A Technique To Design Broadband Antenna

Thesis Submitted in Partial Fulfilment of the Requirement For the Degree of

Master of Engineering
in
Electronics and Tele-Communication Engineering

Thesis Submitted By

PRITISH MAHAJAN
University Registration No.:160215 of 2021-2022
Class Roll No.: 002110702019
Exam Roll No.: M4ETC23016

UNDER THE GUIDANCE
OF
PROFESSOR MANOTOSH BISWAS

Department of Electronics and Tele-Communication Engineering
Faculty Council of Engineering and Technology Jadavpur University
Kolkata–700032, India

2021-2023

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"A Technique To Design Broadband Antenna"** submitted by Pritish Mahajan under my guidance and supervision and be accepted in partial fulfilment of the requirement for awarding the degree of Master of Engineering in Electronics and Telecommunication Engineering of Jadavpur University. The research results presented in this thesis have not been included in other paper submitted for the award of any degree to any other Institute or University.

Manotosh Biswas 15/06/23

Prof. Manotosh Biswas
Thesis Supervisor Dept. Electronics and Telecommunication Engineering Jadavpur University Kolkata 700032, West Bengal, India

MANOTOSH BISWAS
Professor and Head
Electronics and Telecommunication Engineering
Jadavpur University, Kolkata - 32

Manotosh Biswas 15/06/23

Head of the Department
Dept. Electronics and Telecommunication Engineering Jadavpur University Kolkata 700032, West Bengal, India

MANOTOSH BISWAS
Professor and Head
Electronics and Telecommunication Engineering
Jadavpur University, Kolkata - 32

Ardhendu Ghoshal 15/06/23

Dean
Faculty of Engineering and Technology
Jadavpur University Kolkata 700032, West Bengal, India

DEAN
Faculty of Engineering & Technology
JADAVPUR UNIVERSITY
KOLKATA-700 032

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work done by the undersigned candidate, as a part of his degree of Master of Engineering in Electronics and Telecommunication Engineering of Jadavpur University. All the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

15/06/2023

Date:

Pritish Mahajan

PRITISH MAHAJAN

University Registration No.:160215 of 2021-2022

Class Roll No.: 002110702019

Exam Roll No.: M4ETC23016

CERTIFICATE OF APPROVAL

The foregoing thesis is hereby approved as a credible study of an Engineering Subject carried out and presented in a manner of satisfactory to warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is to be understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

Committee on final examination
for the evaluation of the Thesis

(Signature of the Supervisor)

(Signature of the Examiner)

Dedication

This thesis work is dedicated to my parents and my younger brother

Acknowledgement

At the very begining I would like to take opportunity to express gratitude to Prof. Manotosh Biswas, my project supervisor of Master degree thesis for suggesting and guiding me for the project in the field of Ultra wide band antenna and I acknowledge him for being supportive and friendly always like a family member through out the year of my post graduation degree.He always open to me and never pressurize related to anything and given free hand for my work.Another big thing he has done for me is that he send his feedback and recommendation for attending interview for Ph.d admission at IIT kanpur where I get selected as ph.d scholar with fellowship.I would also like to express my deep gratitude and respect to Prof. Bhaskar gupta also who also send his recommendation for the same.I would also like to thank everybody who were involved with me in the university during my work.

I am grateful to all the faculty members of the Electronics and Tele- Communication Engineering Department, Jadavpur University, for getting some valuable advices to gather knowledge in different subjects included in syllabus of Master of Engineering and get success in each semester exams. Suggestions from Prof. S. Chatterjee, Prof. S. Ray, Prof. A. Konar and Prof. M.K Naskar have helped me in all the time.

This thesis would not have been completed without help and co - operation of all my seniors of JU Microwave Lab. I would like to thank Mr.Biplab Biswas,Mr. Soham Ghosh,Mrs Baisakhi Naskar,Mr. Sheershenduish Bhattacharya Mr. Joydeep Pal and Mr. Sayan Sarkar and for their suggestion as well as helps to complete the thesis in simulation work and practical work as well.I also grateful to my all fellow classmates who discussed suggested various topics on academics and carrier perspectives.

Lastly, but more importantly, I would like to thank all my family members and my loved one and well-wishers who always encourage me to pursue my studies, stay with me and hold my hand sin all ups and downs up to this journey in my life and motivate me to overcome all difficulties.Special thanks to all my school and college friends who are always with me wherever they stay. I also like to acknowledge AICTE (All India Council for Technical Education) for providing me PG Scholarship to pursue my PostGraduate Degree course in duration of 2020-2022. Without their blessings, I could not complete this work successfully with little smile in my face.

List of Figures

List of Tables

Contents

Chapter 1

Introduction

1.1 Intorduction

Communication is the way of transferring information from one point to another point.It can be between two persons or between two devices.From one point the information is transmitted which is called transmitter.And it is another received at another point that is called receiver.Generally for human or other living object only short distance communication is possible.But for devices to be specific electronic devices to establish communication certain set of rule is there which is called protocol[1].For transmission and reception of the information medium is required.That medium cab be wired or wireless medium[2].Depending on the medium of communication i.e channel the security reliability and accuracy etc varies and all these important parameter should be taken care of before establishing the communication between two electronic devices.The fig1.1 shows basic communication process between various electronic components using wireless channel.

In case of wired medium a physical medium is connected between transmitter and receiver through which the electrical form of the message travels.That physical medium can be twisted pair cable,optical fibre cable, coaxial cable etc [3].For wireless medium the electrical form of the message is travels through free space.Today's world is directly or indirectly depending on the wireless technology in many aspects.we can not imagine our day to day life without wireless technological tools like mobile phone, blue tooth devices,Wi-Fi, Wi-Max, TV broadcasting, radio, satellite communication and so many[4].In all these technology the information travels in free space in the form of electromagnetic wave [5].In all wireless communication one common requirement is antenna.Antenna is a transducer which transmits the electromagnetic waves into the space by converting the electric power given at the input into the radio waves and at the receiver side the antenna receives these radio waves and again converts them back

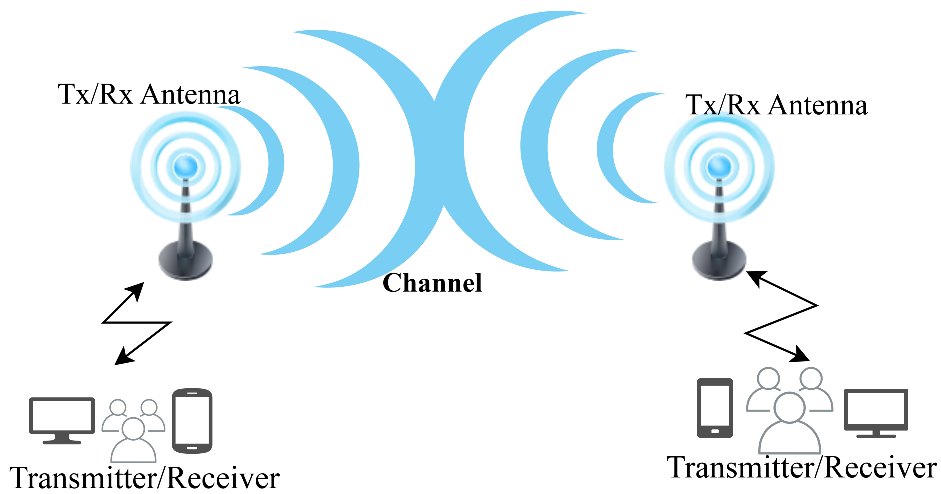


Figure 1.1: Simple wireless communication process

into the electrical power[6, 7]. There are various aspect for designing an antenna like return loss, gain,efficiency directivity, polarisation, impedance, bandwidth etc.Due to large number of data transmission and bandwidth requirement various challenges are there.We know from shannon channel capacity theorem [8] the channel capacity is related to bandwidth and signal to noise ratio by the equation

$$C = B\log_2(1 + SNR) \tag{1.1}$$

Where C is the channel capacity in bits and B is the bandwidth.
SNR is the signal to noise ratio.

Therefore more channel capacity more bandwidth required.Band width is a very important parameter for designing an antenna.The bandwidth of an antenna is the range of frequency over which the performance of the antenna,in terms of some standard characteristic, remains upto a specified standard[9].For antenna there are two types of characteristics one is radiation characteristics and another one is input characteristics[10].Radiation characteristics are gain , directivity, polarisation, radiation pattern and affective apperture etc.Input characteristics are input impedance , bandwidth , VSWR, reflection coefficient etc.While designing both input and radiation characteristics has to be considered. The bandwidth of an antenna can also be defined by the other input characteristics like VSWR, reflection co-efficient, and input impedance by the following equation[11, 12].

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}} \tag{1.2}$$

Where $VSWR$ is the voltage standing wave ratio and Q is the quality factor.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{1.3}$$

Γ =reflection co-efficient.

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{1.4}$$

Z_{in} = Input impedance, Z_0 = Characteristics impedance.

All the above mention wireless technologies are narrow band technology that is their bandwidth is very small.In free space the entire spectra is used for various application based on their allocated frequency range by various international and national bodies[13, 14].Based on frequency range the entire spectra is classified as VHF,UHF,L,S,C,X,Ku,K ,ka,V,W and milimeter wave[15, 16].All these band has different frequency range and each band is used by diffrent wireless technology.Due to rapid growth in various WPAN devices application research towards near field communication also rapidly growing.After rapid growth in 4G now 5G even in 6G and tera hertz also various development related to compatibility ,safety and environmental hazards etc. now opening new area of research in antenna and microwave domain. Talking about near field communication the devices used in the process must satisfy low power requirement safety security and miniaturized as well.UWB devices can be an alternative to all these existing technologies due to its various features[17].

In this thesis a monopole antenna with CPW feed and micro strip feed has been designed for ultra wide band frequency.The antenna is fabricated and its various characteristics also measured.

1.2 Introduction to UWB

UWB is a technology that promises to provide high bandwidth which in terms provides high rate of data transmission.It also gives new services to all other narrow band technologies like wi-fi bluetooth and co-exist.UWB transmits and receives pulse based wave forms which is compressed in time whereas other narrow band technology uses compression in frequency[18].Compression in time allows transmission over a wide band width with very low power spectral density.UWB transmits large amount of data with a duration of less than 1 nano second.UWB pulses can sense distances between two transmitters.In UWB we can achieves real-time accuracy because it transmits up to 1 billion pulses per second (about 1 per nanosecond).Shorter the duration of the impulse, the more precisely the distance measurement can be done.UWB also called carrier free or impulse radio of baseband radio as it does not require any high frequency carrier for transmission.UWB is known for its precise positioning and tracking kind application.It is also secure compare to other wirless technology[19]. Ultra wide band is mainly for short distance wireless communication with high bandwidth.Use of large bandwidth also creates challenges in antenna design and its performance.

According to Federal Communication Commission's (FCC's)definition, UWB is the one for which the fractional bandwidth is greaterthan 20% or occupying an instantaneous bandwidth of at least 500 MHz [20]. Fractional bandwidth is a factor used to defined the bandwidth characteristics of an antenna which is given by the equation[21]

$$FBW = \frac{f_h - f_l}{f_0} \times 100\% \tag{1.5}$$

Here f_0 is the center frequency and it is given by the equation

$$f_0 = \frac{f_h + f_l}{2} \tag{1.6}$$

For using spectrum by any technology it requires government regulation by international/national regulatory bodies.Federal communication commission(FCC) which is world wide regulating body for frequency allocation in the year 2002 allocated 3.1 to 10.6 Ghz for UWB technology.*i.e* for UWB communication i.e fractional bandwidth is approximately 109.5% [22].Since then UWB has gained lot of attraction in academics and industry.The figure shows various spectrum used by various wireless technology.The IEEE standard for UWB is 802.15. 4a and 802.15.4z [23].The figure 1.2shows various wireless technologies and their frequency ranges.

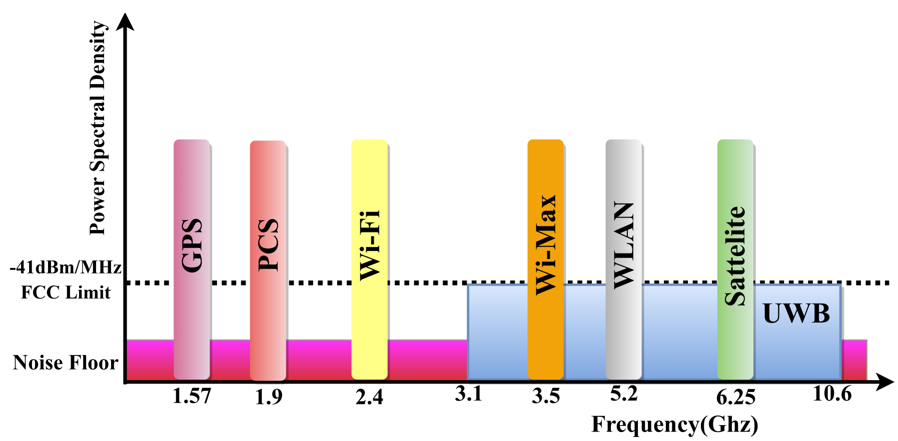


Figure 1.2: Spectrum of various technology

Incorporating UWB into the design of devices can vary depending on region. As it occupies such a wide frequency band spectrum, there is a possibility that UWB can interfere with other telecommunication services occupying the same frequencies[24].

1.3 History

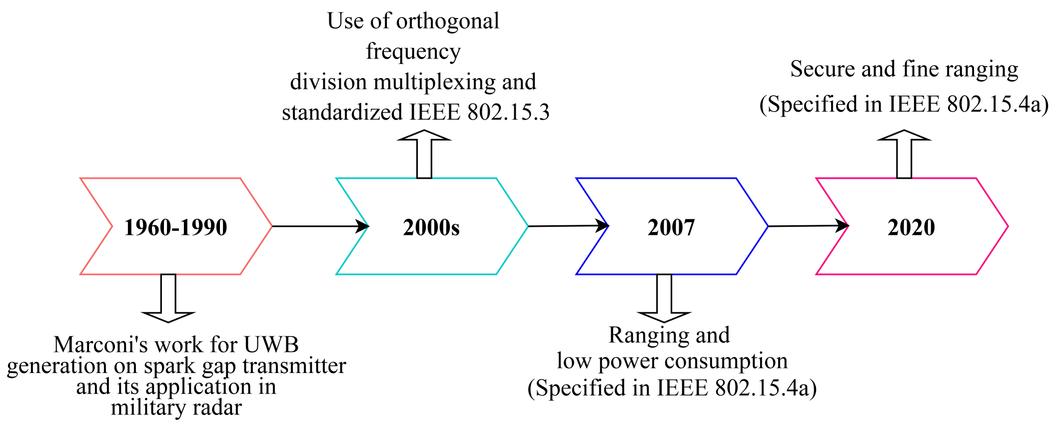


Figure 1.3: History of UWB(Source: FiRa Consortium)

UWB is not completely new technology.It was introduced in 1960 by research on electromagnetic wave propagation studies[25].In 1887 Hertz first generated UWB signal in the form of spark and it was then transmitted using wide band loaded dipoles[20].In 1901 Markoni refined Hertz work by using spark gap radio transmitter for Morse code transmission over Atlantic ocean.In 1950 the pulse based transmission gained interest in military applications when impulse radars was implemented.In 1960 approximately 50 years after Marconi's work UWB development was started by Harmuth at Catholic University of America, Ross and Robbins at Sperry Rand Corporation, Paul van Etten at the USAF's Rome Air Development Centre and in Russia[26] [9].In 1969-1984 Harmuth published papers on the basic design for UWB transmitters and receivers.Ross's US patent (1973) was a landmark in UWB communications [27].

1.4 Application

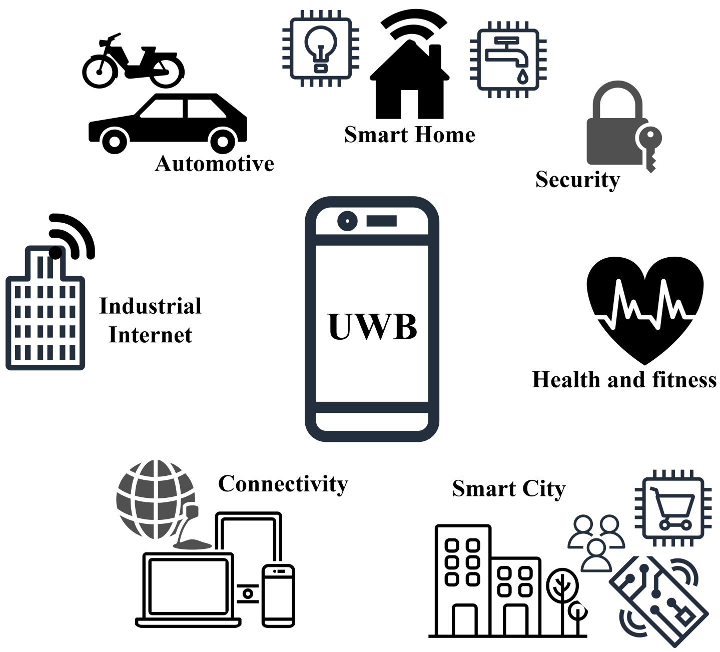


Figure 1.4: Application of UWB

Ultra wide band technology can be used in various fields.Following are the some application area [28–30]

- **Precise Tracking**-Indoor Navigation, Warehouse positioning,Sports and fitness tracking are the major domain for precise tracking kind of application.

- **Communication application** [31]- For high data rate and low power requirement of UWB over short range it is suitable for WPAN.UWB also can resolve the wire complexity issue around personal computers (PC) by wirelessly connecting PC peripherals such as storage, I/O devices and wireless USB (Universal Serial Bus) scanners and video cameras.

- **Radar Application**[32]- For ground penetrating radar(GPR), Medical radar,Wall imaging are the major field of UWB based radar application.

- **Military Application**-Because of its low power and short duration pulse and no carrier modulation UWB is secure compare to other communication protocols.For that it is very useful for military communication like covert sensor networks.

- **Commercial Application**-Various RFID tag and industrial RF monitoring system UWB can be used.Various UWB sensor also is very popular nowadays.
- **Medical Application**-UWB antenna is also applicable for WBAN devices and for capsule endoscopy devices[33].

1.5 Motivation

Though significant development has been done by the researcher on UWB over past years but still the challenges are there regarding the design of UWB antenna with desirable performance and reducing the interference with the existing narrow band technology.As day by day rate of data transmission, internet access increasing use of UWB also increasing[34].In 2019 apple used UWB in I-phone.Apart from apple other companies also like BMW, LG, Panasonic, Samsung, VW etc they are also now focusing UWB chips for their various devices.ABI Research anticipates that around 25% of cars shipping in 2025 will come equipped with UWB access technology, with UWB expected to become the major mobile car access technology in the future.So antenna designing for all those devices will become a challenging task.Various conventional broadband antennas like wire monopole antenna, Vivaldi antenna, biconical antenna, log periodic antenna suffers lot problem like directional radiation, size and portability issues[35].So to overcome all those issues suitable antenna design for UWB communication is required.Microstrip antenna is one solution for portable devices and other various UWB enabled wireless devices.Again designing of UWB antenna also suffers the problem of impedance matching and gain issues.

The proposed work in this theis is motivated from the demand of small size , higher bandwidth and cost effective high gain and high efficiency antenna design.

1.6 Organisation of thesis

The thesis organised in seven chapters. In chapter 1 introduction of wireless technology and antenna for narrow band wide band.Some application of ultra wide band and the motivation of the thesis is explained in brief.
In chapter 2 some previous work related to ultra wide band antenna and their result is explained.Extensive study related to broadband antenna and their application has been done and try to find out the new research in these domain
In Chapter 3 is microstrip antenna basics how microstrip antenna is constructed and working principle is explained.Some of the advantages and disadvantages of micro strip antenna also explained in this chapter.Later simple equivalent circuit of microstrip antenna is alos explained in brief
Chapter 4 explains the ultra wide band mono pole design.This is the main proposed

work chapter.A CPW feed UWB monopole is designed and various parametric study related to optimal design is discussed in detail.later part of this chapter a microstrip feed monopole also designed in CST.
In Chapter 5 an antenna equivalent circuit is proposed based on the cascaded parallel resonator circuit.And the simulation of the equivalent circuit in ADS software.
Chapter 6 is about use of Python library i.e Scikit-Rf in RF engineering and our result in Python.Here the open source python package for RF engineering domain is expalined and it is new area of research for RF engineer using Python.

Chapter 7 is about verification of simulation result and measured result.Here all the related result obtained from simulation as well as measurement is given.

Bibliography

[1] J. Dong. *Network Protocols Handbook*. Online access: EBSCO Computers & Applied Sciences Complete. Javvin Press, 2007.

[2] David Tse and Pramod Viswanath. *Fundamentals of wireless communication*. Cambridge university press, 2005.

[3] Dana George Reed et al. *The ARRL handbook for radio communications*. Amer Radio Relay League, 2002.

[4] Theodore S Rappaport, Robert W Heath Jr, Robert C Daniels, and James N Murdock. *Millimeter wave wireless communications*. Pearson Education, 2015.

[5] D. Tse and P. Viswanath. *Fundamentals of Wireless Communication*. Wiley series in telecommunications. Cambridge University Press, 2005.

[6] Robert E Collin. *Field theory of guided waves*, volume 5. John Wiley & Sons, 1990.

[7] Simon R Saunders and Alejandro Aragón-Zavala. *Antennas and propagation for wireless communication systems*. John Wiley & Sons, 2007.

[8] E Desurvire. Gaussian channel and shannon–hartley theorem. *Classical and Quantum Information Theory*, pages 264–272, 2009.

[9] Constantine A Balanis. *Antenna theory: analysis and design*. John wiley & sons, 2016.

[10] A.R. Harish and M. Sachidananda. *Antennas and Wave Propagation*. Oxford higher education. Oxford University Press, 2007.

[11] Girish Kumar and Kamala Prasan Ray. *Broadband microstrip antennas*. Artech house, 2002.

[12] DM Pozar and DH Schaubert. Microstrip antennas-the analysis and design of microstrip antennas and arrays, new york, usa: The ieee, 1995.

[13] XX. Approved ieee draft amendment to ieee standard for information technology-telecommunications and information exchange between systems-part 15.4:wireless medium access control (mac) and physical layer (phy) specifications for low-rate wireless personal area networks (lr-wpans): Amendment to add alternate phy (amendment of ieee std 802.15.4). *IEEE Approved Std P802.15.4a/D7, Jan 2007*, 2007.

[14] Christian Hoymann. Analysis and performance evaluation of the ofdm-based metropolitan area network ieee 802.16. *Computer networks*, 49(3):341–363, 2005.

[15] Roberto Sorrentino and Giovanni Bianchi. *Microwave and RF engineering*. John Wiley & Sons, 2010.

[16] Jin Au Kong. Theory of electromagnetic waves. *New York*, 1975.

[17] Renato Cicchetti, Emanuela Miozzi, and Orlandino Testa. Wideband and uwb antennas for wireless applications: A comprehensive review. *International Journal of Antennas and Propagation*, 2017, 2017.

[18] K.Y. Yazdandoost and R. Kohno. Ultra wideband antenna. *IEEE Communications Magazine*, 42(6):S29–S32, 2004.

[19] M.A. Peyrot-Solis, G.M. Galvan-Tejada, and H. Jardon-Aguilar. State of the art in ultra-wideband antennas. In *2005 2nd International Conference on Electrical and Electronics Engineering*, pages 101–105, 2005.

[20] Moe Z Win, Davide Dardari, Andreas F Molisch, Werner Wiesbeck, and W Jinyun Zhang. History and applications of uwb. Institute of Electrical and Electronics Engineers, 2009.

[21] FCC Fcc. First report and order on ultra-wideband technology. *FCC, Washington, DC, USA*, 2002.

[22] Federal Communications Commission et al. Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems. *First report and order*, 2002.

[23] Dieter Coppens, Adnan Shahid, Sam Lemey, Ben Van Herbruggen, Chris Marshall, and Eli De Poorter. An overview of UWB standards and organizations (IEEE 802.15.4, FiRa, apple): Interoperability aspects and future research directions. *IEEE Access*, 10:70219–70241, 2022.

[24] G.M. Galvan-Tejada, M.A. Peyrot-Solis, and H.J. Aguilar. *Ultra Wideband Antennas: Design, Methodologies, and Performance*. Taylor & Francis Group, 2016.

[25] H.G. Schantz. A brief history of uwb antennas. *IEEE Aerospace and Electronic Systems Magazine*, 19(4):22–26, 2004.

[26] Kiminami, Hirata, and Shiozawa. Double-sided printed bow-tie antenna for uwb communications. *IEEE antennas and wireless propagation letters*, 3:152–153, 2004.

[27] Terrence W Barrett. History of ultra-wideband (uwb) radar & communications: Pioneers and innovators. progress in electromagnetics symposium (piers 2000). *Cambridge, Massachusetts*, 2000.

[28] Sana Ullah, Murad Ali, Asdaque Hussain, and Kyung Sup Kwak. Applications of uwb technology. *arXiv preprint arXiv:0911.1681*, 2009.

[29] Yusnita Rahayu, Tharek Abd Rahman, Razali Ngah, and Peter S Hall. Ultra wideband technology and its applications. In *2008 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN'08)*, pages 1–5. IEEE, 2008.

[30] Chinmoy Saha, Jawad Y Siddiqui, and Yahia MM Antar. *Multifunctional ultra-wideband antennas: trends, techniques and applications*. CRC Press, 2019.

[31] Symeon Nikolaou and Abdul Quddious. Antennas for uwb applications. In *UWB Technology-Circuits and Systems*. IntechOpen, 2019.

[32] Igor I Immoreev and PGS Dmitry V Fedotov. Ultra wideband radar systems: advantages and disadvantages. In *2002 IEEE Conference on Ultra Wideband Systems and Technologies (IEEE Cat. No. 02EX580)*, pages 201–205. IEEE, 2002.

[33] Yang Feng, Shao-Peng Pan, Jia-Wei Li, Pan Chen, Lin Qi, and Gao-Sheng Li. Design of ultra-wideband conformal capsule antenna for wireless capsule endoscopy system. In *2020 Cross Strait Radio Science & Wireless Technology Conference (CSRSWTC)*, pages 1–3, 2020.

[34] Mian Ahmad Jan, Fazlullah Khan, and Muhammad Alam. *Recent trends and advances in wireless and IoT-enabled networks*. Springer, 2019.

[35] Om Prakash Kumar, Pramod Kumar, Tanweer Ali, Pradeep Kumar, and Shweta Vincent. Ultrawideband antennas: Growth and evolution. *Micromachines*, 13(1):60, 2021.

Chapter 2

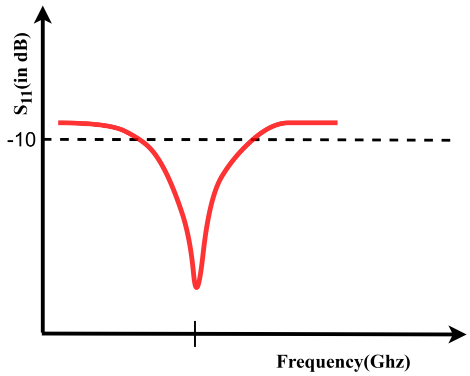
literature review

2.1 Introduction

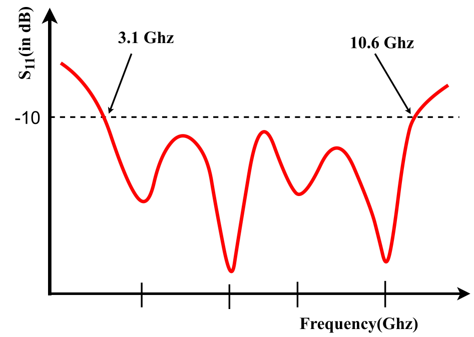
In 1918, UWB was banned as it was interfering with narrow-band frequencies and it was restricted to only military applications.UWB made a resurgence in the early 1980s but it was still limited to military applications.In 2002 The Federal Communications Commission (FCC) of the United States has allocated a band covering of 7.5 GHz (3.1GHz to 10.6GHz) for the unlicensed use of UWB applications. In Europe, the Electronic Communications Committee (ECC) has allocated various frequency ranges of 3.1GHz – 4.8GHz, 6GHz – 8.5GHz, and 8.5GHz – 9GHz across most countries in the region. Other regions and countries vary in permitted frequency bands which must be taken into account when implementing UWB antennas into any design.

Various types of planar and non-planar UWB antennas proposed by researchers worldwide.Out of all those for compact and portable devices UWB planar monopole have gained attention because of its simple structure, large impedance bandwidth coverage and omni directional radiation pattern. This has made UWB planar monopole antennas a promising candidate for UWB communication systems. This chapter present the literature review on monopole antennas with CPW feed and microstrip feed for UWB applications and various techniques for achieving broad band width.

After finalising the mono pole antenna a two element UWB MIMO antenna also designed.In today's wireless communication scenario one of the major problem is multi path fading and MIMO antenna is one solution to minimize that[1].As UWB covers wide bandwidth so it suffers multipath fading which can be overcome using MIMO antenna[2].MIMO antenna provides multiplexing gain and diversity gain which can further improve the capacity and link quality[3].Main problem for the design of MIMO antenna is the isolation between the elements of the MIMO antenna.Various design suggested for better isolation which is explained in the later part of these chapter.Like



(a) S_{11} of narrow band antenna



(b) S_{11} for ultra wideband antenna

Figure 2.1: Return loss for narrowband and UWB antenna

for getting optimum characteristics of an antenna we try to improve $S_1$1parameter i.e return loss similarly for good isolation S_{12} and S_{21} parameter i.e isolation should be improved[4].Appart from these other important parameters for MIMO antenas are Envelope Correlation Coefficient (ECC),Diversity Gain (DG),Channel Capacity Loss (CCL),Mean Effective Gain (MEG) and Total Active Reflection Coefficient (TARC) [5].

2.2 Various methods to achieve broadband

After designing an antenna we must ensure that it should radiate.Whether the antenna is suitable for application is characterise by observing its S_{11} parameter which is also called return loss if it is represented in terms of db.The figure shows how the S_{11} parameter looks like for narrow band and ultra wide band antenna.

There are various methods proposed in literature to increase bandwidth of micro strip antenna.Some of the techniques are based on the structures like intrinsic technique,parasitic patch and stacked patch and some are based on feeding methods like proximity coupled feed and apperture coupled feed CPW feed and microstrip feed .For structural design intrinsic technique proximity coupled and stacked patch.

For most of the cases coaxial probe is used to feed the radiating patch for that input impedance becomes more inductive to get proper impedance matching. In monopole the patch is feed form the periphery with additional ground plane[6].Microstrip monopole is useful for large impedance bandwidth. Here specially two types of feeding method studied these are CPW feed and microstrip feed.

2.3 CPW feed monopole antenna

CPW feeding is one method to achieve wide bandwidth. Many academicians and industry personals presented their work related to CPW feed UWB antenna.Antenna design and its equivalent circuit characteristics has been studied in [7, 8].In [8] stair case rectangular patch with C slot and CPW feed is proposed.The material used is Rogers (RT/5880) with $\epsilon_r = 2.2, \tan\delta = 0.009, h = 0.8mm$.The bandwidth obtained is 1.55–16.95 GHz (166.51%). Transmission line model of the antenna also studied.And it is verified using AWR circuit simulator.

A microstrip line UWB monopole antenna and a CPW fed UWB monopole antenna. First, a monopole antenna to cover the entire UWB band of 3.1-10.6GHz is designed. Different types of tapers are investigated to achieve the impedance match over the desired band. Next, two band-rejection notches at 5.2GHz and 5.8GHz are introduced by combining two traditional band-notching techniques. Performance of the proposed antennas has been investigated in both frequency and time domain. It is found that the antennas exhibit omnidirectional radiation in H-Plane, with a gain of 2-4dB except at the notch frequencies[9].

Novel Compact UWB Planar modified hexagonal Monopole Antenna Using a Ribbon-Shaped Slot is proposed in [10].Here obtained bandwidth is 3.1 to 10.8 Ghz.A ribon slot is used for matching and for feeding CPW line is used.Both ground plane is modified with uniformly separated circular slot.FR-4 substrate with $\epsilon_r = 4.4$ 1mm thickness and loss tangent of 0.02 is used for fabrication.One of the major application of UWB is UWB radar which is useful for medical and IOT application.In [11] an inkjet-printed circular-shaped monopole ultra-wideband (UWB) antenna with an inside-cut feed structure was implemented on a flexible polyethylene terephthalate (PET) substrate.The dimension of the antenna is 47 mm × 25 mm × 0.135 mm.The range of frequncy is 3.04–10.70 GHz and 15.18–18 GHz. In [12]a compact coplanar-waveguide-fed single-layer printed antenna with an ultrawideband (UWB) rectangular monopole radiator etched with a half-elliptical slot is presented. Collaborating with the UWB radiator, two symmetrical open-circuit stubs are extended from the ground plane to jointly achieve an ultrawideband impedance match with a compact size. The proposed antenna is fabricated and tested in an anechoic chamber, showing an ultra-wide operating frequency range from 3.7 to 10.1 GHz with a quasi-omnidirectional gain from 2.0 to 7.3 dBi.

In [13] an ultrawideband antenna with CPW feed and microstrip feed is proposed for wireless application.FR4 glass epoxy substrate with 1.6mm thickness and dielectric constant 4.4 is used for fabrication.Obtained frequency bandwidth is 1.68-20 Ghz.In [14] compact UWB antenna with flexible substrate ROGERS 5880 is proposed.The size of the antenna is 15×20 and 2.73–9.68 GHz bandwidth is obtained.UWB antenna is useful for WBAN devices also.[15] explains the idea of ON-OFF Body (UWB) Antenna for Wireless Body Area Networks.Here CPW feed antenna is designed with a dimension of (23×25×1.6) mm^3 with FR-4 substrate and the frequency coverage is 4.9 – 25 GHz.

A novel miniaturized all-metal ultrawideband (UWB) magneto-electric monopole (MEM) antenna in this communication is proposed in[16]. The proposed antenna is composed of a half-ellipse electric monopole and a quarter magnetic loop. The half-ellipse electric monopole consists of a half ellipse with a rectangular slot, a loaded patch, and an L-shape ground fed by a coaxial connector. Enhanced robustness to severe surrounding environments and lower loss can be achieved by employing an all-metal structure instead of the structure including dielectric materials. A prototype was fabricated and measured. Results show that the proposed MEM antenna can operate in the frequency band of 2.5-13 GHz even higher frequency.

The design nuances and associated performance characteristics of two printed planar ultrawideband (UWB) antennas are reported in [17]. The designs achieve improved broadside-realized gains, particularly at the high-frequency side of the UWB band. An arc-shaped slot is etched into the radiating patch of a standard compact elliptically shaped UWB monopole antenna. The resulting parasitic element is engineered to produce its fundamental resonant mode in such a manner that a more compact overall design is realized and the broadside-realized gain in the upper UWB frequency range is improved while maintaining impedance matching without any significant changes to the original design parameters. In agreement with simulations, a 61.7% reduction in size from previous designs is demonstrated with more than a 6 dB increase in the realized gain near 10 GHz.

A coplanar waveguide (CPW)-fed monopole antenna is proposed, which is composed of a rectangular monopole patch notched at the bottom, a T-shaped CPW ground in the notch, and a tapered CPW ground out of the notch. The simulated and experimental results show that the antenna achieves a fractional impedance bandwidth of 164%[18].

UWB is used in GPR application.Previously many work reported on UWB antenna in GPR applications[19–21].In [22] A compact umbrella shaped UWB antenna is designed with the dimension 35 ×30×0.8 mm^3 using FR-4 substrate for GPR application. UWB antennna is used in biomedical application.Various work is proposed based on those applications.[23] is the proposed work for detecting breast cancer using CPW fed UWB antenna.A textile WBAN antenna is proposed in[24].In [25] also fractal pentagonal CPW feed UWB antenna is proposed for microwave imaging application.

A compact, low-profile ultrawideband directional antenna for a wireless body area network (WBAN) is reported in [26]. The directional antenna is designed using a monopole backed with an electromagnetic bandgap (EBG) structure, which acts as a reflector. The beveled Y-shaped monopole antenna covers the ultrawide bandwidth from 3.1 to 10.6 GHz.

2.4 Microstrip line feed monopole antenna

Mirostrip feeding with defected ground is another method for getting ultra wideband response.In [27]staircase rectangular patch with defected groud plane in the backside and microstrip line feed antenna has proposed for ultra wideband application.Bandwidth obtained form 2.33-12.4 Ghz i.e fractional bandwidth of 136.5% .

A novel and compact ultra-wideband (UWB) microstrip-fed monopole antenna having frequency band notch function is presented in[28]. To increase the impedance bandwidth of an antenna, a narrow slit is used. By inserting a modified inverted U-slot on the proposed antenna, the frequency band notch characteristic is obtained. The designed antenna satisfies the voltage standing wave ratio requirement of less than 2.0 in the frequency band between 3 and 11 GHz while showing the band rejection performance in the frequency band of 5.0 to 5.9 GHz.

In[29] micro strip feed Diamond Slotted Patch Antenna with Enhanced Bandwidth is proposed.Here 3.28 GHz to 19.64 GHz band width is obtained. [30] proposed microstrip antenna for breast cancer detection using SE-DGS Tapered-Fed Notched UWB Antenna Integrated with Ku/K Band.The antenna is fabricated with FR-4 substrate and bandwidth obtained is 4.11–29.77GHz, i.e fractional bandwidth of 151.47%.In [31] UWB monopole antenna with microstrip feed is presented with defected ground in the back side.

A high gain and miniaturized super wide band microstrip patch antenna is prresented in [32].Here the antenna is placed above FSS to obtain high gain.In [33] a microstrip feed UWB antenna is proposed with SRR structure . The antenna is fabricated usign FR4 substrate with a dimension of 50×50 and the obtained frequency range is 1.5 to 11Ghz.

2.5 UWB MIMO antenna

In [34] a Four-Port Flexible UWB-MIMO Antenna with High Isolation for Wearable and IoT Applications is proposed by the author.The single element antenna is a CPW fed mono pole which is fabricated on LCP substrate.The bandwidth of the antenna is 2.66–11.39 GHz.The MIMO combination provides good isolation and its various parameter has studied.[35] also explains a MIMO on flexible material with CPW fed line.flexible Rogers's 3003 material is used for fabrication and size of the antenna is 24 by $30mm^2$ and the bandwidth is from 3.5 GHz up to 11 GHz.A compact multiple-input–multiple-output (MIMO) antenna is presented for ultrawideband (UWB) applications. The antenna consists of two open L-shaped slot (LS) antenna elements and a narrow slot on the ground plane. The antenna elements are placed perpendicularly to each other to obtain high isolation, and the narrow slot is added to reduce the mutual coupling of antenna elements in the low frequency band (3-4.5

GHz). The proposed MIMO antenna has a compact size of 32×32 mm^2 , and the antenna prototype is fabricated and measured. The measured results show that the proposed antenna design achieves an impedance bandwidth of larger than 3.1–10.6 GHz, low mutual coupling of less than 15 dB, and a low envelope correlation coefficient of better than 0.02 across the frequency band, which are suitable for portable UWB applications[36].

In [37] 42mm by 25 mm microstrip feed UWB MIMO is proposed.Obtained bandwidth is 3.2 GHz to 12 GHz .A good isolation over widebandwidth also obtained.UWB MIMO radar application antenna is proposed in [38].CPW Fed Flexible 4Port MIMO Antenna for UWB, X, and Ku Band Applications in [39].The maximum gain and efficiency are 6.8 dBi and 89% respectively and the obtained bandwidth is 3.89-17.09 GHz. 2 port MIMO antenna is constructed and its diversity performance is estimated in [40] over the frequency 3.1 to 10.9 GHz. In[41] a compact antenna with three operational bands, including a (notched) ultra-wideband (UWB), and its array for multiple-in multiple-out (MIMO) applications are reported. The antenna is composed of a folded patch with a shoring wall fed by a folded planar monopole with a 3-D U-slot cut. The operation of the antenna relies on the monopole-fed patch mode at low frequencies and reflector-backed monopole radiation in the middle- and high-frequency bands, which is able to cover almost all the wireless service bands in the sub-6 GHz regime, including a continuous UWB with a ratio bandwidth of 4:1. A narrow stopband can be placed within the UWB by integrating a symmetric pair of 3-D meandered slots on the folded monopole feed.

A novel optically transparent multiple-input multiple-output (MIMO) antenna for automotive applications is presented in [42]. The MIMO antenna consists of a two-semicircular slot-loaded monopole with a staircase ground structure. It is developed on a glass substrate with dimension 29×50 mm^2 .

A two-port structure-shared planar ultrawideband (UWB) antenna with high isolation is presented in [28]. The proposed antenna consists of a planar monopole and two back-to-back tapered slots etched on the monopole. The monopole and the tapered slots are fed by the microstrip line and the differential feeding network, respectively.

Bibliography

[1] Kunal Srivastava, Ashwani Kumar, Binod K. Kanaujia, Santanu Dwari, and Sachin Kumar. A cpw-fed uwb mimo antenna with integrated gsm band and dual band notches. *International Journal of RF and Microwave Computer-Aided Engineering*, 29(1):e21433, 2019.

[2] Jian Ren, Wei Hu, Yingzeng Yin, and Rong Fan. Compact printed mimo antenna for uwb applications. *IEEE Antennas and Wireless Propagation Letters*, 13:1517–1520, 2014.

[3] Shobhit Saxena, Binod K. Kanaujia, Santanu Dwari, Sachin Kumar, and Rahul Tiwari. A compact dual-polarized mimo antenna with distinct diversity performance for uwb applications. *IEEE Antennas and Wireless Propagation Letters*, 16:3096–3099, 2017.

[4] Vandana Satam and Shikha Nema. Defected ground structure planar dual element mimo antenna for wireless and short range radar application. 02 2015.

[5] Preeti Sharma, Rakesh N. Tiwari, Prabhakar Singh, Pradeep Kumar, and Binod K. Kanaujia. Mimo antennas: Design approaches, techniques and applications. *Sensors*, 22(20), 2022.

[6] Girish Kumar and Kamala Prasan Ray. *Broadband microstrip antennas*. Artech house, 2002.

[7] Budhadeb Maity and Sisir K Nayak. Design of compact cpw-fed symmetrical staircase-shaped uwb antenna using transmission line model. *Progress In Electromagnetics Research C*, 115:187–204, 2021.

[8] Budhadeb Maity and Sisir Kumar Nayak. Design of cpw-fed star-shaped monopole antenna for uwb applications using transmission line model. *Progress In Electromagnetics Research C*, 2021.

[9] S. Theepak and Sachendra Sinha. Uwb antenna designs with double band-notches for wlan frequencies including time domain analysis. In *2012 Loughborough Antennas Propagation Conference (LAPC)*, pages 1–5, 2012.

[10] Seungyong Park and Kyung-Young Jung. Novel compact uwb planar monopole antenna using a ribbon-shaped slot. *IEEE Access*, 10:61951–61959, 2022.

[11] Sharadindu Gopal Kirtania, Bachir Adham Younes, Abdul Rakib Hossain, Tutku Karacolak, and Praveen Kumar Sekhar. Cpw-fed flexible ultra-wideband antenna for iot applications. *Micromachines*, 12(4):453, 2021.

[12] Kuiwen Xu, Zhongbo Zhu, Huan Li, Jiangtao Huangfu, Changzhi Li, and Lixin Ran. A printed single-layer uwb monopole antenna with extended ground plane stubs. *IEEE Antennas and Wireless Propagation Letters*, 12:237–240, 2013.

[13] Narinder Sharma and Sumeet Singh Bhatia. Design of printed uwb antenna with cpw and microstrip-line-fed for dcs/pcs/bluetooth/wlan wireless applications. *International Journal of RF and Microwave Computer-Aided Engineering*, 31(1):e22488, 2021.

[14] Esraa Mousa Ali, Wahaj Abbas Awan, Mohammed S Alzaidi, Abdullah Alzahrani, Dalia H Elkamchouchi, Francisco Falcone, and Sherif SM Ghoneim. A shorted stub loaded uwb flexible antenna for small iot devices. *Sensors*, 23(2):748, 2023.

[15] Sarmad Nozad Mahmood, Asnor Juraiza Ishak, Alyani Ismail, Azura Che Soh, Zahriladha Zakaria, and Sameer Alani. On-off body ultra-wideband (uwb) antenna for wireless body area networks (wban): a review. *IEEE Access*, 8:150844–150863, 2020.

[16] Chungang Zhang, Yongjun Xie, Yangjing Wang, Legen Dai, and Liqiang Niu. Novel miniaturized all-metal uwb magneto-electric monopole (mem) antenna for multistandard applications. *IEEE Transactions on Antennas and Propagation*, 69(7):4195–4200, 2021.

[17] Ming-Chun Tang, Ting Shi, and Richard W. Ziolkowski. Planar ultrawideband antennas with improved realized gain performance. *IEEE Transactions on Antennas and Propagation*, 64(1):61–69, 2016.

[18] Chao Deng, Yong-jun Xie, and Ping Li. Cpw-fed planar printed monopole antenna with impedance bandwidth enhanced. *IEEE Antennas and Wireless Propagation Letters*, 8:1394–1397, 2009.

[19] Mohammed Guerroui, Abdelhalim Chaabane, Samir Ikni, Ahcene Boualleg, Nassima Guebgoub, and Omar Mahri. A printed u-shaped coplanar waveguide feed uwb antenna for gpr applications. *Advanced Electromagnetics*, 11(4):51–59, 2022.

[20] Tale Saeidi, Adam RH Alhawari, Abdulkarem HM Almawgani, Turki Alsuwian, Muhammad Ali Imran, and Qammer Abbasi. High gain compact uwb antenna for ground penetrating radar detection and soil inspection. *Sensors*, 22(14):5183, 2022.

[21] Pratyancha Prasad, Shivanand Singh, and Akhilesh Kumar. A wheel shaped compact uwb antenna for gpr applications. In *2021 6th International Conference for Convergence in Technology (I2CT)*, pages 1–5. IEEE, 2021.

[22] Surajit Kundu and Sanjay Kumar Jana. A compact umbrella shaped uwb antenna for ground-coupling gpr applications. *Microwave and Optical Technology Letters*, 60(1):146–151, 2018.

[23] Amit Baran Dey and Wasim Arif. Design and analysis of a cpw-fed flexible ultrawideband antenna for microwave imaging of breast cancer. *International Journal of RF and Microwave Computer-Aided Engineering*, 32(9):e23262, 2022.

[24] Linda A Yimdjo Poffelie, Ping Jack Soh, Sen Yan, and Guy AE Vandenbosch. A high-fidelity all-textile uwb antenna with low back radiation for off-body wban applications. *IEEE Transactions on Antennas and Propagation*, 64(2):757–760, 2015.

[25] Suneel Kumar Rath, Madhusmita Sahu, Shom Prasad Das, Sukant Kishoro Bisoy, and Mangal Sain. A comparative analysis of svm and elm classification on software reliability prediction model. *Electronics*, 11(17):2707, 2022.

[26] Padmathilagam Sambandam, Malathi Kanagasabai, Shini Ramadoss, Rajesh Natarajan, M. Gulam Nabi Alsath, Shanmathi Shanmuganathan, Muthuramalingam Sindhadevi, and Sandeep Kumar Palaniswamy. Compact monopole antenna backed with fork-slotted ebg for wearable applications. *IEEE Antennas and Wireless Propagation Letters*, 19(2):228–232, 2020.

[27] Zain Ul Abedin and Zahid Ullah. Design of a microstrip patch antenna with high bandwidth and high gain for uwb and different wireless applications. *international journal of advanced computer science and applications*, 8(10), 2017.

[28] Li Ying Nie, Xian Qi Lin, Zi Qiang Yang, Jin Zhang, and Bao Wang. Structure-shared planar uwb mimo antenna with high isolation for mobile platform. *IEEE Transactions on Antennas and Propagation*, 67(4):2735–2738, 2019.

[29] Chia Ping Lee and Chandan Kumar Chakrabarty. Ultra wideband microstrip diamond slotted patch antenna with enhanced bandwidth. *International Journal of Communications, Network and System Sciences*, 4(7):468, 2011.

[30] VLN Phani Ponnapalli, S Karthikeyan, J Lakshmi Narayana, and VN Koteswara Rao Devana. A compact se-dgs tapered-fed notched uwb antenna integrated with ku/k band for breast cancer detection. *IETE Journal of Research*, pages 1–11, 2023.

[31] Carlos Ramiro Peñafiel-Ojeda, Carlos Efrain Andrade, Ricardo Baez-Egas, and Vladimir Garcia-Santos. An ultrawideband printed monopole antenna analyzed with the theory of characteristic modes. *IEEE Latin America Transactions*, 20(6):948–954, 2022.

[32] Tapas Tewary, Smarajit Maity, Surajit Mukherjee, Avisankar Roy, Partha Pratim Sarkar, and Sunandan Bhunia. High gain miniaturrized super-wideband microstrip patch antenna. *International Journal of Communication Systems*, 35(11):e5181, 2022.

[33] Dalia M Elsheakh and Esmat A Abdallah. Ultra-wide-bandwidth (uwb) microstrip monopole antenna using split ring resonator (srr) structure. *International Journal of Microwave and Wireless Technologies*, 10(1):123–132, 2018.

[34] Jie Zhang, Chengzhu Du, and Ruohui Wang. Design of a four-port flexible uwb-mimo antenna with high isolation for wearable and iot applications. *Micromachines*, 13(12), 2022.

[35] Ahmed A Ibrahim, Mohamed I Ahmed, and Mai F Ahmed. A systematic investigation of four ports mimo antenna depending on flexible material for uwb networks. *Scientific Reports*, 12(1):14351, 2022.

[36] Jian Ren, Wei Hu, Yingzeng Yin, and Rong Fan. Compact printed mimo antenna for uwb applications. *IEEE Antennas and Wireless Propagation Letters*, 13:1517–1520, 2014.

[37] Gunjan Srivastava and Akhilesh Mohan. Compact mimo slot antenna for uwb applications. *IEEE Antennas and Wireless Propagation Letters*, 15:1057–1060, 2016.

[38] Yongkun Song, Tian Jin, Yongpeng Dai, and Xiaolong Zhou. Efficient through-wall human pose reconstruction using uwb mimo radar. *IEEE Antennas and Wireless Propagation Letters*, 21(3):571–575, 2022.

[39] Arpan Desai, Jayshri Kulkarni, M. M. Kamruzzaman, Štěpán Hubálovský, Heng-Tung Hsu, and Ahmed A. Ibrahim. Interconnected cpw fed flexible 4-port mimo antenna for uwb, x, and ku band applications. *IEEE Access*, 10:57641–57654, 2022.

[40] M. Gulam Nabi Alsath and Malathi Kanagasabai. Compact uwb monopole antenna for automotive communications. *IEEE Transactions on Antennas and Propagation*, 63(9):4204–4208, 2015.

[41] Zhi Hao Jiang, Lei Zhang, Yan Zhang, Chao Yu, Longzhu Cai, Sidou Zheng, and Wei Hong. A compact triple-band antenna with a notched ultra-wideband and its mimo array. *IEEE Transactions on Antennas and Propagation*, 66(12):7021–7031, 2018.

[42] Devisowjanya Potti, Yarasi Tusharika, Mohammed Gulam Nabi Alsath, Savarimuthu Kirubaveni, Malathi Kanagasabai, Radha Sankararajan, Santosh Narendhiran, and P. Balaji Bhargav. A novel optically transparent uwb antenna for automotive mimo communications. *IEEE Transactions on Antennas and Propagation*, 69(7):3821–3828, 2021.

Chapter 3

Microstrip Antenna

3.1 Introduction

In the year 1953 the concept of micro strip patch antenna was proposed by Deschamps[1].The first practical MPA was developed almost after 20 years by Howell[2] and Munson[3].Microstrip patch antennas (MPA) are a class of planar antennas which have been researched and developed extensively in the last four decades. They have become favorites among antenna designers and have been used in many applications in wireless communication systems, both in the military sector and in the commercial sector. The idea of microstrip patch antennas arose from utilizing printed circuit technology not only for the circuit components and transmission lines but also for the radiating elements of an electronic system[4].Due to large size and weight the waveguide antenna are not preferable in some applications. In those cases MSA is used for its compactness.

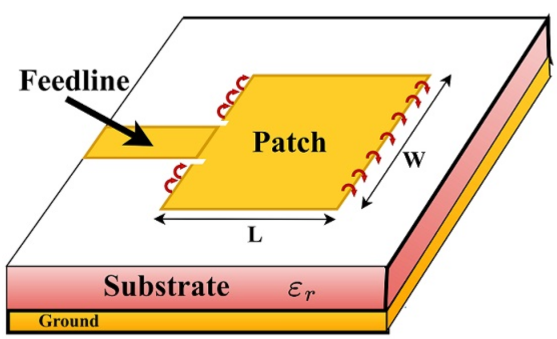


Figure 3.1: Structure of basic microstrip antenna

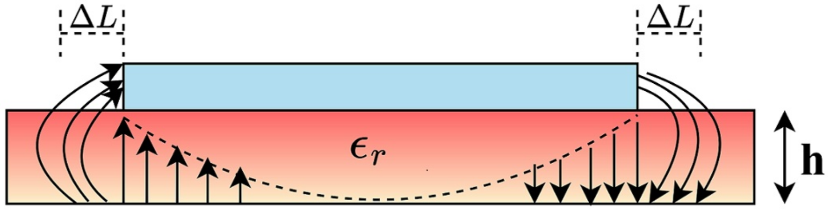


Figure 3.2: side view

Microstrip antenna is consist of a area of metalization which is called patch.The patch is supported above a ground plane by a thin dielectric substrate.The geometry of the patch can be rectangle, circular triangular or ring type based on the requirement of desired frequency. The frequency depends on various parameters like length,width of the patch[5]as well as dielectric constant and thickness of the substrate.the following equations shows the variation of frequency with respect to its various parameters[6–8]

$$f_0 = \frac{c}{2\sqrt{\epsilon_e}} \left[(\frac{m}{L})^2 + (\frac{n}{W})^2 \right]^{\frac{1}{2}} \tag{3.1}$$

$$L_e = L + 2\Delta L = \frac{c}{2f_0\sqrt{\epsilon_e}} \tag{3.2}$$

$$W = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{3.3}$$

$$\Delta L = \frac{h}{\sqrt{\epsilon_e}} \tag{3.4}$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + \frac{10h}{W} \right]^{-\frac{1}{2}} \tag{3.5}$$

Here L_e=the effective length of the patch.
W=width of the patch ϵ_e= effective dielectric constant.
ϵ_r=Dielectric constant of the substrate material. h=substrate height.
f_0=Resonant frequency. c=Speed of light.
m, n=number of modes along L and W respectively.

The radiation in the microstrip antenna can be determined by the field distribution between the patch and ground plane or it can be described from the surface current distribution in the metal patch[9].After the excitation of the patch by microwave source a charge distribution establishes in the upper and lower side of thr patch and in the ground plane.If the the length of the patch is half of the wavelength for dominant mode[10] then positive and negative charge distribution arises.As a result the like charges tend to repeal some charges towards the edges.This creates current densities at the top and bottom surfaces.For lower aspect ratio the attractive force between positive and negative charges dominates and current remains below the patch. A small amount of current flows along the boundary of the patch toward the top layer.This current is responsible for weak magnetic field which is tangential to the edges[11].So one simple assumption can be taken that tangential magnetic field is zero.For substrate material the substrate height is very small compare to wavelenth so field remains almost constant along the substrate height and electric field is almost normal to the patch.So it can be modelled as a cavity with two electric walls(top and bottom)and four magnetic walls along four edges of the patch.So only TM modes is possible inside this cavity.For supporting single mode dielectric filling should be uniform but in microstrip it is not so the mode which exist in microstrip is called Quasi TEM.[12] is due to the fringing field from patch to air which is shown by curved arrows in the given figure.

3.2 Various feeding technique

The feeding methods influences the input impedance and other characteristics of the microstrip antenna.So method of excitation also is an important factor while designing antenna.There are several methods to excite the antenna for transmission.Some popular methods are[13–15]

- Microstrip line feeding.
- Coaxial feeding.
- CPW feeding.
- Apperture coupled feeding.
- Proximity feeding.

Here various feeding methods is explained in brief.

Microstrip line feeding- A conducting line which is very narraw compare to the main patch is fabricated on the same plane of the patch.In this technique two methods are followed one is edge feeding another one is inset feeding.Sometime in edge feeding we don't get proper matching then inset feeding is used.

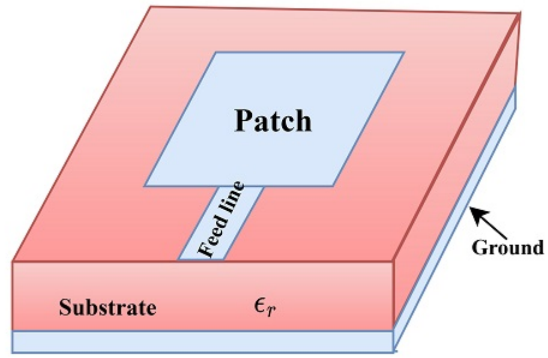


Figure 3.3: Microstrip line feeding

Coaxial feeding- In coaxial feeding from ground plane a central conductor is passed through substrate upto the patch.The location of the feeding point is determined where we can achieve proper matching.

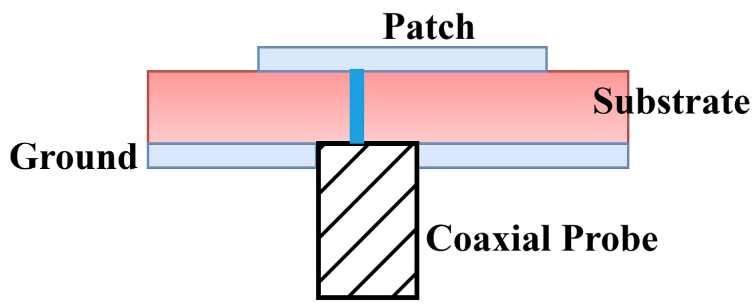


Figure 3.4: Coaxial feeding

CPW feeding- In this feeding technique the signal and ground current are etched on the same layer[14, 16].The coupling between the feed line and ground plane is done using slots.Some time a ground plane is also used in the opposite side of the substrate then it is called CPW with ground(CPWG)[5]

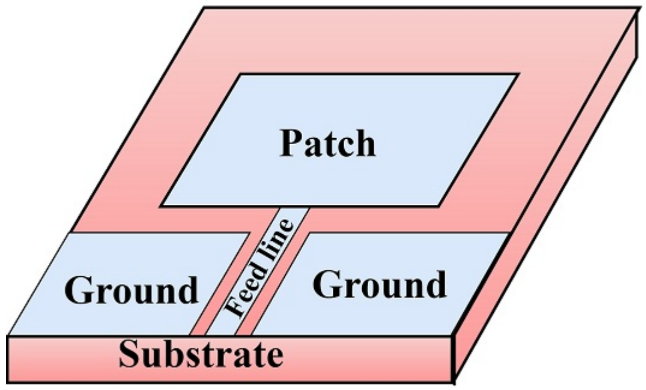


Figure 3.5: CPW feeding

Apperture coupled feeding- In microstrip line and coaxial feeding some higher order modes also generated and for that they produces cross polarised radiation.In this method two substrates are separated by a common ground plane.From lower substrate the excitation is given using a microstrip line and the energy is coupled with the patch through a slot on the separating ground plane.

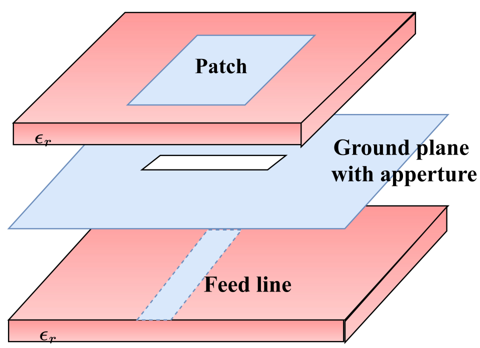


Figure 3.6: Apperture coupled feeding

Proximity feeding- Proximity coupling is also called electromagnetic coupling.In this method the feedline is placed below the patch and above the ground plane.It uses two layer of substrate where in the lower layer microstrip line is placed and in the upper layer patched is placed. The feedline remain open below the patch.

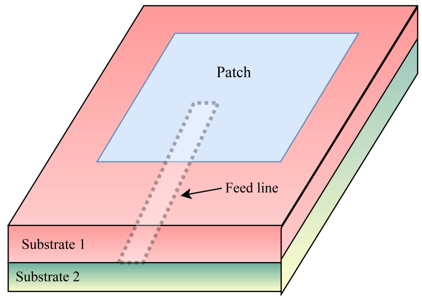


Figure 3.7: Proximity coupled feeding

3.3 Application

There are various field where microstrip antenna is used [17].Day by day its domain of application is increasing. Some of the important applications are listed here.

- Satellite communication and mobile communication.
- Biomedical appllication.
- Radar application and broadcasting services.
- Remote sensing, Missiles and telemetry.
- Radio altimeters etc.

Microstrip antenna has some advantages and disadvantages based on its construction and area of application[9, 18, 19].There are various antenna characteristics parameter based on which the suitable antenna is chosen. Considering those factors some advantages and disadvantages are listed here

3.4 Advantages

- Light weight and less volume.
- Simple in construction.
- Array formation is simple.
- Simple fabrication process and can be modified easily.
- Both linear and circular polarization is possible.

- Can be made conformal with both planar and non planar surfaces.
- Compatible with MMIC etc.

3.5 Disadvantages

- Narrow bandwidth
- Lower efficiency and gain.
- Extra radiation from its feeds and junctions.
- Low power handling capacity.
- Surface wave excitation and tolerance problem etc.

3.6 Equivalent circuit of microstrip antenna

The response of microstrip antenna can be modeled using parallel R L C circuit[13].For narrowband antenna it can be approximated a simple RLC parallel circuit and for broadband antenna it is approximated as a cascaded parallel RLC as it resonates for multiple frequencies[20].The values of the RLC varies according to frequency and the dimension of the patch.In most of the cases impedance mismatch issue appears while designing any micros trip antenna as it operate in high frequency.For that Equivalent circuit model gives a good approach to resolve this mismatch problem by placing a lumped element for various parts of the antenna[21].whenever we know the circuit components then it become easy to analyse the system. In order to deter-mine the correct value for this element, So it is necessary to cor-correctly model the antenna for determining its lumped component values.Various method has been suggested by the researchers to obtain the equivalent circuit of an antenna[22–25].Transmission line modeling of micros trip antenna is popular and simple[26].The figure shows simple equivalent circuit model of a rectangular patch antenna.

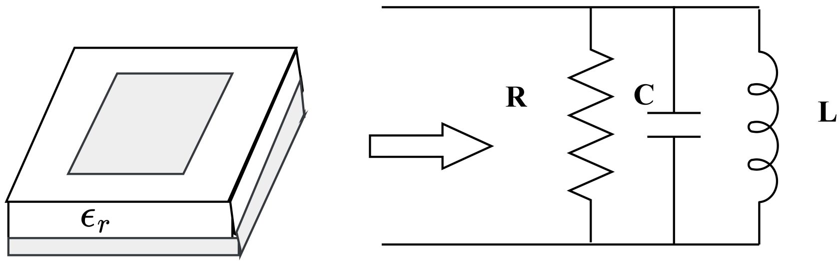


Figure 3.8: Simple Microstrip antenna and its equivalent circuit

Bibliography

[1] Ramesh Garg, Prakash Bhartia, Inder J Bahl, and Apisak Ittipiboon. *Microstrip antenna design handbook*. Artech house, 2001.

[2] Keith Carver and James Mink. Microstrip antenna technology. *IEEE transactions on antennas and propagation*, 29(1):2–24, 1981.

[3] R Munson and J Krutsinger. Single slot cavity antenna assembly, January 23 1973. US Patent 3,713,162.

[4] Kai Fong Lee, Kwai Man Luk, and Hau Wah Lai. *Microstrip patch antennas*. World Scientific, 2017.

[5] Shobhit Kumar Patel, Christos Argyropoulos, and Yogeshwar P Kosta. Pattern controlled and frequency tunable microstrip antenna loaded with multiple split ring resonators. *IET Microwaves, Antennas & Propagation*, 12(3):390–394, 2018.

[6] Girish Kumar and Kamala Prasan Ray. *Broadband microstrip antennas*. Artech house, 2002.

[7] Alireza Foroozesh, Robert Paknys, David R Jackson, and Jean-Jacques Laurin. Beam focusing using backward-radiating waves on conformal leaky-wave antennas based on a metal strip grating. *IEEE Transactions on Antennas and Propagation*, 63(11):4667–4677, 2015.

[8] Rod Waterhouse. *Microstrip Patch Antennas: A Designer's Guide: A Designer's Guide*. Springer Science & Business Media, 2003.

[9] Randy Bancroft. *Microstrip and printed antenna design*. Institution of Engineering and Technology, 2019.

[10] James R James, Peter S Hall, and Colin Wood. *Microstrip antenna: theory and design*, volume 12. Iet, 1986.

[11] Kuldip C Gupta and Abdelaziz Benalla. *Microstrip antenna design*. Artech House Microwave Library, 1988.

[12] Terry C Edwards and Michael B Steer. *Foundations for microstrip circuit design*. John Wiley & Sons, 2016.

[13] Ashish Singh, Krishnananda Shet, Durga Prasad, Akhilesh Kumar Pandey, and Mohammad Aneesh. A review: circuit theory of microstrip antennas for dual-, multi-, and ultra-widebands. *Modulation in Electronics and Telecommunications*, page 105, 2020.

[14] Jayesh Pathak and Rekha Labade. Comparative analysis of microstrip feed, cpw feed & acs feed uwb antenna. In *2017 International Conference on Data Management, Analytics and Innovation (ICDMAI)*, pages 285–289. IEEE, 2017.

[15] Hemant Kumar Varshney, Mukesh Kumar, AK Jaiswal, Rohini Saxena, and Komal Jaiswal. A survey on different feeding techniques of rectangular microstrip patch antenna. *International Journal of Current Engineering and Technology*, 4(3):1418–1423, 2014.

[16] T Shanmuganantham, K Balamanikandan, S Raghavan, et al. Cpw-fed slot antenna for wideband applications. *International Journal of Antennas and Propagation*, 2008, 2008.

[17] Indrasen Singh and Dr Tripathi. Micro strip patch antenna and its applications: a survey. *International Journal of Computer Technology and Applications*, 2:1595–1599, 09 2011.

[18] Amel Boufrioua. Analysis of a rectangular microstrip antenna on a uniaxial substrate. *Chapter*, 2:27–42, 2011.

[19] Jim R James et al. *Handbook of microstrip antennas*, volume 1. IET, 1989.

[20] Mohammadali Ansarizadeh, Ayaz Ghorbani, and Raed A. Abd-Alhameed. An approach to equivalent circuit modeling of rectangular microstrip antennas. *Progress in Electromagnetics Research B*, 8:77–86, 2008.

[21] Hilal Koc Polat, M.Dilruba Geyikoğlu, and Bulent Cavusoglu. Modeling and validation of a new reconfigurable patch antenna through equivalent lumped circuit-based design for minimum tuning effort. *Microwave and Optical Technology Letters*, 62, 06 2020.

[22] Ashish Singh, Krishnananda Shet, Durga Prasad, Akhilesh Kumar Pandey, and Mohammad Aneesh. A review: Circuit theory of microstrip antennas for dual-,

multi-, and ultra-widebands. In George Dekoulis, editor, *Modulation in Electronics and Telecommunications*, chapter 7. IntechOpen, Rijeka, 2020.

[23] Aghoutane Bilal, El Ghzaoui Mohammed, El Faylali Hanan, and Das Sudipta. Investigation of equivalent circuit model for a 5g microstrip patch antenna. 2021.

[24] Akshay Kumar, Amarveer Singh, and Ekambir Sidhu. Equivalent circuit modelling of microstrip patch antenna (mpa) using parallel lcr circuits. 2015.

[25] Alishir Moradikordalivand, TA Rahman, Sepideh Ebrahimi, and S Hakimi. An equivalent circuit model for broadband modified rectangular microstrip-fed monopole antenna. *Wireless personal communications*, 77:1363–1375, 2014.

[26] Shailendra Singh Pawar, Madhu Shandilya, and Vijayshri Chaurasia. Parametric evaluation of microstrip log periodic dipole array antenna using transmission line equivalent circuit. *Engineering science and technology, an international journal*, 20(4):1260–1274, 2017.

Chapter 4

UWB Antenna design

4.1 Introduction

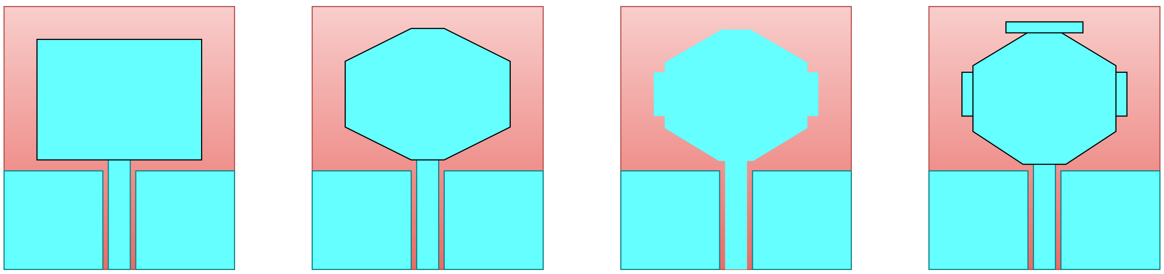
The bandwidth of an antenna is the range of frequency in which various parameter like impedance gain and efficiency etc. falls in some standard value.Bandwidth can be defined in terms of VSWR or input impedance variation with frequency or it can be defined in terms of radiation parameters[1,2,3].It can also be defined in terms of Axial ration(circular polarization)[1]

UWB antenna operates over wide bandwidth. Several advances in antennas for UWB antennas were registered in the literature.But three dimensional and planar monopole are not suitable for UWB application for their volume and probe feeding.For that printed monopole are more popular for wireless devices for compact size and integration with MMICs.UWB monopole antenna consist of a monopole and a ground plane on the same side of a substrate i.e CPW line.Here a monopole and with CPW line is proposed and parametric variation related to various dimensions and substrate material has been carried out and an optimal design is acheived for UWB application.

4.2 Proposed design

After extensively studied from various work mentioned in literature A hexagonal patch with some side and upper stub usign CPW feed line is proposed in the thesis.In regard to feeding of an antenna, coplanar waveguide (CPW) feeding attracts more and more attention lately due to its advantages over microstrip feeding. It has wider bandwidth performance with lower dispersion and lower radiation leakage than microstrip feed line. Furthermore, its implementation to active and passive devices is easier.The patch is loaded with a stub.A low cost and less loss factor(loss tangent) substrate which is

Roger RT duroid.Dielectric constant of the material is 2.33 and substrate thickness is 1.575 and loss tangent is 0.0012.Though other substrate also used for UWB antenna making in literature here RT Duroid is our best choice out of other substrate available in our lab.The complete design procedure is shown step by step to obtain the final design of the antenna in fig 4.1 CST microwave studio 2018 version is used for the simulation of the antenna.Out of all the simulation software related to rf fiels CST is very handy and easy to operate and its various features attracts the antenna engineers for their design.



(a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

Figure 4.1: Design Steps

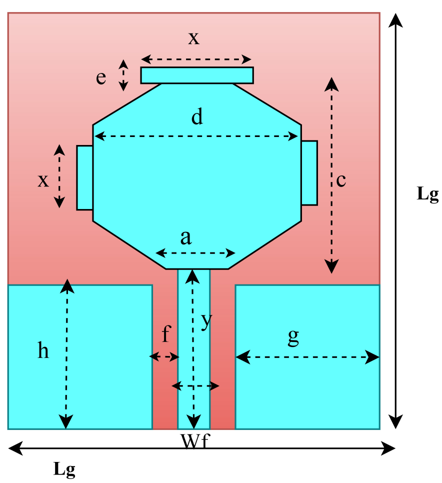


Figure 4.2: Proposed antenna with dimension

Table 4.1: Parameter list

Parameter	Unit(in mm)	Parameter	Units(in mm)
Lg	36	Wg	30
a	2	c	20
d	21	e	1.4
f	0.5	g	13.5
h	10.7	Wf	2
x	9	y	11.5

4.3 Parametric study

While designing the antenna some of the important observations are obtained like which substrate will useful how the impedance can be matched and how the broad bandwidth can be obtained.So for that some parametric study also done for better understanding and for getting optimal design. Here various design parameters related to antenna design before getting the optimal design is studied[2].These parameters include substrate selection, ground height and coupled gap of CPW line and and feed line variation.These are shown in the following figures in terms of S_{11} parameter.

Gound plane is an important factor when it comes to CPW feed design[3]. A detailed study has been carried out how the ground plane variation can impact the matching of the antenna here the fig 4.3 shows how S parameter changes for the proposed design when the dimension of the ground plane varies.

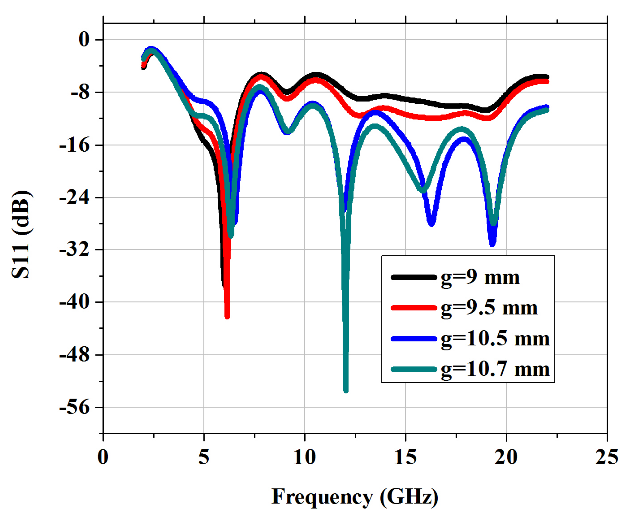


Figure 4.3: variation in the CPW ground plane

Next parameter which impacts the wideband matching is the gap between the feed line and the ground plane of the CPW feed antenna.The fig 4.4 shows for some close values of that parameter from that it is clear that how much impact is there for this gap value related to the CPW design.

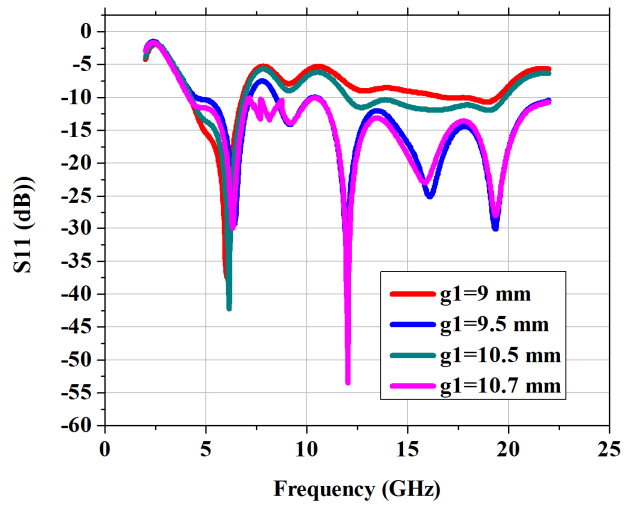


Figure 4.4: Variation of coupled gap (in fig g1=f according to proposed design)between feed line and ground plane

After defining all the dimensions related to the proposed design next possible variation is choosing the proper substrate.In microstrip antenna specially for CPW line feed wideband antenna substrate variations also impacts the wideband matching like substrate height and dielectric constant related to various substrate and their corresponding loss factor.Depending on these substrate parameters antenna characteristics also chages.In fig 4.5 some of the mostly available and widely used substrate variations associated with the proposed design is shown and out of all these Rt/Duroid 1 whose specification is mentioned earlier is chosen and used for further experimental studies in this proposed work.

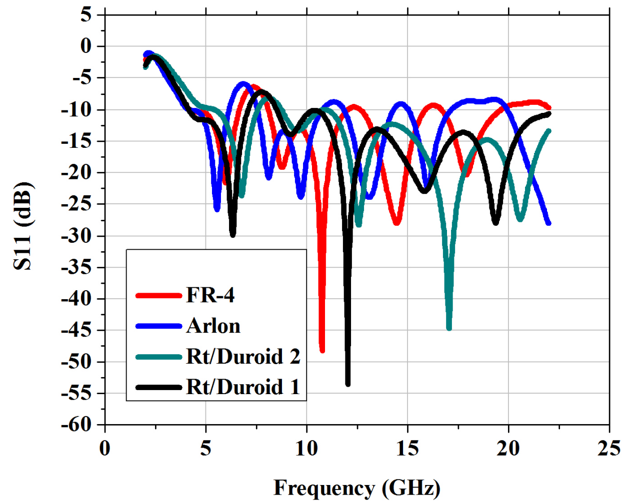


Figure 4.5: variation of S parameter for various substrate

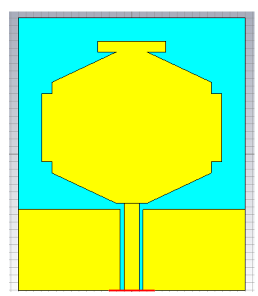
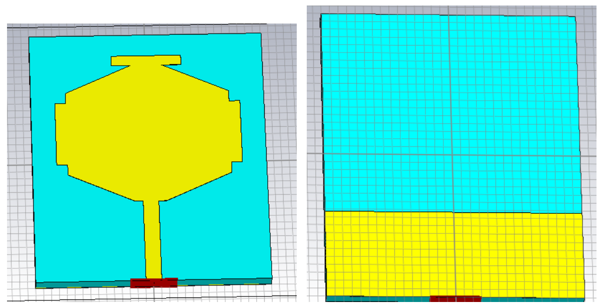


Figure 4.6: Proposed design in CST

4.4 Microstrip line feed monopole

As from literature review it is observed that for ultra wide band most suitable and simple is microstrip monopole antenna with cpw line and microstrip line feed.Initially from literature study it has been decided to go for CPW feed[4] monopole antenna but same design with all the dimensions same as earlier one a microstrip line feed monopole antenna also simulated and its characteristics has been observed what are the variations comparison with CPW feed monopole antenna.In figure comparison between these two kind of monopole antenna in terms of their S parameter is shown.

Related to the entire proposed work several mathematical formulations also are there in the literature here all the mathematical modeling related to the ground plane height with respect to frequency variations and other foumulation how to cover lower frequency for ultra wide band antenna design these mathematical calculations are not explained extensible for this work which can be further extension of this proposed work.



(a) front side (b) Back side

Figure 4.7: Microstrip feed monopole in CST

Bibliography

[1] Jim R James et al. *Handbook of microstrip antennas*, volume 1. IET, 1989.

[2] Dalia M Elsheakh and Esmat A Abdallah. Ultra-wide-bandwidth (uwb) microstrip monopole antenna using split ring resonator (srr) structure. *International Journal of Microwave and Wireless Technologies*, 10(1):123–132, 2018.

[3] Muhammad Zahid, Sultan Shoaib, Yasar Amin, Peter Excell, and Sergey Lupin. Ultra wideband antenna for future 5g. In *2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, pages 2280–2283, 2020.

[4] VLN Phani Ponnapalli, S Karthikeyan, J Lakshmi Narayana, and VN Koteswara Rao Devana. A compact se-dgs tapered-fed notched uwb antenna integrated with ku/k band for breast cancer detection. *IETE Journal of Research*, pages 1–11, 2023.

Chapter 5

Equivalent Circuit in ADS

5.1 Introduction

It is known that the maximum amount of power in an electrical or electronic system will be transferred to the load when its input impedance is the complex conjugate of the source impedance, although, maximum transfer efficiency can be only 50%[1].Being an electronic passive system it is equally applicable for the antenna system also.As antenna radiates in free space. Typical Thevinin's and Norton's theorem can not be applied to the antenna system as antenna is not replacable only in terms of simple voltage and current source.The fundamental antenna which is a dipole antenna its approximated circuit has been discussed[2].So to know more about antenna characteristics more mathematical analysis an accurate circuit model is desirable.Over the years various methods has been suggested but still its an exploring topic as antenna is a high frequency operating system where voltage current concept is not that much applicable and all the analysis related to electric and magnetic field only which are related by Maxwell's equations[3]. An antenna with wideband characteristics can be considered as a radiating element producing several closely associated resonances, in which some adjacent bands overlap with each other[4].Since the transmitter is an electrical system it is useful to model the equivalent circuit of an antenna.From circuit analysis antenna can be modelled as passive one port circuit.An approach to model an UWB antenna is represented in [5].There are various articles in which equivalent circuit concept is reported[6–8].To characterise the broadband matching potential of a microstrip antenna determination of the lumped wideband equivalent circuit is required which can model the input impedance of the antenna over wide frequency range.The most general method to represent an wideband radiating antenna as a series combination of multiple parallel resonator circuit[9, 10].Taking multiple resonating frequency from the wideband response corresponding impedance value can be calculated.From which lumped element value i.e resistance inductance and capacitance also calculated[11].Another way to approximate the equivalent circuit is from input impedance characteristics from which the series and parallel resonance circuit can me approximated[12].From transmission transmission line model also equivalent circuit of an antenna can be approximated[13].From approximated circuit the response can be verified in a circuit simulator here we have used ADS.There are other simulator also like AWR.After that by tuning the lumped element values proper response can be obtained.

5.2 ADS introduction

Advanced Design System (ADS) is an electronic design automation software system.It is developed by Path Wave Design, which is a division of Keysight Technologies. It provides an integrated design environment for the designers of RF electronic systems such as mobile phones,pagers, wireless networks, satellite communications, radar systems, and high-speed data links[14].

Keysight ADS supports every step of the design process — schematic capture, layout, design rule checking, frequency-domain and time-domain circuit simulation, and electromagnetic field simulation.It allows the engineer to fully characterize and optimize an RF design without changing tools[15].

5.3 ADS circuit simulation

As wide band antenna can be thought as a cascaded parallel resonator and combining all frequency response of each resonator the overal response will be a wide band response though feed line modelling affects the matching for that some tunning is required which can be done in ADS.In this work observing the S Parameter the resonating frequencies are 6.33 GHz, 12 GHz,15.801GHz and 19.403 GHz.From the simulation the corresponding values of the impedance are recorded in the table and the from the following equations the corresponding lumped elementare calculated and the circuit is simulated in ADS.

$$R = Real(Z(f_i) \tag{5.1}$$

$$Q = 2\pi R_i C_i \tag{5.2}$$

$$C_i = \frac{Q}{2\pi f_i R_i} \tag{5.3}$$

$$L_i = \frac{R^2 C_i}{Q_i^2} \tag{5.4}$$

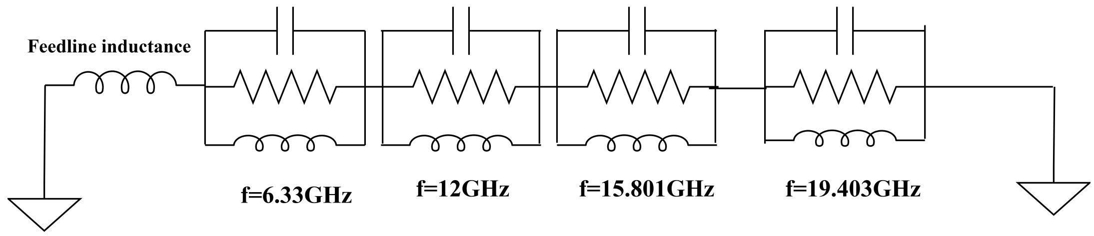


Figure 5.1: Equivalent circuit

Here all the equations are written in Python for calculating the lumped elements.After executing the code when it asks the real and imaginary values of the impedance and corresponding frequency from that resistance, inductance and capacitance are noted in the table5.1.

Table 5.1: Equivalent circuit parameter values

Frequency(GHz)	Impedance(ohm)	Resistance(ohm)	Inductance(nH)	Capacitance(pF)
6.33	91+3.47j	91	0.08729	7.249
12	94−0.19j	94	0.0025	69.84
15.801	97.65−13.78j	97.65	0.13886	0.7313
19.403	91+7.49j	91	0.0614	1.0956

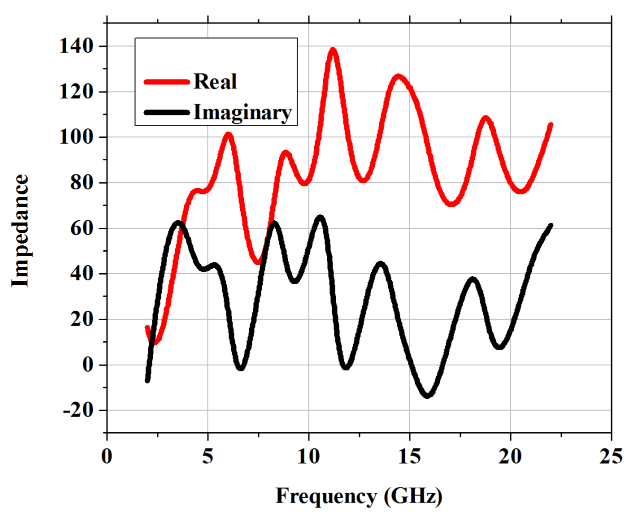


Figure 5.2: Real and imaginary values of impedance

Bibliography

[1] Yi Huang, Ahmed Alieldin, and Chaoyun Song. Equivalent circuits and analysis of a generalized antenna system [antenna applications corner]. *IEEE Antennas and Propagation Magazine*, 63(2):53–62, 2021.

[2] Ted L. Simpson. Equivalent circuits for electric dipoles. In *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*, pages 443–444, 2020.

[3] Frederick Tombe. Maxwell's original equations. 12 2011.

[4] Muhammad Yousaf, Ismail Mabrouk, Muhammad Zada, Adeel Akram, Y. Amin, Mourad Nedil, and Hyoungsuk Yoo. An ultra-miniaturized antenna with ultra-wide bandwidth characteristics for medical implant systems. *IEEE Access*, PP:1–1, 03 2021.

[5] Mohammadali Ansarizadeh, Ayaz Ghorbani, and Raed A Abd-Alhameed. An approach to equivalent circuit modeling of rectangular microstrip antennas. *Progress In Electromagnetics Research B*, 8:77–86, 2008.

[6] Khaled A Obeidat, Bryan D Raines, and Roberto G Rojas. Discussion of series and parallel resonance phenomena in the input impedance of antennas. *Radio Science*, 45(06):1–9, 2010.

[7] Bilal Aghoutane, Mohammed El Ghzaoui, Hanan El Faylali, and Sudipta Das. Investigation of equivalent circuit model for a 5g microstrip patch antenna. *Journal of Nano-and Electronic Physics*, 13(3), 2021.

[8] Bing Yang and Shaocheng Qu. A compact integrated bluetooth uwb dual-band notch antenna for automotive communications. *AEU-International Journal of Electronics and Communications*, 80:104–113, 2017.

[9] Warsha Balani, Mrinal Sarvagya, Ajit Samasgikar, Tanweer Ali, and Pradeep Kumar. Design and analysis of super wideband antenna for microwave applications. *Sensors*, 21(2):477, 2021.

[10] Hiwa Taha Sediq, Javad Nourinia, Changiz Ghobadi, and Bahman Mohammadi. A novel shaped ultrawideband fractal antenna for medical purposes. *Biomedical Signal Processing and Control*, 80:104363, 2023.

[11] Ayan Karmakar and Balaka Biswas. Electrical equivalent circuit modeling of various electrically small antennas for biomedical applications. *Annals of Applied Sciences*, 1, 2022.

[12] Hari Shankar Mewara, Jitendra Kumar Deegwal, and Mahendra Mohan Sharma. A slot resonators based quintuple band-notched y-shaped planar monopole ultra-wideband antenna. *AEU-International Journal of Electronics and Communications*, 83:470–478, 2018.

[13] Budhadeb Maity and Sisir K Nayak. Design of compact cpw-fed symmetrical staircase-shaped uwb antenna using transmission line model. *Progress In Electromagnetics Research C*, 115:187–204, 2021.

[14] Mingmin Li and Xuemei Lei. Theoretical research and ads simulation of tunable band-pass filter. In *2016 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB)*, pages 1–4, 2016.

[15] Mahesh B Patil and VVS Hari. Circuit simulation using explicit methods. *arXiv preprint arXiv:2301.04595*, 2023.

Chapter 6

RF in Python

6.1 Introduction

Python is an interpreted high level ,general purpose, and object-oriented programming language.It is world wide used for various application like web design, game development, machine learning, artificial intelligence, data science etc.Python is very popular language for its vast library.Nowadays researchers preferring python over MATLAB because of its library related to various domain like signal processing,image processing.It was first created by Guido van Rossum in 1991 and later it is developed by the Python Software Foundation.Talking about its features it free and open source and writing code is easy compare to other high level object oriented language.Another feature is that python is platform independent and its GUI support[1].

6.2 Introduction to Scikit RF

For RF and microwave also one python library available which is Scikit-rf.It is a package in python for RF and microwave.The package provides a modern, object oriented library for RF network analysis, circuit building,calibration, and simulation.Besides offering standard microwave network operations, such as reading/writing Touchstone files (.sNp files), connecting or de-embedding N-port networks, frequency/port slicing, concatenation, or interpolations, it is also capable of advanced operations, such as vector network analyzer (VNA) calibrations, time gating, vector fitting, interpolating between an individual set of networks, deriving network statistical properties, and support of virtual instruments for direct communication to VNAs. The package also allows straightforward plotting of rectangular plots (decibels, magnitude, phase,group delay, and so on), Smith charts or automated uncertainty bounds[2].To characterise the equivalent circuit of an antenna more precisely and accurately another way to analyse the system is the rationalization of the impedance function.Which further helps to get the lumped element values.This can be done using vector fitting method[3–5].For vector fitting algorith implementation Scikit-rf is a useful tool.This kind of work is not explored that much only very feq articles are availabel in the literature [6].With the advent of AI and machine learning research related to various domain shifting towards more software and simulation in details and Rf domain is also not different.Till now there are not that much resources available related to Scikit-rf work .Still it is in developing stage as it is open source so new ideas and new features will be add on in future so that other extensive study can be done in RF domain.

6.3 Our work in Scikit RF

Based on the various features available on Scikit-rf the proposed work is imported to the scikit-rf and its characteristics has been analysed.From simulation result in CST various form of data can be exported.Two of these are touchstone format and ASCII format.After exporting from CST in touchstone format it can be opened in any of the python compiler like jupyter notebook or pycham.Make sure that compiler has the scikit-rf package extension.If it is not then first adding extension of scikit-rf then touchstone file can be opened.Other data plotting packages of python like matplotlib and pandas also required for visualisation of the datas.For our work the touchstone file is saved in the location C:Users dmin Desktop ME Thesis Work project-1.s1p .Here only project-1 is our main touchstone file. Various work performed on Scikit-rf based on proposed work are as follows-

- Reading the network type-For that the following code is written.For S parameter data reading

  ```
  import skrf as rf
  ntwk=rf.Network(r'C:\Users\admin\Desktop\ME Thesis Work\project_1.s1p.s1p')
  df=rf.one_port_2_two_port(ntwk)
  y=df.to_dataframe('s')
  print(y)
  ```

  After this code it will show what is the network type and what are the fequency range of the network etc.

- Plotting the S parameter- For ploting s parameter in db the code for our file is

  ```
  import matplotlib.pyplot as plt
  import skrf as rf
  ```

```
ntwk=rf.Network(r'C:\Users\admin\Desktop\ME Thesis Work\project_1.s1p')
df=ntwk.to_dataframe('s')
print(df)
ntwk.plot_s_db()
plt.show()
```

For ploting s parameter in Smith chart the code for our file is

```
import matplotlib.pyplot as plt
import skrf as rf
ntwk=rf.Network(r'C:\Users\admin\Desktop\ME Thesis Work\project_1.s1p')
df=ntwk.to_dataframe('s')
print(df)
ntwk.plot_s_smith()
plt.show()
```

- Plotting the Z parameter-For Z parameter real and imaginary values the following codes are used.

```
import matplotlib.pyplot as plt
import skrf as rf
ntwk=rf.Network(r'C:\Users\admin\Desktop\ME Thesis Work\project_1.s1p')
df=ntwk.to_dataframe('z')
print(df)
ntwk.plot_z_re()
plt.show()
```

For imaginary value code is

```
import matplotlib.pyplot as plt
import skrf as rf
ntwk=rf.Network(r'E:\Circleeee_1_1.s1p')
df=ntwk.to_dataframe('z')
print(df)
ntwk.plot_z_im()
plt.show()
```

Bibliography

[1] Reshma Nitnaware. Basic fundamental of python programming language and the bright future. *A Peer-Reviewed Journal About*, VIII:71–76, 06 2019.

[2] Alexander Arsenovic, Julien Hillairet, Jackson Anderson, Henrik Forsten, Vincent Rieß, Michael Eller, Noah Sauber, Robert Weikle, William Barnhart, and Franz Forstmayr. scikit-rf: An open source python package for microwave network creation, analysis, and calibration [speaker's corner]. *IEEE Microwave Magazine*, 23(1):98–105, 2021.

[3] Fatima Ez-zaki, Khaoula Ait Belaid, Sarosh Ahmad, Hassan Belahrach, Abdelilah Ghammaz, Ahmed Jamal Abdullah Al-Gburi, and Naser Ojaroudi Parchin. Circuit modelling of broadband antenna using vector fitting and foster form approaches for iot applications. *Electronics*, 11(22):3724, 2022.

[4] Sivaranjan Goswami, Pranjal Borah, Kumaresh Sarmah, and Kandarpa Kumar Sarma. Design of a dual-band multilayer antenna and its equivalent circuit modeling with vector-fitting and genetic algorithm. *AEU-International Journal of Electronics and Communications*, 138:153838, 2021.

[5] Bjorn Gustavsen and Adam Semlyen. Rational approximation of frequency domain responses by vector fitting. *IEEE Transactions on power delivery*, 14(3):1052–1061, 1999.

[6] Julien Hillairet. RF network analysis of the WEST ICRH antenna with the open-source python scikit-RF package. *AIP Conference Proceedings*, 2254(1), 09 2020. 070010.

Chapter 7

Results and discussion

7.1 Simulation Result

Once the simulation of the proposed design is completed then the various parameter related to the antenna is studied from the simulated result and the measured result.In CST microwave studio we can get the gain efficiency Electric field,magnetic field and current distributions for different frequency.Which are given in the following figure.With the simulation result there is another feature is that we can directly export all the data corresponding the particular result.Which can be further used to plot the result in a better format and with detail identification.Here Origin Pro software is used to plot all the graphs after simulation as well as measurement.Using this software feature we can compare multiple result in a single graph and then it can be explain precisely. From the gain plot it can be observed that maximum upto 5 dbi gain is obtained for the proposed design and the efficiency of the antenna is around 1.The surface current densities for the different resonance frequency also studied.From this it can be observed that at which frequency where the surface current is concentrated and how the patch structure effects the current distribution which further effects the matching issues.Another parameter which is VSWR also can be measured here that parameter is not shown.As the impedance and S parameter over wideband is studied so from that VSWR can be calculated.In fig 7.4 the gain of the antenna in terms of E plane and H plane for various frequency also shown.

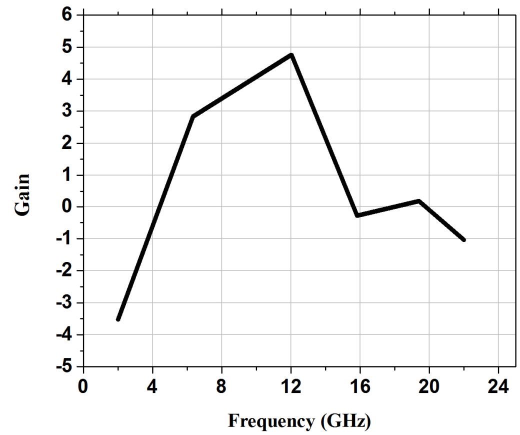


Figure 7.1: Simulated gain

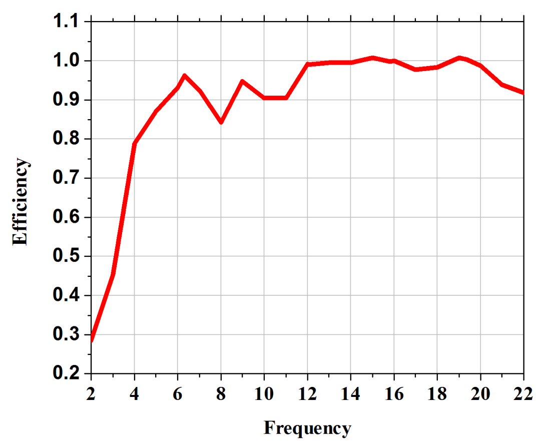
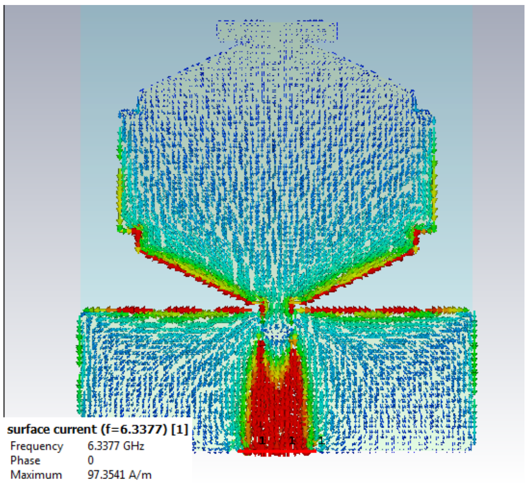
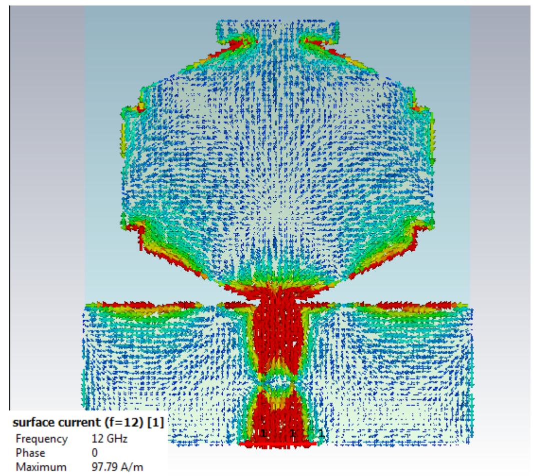


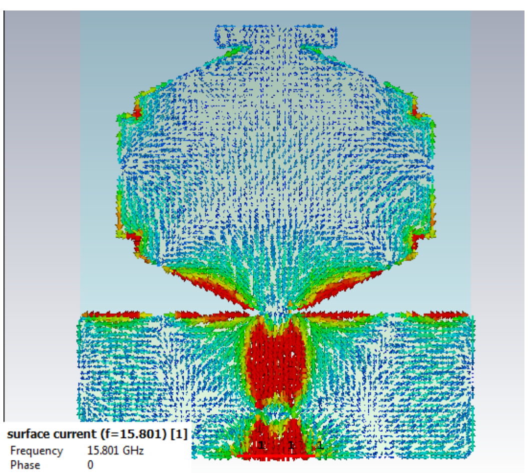
Figure 7.2: Simulated efficiency



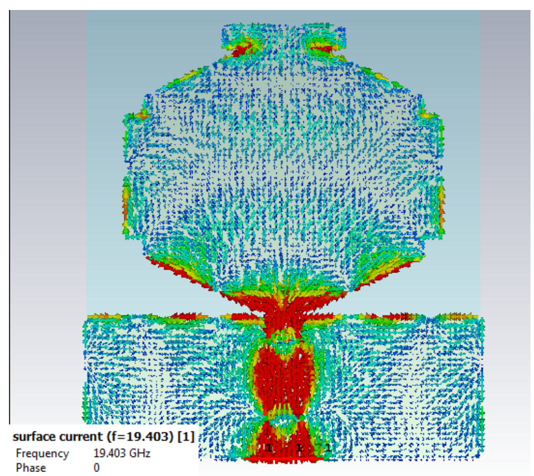
(a) f=6.33 GHz



(b) f=12 GHz

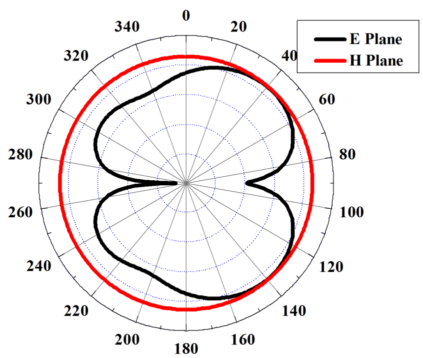


(c) f=15.801 GHz

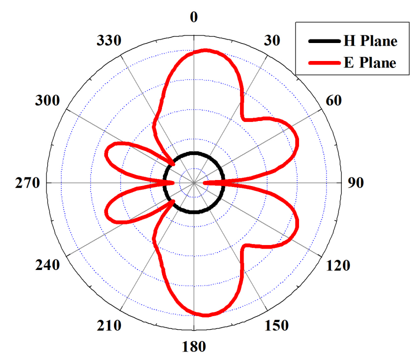


(d) f=19.403 GHz

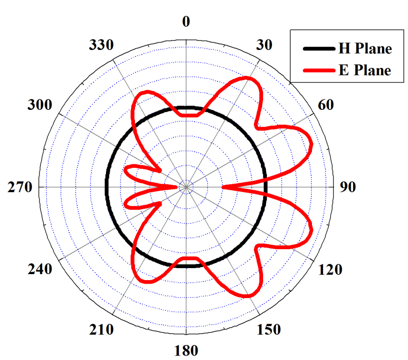
Figure 7.3: Surface current densities at various frequency



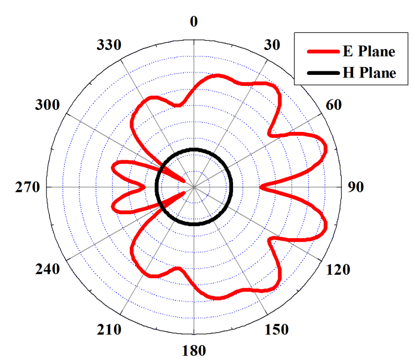
(a) f=6.33 GHz



(b) f=12 GHz



(c) f=15.801 GHz



(d) f=19.403 GHz

Figure 7.4: E and H plane at various resonating frequency

7.2 Experimental Result

In antenna designing process first step is design the antenna using any of the high frequency simulation software like HFSS,CST or IE3D.These three are widely used worldwide by antenna users.After getting satisfactory result associated to various parameters like gain, directivity,efficiency and polarisation pattern then the practical antenna making is done for the actual purpose.In this work also after observing all the result in simulation antenna fabrication is done.The fabrication of the microstrip antenna follows the following procedures

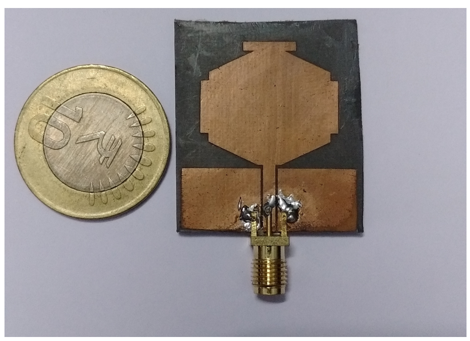
- substrate preparation-Here the actual substrate which parameters like dielectric constant,loss tangent etc is used during the simulation is prepared from the by taking actual dimension given in chapter 4.After that it is cleaned by acetone and kept for some time.

- Photo lithography- It is done using a photo resist solution.Here positive photo resist is used.After putting a layer of photoresist a small amount of heat is given to the material for drying the photoresist.The utmost care is taken during this entire process as it is light sensitive so this photolithography process is done in a dark room.Then the actual mask of the patch antenna which is exported from CST is placed on the substrate and it is exposed to uv light.About 17 minute later it is taken out and kept for some time.After removing the mask a developer solution is used the remove the light exposed portion of the patch.After that the actual patch can be seen.

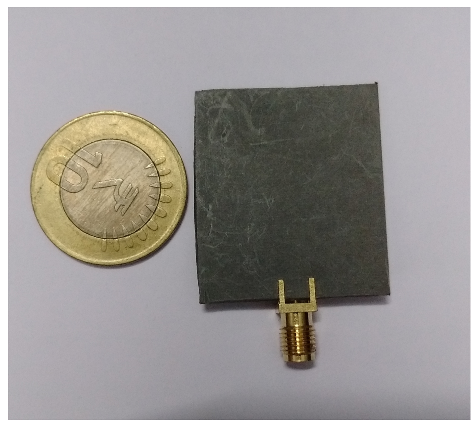
- Etching-After developing the patch etching is done.Ferric chloride solution of is used for etching.This process takes some time.Dilute HCL also can be used with some precautions.Once etching is done then the antenna is prepared and it cleaned usig acetone.For further measurement a SMA connector is connected using soldering kit.Fig 7.5 and fig 7.6a shows work done in the lab for fabrication.

After fabrication next step is measurement where fundamental parameter like S_{11} impedance gain radiation pattern is measured.The S parameter is measured using a vector network analyser(VNA).which is shown is shown in figure 7.7.Before connenctig the antenna VNA should be properly calibrated using various standard load that is open short and matched load.After S parameter measurement the radiation pattern measurement is done. Which is required an anechoic chamber.An anechoic chamber provides an environment by absorbing the electromagnetic radiation so that reflected wave does not effect the measurement.After measurement is completed a graphical comparison between the simulated and measured result which are shown in fig7.9 and 7.10.

Figure 7.5: Substrate preparation



(a) Front side



(b) Back side

Figure 7.6: Fabricated CPW feed antenna

7.3 Conclusion and future scope

After all the simulation and measurement experiment is done it is observed that the a good agreement between simulated and measured result. So the antenna can be useful over the wideband of 4.1 GHz to 22.4 GHz.A good impedance matching can further improve the antenna performance.This antenna can be useful various ultra wideband application as it cover the UWB band that is 3.1 GHz to 10.6 GHz.This antenna can be further used to make UWB MIMO which is the next step of this work.Using this a 2 by 2 and 4 by 4 MIMO antenna can be possible moreover using this single antenna also can be used for other application lile UWB GPR applications, and UWB wireless application and UWB sensor applications.Certain problems faced during this design process is fabricating very thing coupled gap and feed line width dimension so for further study and these things should be taken care of and scope of improvement is there related to miniaturization of the antenna as well as performance improvement

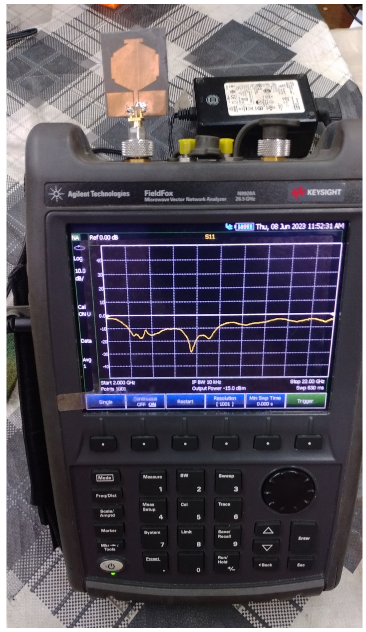


Figure 7.7: Measurement of S_{11} parameter

and getting wide impedance bandwidth.Other work can be done using this antenna by using metasurface or frequency selective surface to improve the gain and to increase the area of application of this antenna.There are various scope of improvement and area of work using UWB antenna in terms of its design in terms of circuit analysis or in terms of mathematical analysis related to its characteristics.Lot of research is going on related to UWB antenna design due to its broader application so working in this domain and implementing some new design will be recognizable.Again use of python Scikit-rf is again a new area of study which can open another direction of work using python coding and using various features of python package analysis of antenna can be done further extensively.

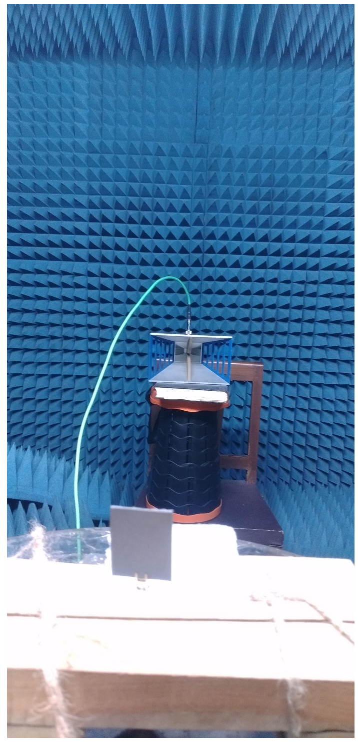


Figure 7.8: Radiation pattern measurement in anechoic chamber

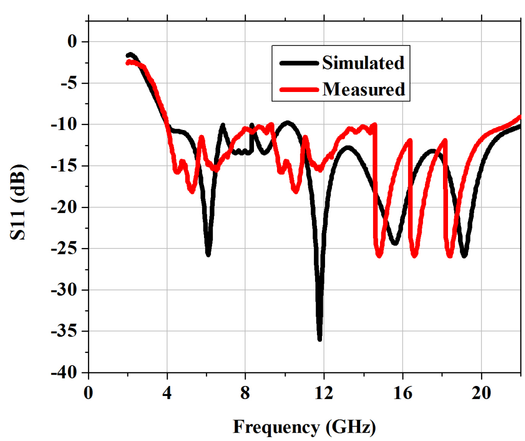


Figure 7.9: Comparison of S_{11} parameter between simulated and measured value

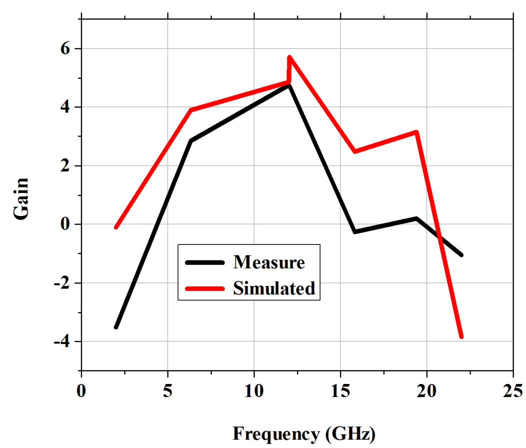


Figure 7.10: Simulated and measured gain