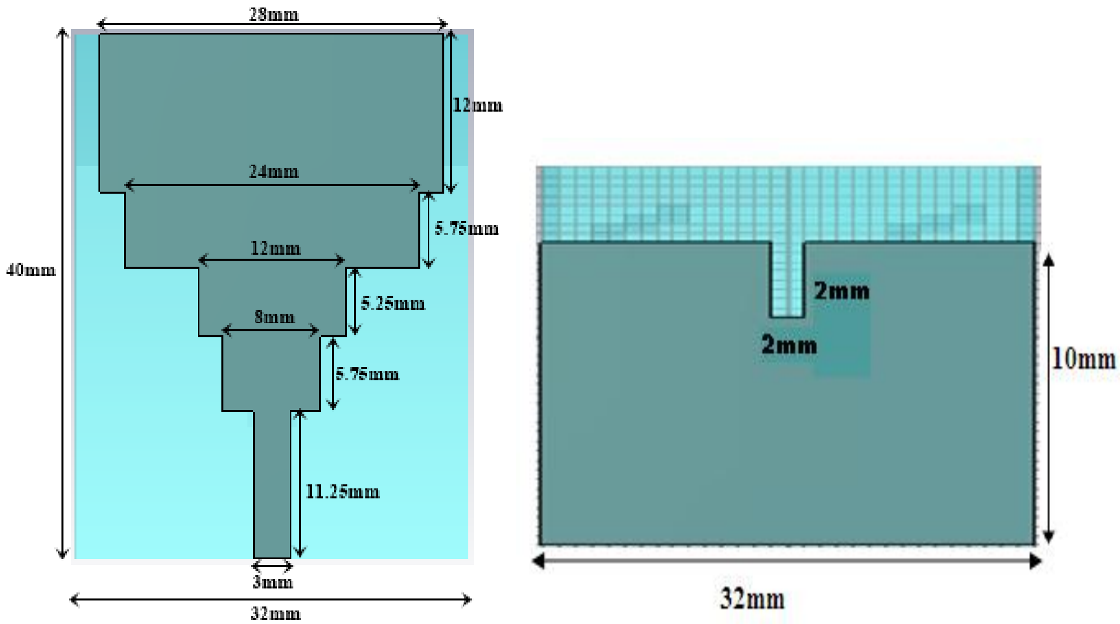


Fig. 5.8: Geometry of proposed antenna



(a) **(b)**

Fig 5.9 (a), (b) Dimension of proposed antenna with ground plane.

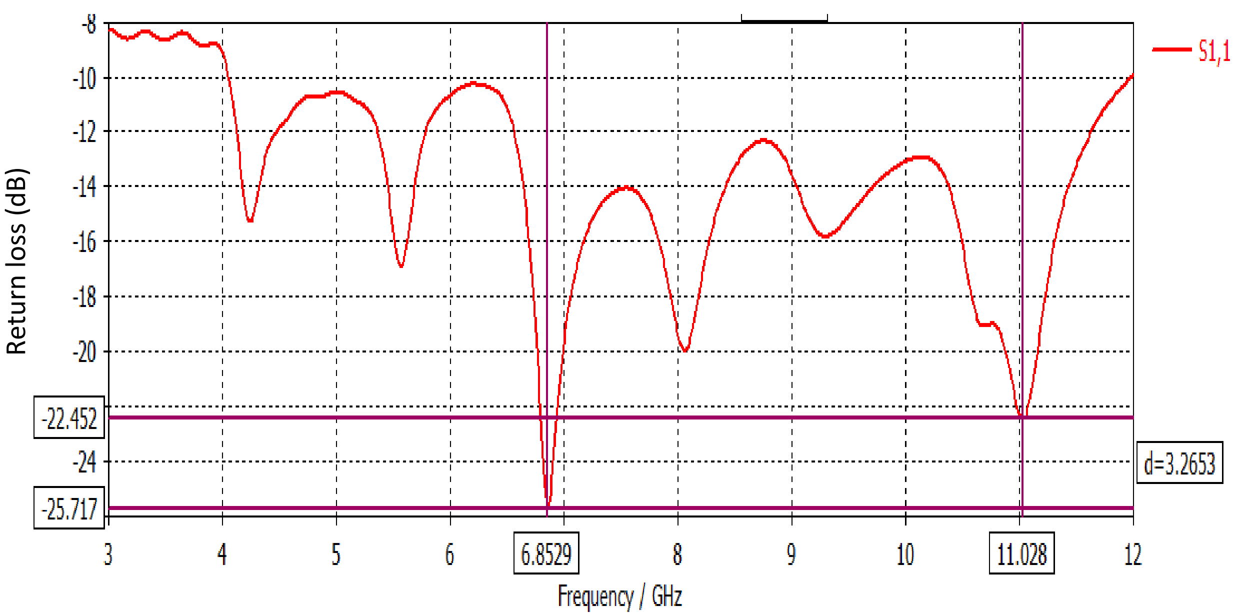


Fig. 5.10: Simulated reflection coefficients (S_{11}, dB) versus frequency (GHz) plot for antenna design.

The geometrical parameters of proposed antenna shown in figure 5.9(a), (b) are selected cautiously by running various parameter sweeps and finally the best possible parameters for proposed configuration are obtained as shown in Table 5.1 in tabular form.

Table 5.1: Optimal design parameters of the proposed UWB antenna

Size of substrate	**32x40mm**
Ground plane Size	**32x10 mm**
Various patch steps of antenna **(A) W1 x S1** **(B) W2x S2** **(C) W3x S3** **(D) W4 x S4**	 **28 x 12 mm** **24 x 5.75 mm** **12x 5.25mm** **8 x 5.75 mm**
Length ofFeed Line (Lf)	**11.25**
Width of Feed Line (Wf)	**3 mm**
Length and width of notch in ground plane	**2mm,2mm**

5.3 Radiation pattern and VSWR

The radiation patterns of the final optimized antenna are shown in Fig 5.11 to Fig 5.14. The radiation patterns in elevation plane are shown in Fig. 5.11 (a), (b) to Fig 5.14 (a), (b) at frequency 4.35 GHz, 5.0 GHz, 6.85 GHz, 8.0 GHz and 9.3 GHz, respectively. Fig. 5.11 (c) to Fig 5.14 (c). Illustrates radiation pattern in azimuth plane and antenna achieves Omni-directional properties at aforementioned frequencies. The half power beam width and side lobe level at 9.3GHz are 50.5 degrees and -1.6 dB respectively.

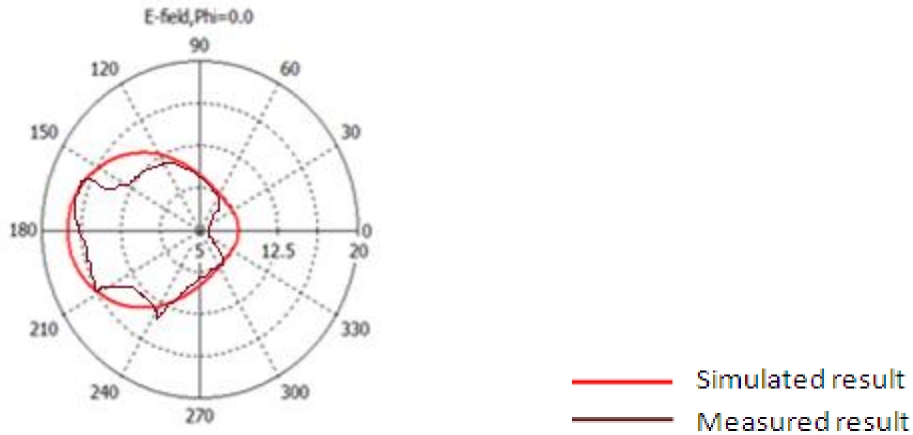


Fig .5.11 (a): Elevation plane Radiation Pattern at 4.35 GHz (Phi=0 degree)

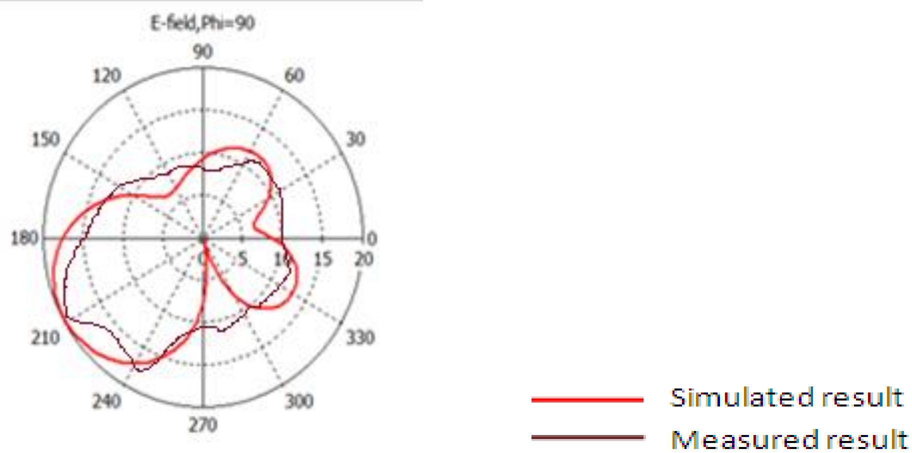


Fig .5.11 (b): Elevation plane Radiation Pattern at 4.35 GHz (Phi=90degree)

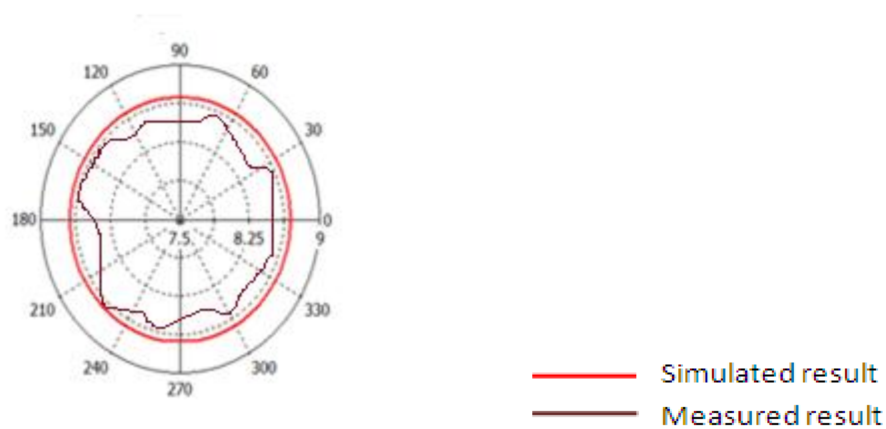


Fig .5.11(c): Azimuth plane Radiation Pattern at 4.35 GHz (Theta=0)

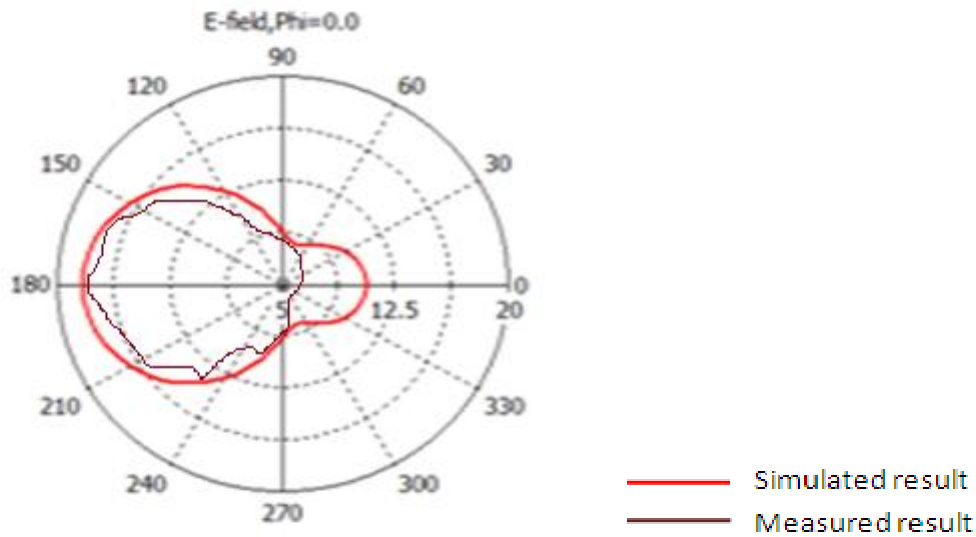


Fig. 5.12 (a): Elevation plane Radiation Pattern at 6.85 GHz (Phi=0degree)

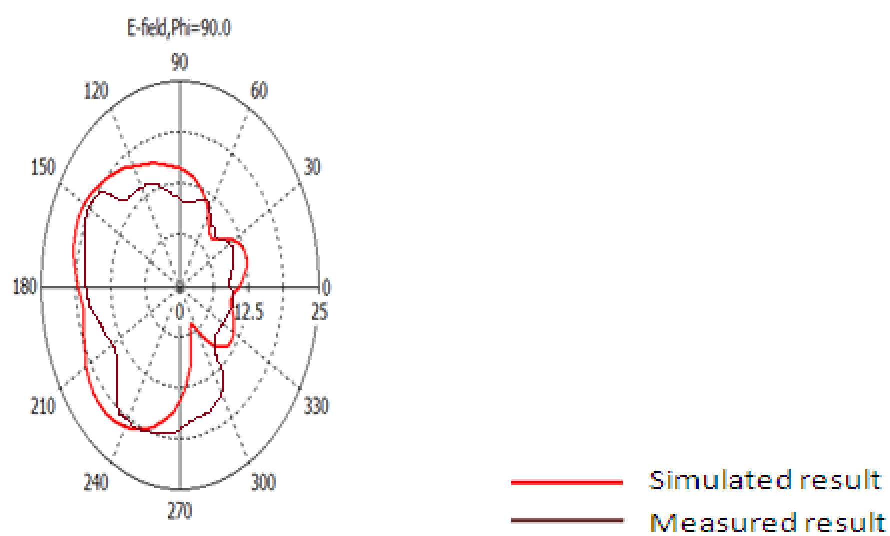


Fig. 5.12(b): Elevation plane Radiation Pattern at 6.85 GHz (Phi=90degree)

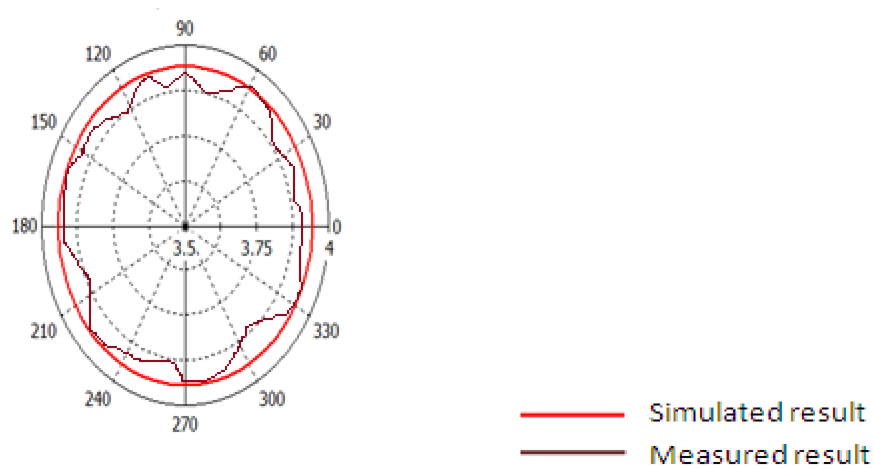


Fig. 5.12(c): Azimuth plane Radiation Pattern at 6.85 GHz (Theta=0degree)

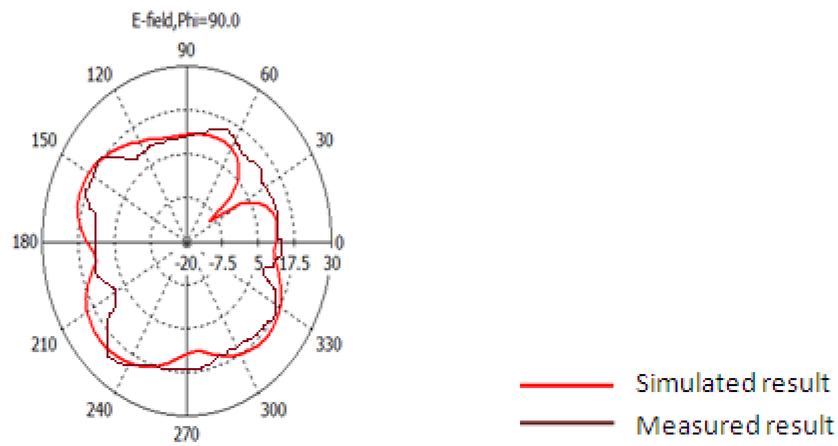


Fig. 5.13 (a): Elevation plane Radiation Pattern at 8.0 GHz (Phi=0degree)

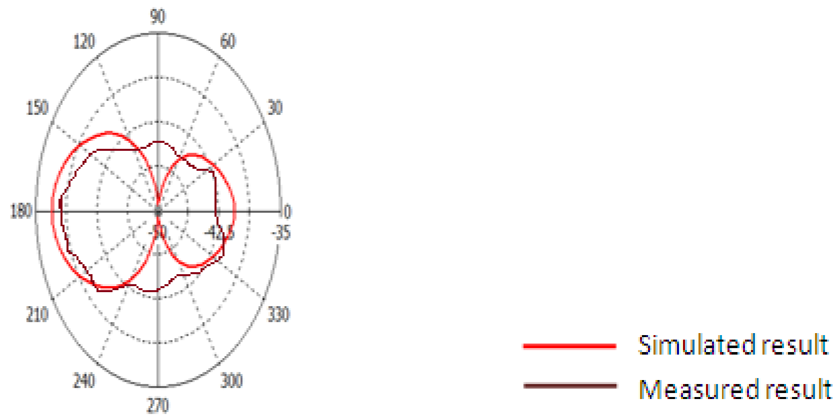


Fig. 5.13 (b): Elevation plane Radiation Pattern at 8.0 GHz (Phi=90degree)

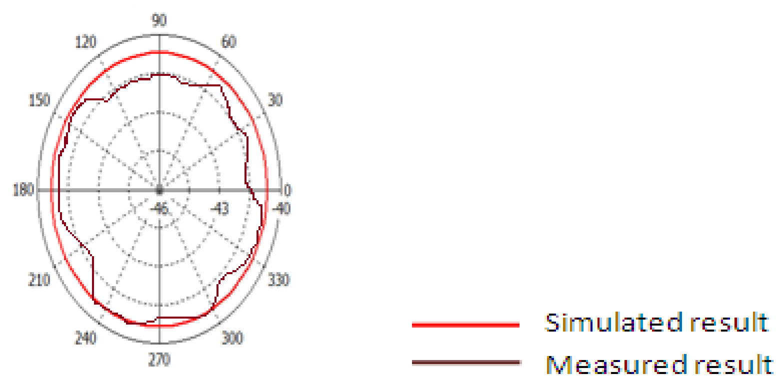


Fig. 5.13(c): Azimuth plane Radiation Pattern 8.0 GHz (Theta=0degree)

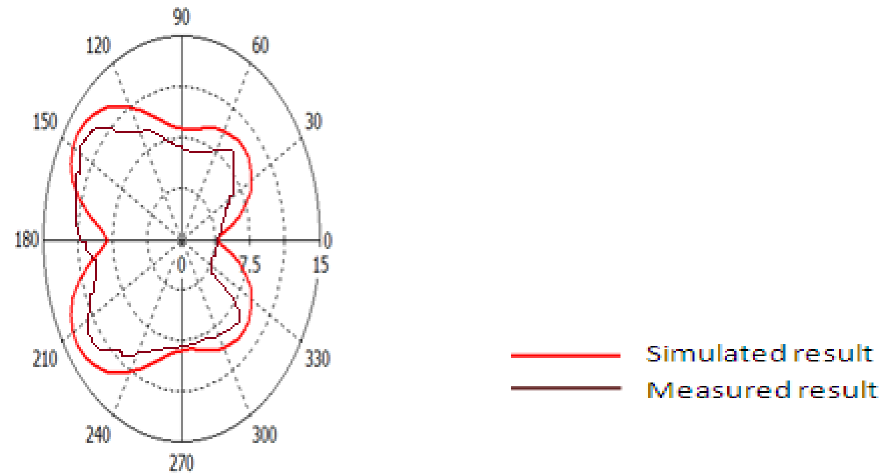


Fig. 5.14(a): Elevation plane Radiation Pattern at 9.3 GHz (Phi=0degree)

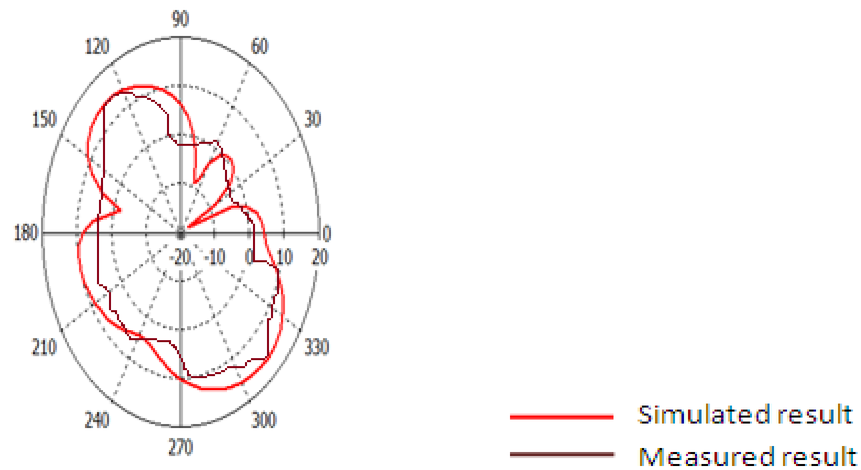


Fig. 5.14(b): Elevation plane Radiation Pattern at 9.3 GHz (Phi=90degree)

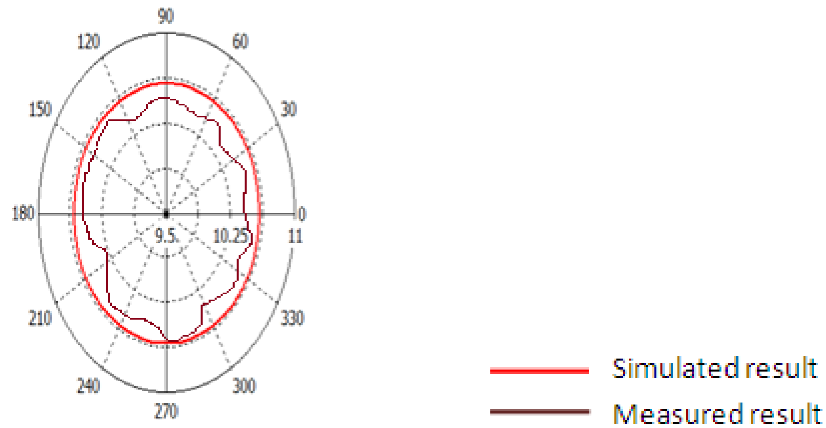


Fig.5.14(c): Azimuth plane Radiation Pattern at 9.3 GHz (Theta=0degree)

5.3.1 VSWR

VSWR (Voltage Standing Wave Ratio) is described as maximum voltage to minimum voltage ratio of antenna. It is desirable that the value of VSWR should be between 1 and 2 for efficient working of antenna. As clear from the Fig. 5.15 the value of VSWR is less than two in the whole frequency range (4.2 GHz to 11 GHz) which improve the performance of proposed antenna

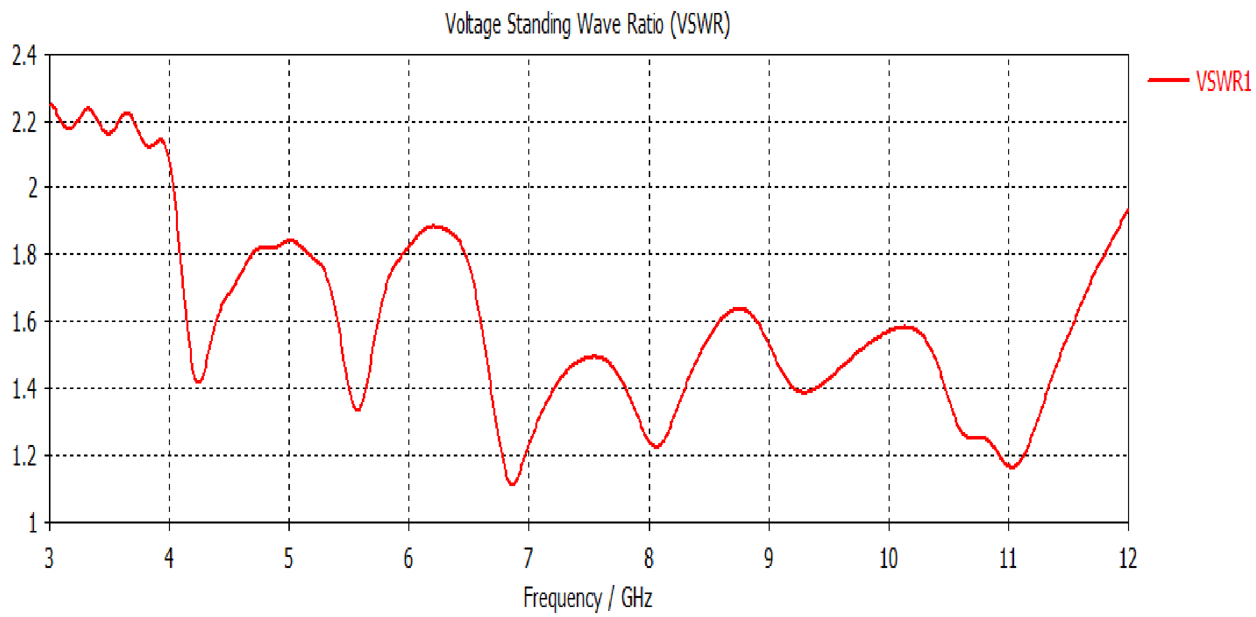


Fig .5.15: VSWR of proposed antenna

5.4 Neural Network Model

The prime objective of this work is to design and optimize the proposed antenna structure .The optimized patch structure of the proposed antenna is achieved as a function of input variables, such as thickness of the substrate material (*t*), permittivity of the material ($\varepsilon_{rel,}$)and the resonance frequency (*fc*), using NN techniques. In the same way, in the study of NN, the resonant frequency of the microstrip antenna is achieved as a function of patch dimensions width (*w*), length (*l*), thickness of the material, and permittivity of the material.

5.4.1 The Forward Side of the model:

The forward side design consists of inputs like resonant frequency (*fc*), thickness of substrate (*t*) and permittivity (εrel) to get the patch dimensions in the form of width (*w*) and length (*l*) (Fig.5.16).

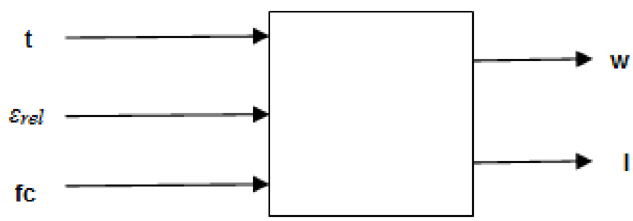


Fig. 5.16: Forward side of ANN model.

5.4.2 The reverse side of model

In the same way, the using reverse model of NN, the resonant frequency of the microstrip antenna is obtained as the property of patch dimensions (*w*, *l*), dielectric material thickness (*t*) and dielectric constants of the substrate as shown in figure 5.17.

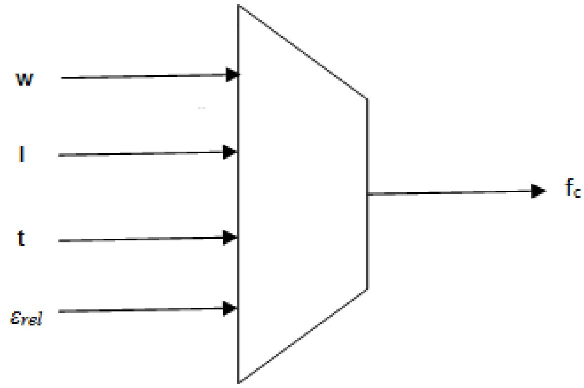


Fig. 5.17: Reverse side ANN model.

5.4.3 Optimization using neural network

In this study, the NN is working as a tool in defining the dimensions of proposed micro strip antennas as shown in Fig. 5.18. The NN training procedures are used in simulation of results for training the samples. The most widely held algorithm of NN for correcting weights during the training phase is known as back-propagation. Both Radial Basis Function (RBF) and Multilayer Perception (MLP) networks were used in ANN algorithm. RBF networks are used to build ANN model.

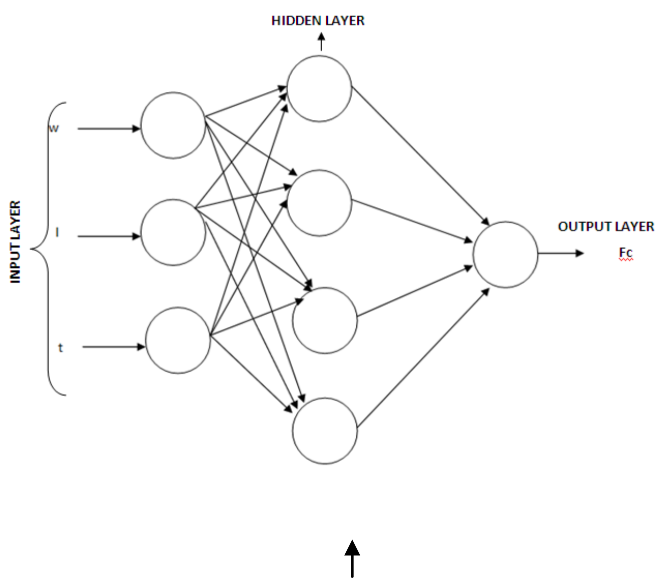


Fig. 5.18: The analysis ANN model

RBF is called feed forward NNs with a single layer of hidden and it applies radial basis activation functions for neurons of hidden layer and that's why known as RBF networks. These networks are used for various microwaves modeling applications In Fig.5.19, RBF network structure is shown. The parameters λ_{ji} and c_{ji} are standard deviations and centers of radial basis (RB) activation functions. Gaussian and multiquadratic are generally used as radial basis activation functions.

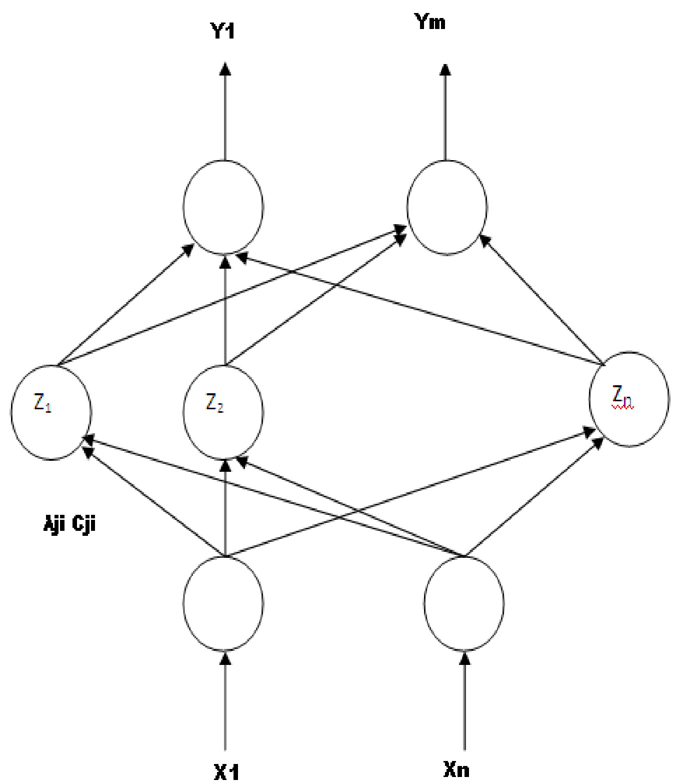


Fig.5.19: Structure of RBF neural network.

x is the given input and the total input given to the j^{th} hidden neuron γ_j is given by

$$\gamma_j = \sqrt{\sum_{i=1}^{n} \frac{(x_j - c_{ji})}{\lambda_{ji}}} \quad ,j = 1,2,......,N \qquad ....\ldots\ldots\ldots\ldots\ldots(5.5)$$

Where, n is the hidden neurons amount. The output of the jth hidden neuron is $z_{ji} = \sigma(\gamma_j)$, where $\sigma(\gamma)$ denotes RBF. As a final point, the output values of the RBF network are computed from hidden neurons as

$$y_k = \sum_{i=0}^{n} w_{ki} z_{ki} \qquad ....\ldots\ldots\ldots(5.6)$$

Where w_{ki} is the weight of the link between the *k*th neuron of the layer of output *and i*th neuron of the layer of hidden.

MLP neural networks are the easiest ANN models, and for that reason most commonly used [80, 81].Further, MLPNNs is trained through the standard back propagation algorithm .It has generally three layers, named as, an input layer, a hidden or intermediate layer and an output layer. The neurons of input layer allocate the input values x_j to the hidden layer(s) neurons.
Each neuron of hidden layer *j* adds up its input values x_j after assigning weight to them and thus strengthens the individual connections w_{ji} as of the input layer and calculates its output value y_i as a mathematical function f of the addition:

$$y_i = f\left(\sum w_{ij}\, x_j\right) \qquad \text{……………………….…..(5.7)}$$

Where *f* notation used to represent a hyperbolic or sigmoid tangent function. In the same way neurons of output layer is calculated.

Training an ANN involves the adjustment of weights of the network by means of a learning algorithm. Here, the back propagation learning algorithm [79] is used which is also called the gradient descent algorithm that provides the modification in $w_{ij(k)}$ in the form of weighted connection among neurons *i* and *j* in this way:

$$\Delta w_{ij\,(k)} = \alpha \delta_i x_j + \mu \Delta w_{ij}\ (k - 1) \qquad \text{……………………(5.8)}$$

Where α denotes the learning coefficient, x_j represent the input value, μ designates as the momentum coefficient, and δ_i belongs to a term depending on whether neuron *i* is a hidden neuron or a output neuron.
In the training of neural network, gradient descent with adaptive learning rate algorithm is used and K-fold cross-validation is used for the test result to be more valuable .We used this method for finding the best ANN structural design. The model developed is trained with data, which is collected by CST Simulation Software. Eight antenna dimensions having different length and width of i.e. w1,w2,w3,w4 are the width and s1,s2,s3,s4 are the length of steps used for proposed antenna. These eight dimensions are diverse from 0.1 to 2 mm and related simulated resonance frequencies are taken with the help of CST software. The sampled values are then scaled within the range 1to -1 and used as the training data for the network. In neural network during training process weights are adjusted automatically a thresh hold values so that there is minimum error between the predicted and sampled value. Back propagation algorithm is used to

compute these adjusted values. In this model 100 data samples are worn to design MSA from which details of 15 data samples have been given in Table5.2. Mainly three layers are used in algorithm i.e. input layer, hidden layer and output layer (Fig.5.20). Out of the 100 data generated, 70 are used for training and the rest are used for testing of the trained neural network. The optimized values of different parameters, which are obtained by trial and error for the training of the network, are: (1) the number of input nodes = 3; (2) in the hidden layer, the number of neurons =30; (3) the number of output node = 2; (4).

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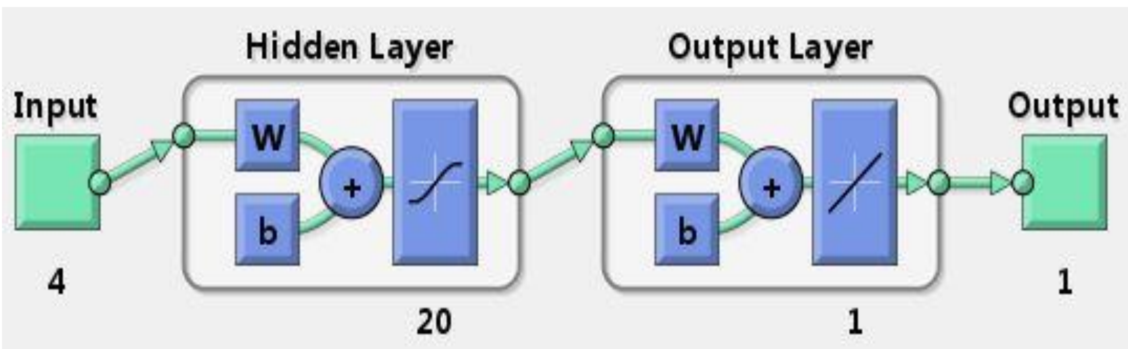

Fig. 5.20: Backward side model of NN (using Matlab).

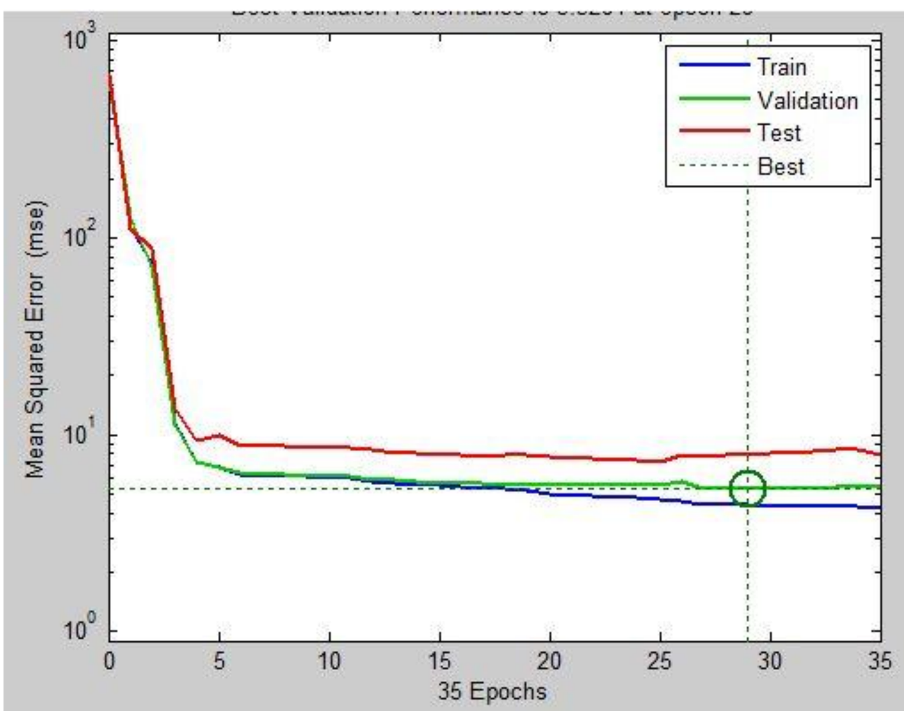

Fig. 5.21: Number of epochs to attain minimum means square error level

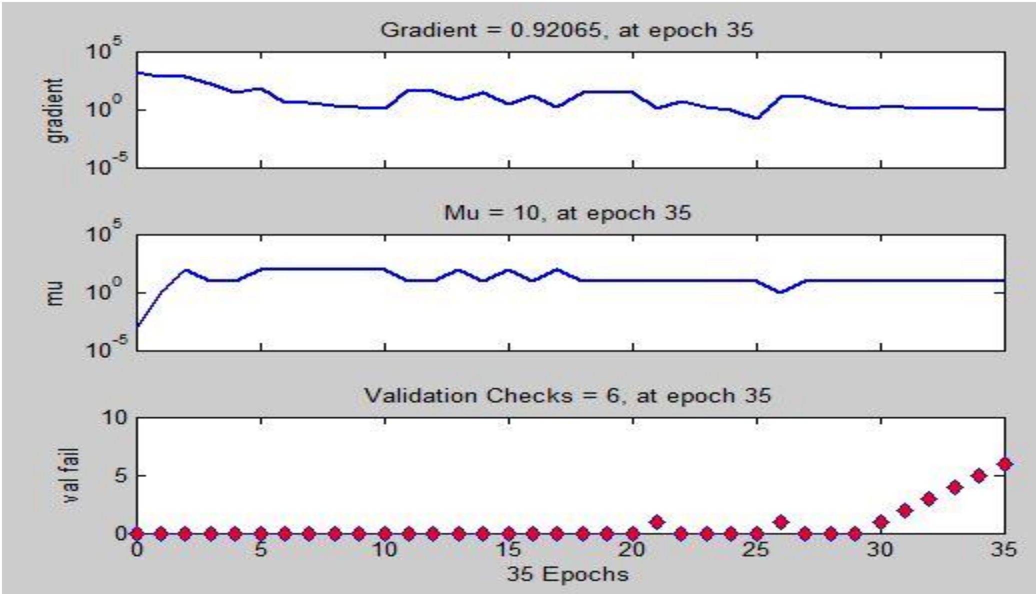

Fig. 5.22: Gradient and mu results at epochs 35

The training algorithm used is trainlm. The preferred transfer function is tansig and purelin. The feed forward back propagation network architecture is simulating the antenna design with high efficiency and accuracy. The training and testing result is as shown Table 5.2. Best validation performance of the network is at epoch 35 as shown in Fig.5.21 and corresponding gradient and mu are shown in Fig.5.22.

Table 5.2: Comparison of resonant frequency using CST and NN

S.No.	w1	w2	w3	w4	s1	s2	s3	s4	freq(GHz)using CST	Freq(GHz)using ANN	percentage error
1	28	24	12	8	12	5.75	5.25	5.75	6.897	6.897	000
2	28.5	23.5	12.5	8.5	11.9	5.65	5.1	5.65	6.825	6.827	0.0001
3	27.5	23.7	12.8	7.5	11.7	5.5	5	5.5	6.769	6.767	0.0001
4	28	24	11.8	7.5	11.5	4.85	5.25	4.85	6.897	6.894	0.0666
5	27.5	23.8	11.5	7.3	12	4.75	5	4.75	6.709	6.709	0
6	27.7	24.2	11.9	7.7	12.2	4.6	4.8	4.6	6.775	6.776	0.0067
7	28.2	23.6	12	8.2	12.4	5.2	4.8	5.2	6.835	6.835	0
8	28.5	23	12.4	8.4	12.6	5.5	4.75	5.5	6.846	6.844	0.0001
9	28.8	24	12.3	8	12.8	4.8	4.5	4.8	6.837	6.536	0.0001
10	27.2	24.2	12.6	8.1	11.5	4.75	5.5	4.75	6.664	6.664	0
11	28.4	24.6	12.7	7.9	11.7	4.9	5.2	4.9	6.808	6.809	0.0067
12	28.6	24.8	12	7.7	11.8	5	5	5	6.792	6.790	0.0001
13	28	23.8	11.5	8	12	5.5	5	5.5	6.897	6.897	0
14	27.4	24.5	12	8	12.4	5.25	5	5.25	6.734	6.733	0.0067
15	27.8	24	11.8	7.6	12.2	5.75	5.25	5.75	6.895	6.895	0

Table 5.2 represents the resonant frequencies obtained by using CST software and the by using Feed-Forward Back Propagation (FFBP) algorithm. The percentage error has been computed as the difference between the value obtained by CST software and the FFBP algorithm and it has been observed that it is very less and close to zero. So the antenna dimensions are well optimized using NN.

5.5 Measured reflection coefficient

The simulated antenna after NN optimization is fabricated on Flame Retardant4 (FR4) substrate material. The proposed antenna is fabricated using photolithography process as shown in Fig.5.23.The fabricated antenna is then tested for return loss using VNA. Both the simulated result of proposed antenna (Fig.5.9) and measured results of fabricated antenna (Figure 5.23) are shown in Fig.5.24. The measured and simulated results are in agreement except some distortion in measured frequency bands due to dimensional error in fabrication, or due to noise or interference from internal as well as external sources.

Fig.5.23: Prototype of proposed antenna.

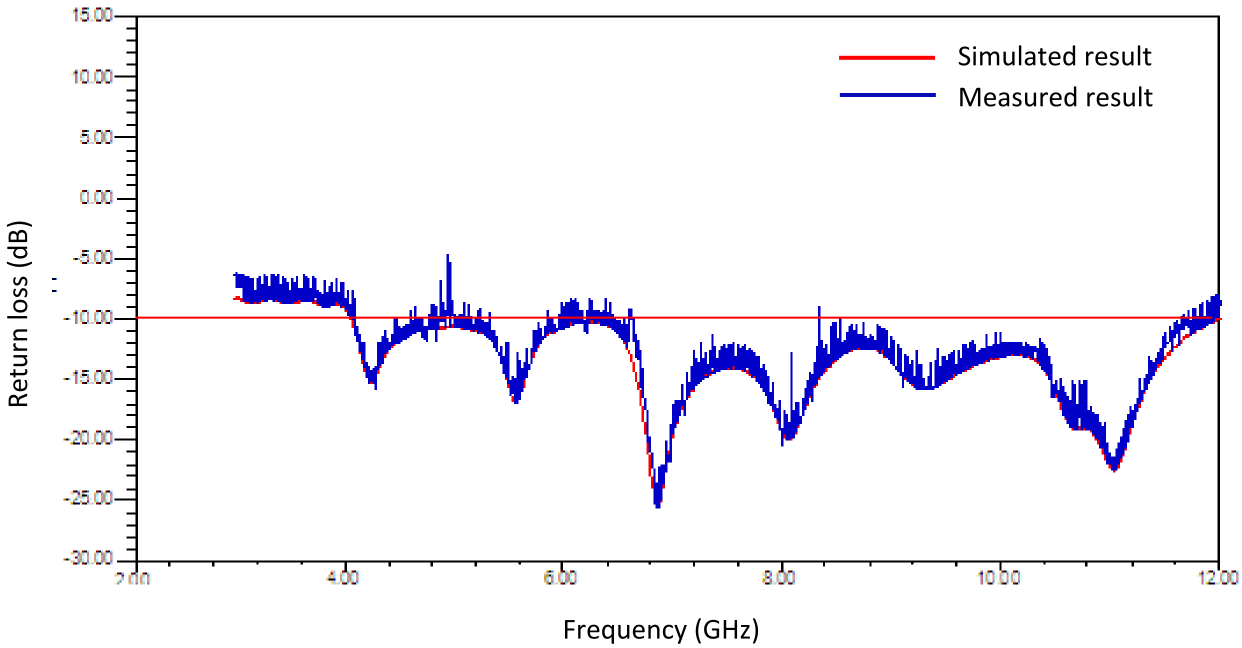

Fig. 5.24: Simulated and measured result of proposed antenna.

5.6 Conclusion

NN is considered as a computational tool in the designing of proposed micro strip antenna in this research. Forward side of the design procedure is the synthesis and the reverse side is the analysis of the design. So the geometric dimensions i.e. width and the length of the patch with high accuracy can be obtained at the output of the synthesis network in terms of height and dielectric constant of the used substrate. At the final stage, design procedure is analyzed; the data attained by move backward the input-output information of the synthesis work is used for determining the parameters of the optimized antenna. The synthesized resonant frequency is compared with the targeted resonant frequency in the analysis ANN. In conclusion, in this research work, a generalize design method for the micro strip antennas is proposed using ANN and this is validated by means of the patch structure.

Chapter 6

Conclusions and Future Scope of Proposed Work

6.1 Conclusions

The UWB antenna seems to be the solution for the future WPAN devices due to its capability to attain very high data rate. This chapter lastly concludes the simulated and measured results obtained from various structures of antenna designed and discussed in this thesis work to fulfill UWB technology requirements. The study and design of the proposed antennas for UWB Communications and applications in the 3.1-10.6 GHz bandwidth are pursued using the commercially available full wave simulation software HFSS. First of all the requirement of UWB antenna, motivation and objective of the present thesis work has been discussed. The literature survey has been also done to know about the importance of UWB antenna as well as various concepts used to improve the bandwidth, gain and reduction in size of UWB antenna. It is found that UWB antenna is the main interest area for researcher due to wideband and low power emission. In this thesis three different UWB antennas are considered, studied and designed for WPAN applications.

6.1.1 Hexagon Shape Ultrawideband Antenna conclusions

Hexagonal shaped patch antennas with very compact size (17mm × 17mm) have been proposed as first design. The current density distribution and 3D and 2D radiation pattern of hexagonal patch in E-plane and H-plane has been discussed. The radiation pattern of the proposed antenna attributed good gain for short range communication which makes it suitable for WPAN applications. The simulated reflection coefficient of proposed antenna show that the antenna cover the most of the UWB range (4.2GHz to10.6GHz). Proposed antenna was also fabricated and measured using VNA and there is very close proximity between the simulated and measured results. The antenna achieves the optimum gain of 5dBi with little variation at different frequencies and VSWR<2:1. Proposed antenna is further modified by taking different ground plane are in form of rectangular, circular and semicircular. This variation in ground plane has been done to know the effect on impedance bandwidth. Different frequency bands are achieved at 4.3GHz (4.1GHz-5.2GHz), 7.9 GHz (6.8GHz -8.2GHz) ,10.2GHz (9.8GHz -11.2GHz) which can be used for WLAN, X band, C band, PCS, UWB, and WPAN applications.

6.1.2 Staircase Ultrawideband Antenna with Flowery DGS and conclusions

In chapter 4 design of new printed monopole staircase antenna with flowery DGS has been discussed for UWB applications. The shape of rectangular radiator is cut into stairs like structure to achieve the UWB frequency range. The concept of etching the ground plane i.e. DGS is introduced in this chapter.DGS is the latest technology used to improve the quality and properties of antenna as well as this is also used to enhance the impedance bandwidth and reduce the size of antenna. The simulation and Measured results of the antenna prove good conformity that it has a good impedance matching over the UWB frequency range from 3.5 -10.4GHz for proposed antenna. Further, the Stair shape antenna has been modified by cutting a vertical single strip line and double stripline slot from the radiator. It has been observed that by using these slots antenna can work for various wireless bands such as Wi-Max and Wi-Fi without interference. The proposed antenna due to its simple structure is the best candidate for UWB systems and can be used for various WPAN applications.

6.1.3 ANN Optimization Technique for UWB Antenna conclusion statements

A different optimization method has been discussed in chapter- 5 for UWB antenna. There are various optimization techniques such as PSO, BBO, GA, SNLP and ANN. ANN algorithm is used in this chapter to optimize the proposed UWB antenna due to its simplicity and flexibility This method is also chosen over other optimization techniques due to its experimental behavior, based upon the statement of material phenomenon and capability to provide output in small amount of time.RBF and FFBP method are used for forward and reverse side ANN model respectively. By varying the length and width of different slots of proposed antenna the resonant frequency is obtained with the help of CST software and then optimized using ANN.

The percentage error for resonant frequency using CST and ANN has been calculated it is found very less (0.001). Further, the optimized antenna is also fabricated and measured to validate the results. The return loss with respect to frequency for simulated and measured has been observed similar except some distortion due to noise or other interference sources. The proposed antenna achieves the frequency range of 4.2GHz to 11.4GHz with VSWR less than 2:1 for whole spectrum with reasonably good radiation characteristics. So, this antenna due to its large band width is suitable for various UWB applications.

The design properties used to describe the different antenna in this thesis are: All antennas are fed by the 50 ohms-microstrip line. Different shape of ground planes (semi-circle, circular etc.) are introduced to check the effect of ground plane on antenna design. DGS is also introduced in one of antenna design to reduce the effect of surface wave as well as to miniaturize the size of antenna. Furthermore the notch is also cut from a staircase patch radiator. The basic idea behind to cut the notch is to improve impedance matching bandwidth and to reduce the size of the antennas. The notch cut also give further liberty for design and provides more space for other RF circuit elements. It is also observed that sometime radiation properties do not change significantly by cutting the notch in certain limit however; it affects operational bandwidth and radiation pattern in some band of frequencies beyond limits. It has been found that the proposed antennas are suitable for UWB technology. They can provide acceptable performance, including ultra wide bandwidth with nearly omni-directional radiation patterns.

6.2 Future Scope of proposed Work

Though this thesis work has covered the various issues related to UWB antenna still there is large scope of improvement in UWB antenna. So, future work can be described as mentioned below.

The UWB antenna is discussed for WPAN applications only however the study is further extended for medical applications and impact on human body can also be studied.

More research work and techniques are to be investigated to further reduce the size of UWB antenna for portable devices apart from presently used techniques i.e. DGS and notches cut from ground plane.

UWB system mainly exhibits the omni-directional property however in some communication systems and for military applications highly directional antenna is required. So, in future UWB directional antenna can be the interest area for researchers.

UWB antenna with band notch\band rejection properties may also be in demand in future research work to operate at some specific frequency band for a particular wireless system.

Finally the time domain characteristics play major role in UWB antenna. Hence further studies can be carried out to improve the time domain performance by carefully designing the UWB antenna.

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