

DESIGN OF DUAL-BAND FLEXIBLE ANTENNA FOR WIRELESS APPLICATIONS

Submitted in partial fulfillment of the requirement for the award of Bachelor of
Engineering Degree in Electronics and Communication Engineering

By

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

SCHOOL OF ELECTRICAL AND ELECTRONICS

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC
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CHENNAI – 600119

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BONAFIDE CERTIFICATE

This is to certify that this Project is the bonafide work of **KURAPATI SHAKTHI NAGA GOPI (39130250)** and **MADHINENI JAGADEESH(39130268)** Who carried out the project entitled “**Design Of Dual Band Flexible Antenna For Wireless Application**” under my supervision for November 2022 to April 2023.

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DECLARATION

We, **KURAPATI SHAKTHI NAGAGOPI (39130250)** and **MADHINENI JAGADEESH (39130268)** hereby Declare that the Project Report entitled “**Design of Dual Band Flexible Antenna for Wireless Application**” was done by us under the guidance of **Mr. M.A MUTHIAH., M. Tech** at Sathyabama Institute of Science and Technology, Chennai-600119 is submitted in partial fulfillment of the requirements for the Bachelor of Engineering degree in **Electronics and Communication Engineering**.

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ABSTRACT

A dual-band flexible patch antenna for WLAN and X-band applications is proposed. The proposed antenna consists of a truncated rectangular patch and defected ground structure. A number of simulations are focusing on WLAN applications. A comparative analysis is to be done using antenna parameters. The antenna design and simulation are carried out by Ansys HFSS which is based on the Finite Element Method (FEM). The proposed flexible antenna operates at 2.45 GHz and 11.3 GHz with high gains of 6.2 dB and 6 dB respectively. The bandwidth covers 2.4 GHz to 2.5 GHz for WLAN applications and 10 GHz to 11.6 GHz for X-band applications. The proposed thin and flexible antenna shows stable characteristics and is suitable for WLAN and X-band applications. Because of the development of wireless communication technology and the use of frequency bands without any need for authorization, the application of WLAN is becoming more and more extensive. As the key part of the WLAN system, the antenna must also be able to get adapted to the development of WLAN communication technology. A Wireless local area network (WLAN) is a technology that combines the computer network with wireless communication technology. We proposed two new dual-frequency microstrip antennas with the use of electromagnetic simulation software-High Frequency Structure Simulation (HFSS). Simulation experiments prove that the two designed antennas have a higher gain and a favorable transmission characteristic in the working frequency range, which is to the requirements of WLAN communication.

TABLE OF CONTENT

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	V
	LIST OF FIGURES	VII
	LIST OF ABBREVIATIONS	VIII
1	INTRODUCTION	
	1.1 DUAL-BAND WIFI ANTENNAS	4
	1.2 THE 2.4 GHz FREQUENCY BAND	4
	1.3 THE 5 GHZ FREQUENCY BAND	5
	1.4 ANTENNA PARAMETERS	7
	1.5 MATERIALS FOR A FLEXIBLE ANTENNA	7
	1.6 PARAMETERS TO BE CONSIDERED FOR THE DESIGN AND ANALYSIS OF A FLEXIBLE ANTENNA	8
2	LITERATURE SURVEY	
	2.1 LITERATURE REVIEW	13
	2.2 SUMMARY OF SURVEY	17
3	EXISTING SYSTEM	
	3.1 FLEXIBLE ANTENNAS	19
	3.2 ANTENNA FOR WIRELESS POWER TRANSFER	20
	3.3 TESTING FOR FLEXIBLE ANTENNA	21
	3.4 CHARACTERISTICS OF A FLEXIBLE ANTENNA	24
4	PROPOSED SYSTEM	
	4.1 CHARACTERISTICS OF PROPOSED SYSTEM	27
	4.2 WORKING OF SIX BANDS	28
	4.3 OBJECTIVE	32

	4.4 SOFTWARE REQUIREMENTS AND ADVANTAGES	32
5	RESULTS AND DISCUSSIONS	33
6	CONCLUSION AND FUTURE SCOPE	48
7	REFERENCES	51

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1.1	Ultra-Wideband (UWB) Flex Antenna	6
1.2	Effect of bending on the gain	10
1.3	Multiband slotted antenna	11
3.1	3D Radiation Pattern of Antenna	20
3.2	Testing of flexible antenna	21
3.3	Rigid brass with flexible spring	23
3.4	Characteristics of a flexible antenna	25
4.1	Block Diagram of Proposed System	27
4.2	Working in six bands	28
4.3	Graph of 6 Working bands	29
4.4	Substrate dimensions	30
4.5	Radiation box dimensions	31
5.1	Rectangular contour plot	33
5.2	Radiation Pattern	34
5.3	3D polar plot	35
5.4	Smith Chart of the Antenna	36
5.5	VSWR	37
5.6	Electrical Field Of Antenna	38
5.7	Magnetic Field of Antenna	39
5.8	3D Rectangular Plot of Magnitude of Impedance	40
5.9	Bending Effect of Antenna	41
5.10	Directivity of the Antenna	42
5.11	Radiation Efficiency plot of Microstrip Antenna	43

5.12	Radiation Intensity plot of Microstrip Antenna	44
5.13	Front-to-back ratio plot of Microstrip Antenna	45
5.14	A soft HFSS Antenna Design	46

LIST OF ABBREVIATIONS

HFSS	High-Frequency Structure Simulation
FEM	Finite Element Method
WLAN	Wireless local area network
PET	Polyethylene terephthalate
LCP	Liquid crystal polymer
DGS	Defective ground structure
IEEE	Institute of Electrical and Electronics Engineers
FIT	Finite Integration Technique
UWB	Ultra-Wideband Flex Antenna
WBAN	Wireless body area network
RFID	Radiofrequency identification

CHAPTER 1

INTRODUCTION

An antenna is a crucial device that is used for communication purposes for transmitting and receiving signals through different mediums like air, vacuum, etc., WLAN(wireless local area network) is a widespread technology in the present world. It is considered to be a low-cost and reliable approach to high-speed data connectivity. The antenna proposed is a flexible microstrip patch antenna which is simple to design and fabricate. These antennas are light in weight, ultra-thin, and occupy very low space, so they are easy to carry and install. The proposed design consists of a polyethylene terephthalate (PET) substrate upon which a conducting layer (patch) and below ground is introduced or fabricated. These flexible antennas are very useful in wireless applications like WLAN and X- band implementations and have a hi-efficiency. The frequency range covered is 2.4- 2.5 GHz for WLAN and 10-11.6GHz X-band applications. In previous works, the substrates used are polyimide, liquid crystal polymer (LCP), polyethylene terephthalate (PET), textile, and dielectric liquid. Among all these, we considered PET because of its low loss tangent value of 0.008 [3].

Describes the design of two ultra-thin flexible printed monopole antennas. One antenna is a single-band antenna that operates at 2.4GHz frequency and the other is a dual-band antenna that operates at 2.5GHz and 5.2GHz. The substrate used is the Kapton polyimide substrate. We presented a novel approach to designing a UWB antenna that is printed on a 70-micrometer-thick polyimide substrate. Unequal-height ground planes and CPW feeding are used to increase the bandwidth of the antenna. It is observed that good bandwidth is found when the antenna is flat or bent shape. A natural rubber substrate is used for the flexibility of the antenna. The antenna was observed to be of a dumbbell shape for even current distribution. A minimum return loss of -30dB was observed.

A 3-D printed flexible MPA using atile array substrate was designed using 2 materials to utilize both types' advantages. The first material was Ninja Flex, which has amazing flexibility and mechanical properties, and the second one which has optimal RF properties. In this, we introduce a simple rectangular patch antenna with tiny slots on the patch and negligible substrate thickness to get max gain and it works at a frequency of 2.4GHz. It has a high efficiency for transmission and reception sides observed min return loss is -12.5dB. This gives a detailed study of different substrates which can be used for flexible patch antennas and their properties. It even gives a detailed explanation of fabrication techniques that are used in the past and present, and even which can be used in the future. A flexible antenna with a rubber substrate and a defective ground structure (DGS) design was explained. It is used for WLAN applications. Because of the use of DGS, a 7.5% increment in gain was observed [9].

In this, we use Teflon and PTFE glass as flexible substrates as they tend to forcibly retract to it's the original dimensions after deformation. These antennas designed using different substrates are adequate to be applied for medical, wearable, and wireless applications. About Omnidirectional pattern is discussed. The effect of the slot antenna is discussed in and presents X-band applications. Modern wireless and mobile communication systems require antenna which should have light weight, low profile, low cost and easy to be integrated with RF devices. This demand can be fulfilled by using dual band antennas. Dual band antennas have lots of practical uses, especially for mobile devices. These antennas operate on two bands of frequencies (similar to radio stations) and can either work on these different frequencies one at a time or simultaneously, depending on the capabilities of the individual antenna. The concept of Microstrip antenna was first proposed in 1953, twenty years before the practical antennas were produced. Since the first practical antennas were developed in early 1970's, interest in this kind of antennas was held in New Mexico. Dual frequency operation of antenna is very necessary in recent wireless communication system for some applications such as GPS, WLAN etc., [11].

Microstrip antenna has been established as a separate entity in the field of microwave antenna because of its numerous advantages such communication base stations, and as small size, light weight, low profile, low cost, and ease of integration with other microwave components. It is being used in large variety of applications such as radar, missiles, aircraft, satellite communications, and mobile handsets as well as in biomedical telemetry services. The choice of substrate depends mainly on the application targeted. For example, in the case the of WBAN applications and especially medical applications, polymers that are mostly derived from non-renewable petroleum resources are not recommended. In addition, the development of devices using these kinds of materials generates electronic waste that is harmful to our environment. Therefore, in this study a bio-based polymer is proposed to replace conventional polymers to develop biocompatible wearable RF devices. In particular, a dual band antenna operating at 2.45 GHz and 5.8 GHz is investigated [9].

The biopolymer selected is cellulose laurate that belongs to the Fatty Acid Cellulose Esters (FACES) class obtained by grafting fatty acid chains onto the cellulose backbone. Given the green nature of this polymer, and in order to reduce the environmental footprint of the fabrication process, a chemical-free process has been developed to fabricate the antenna. This later is based on the use of adhesive copper combined with laser structuring. This process is potentially suitable for all types of substrates that do not withstand high temperatures or chemical products. The process starts by fixing the adhesive copper on the substrate, then a laser is used to shape the circuit. The laser parameters are optimized before the cutting to avoid damaging the substrate.

The antennas used in WBAN applications must meet important requirements including a compact size, a high gain, a low SAR and a minimal performance degradation under bending. Various wearable antennas have been published recently in the literature in this context. As an example, proposes a dual band antenna (2.45/3.45 GHz) with high gain (6.7/8.9 dB) and low SAR (0.1/0.04 W/kg) realized on Taconic TLY-5 substrate (loss tangent of 0.0009). In terms of size, proposes a compact

and low-profile (39x39x0.5 mm³) single band (2.45 GHz) antenna on Rogers 5880 substrate (loss tangent of 0.0009). In a compact antenna (14x13x0.8 mm³) at 5.8 GHz on Rogers substrate (RO3010) (loss tangent of 0.0027) is proposed. As can be seen, the substrates selected in these studies have low losses which contribute significantly to the performance of the fabricated antennas. Furthermore, the eco-friendly nature of the substrates is an increasingly important feature in the design of antennas [3].

1.1 DUAL-BAND WIFI ANTENNAS (2.4GHz and 5GHz):

Dual-band antennas provide the functionality of two separate antennas in one unit. A dual-band antenna is an antenna that can send and receive radio frequency signals at two distinct frequencies. Depending on their configuration, these antennas can use either of the two frequencies individually or at the same time. The 2.4 GHz and 5 GHz frequency bands are commonly paired for dual-band antennas, due to their widespread use for Wi-Fi networking. They have proven an advantageous antenna for Wi-Fi because the 802.11 protocol for the functioning of Wi-Fi specifies the use of both the 2.4 and 5 GHz bands, as well as multi-antenna networking which can be supported by our broad range of dual-band antennas. Dual-band antennas operate at key frequencies for Wi-Fi.

1.2 THE 2.4 GHz FREQUENCY BAND:

The 2.4 GHz band spans 2400 MHz to 2485 MHz and is the lower of the two bands served by these dual-band antennas. Within the frequency band, there are up to fourteen overlapping 20 MHz sub-bands known as channels, that can be used for data transfer. Eleven channels numbered 1 to 11 are available in the US, with channels numbered up to 14 in Europe, Africa, and Asia. It is in widespread mainstream use for wireless networking and alongside Wi-Fi can be used to support Bluetooth and ZigBee as well as connectivity for domestic appliances like cordless phones.

It is highly utilized for wireless communication because of the range and penetration it can achieve. Compared to the 5 GHz frequency band, 2.4 GHz transmissions lose less energy as they propagate and with less energy being absorbed as signals pass through materials like wood, insulation, and plaster. This makes 2.4 GHz networking able to provide multi-room coverage in indoor environments. In many ways, this frequency band has found itself a victim of its success, due to the high volume of wireless traffic using this band's finite amount of bandwidth. The main effect of this is interference, with reduced speed and impaired performance of networks. Dual-band networking solutions are a key strategy for addressing the problem of interference at 2.4 GHz [6].

1.3 THE 5 GHz FREQUENCY BAND:

The 5 GHz ISM band has much more bandwidth, spanning 5.15 GHz to 5.35 GHz and 5.725 GHz to 5.825 GHz. The 5GHz frequency band is divided into 4 large sub-bands:

1. A upper (indoor) spans 5.150 GHz to 5.250 GHz
2. A lower (indoor) spans 5.250 GHz to 5.350 GHz
3. B (indoor or outdoor) spans 5.470 GHz to 5.725 GHz
4. C (outdoor) spans 5.735 GHz to 5.850 GHz

Within these large portions of the spectrum are 26 channels that can be used for high-speed and throughput networking with 19 of the channels being non-overlapping and channel widths of up to 160 MHz being possible. 5 GHz radio frequency signals have a much shorter wavelength (6 cm at 5 GHz versus just over 12 cm at 2.4 GHz). It is the availability of bandwidth that makes the 5 GHz frequency band advantageous. As a far less congested frequency, users benefit from connectivity with interference from other commercial and consumer applications. The high-energy signals propagate predominantly by direct line of sight as they are easily reflected, refracted, or absorbed. This limits the coverage that can be achieved by 5GHz Wi-Fi is predominantly for the indoor environment, though it is capable of high speed, high throughput data transmission.

If 5 GHz Wi-Fi is used outdoors a raised limit on radiated power for outdoor transmission at 5 GHz helps to boost coverage for point-to-point links where line of sight is good [20].

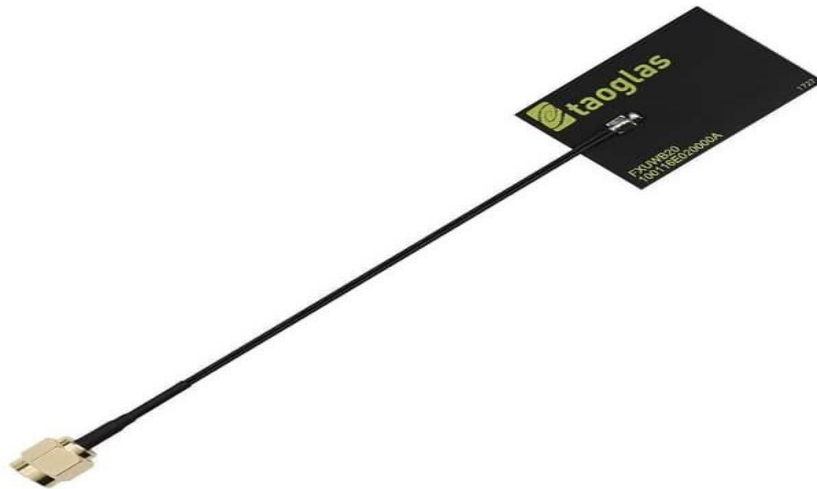


Fig 1.1: Ultra-Wideband (UWB) Flex Antenna

In reception, an antenna intercepts some of the power of a radio wave to produce an electric current at its terminals, In Fig 1.1 that is applied to a receiver to be amplified. Antennas are essential components of all radio equipment. An antenna is an array of conductors (elements), electrically connected to the receiver or transmitter. Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional, or high- gain, or “beam” antennas). An antenna may include components not connected to the transmitter, parabolic reflectors, horns, or parasitic elements, which serve to direct the radio waves into a beam or other desired radiation pattern. Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves that carry signals through the air (or through space) at the speed of light with almost no transmission loss. An automobile's whip antenna, is a common example of an omnidirectional antenna. Antennas are created approximately equally in all directions,

or directional, where energy radiates more along one direction than another. (Antennas are reciprocal, so the same effect occurs for the reception of the return wave the completely uniform omni-direction antenna signal as is physically possible. Some antenna types have a uniform radiation pattern in the horizontal plane, but little energy upward or downward. A "directional" antenna usually is intended to maximize its coupling to the electromagnetic field in the direction of the other station.

1.4 ANTENNA PARAMETERS:

An antenna is an electrical conductor or system of conductors Transmitter Radiates electromagnetic energy into space Receiver - Collects electromagnetic energy from space

1.4.1 Radiofrequency connectors for dual-band antennas:

Dual-band antennas carry a range of commonly encountered radio frequency connectors that maintain a competent mechanical and electrical connection to cabling and wireless equipment. Your selection of antenna may be, in part, determined by the connector it carries. All dual-band antenna connectors are 50 ohms connectors with suitably matched electrical specifications to ensure optimal performance of the network.

RP-SMA connectors are commonly used for consumer Wi-Fi network equipment, including antennas. They are a variant of the SMA connector. The RP-SMA connector mates by screw-coupling and is rated for over 500 mating cycles.

1.5 MATERIALS FOR A FLEXIBLE ANTENNA:

Flexible antennas are made of two kinds of materials: conductive materials and substrates. Both conductive materials and substrates need to be chosen in such a way that the antenna fabricated using these materials should show good radiation characteristics. In the design of any flexible antenna, the choice of substrate material is very important. The substrate is selected based on its dielectric characteristics, and

capacity to bear mechanical deformations including bending, crumpling, and mechanical stresses. Conductive materials, on the other hand, are chosen in terms of their good electrical conductivity, resistivity, tensile strength, and ability to integrate with flexible substrates [5].

1.6 PARAMETERS TO BE CONSIDERED FOR THE DESIGN AND ANALYSIS OF A FLEXIBLE ANTEENA:

The design and analysis of the flexible antenna need a wide range of parameters to be considered, rather than the conventional rigid antenna counterparts. Apart from the design considerations of choosing proper conductive and substrate materials for the flexible antenna as discussed in Session 2, certain parameters must be emphasized for the design, as well as the analysis of the flexible antenna which is discussed as follows:

1.6.1 Reflection Coefficient

One of the main parameters for the design of a flexible antenna is the reflection coefficient. The ratio of the amplitude of the reflected wave to the incident wave is known as an antenna's reflection coefficient. The reflection coefficient represents how much power is reflected from the antenna. The acceptable value is -10 dB so if the antenna is designed with a low loss, most of the power given to the antenna is radiated.

The resonance bandwidth and resonant frequency of the antenna can be used to describe the radiation properties of the flexible antenna. The resonance frequency range at the specified return loss of -10 dB is known as the antenna's resonant bandwidth. Therefore, the reflection coefficient is a parameter that must be considered for the design of a flexible antenna so that any shift in frequencies due to bending, crumpling, temperature difference, or interaction with the human body, should not affect the considerable return loss of the flexible antenna.

1.6.2 Gain

Another figure of merit that describes the performance of a flexible antenna is the gain. The antenna must have an acceptable gain for the intended use to be accepted in the wearable market. A flexible antenna should exhibit a positive gain to become more efficient for wearable applications. An average gain of more than 3 dB is needed

for the flexible antenna for smooth working in 5G applications. Incorporating array, as well as MIMO structures, can improve the gain of the antenna. A greater patch volume can also increase the gain, but an increase in the antenna volume would not be a good choice for wearable applications where the antenna has to be conformal and should accommodate less space.

Radiation Pattern and Radiation Efficiency

A flexible antenna for 5G needs a directional radiation pattern for applications such as cellular networks, base stations, global positioning systems (GPSs) etc. so that the radiation of the antenna becomes more concentrated in only some directions than in others. Applications, including wireless body area networks, incorporate antennas with directional radiation patterns, such that the radiation should be focused in a particular direction. However, an omnidirectional radiation pattern is required in some specific flexible devices incorporating technologies, including Bluetooth, Wi-Fi, etc. Furthermore, another important factor that contributes to the performance of the flexible antenna is radiation efficiency. It is the metrics that describe how efficiently the antenna transmits and receives the radio frequency signals. The radiation efficiency of the flexible antenna should be at accent table level for the smooth working of a flexible antenna in 5G applications.

1.6.4 Bending Analysis

Flexibility, as well as bending tests for on-body measurements, need to be performed in realistic environments. The mechanical deterioration that includes bending, stretching, etc., degrades the performance of the antenna by shifting the frequency of resonance, a change in the gain and radiation patterns, etc., of the antenna for any specific application.

Moreover, the application of a flexible antenna in a wireless body area network involves continuous bending of the antenna across different curvatures of the body. The human body exhibits different curvatures at different positions of the body. Therefore, the positioning of the antenna across such different positions shows different antenna characteristics. The bending analysis of the flexible antenna across different radii shifts the resonant frequency of the antenna. This is because when the

antenna is bent, it varies the effective length of the antenna and thus varies the resonant frequency [5].

The bending of the flexible antenna also changes the gain of the antenna which affects its performance. It is observed that as we increase the radius of the curved surface, the gain and antenna performance increase and on further increasing the radii, it decreases. However, for the surface-like arm, which is similar to a planar surface, the performance is optimum. Therefore, while increasing the bending radius, the antenna gain increases since the antenna's effective areas are more and thereby contribute a good gain. The bending of the conformal antenna should therefore be optimized in such a way that the antenna performance, such as the resonant frequency, gain, etc., should have a very negligible impact on the antenna performance. The effect of bending on the gain for a slotted dipole antenna under flat and bend conditions.

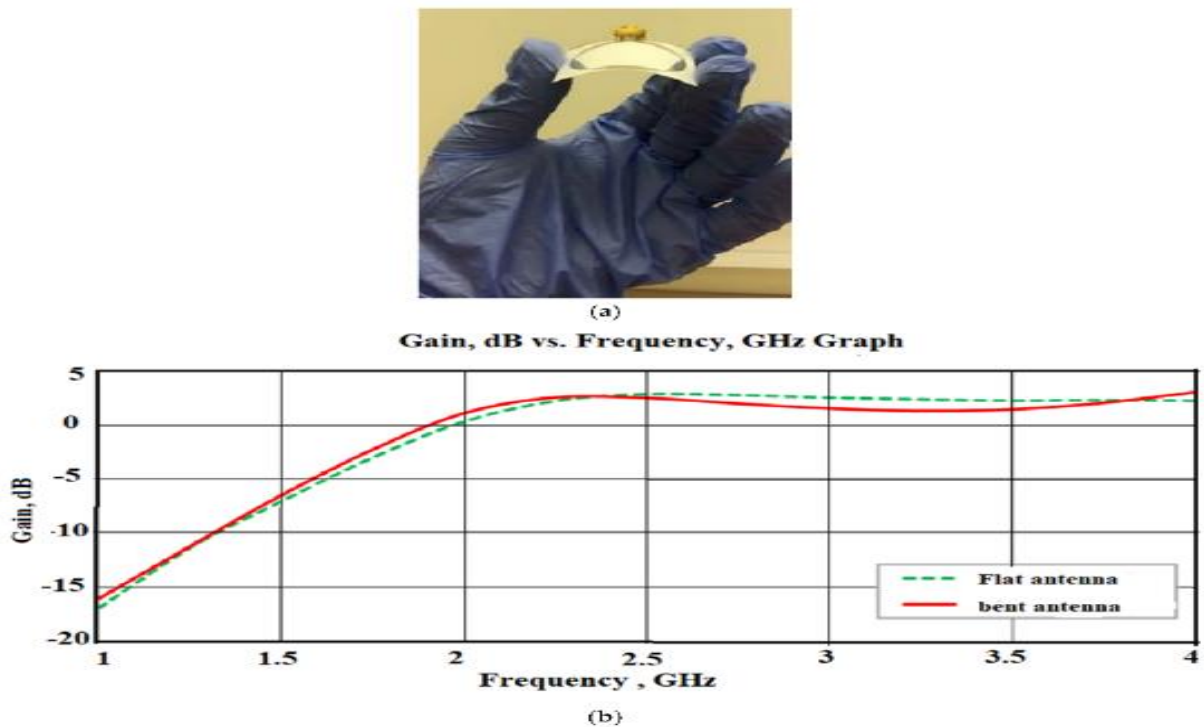


Fig 1.2: Effect of bending on the gain: (a) Bending of a slotted dipole antenna; (b) Gain analysis of the antenna under flat and bent conditions.

In a wideband and tri-band antenna that can be utilized for 5G sub-6 GHz communication with independently controllable notch bands, is proposed. The wideband monopole antenna consists of an octagonal geometry with truncated edges that improves the impedance bandwidth of the antenna. In Fig 1.2 The bandwidth is increased by a rectangular stub covering the whole sub-6 GHz band. The slots are introduced in the wideband antenna structure to achieve the band notches to mitigate the C-band and Wi-Max band. The wideband antenna shows a frequency range of 2.8 to 5.35 GHz, and the tri-band antenna is resonating at frequencies viz. 2.45 GHz, 3.5 GHz, and 4.7 GHz. a, b shows the S-parameter of the wideband and tri-band antennas, respectively. A gain of 3.75 dBi is achieved all along the covered spectrum. As shown in the figure.

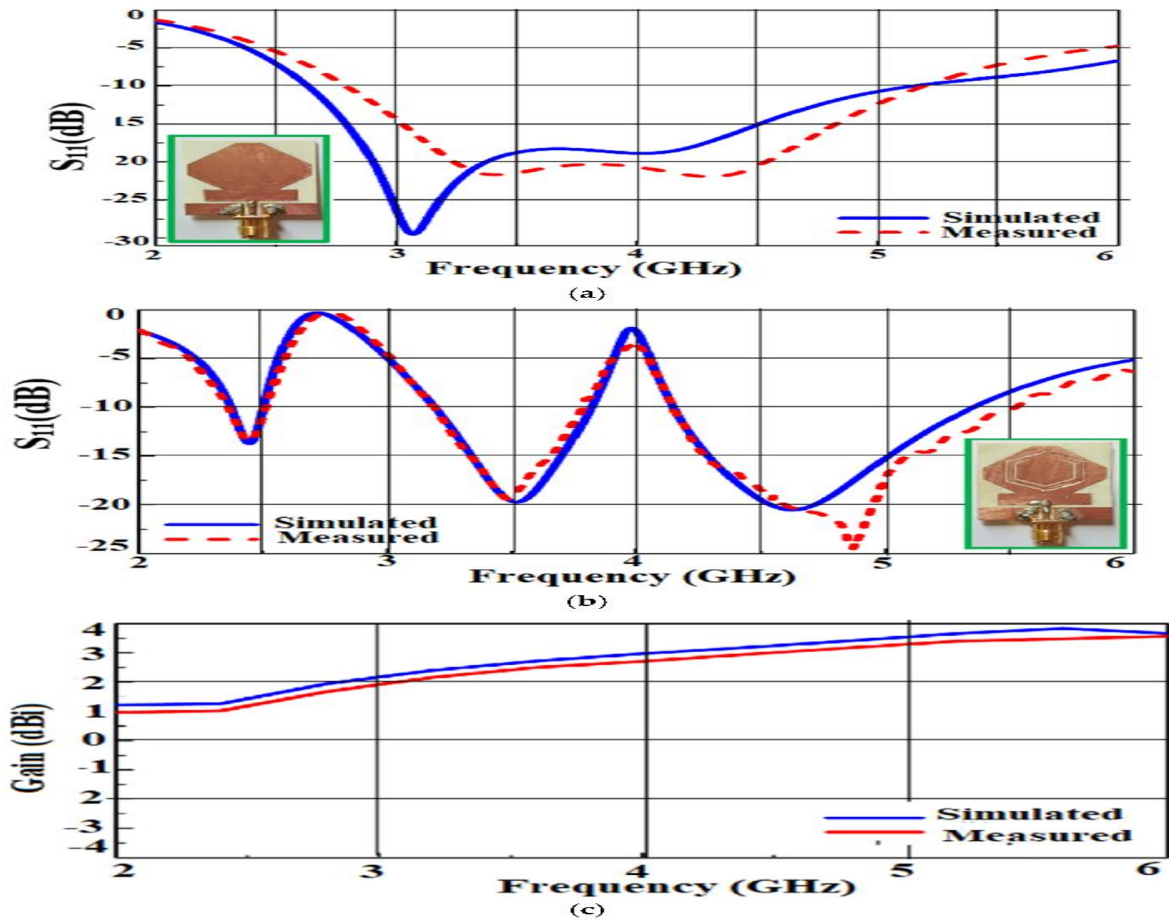


Fig 1.3: Multiband slotted antenna: (a) Return of the loss of the wideband antenna; (b) Return of the loss of the tri-band antenna; (c) Gain analysis of the wideband antenna.

In Fig 1.3 A directional radiation pattern is achieved for the proposed antenna over the entire band. The bending analysis is performed to check the conformability of the antenna. For this, the wideband and tri-band antenna is bent on a Styrofoam cylinder over various radii of 10, 25, and 40 mm. It is seen that there is not much effect on the return of the loss on the various bending radii. The slots are introduced in the wideband antenna structure to achieve the band notches to mitigate the C-band and Wi-Max band. The wideband antenna shows a frequency range of 2.8 to 5.35 GHz, and the tri-band antenna is resonating at frequencies viz. 2.45 GHz, 3.5 GHz, and 4.7 GHz. a, b shows the S-parameter of the wideband and tri-band antennas, respectively. A gain of 3.75 dB is achieved all along the covered spectrum. As shown in the figure.

In recent years, with the rapid development of wireless communication technology, the WLAN communication system has also flourished, and the applied range in the market is increasingly wide. WLAN communication systems generally require two-way sending and receiving data in a fast, high-efficiency, and reliable way, which is reflected in the antenna subsystem. The antenna is an important part of the communication system. Modern society has entered into the information age, and people present higher requirements for the antenna, that is the antenna not only has a wider frequency band, smaller size, and is easier to install, but also has a high radiation efficiency and anti-interference performance, and other characteristics.

At present, extensive studies of dual-band microstrip antenna applied in WLAN have been carried out, and a lot of antenna types that work in dual-band have been put forward, such as dipole antenna, and planar Inverted-F antennas.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE REVIEW:

Flexible printed monopole antennas for WLAN applications (Khaleel, Haider R., Hussain M. Al-Rizzo, Daniel G. Rucker, and Yahiea Al-Naiemy 2011) The presented two thin/flexible printed monopole antennas for Wireless Local Area Network (WLAN) applications. The first design is a single-band antenna that operates at 2.4GHz while the second one is a dual-band antenna that operates at 2.5 GHz and 5.2 GHz. The dimensions of the proposed antennas are (26.5 mm × 25) and (35 mm × 25) mm for the single band and dual band respectively. Antenna properties, such as gain, far-field radiation patterns, and coupling coefficient, expressed in terms of the scattering parameter S_{11} are provided. Design and simulations. They performed using CST Microwave Studio software which is based on the Finite Integration Technique (FIT). Moreover, the effect of folding the antenna was performed experimentally on both designs to study its influence on the antenna performance. The achieved gain for the single-band antenna is 1.8 dB with a measured bandwidth of 270 MHz. The dual-band antenna achieved a gain of 1.8 dB and 4 dB at 2.5 GHz and 5.2 GHz respectively and measured bandwidths of 305 MHz and 480 MHz at the first and second bands respectively. The proposed thin and flexible designs along with antenna characteristics are suitable for integration into flexible technologies for WLAN applications.

Design and Analysis of Dual-Band Circular Patch Antenna for X-Band Applications with Enhanced Bandwidth (Pradeep, Pendli, and S. K. Satyanarayana 2021) An antenna is a crucial component in the wireless communication system which converts electrical waves to EM waves and vice-versa which leads to revolution in wireless communication technology. Due to this reason, the experiment was performed on a simple circular patch antenna for better radiation along with wide transmission bandwidth. A simple circular microstrip antenna structure is designed to operate at dual bands. The proposed antenna consists of a circular radiating patch, a

50-ohm feedline line, a quarter-wave impedance matching transmission line, and a ground plane. It meets significant requirements for large bandwidth, optimized gain, minimum reflections, and small size with high directivity and efficiency. This antenna contains FR4Epoxy substrate material with a permittivity of ϵ_r 4.4 and size 36mm x 36mm x 1.67mm. ANSOFT HFSS simulator is used to analyze various parameters like return loss, VSWR, Impedance, and gain. The Resonant Frequency of the designed antenna is 8.7GHz and 10.6 GHz with minimum Return Losses of -52 dB and -21.66 dB respectively. It was also observed that 1.005 and 1.2 VSWR at 8.77 GHz and 10.6 GHz respectively.

Flexible Patch Antenna Using Different Substrates for WBAN Applications. (Prabhakar, D., M. Akhil Poorvika, M. Venkata Krishna Sai, and M. Subba Naidu 2019) This produces a flexible patch antenna using different substrates. Flexible antennas are becoming popular in the present-day era and these antennas play a key role in Bio-Medical applications. This deals with the primary approach using Polyester, Rubber which is the material used as the substrate for the patch antennas. The mechanical properties of these substrates make the antenna flexible. The antenna operates in the ISM band (2.4-2.5) GHz. The ISM band is suitable for flexible operation. The antenna with measured substrate properties was simulated in the High-Frequency Structure Simulator (HFSS). Approximate values in resonant frequency may be due to finite ground plane dimensions and variations of feed location. The simulated results suggest that flexible substrate antenna can be successfully used for Medical Applications.

A reconfigurable triple-notch-band antenna integrated with defected microstrip structure band-stop filter for ultra-wideband cognitive radio applications (Yasir I. A. Al-Yasir, Mohammed K. Alkhafaji, Hana'a. Alhamadani 2013) The proposed UWB CRA can work in eight modes by controlling switches ON and OFF. Moreover, impedance bandwidth, design procedures, and radiation patterns are presented for analysis and explanation of this antenna. The designed antenna operates over the frequency band between 3.1 GHz and 14 GHz (bandwidth of 127.5%), with three notched bands from 4.2 GHz to 6.2 GHz (38.5%), 6.6 GHz to 7.0 GHz (6%), and 12.2 GHz to 14 GHz

(13.7%). DMS -BSF is analyzed and discussed before CRAs design. The design procedures of the proposed CRA_C are illustrated in detail by analyzing CRA_A and CRA_B separately and then combining them. The reconfigurable functions are obtained using four ideal switches on DMS-BSF and the inverted-shaped slot. The switchable functions and band-notched characteristics are numerically investigated.

Triangular and Circular Dual Band Microstrip Antenna for WLAN Application (Azhari Asrokin, Mohd Kamal Abd. Rahim, Mohd Haizal Jamaluddin, and Mohd Riduan Ahmad- Wireless Communication Centre, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia 2006) The antenna is composed of a C-shaped radiation patch and a modified rectangular ground plane. Through proper adjustment of the angle of two arms of a C-shaped radiation patch, dual desired resonance frequencies are generated. The presented antenna exhibits great independence while being tuned separately. The antenna as proposed has the following merits, such as compact size, low cost, simplicity in configuration, and fine radiation performance, which is a good candidate for WLAN applications. By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling technique, some elements were cut off from the design, and it becomes a frequency-selective antenna or in this case a dual-band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed. Through proper adjustment of the angle of two arms of a C-shaped radiation patch, dual desired resonance frequencies are generated. The presented antenna exhibits great independence while being tuned separately.

A Compact High-Gain Microstrip Patch Antenna for Dual Band WLAN (Bharath Kelothu, K.R.Subhashini, and G.Lalitha Manohar 2012) The maximum gains of the two bands are 8.4 and 7.1dBi, making the proposed antenna appropriate for high-gain applications. The simulated results verify that the designed antenna is a good solution for dual-band WLAN applications. It can be concluded that the performance of the

microstrip antenna depends heavily on the dimension of the slot. As the width and length of the slot increase, the return loss (S_{11}) and VSWR increase but the gain decrease. It can be concluded that the performance of the microstrip antenna depends heavily on the dimension of the slot. As the width and length of the slot increase, the return loss (S_{11}) and VSWR increase but the gain decreases. Other factors that can contribute to the antenna performance are the types, thickness, and dielectric constant of the substrate. Because of using an FR-4 substrate, the proposed antenna production costs are reduced.

A Dual-band microstrip matched printed antenna for WLAN applications (C.J.Tsai, C.S.Lin and W.C.Chen- Department of Computer and Communication, KunShan University Yongkang Dist., Tainan City, Taiwan, R.O.C 2011) The analogs of the measured and simulated results prove that this proposed antenna has good quality in frequency bandwidth, gain value, and low cross-polarization value, which can well be applied to the WLAN/Wi-Max systems. This antenna is constructed with a double-sided FR4. The substrate with the radiator mounted on one side contains one circle and one square element, the microstrip line is fed on the other side to bring the wideband impedance match on the microstrip line and perform the dual and wide band effect. The frequency bandwidth requirement for WLAN/Wi-Max and discuss the influence of the gap values between two radiators and the copper size of parasitic capacity on the return loss value. The analogs of the measured and simulated results prove that this proposed antenna has good quality in frequency bandwidth, gain value, and low cross-polarization value, which can well be applied to the WLAN/Wi-Max systems.

Dual-band rectangular microstrip antenna with orthogonal polarization for WLAN application and Bluetooth (Kanchan D. Katore, M. B. Kadu, R. P. Labadie and S.S. Dongare 2017) The proposed dual-band rectangular microstrip antenna is fully planar, low-cost, and small in size. It can be easily fabricated using a simple PCB etching technique. It exhibits horizontal linear polarization at the Bluetooth band and vertical linear polarization at the WLAN band. The proposed antenna has its radiation pattern in a broadside direction. The radiation of the proposed antenna is in the broadside

direction. It has a directional radiation pattern in the XZ plane while a nearly omnidirectional radiation pattern in the XY plane. The proposed antenna has an axial ratio equal to 40 dB at 2.44 GHz and 28 dB at 5.25 GHz. It exhibits orthogonal polarization at its two operating frequency bands. Hence it is the best choice for MIMO (Multiple Input, Multiple Output) systems. The proposed dual-band rectangular microstrip antenna is fully planar, low-cost, and small in size. It can be easily fabricated using a simple PCB etching technique. It operates at Bluetooth band and lowers the WLAN band. It has return loss ≤ -10 dB from 2.41 GHz to 2.47 GHz (i.e. Bluetooth Band) as well as from 5.05 GHz to 5.45 GHz (i.e. lower WLAN band). It has gain equal to 0.5 dBi at 2.44 GHz and 5 dB at 5.25 GHz. It has an efficiency equal to 25% at 2.44 GHz and 58% at 5.25 GHz.

2.2 SUMMARY OF SURVEY

The demand for flexible wireless systems is rapidly increasing due to their diverse applications in health monitoring, telemedicine, wireless devices in daily life, tracking, patient diagnosis, and emergency rescue. Flexible electronic devices can be practical, low-profile, lightweight, disposable, inexpensive, and environmentally friendly. These devices must be bendable or even stretchable to integrate them with human body parts. Wearable devices, such as activity trackers, smartwatches, fitness bands, smart wear, augmented reality glasses, and fashion electronics are becoming an important part of the next generation of communication systems and Internet of Things (IoT) applications. An antenna is the most significant module of the wearable electronic system as the overall efficiency of the wireless link depends on it. An antenna is the most significant module of the wearable electronic system as the overall efficiency of the wireless link depends on it. Flexible antennas have been widely employed for on-body and off-body communication, wearable sensing systems, radio frequency identification (RFID), wireless body area networks (WBAN), and ingestible and implantable applications. The radiation of the proposed antenna is in the broadside direction. It has a directional radiation pattern in the XZ plane while a nearly omnidirectional radiation pattern in the XY plane. The Proposed antenna has an axial

ratio equal to 40 dB at 2.44 GHz and 28 dB at 5.25 GHz. It exhibits orthogonal polarization at its two operating frequency bands. Hence it is the best choice for MIMO (Multi-input, Multi-Output) systems. The proposed dual-band rectangular microstrip antenna is fully planar and low-cost and small in size. It can be easily fabricated using a simple PCB etching technique. It operates at Bluetooth band and lowers the WLAN band. It can be concluded that the performance of the microstrip antenna depends heavily on the dimension of the slot. As the width and length of the slot increase. The return loss (S_{11}) and VSWR increase but the gain decrease. Other factors that can contribute to the antenna performance are the types, thickness, and dielectric constant of the substrate. Because of using an FR-4 substrate, the proposed antenna production costs are reduced.

The given text contains summaries of different research papers on microstrip antennas. The first paper proposes a technique to reduce the overall size of a microstrip antenna using a partially filled high-permittivity substrate. The disadvantage of this paper is the high return loss. The second paper presents the design of high-gain 24-GHz CPW-fed microstrip patch antennas on high-permittivity substrates, but the disadvantage of this paper is that it is not cost-effective. The third paper introduces a combination of proximity-coupled circular microstrip antenna and a square quasi-planar surface-mounted short horn to increase the gain of a compact circularly polarized patch. The disadvantage of this paper is high directivity. The fourth paper designs textile antennas for materials with three different substrate permittivity and demonstrates the effects of antenna bending at different angles, but the disadvantage of this paper is impedance mismatching. The fifth paper investigates the effect of rainwater and seawater on the permittivity of denim jean substrate and the performance of a UWB eye-shaped textile antenna, but the disadvantage of this paper is limited performance under wet conditions. The sixth paper proposes a dual-band rectangular microstrip antenna with orthogonal polarization for WLAN and Bluetooth applications.

CHAPTER 3

EXISTING SYSTEM

3.1 FLEXIBLE ANTENNAS:

The antenna is a dual-band structured one which can operate in the frequency ranges from 2.4 GHz (802.11g/N) and 5.1 GHz (802.11a/N). The fabricated antenna shows dual operating bands of 3.24–8.29 GHz (5.05 GHz) and 9.12–11.25 GHz (2.13 GHz). Moreover, the antenna is compact, and its reflection coefficient is measured where a good agreement is observed with the stimulated results. A dual frequency band frequency at 2.4 & 5.8GHz range that is suitable for WLAN. The gain is 2dB at the frequency of 2.4GHz and about 3.1dB peak gain at the frequency band of 5.8GHz. The peak antenna efficiency is 70% at lower bands and at the higher bands, an efficiency of 60% is achieved. Flexible antennas are becoming popular in the present-day era and these antennas play a key role in Bio-Medical applications.

The mechanical properties of these substrates make the antenna flexible. The antenna operates in the ISM band (2.4-2.5) GHz. The ISM band is suitable for flexible operation. It exhibits orthogonal polarization at its own two operating frequency bands. Hence it is the best choice for MIMO (Multi-Input, Multi-Output) system. The dual-band rectangular microstrip antenna is fully planar, low-cost, and small in size. It can be easily fabricated using a simple PCB etching technique. A simple circular microstrip antenna structure is designed to operate at dual bands. The antenna consists of a circular radiating patch, a 50-ohm feedline line, a quarter-wave impedance matching transmission line, and a ground plane. It is also noteworthy that flexible antennas are becoming popular in the present-day era, and these antennas play a key role in Bio-Medical applications.

The mechanical properties of these substrates make the antenna flexible, and it can operate the ISM band (2.4-2.5) GHz, which is suitable for flexible operation. Finally, the dual-band regulator microstrip antenna is fully planar, low-cost, and small in size, and it can be easily fabricated using a simple PCB etching technique. Similarly, the

simple circular microstrip antenna structure designed to operate at dual bands is composed of a circular radiating patch, a 50-ohm feedline, a quarter-wave impedance matching transmission line, and a ground plane. Overall, the information you shared highlights the importance of antennas in various applications and the different types of antennas that are available for different purposes. Design and performance analysis of dual band wearable compact low-profile antenna. The design is based on a modified planar dipole with parasitic elements, meandered lines, and a rectangular reflector embedded into a hydrophobic rubber-textile multilayer substrate in order to get both good antenna performance and mechanical properties, The antenna structure is analyzed and optimized in free space (FS), on a numerical and an experimental homogeneous flat phantom [6].

3.2 ANTENNA FOR WIRELESS POWER TRANSFER

The overall dimensions of the antenna are 50 mm * 40 mm * 4.6 mm and a prototype mass of 11 g, which makes it suitable for practical applications in BCWs. The built prototype resonated at 2.47 GHz with an S_{11} -26.90 dB and at 5.43 GHz with an S_{11} -24.60 dB in the FS. The measured bandwidths are 500 MHz (2.2-2.7 GHz) and 1000MHz (4.65-5.75 GHz) at lower and higher bands, respectively. The antenna exhibits a measured maximum gain of 1.177 dB at 2.66 GHz and a radiation efficiency of 28.44% in FS. The 10g average maximum specific absorption rate is 0.165 W/kg at 2.70 GHz and 0.520 W/kg at 5.24 GHz when the antenna is placed on the numerical phantom at a net input power of 0.1 W.

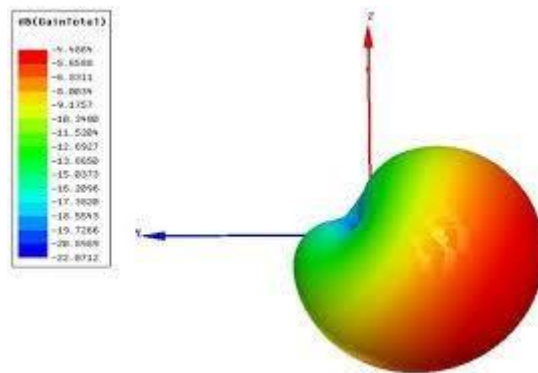


Fig 3.1: 3D Radiation Pattern of the Antenna

Antenna without a ground plane exhibits higher SAR values since the SAR of on-body antennas relies on the near-field coupling to the body. Hence, many of the methods to reduce SAR value rely on altering the ground plane. In Fig 3.1 One of the techniques is to use Electromagnetic Bandgap (EBG) structures or Periodic. Conductive structures to filter electromagnetic waves with certain frequency bands. Similarly, using High Impedance surfaces (HIS) help block electromagnetic waves within a certain frequency band. High Impedance surfaces placed behind wearable antennas increase the front-to-back radiation ratio reducing the specific absorption rate (SAR) in the human body. HIS also prevents propagating surface waves and reflects electromagnetic waves with no phase reversal.

3.3 TESTING OF FLEXIBLE ANTENNA



Fig 3.2 Testing of flexible antenna

In Fig 3.2 Testing of flexible antennas can involve several methods, depending on the specific type of antenna and the requirements of the application. Here are some common techniques used in the testing of flexible antennas:

1. Return loss measurement: This method involves measuring the amount of signal reflected by the antenna back towards the signal source. A higher return loss indicates a better match between the antenna and the signal source, which translates into better antenna performance. Return loss measurement can be done using network analyzers or other similar devices.
2. Radiation Pattern Measurement: The radiation pattern of an antenna determines the direction and strength of the electromagnetic waves it emits. Measuring the radiation pattern of a flexible antenna involves setting up the antenna in an anechoic chamber and measuring the signal strength at various angles and distances from the antenna.
3. Impedance Matching: Impedance matching is the process of matching the impedance of the antenna to the impedance of the signal source or transmission line.
4. Durability Testing: Flexible antennas are often subjected to various environmental factors such as bending, twisting, and stretching. Durability testing involves subjecting the antenna to these conditions to determine its ability to withstand them and continue functioning correctly.
5. Electromagnetic Compatibility testing: EMC testing involves measuring the ability of the antenna to operate without interfering with other electronic devices in the vicinity. This is particularly important in applications where multiple devices are operating in the same frequency band.

Overall, testing of flexible antennas is critical to ensure optimal performance, and a combination of these methods is often used to obtain a comprehensive understanding of antenna behavior in various conditions. Measuring the radiation pattern of a flexible antenna involves setting up the antenna in an anechoic chamber and measuring the signal strength at various angles and distances from the antenna. A higher return loss indicates a better match between the antenna and the signal source,

which translates into better antenna performance. Return loss measurement can be done using network analyzers or other similar devices.



Fig 3.3 Rigid brass with flexible spring

A possible application of a combination of rigid brass and a flexible spring could be in the construction of a mechanical pencil. In Fig 3.3 the rigid brass could be used for the outer barrel and the tip of the pencil, while the flexible spring could be used as a mechanism to advance the lead.

The brass barrel and tip would provide a sturdy and durable casing for the lead, while the flexible spring would allow for easy movement of the lead and help prevent breakage. The spring would be compressed when the user clicks the button to advance the lead, and then expand when released, pushing the lead forward. Another possible application could be in the construction of a retractable badge holder. The brass could be used to make the outer casing, while the spring could be used to retract the cord. The spring would be attached to the cord and wound up inside the brass casing, and when the user pulls the cord out, the spring would retract it back inside.

Overall, the combination of rigid. Brass a flexible spring can be useful in various mechanical applications where strength and flexibility are needed. The spring would be compressed when the user clicks the button to advance the lead, and then expand when released, pushing the lead forward. The brass could be used to make the outer casing, while the spring could be used to retract the cord. The spring would be compressed when the user clicks the button to advance the lead, and then expand when released, pushing the lead forward.

3.4 CHARACTERISTICS OF FLEXIBLE ANTENNA

Wireless communication has witnessed a huge transformation over the past few decades. The recent advancements in wireless communication need a huge number of devices connected to the internet which cannot be managed by the existing 4G LTE (fourth generation long term evolution) system. The fifth-generation (5G) communication system is a promising technology that fulfills the increasing requirements of data rates and also enables its integration with various services 5G can solve the issues that existed in the previous generation, in terms of bandwidth, QoS (quality of service), latency rate, and data transmission rates. The connection of a huge number of devices with high data rates, low latency, more connectivity, and efficiency is achieved with 5G. The 5G network will be beneficial to many industries, including improved health care, smart cities, 3-D imaging, the IoT (internet of things), and more.

The entire spectrum of 5G is classified into mainly three frequency bands viz a low band ranging from 600 to 700 MHz, a sub-6 GHz band ranging from 3 to 5 GHz, and a millimeter-wave band ranging from 24 to 100 GHz. It gives an overview of the 5G sub-6 GHz mid-band spectrum utilized in different countries. A sub-6 GHz (Mid band) has become the main focus of researchers due to the limitation of mm-waves. Since mm-waves are high-frequency waves, they can only cover very short ranges. So, the implementation of mm-wave devices is expensive. Moreover, the implementation of sub 6-GHz could be achieved with the already existing 4G LTE bands thus making it an appropriate choice for 5G communication. One of the technological advancements with the outbreak of the fifth generation is in the area of flexible industry. Flexible devices are adaptable, lightweight, inexpensive, and environmentally friendly. Such flexible devices need an antenna to operate in particular frequency bands in order to give a good wireless connectivity. The general characteristics of a flexible antenna are given in figure 3.4. 5G can solve the issues that existed in the previous generation, in terms of bandwidth, QoS (quality of service), latency rate, and data transmission rates.

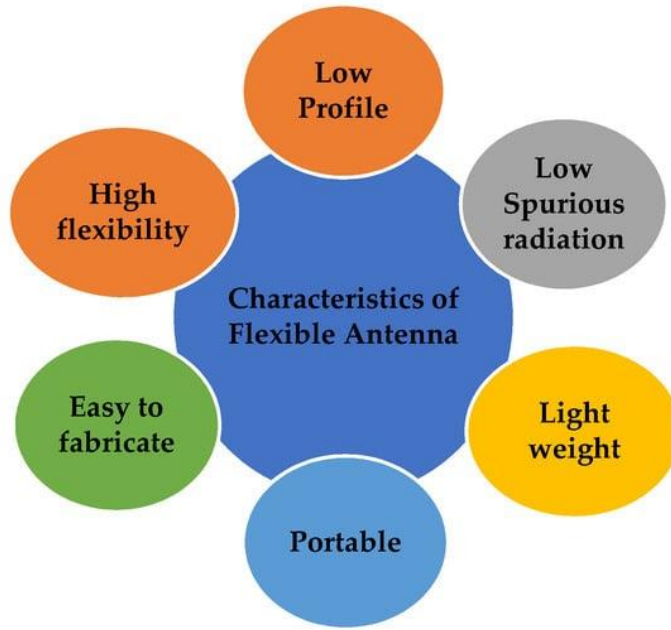


Fig 3.4 Characteristics of a flexible antenna.

The market for flexible electronics is increasing due to the high demand for wearable devices, especially health monitoring systems. Therefore, research on several flexible antennas has increased in recent years in biomedical applications. Flexible and conformal antennas provide good mechanical properties that make them suitable for wireless body area networks (WBANs) since continuous bending of the antenna should not degrade its performance of the antenna. In Fig 3.4 Moreover, the human body also has different dimensions and curvatures in different parts of the body. As a result, a flexible antenna plays a key role in this regard, as it must bend to match the curve of the human body when positioned in various places of the body.

Recently, the flexible antenna has marked a significant role in military applications. An all-textile cavity-backed substrate integrated waveguide (SIW) antenna is proposed for military applications. Several recent investigations have reported that provide extensive review on materials, fabrication, and applications of different flexible and wearable antennas. A practical guideline for designing and fabricating both nontextile and fully textile wearable antennas has been reported in. In another article the main focus was the different fabrication technologies for flexible antennas along with a design and analysis of a printed monopole antenna.

A complete survey of recently used materials and fabrication methods of wearable antennas, ranging from Very High Frequency (VHF) to millimeter-wave band was presented earlier. In another article, the main focus of the review was on materials and fabrication techniques for only wearable antenna designs with their applications, limitations, and solutions. The recent progress in the field of wearable ultrawideband antennas and their application in wireless body area network (WBAN) systems were demonstrated in an earlier study. Different types of implantable antennas, their design requirements, and performance comparison was surveyed in a prior article. The uniqueness of this article stems from the fact that this paper is the fact that we cover the entire area of flexible antenna rather than focusing on any subset such as wearables. Further, the authors discuss antenna applications covering a wide frequency band unlike other articles restricting the scope on the working frequency. Moreover, the human body also has different dimensions and curvatures in different parts of the body. As a result, a flexible antenna plays a key role in this regard, as it must bend to match the curve of the human body when positioned in various places of the body [9].

CHAPTER 4

PROPOSED SYSTEM

4.1 CHARACTERISTICS OF THE PROPOSED SYSTEM

The proposed flexible antenna operates at 2.45 GHz and 11.3 GHz with high gains of 6.2 dB and 6 dB respectively. The bandwidth covers 2.4 GHz to 2.5 GHz for WLAN applications and 10 GHz to 11.6 GHz for X-band applications. The proposed thin and flexible antenna shows stable characteristics and is suitable for WLAN and X-band applications. The parametric study is performed to understand the characteristics of the proposed antenna. The return loss, radiation pattern, and gain are studied too. The simulation return loss indicates the suitability of this antenna for WLAN applications.

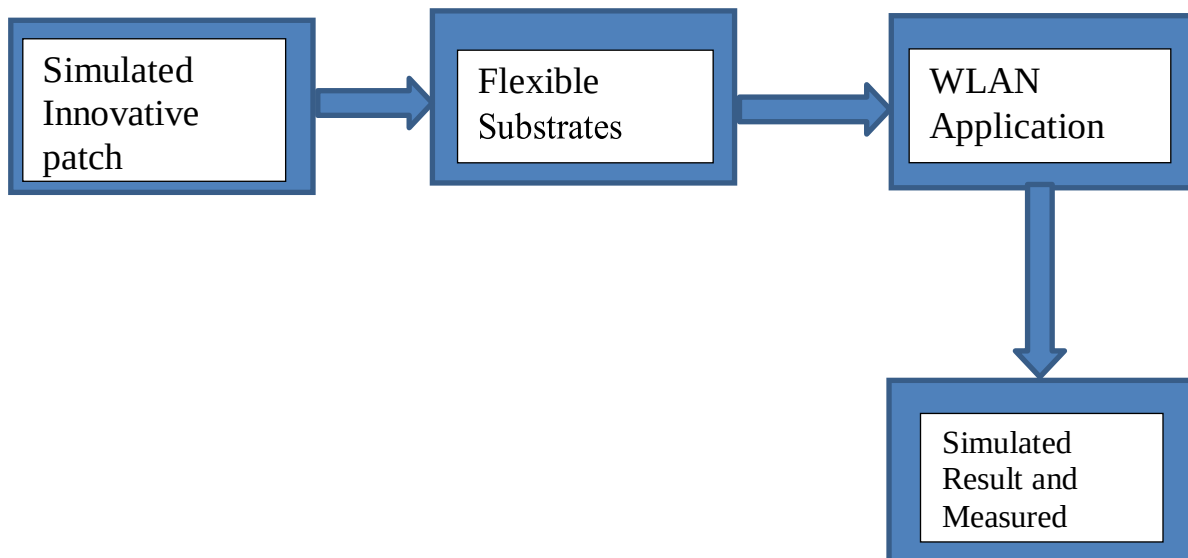
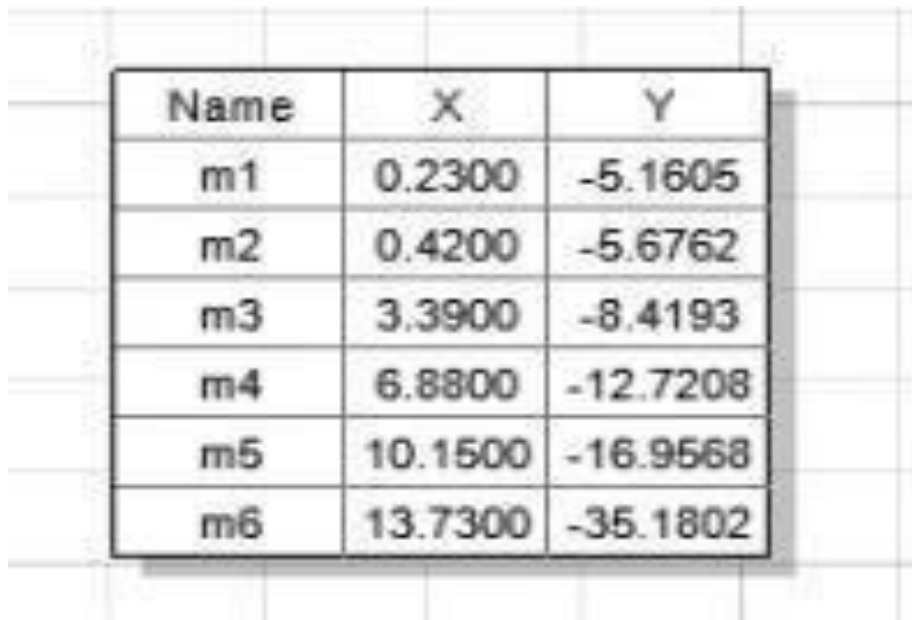


Fig 4.1: Block Diagram of Proposed System

4.2 WORKING OF SIX BANDS:



Name	X	Y
m1	0.2300	-5.1605
m2	0.4200	-5.6762
m3	3.3900	-8.4193
m4	6.8800	-12.7208
m5	10.1500	-16.9568
m6	13.7300	-35.1802

Fig 4.2: Working in six bands

An antenna that is designed to work in six different frequency bands is commonly known as a multi-band antenna. In Fig 4.2 Multi-band antennas are useful because they can provide coverage over a wide range of frequencies with a single antenna. There are various types of multi-band antennas, but the most common ones are wire antennas and patch antennas. Wire antennas are typically made of a length of wire that is cut to a specific length for each frequency, and they can be designed to operate in several frequency ranges. On the other hand, patch antennas are planar antennas that are designed to operate in multiple frequency bands by using multiple resonant elements.

To achieve multi-band operation, the antenna designer must carefully select the antenna's geometry, dimensions, and materials used. The antenna must be designed to resonate at each of the desired frequencies and have a suitable radiation pattern for the intended application. Some examples of applications for multi-band antennas include mobile communication devices, satellite communication systems, and wireless local area networks (WLANs).

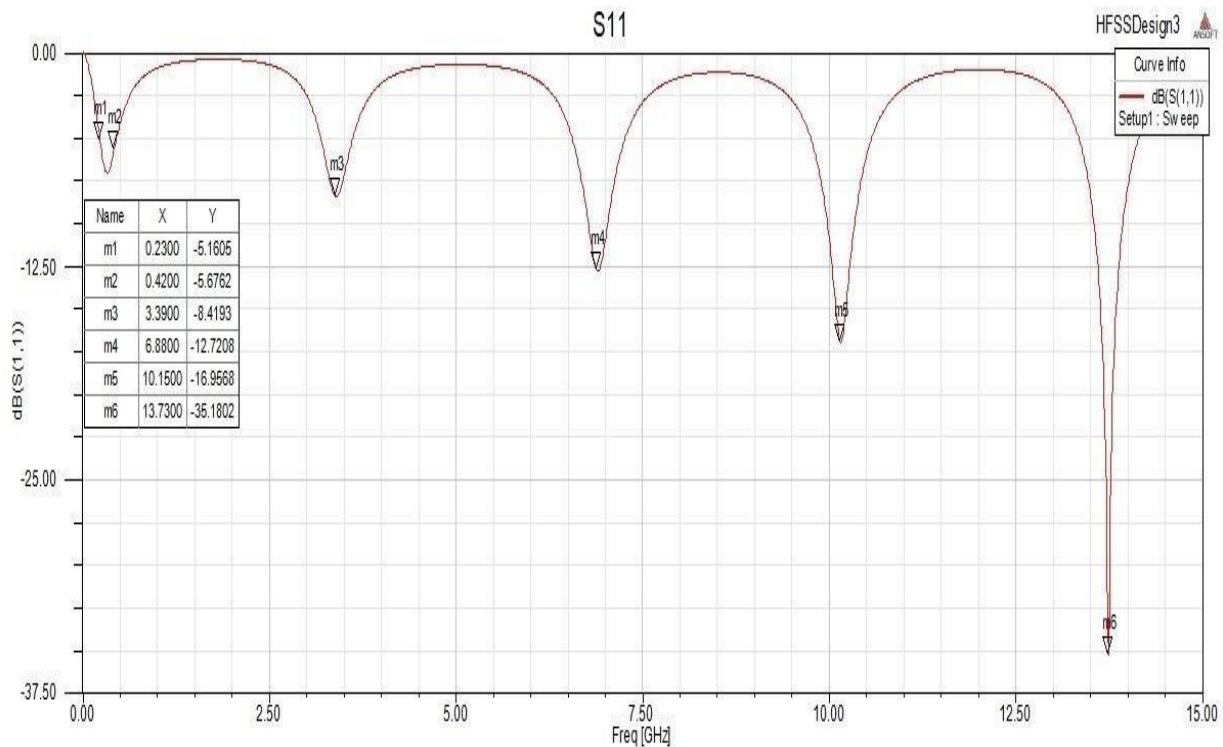


Fig 4.3: Reflection coefficient

The above plot Fig 4.3 describes the S-Parameter of the antenna. Scattering parameters or S-parameters describe the electrical behavior of linear electrical networks when undergoing various steady-state stimuli by electrical signals. S-parameters are used to describe how energy can propagate through an electric network, when it becomes especially important to describe a network in terms of amplitude and phase versus frequencies, rather than voltages and currents.

Various optimizations are done to get the return loss at the required frequency (2.4-8.1 GHz), which is also used in the antenna design. This is achieved by varying patch size and the feedline size, and in the ground layer by applying half ground, a quarter ground, and SRR in the ground (Split Ring Resonator). Impedance matching is done between the patches to get the maximum power transfer. The above graph shows the required frequency output at nearly -11dB exactly at 2.4 GHz. Before receiving the required output on the plot, front- the to-back ratio is observed, which is the primary thing to get this output. The front-to-Back ratio is nothing, but the gain is 180 degrees

more in the forward and 90 degrees less in the back from the required frequency. With this, the required frequency is obtained.

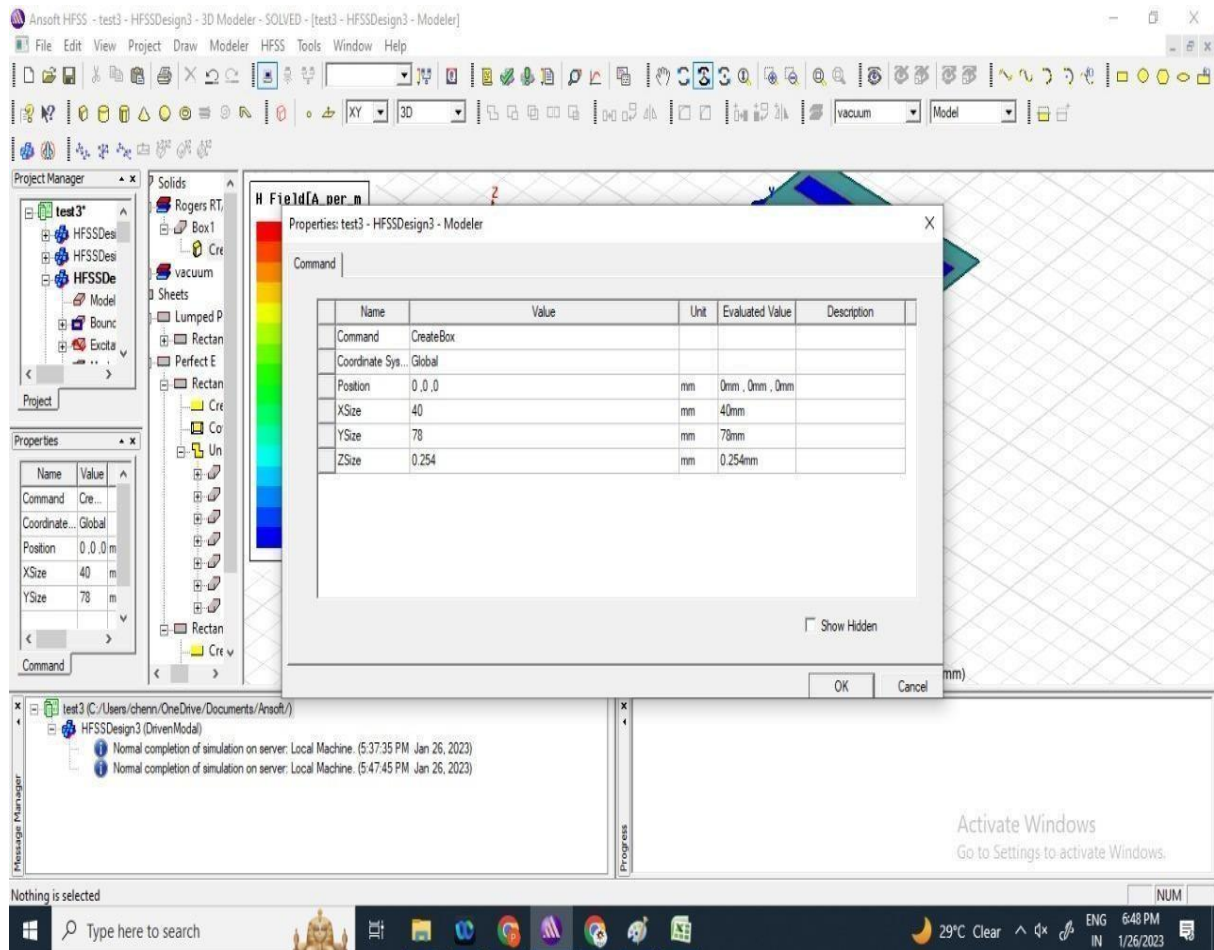


Fig 4.4: Substrate dimensions

The substrate and ground only have to be a bit larger than the patch to get the impedance right - with about 3 times the substrate thickness all around. In Fig 4.4 the theoretical radiation pattern assumes an infinite ground plane. A smaller ground will introduce ripples in the pattern, higher sidelobes, and back lobes. You should be able to find papers on the effect of the ground plane on sidelobes and ripple. To avoid the effect of substrate edges on antenna performance, you should choose the length and width of the substrate equal to 3 times the length and width of the patch antenna respectively.

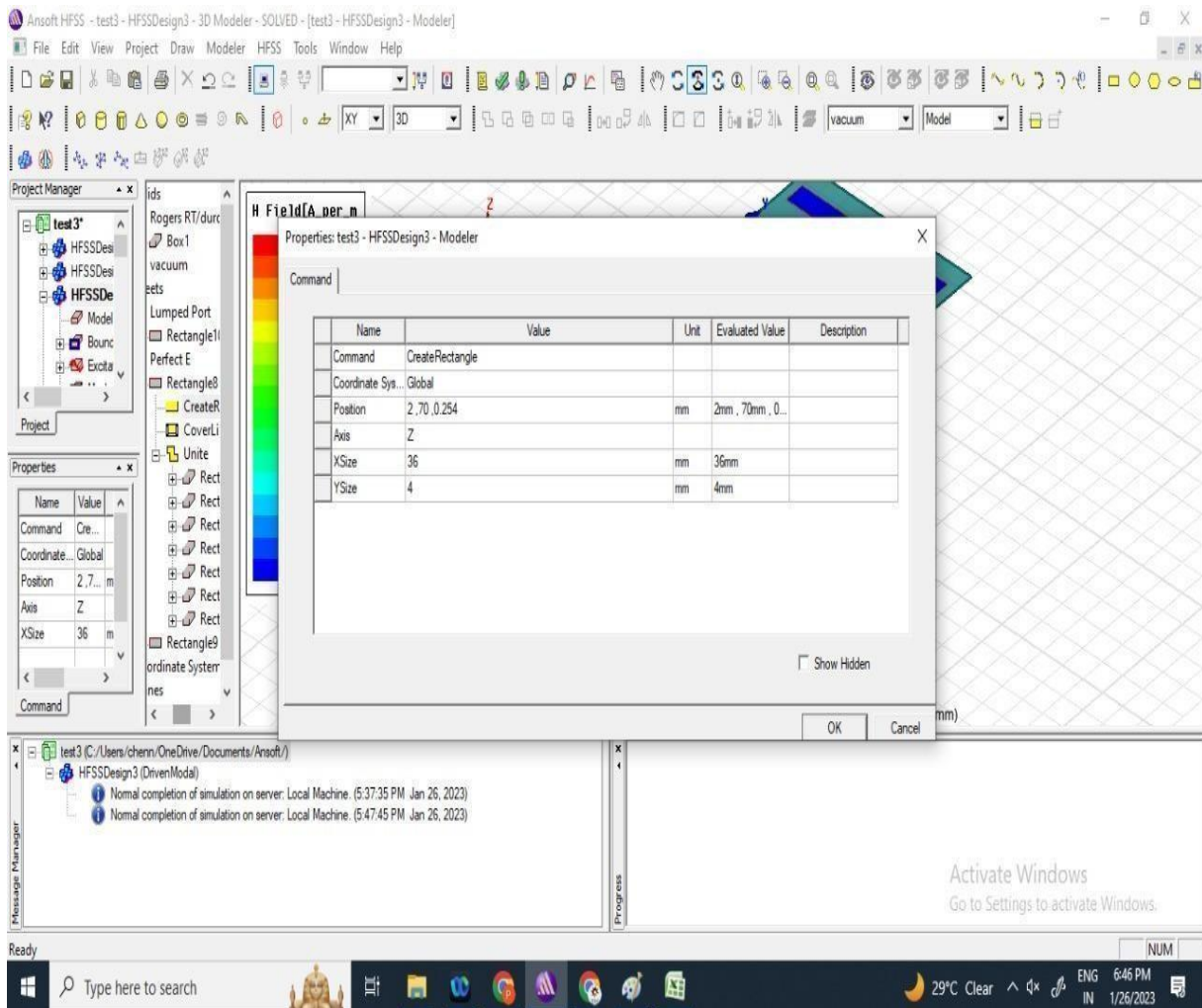


Figure 4.5: Radiation box dimensions

The radiation box is about the size of $\frac{1}{4}$ the wavelength for a box with a length of about 9mm. In Fig 4.5 one approach to finding the correct dimensions for the radiation box is to start with a large box (greater than $\lambda/4$) and then gradually decrease the size of the box in small steps (for example, by 0.1λ or 0.2λ). After each step, re-run the simulation and plot the S11 parameter. Compare the results and look for any changes in the resonant frequency or the S11 dB magnitude, and select the dimensions that give the most accurate and consistent results. Additionally, you can use some other parameters like return loss to check the simulation results and compare them with the expected values.

In the latest version of HFSS, we get the option of drawing a radiation box (right-click on the mouse by keeping the cursor on the antenna design and choose Radiation Box, it will ask for central frequency, then specify your resonant frequency then you will get Radiation box.

4.3 OBJECTIVES

1. A dual-band flexible patch antenna is presented for WLAN and X-band. The proposed antenna consists of truncated rectangular
2. To develop the proposed antenna on different substrates.
3. To simulate the design in HFSS software

4.4 SOFTWARE REQUIREMENTS AND ADVANTAGES

ANSYS HFSS 15.0 (64 bit)

ADVANTAGES:

1. Ease of manufacturing.
2. High Gain.
3. The simulated results suggest that flexible substrates can be successfully used for medical applications
4. Stable wireless connection

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 RESULTS OF DUAL-BAND ANTENNA

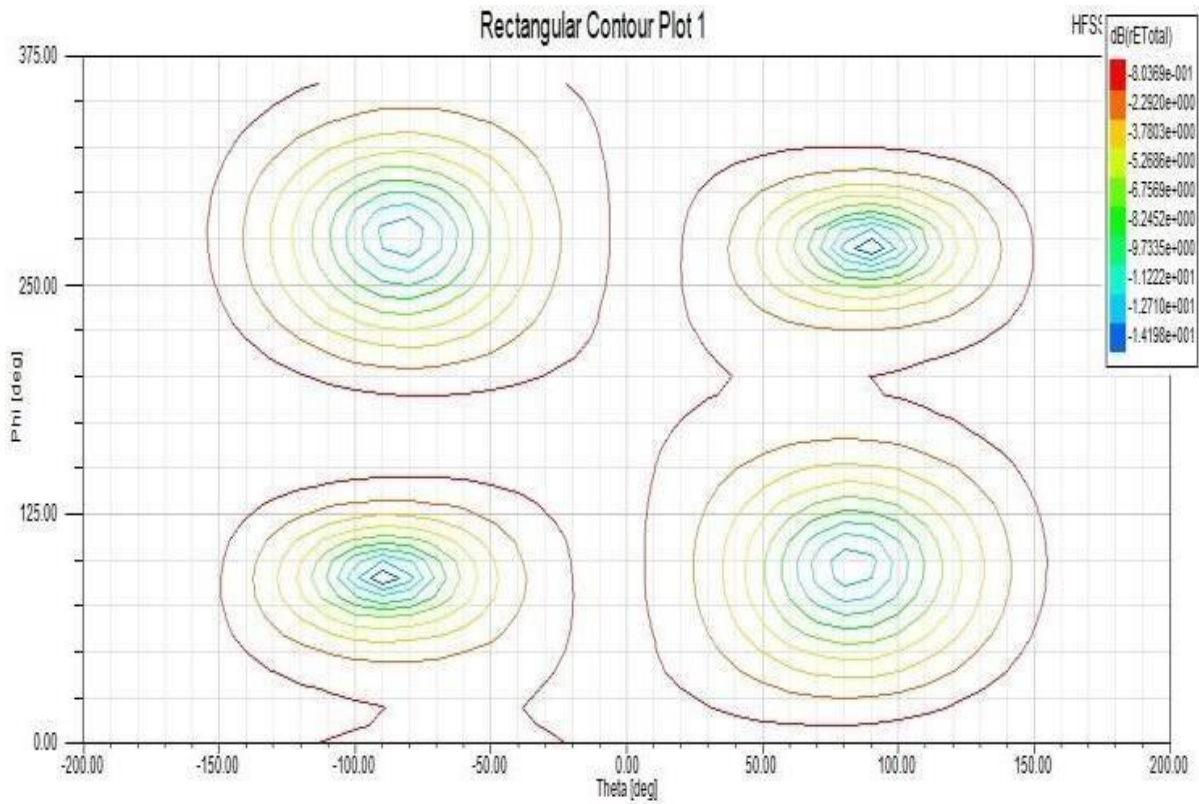


Fig 5.1: Rectangular contour plot of the antenna

Contour plots (sometimes called Level Plots) are a way to show a three-dimensional surface on a two-dimensional plane. In Fig 5.1 it graphs two predictor variables X Y on the y-axis and a response variable z as contours. These contours are sometimes called z-slices or iso-response values. This type of graph is widely used in cartography, where contour lines on a topological map indicate elevations that are the same. Many other disciplines use contour graphs including astrology, meteorology, and physics. Contour lines commonly show altitude (like the height of geographical features) but can also be used to show density, brightness, or electric potential.

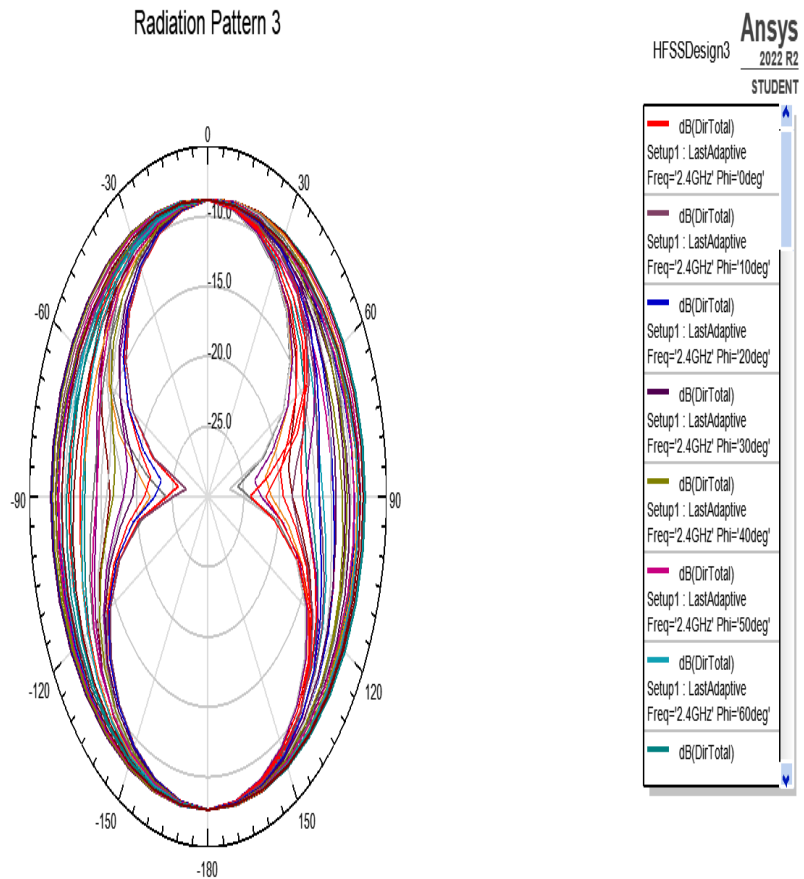


Fig 5.2: Radiation Pattern of the antenna

The above Fig 5.2 shows the Radiation pattern of the microstrip patch array antenna. Fig 5.2 shows the pattern when theta is zero and phi is 90-degree value for 2.4GHz and similarly shows for theta 90 degrees and phi zero degrees at 2.4GHz. The radiation from the antenna is an electromagnetic wave, by calculating and measuring the strength of this electromagnetic wave at a distant point. This far point is where the wave is considered a plane wave and is perpendicular to the direction of the antenna. A radiation pattern is a graphical representation of the directional properties of an antenna or other electromagnetic radiation source. It shows how the electromagnetic waves emitted by the source are distributed in space, and how strong the waves are in different directions. The radiation pattern of an antenna is determined by its physical characteristics, such as its shape, size, and orientation, as well as by the frequency of

the electromagnetic waves it produces.

There are two main types of radiation patterns:

1. Omnidirectional: Where the radiation is emitted equally In all directions, like a light bulb or dipole antenna.
2. Directional: Where the radiation is concentrated in one or more directions, like a satellite dish or a Yagi antenna.

Radiation patterns are often represented in two-directional or three-dimensional diagrams, which can show the intensity of the radiation in different directions as well as the shape of the pattern.

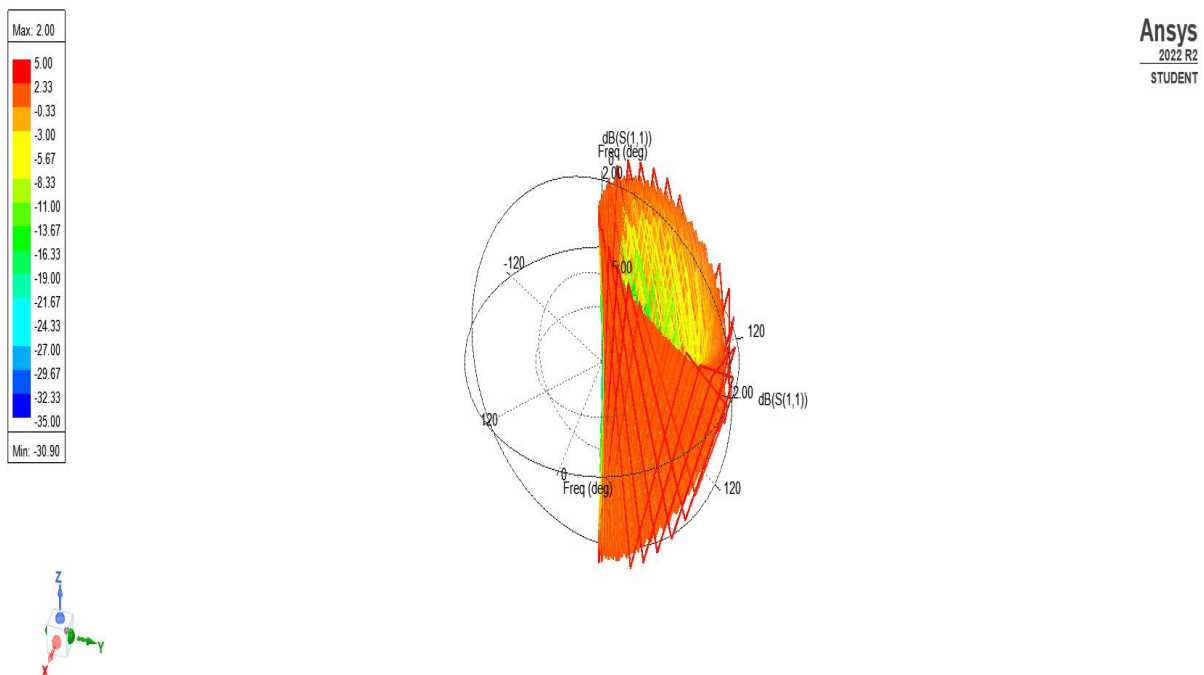


Fig 5.3: Gain of the 3D polar Plot of the antenna

The Gain of the antenna in a 3D polar plot is shown in Fig 5.3 in which all the values at which the resonance frequencies have been investigated with respect to theta and azimuthal angle. The radiation pattern of gain frequency is also Fig 5.3. Antenna gain is the measure of how strong the signal of an antenna can transmit or receive in a particular direction. So, the remaining work in this project is to get better gain and directivity. Using ground-based electromagnetic band gap structure, or EBG Structure, we will increase the antenna's gain. The EBG Structure is

essentially a periodic structural arrangement of metallic conductors, a high and low dielectric substrate, and both. Here, we're employing PGB for mushrooms (Photonic crystal and band gaps). Due to its unique electromagnetic properties, the EBG structure has recently received a lot of interest.

The above Fig 5.3 shows the gain of the antenna. As we know, Antenna Gain is the measure of how strong the signal of an antenna can transmit or receive direction. Here the gain is 3 maximum which is strong enough to transfer power and information. The EBG Structure consists basically of periodic structure arrangements of a high and low dielectric substrate and metallic conductors. Here we are using mushroom PGB (Photonic- crystals and Band Gaps). The EBG structure has attracted much attention recently due to its unique electromagnetic features. Applications of microstrip antennas on high dielectric constant substrates are of growing interest due to their compact size and conformability with monolithic microwave integrated circuits. By this, we can get the proper gain plot that we needed.

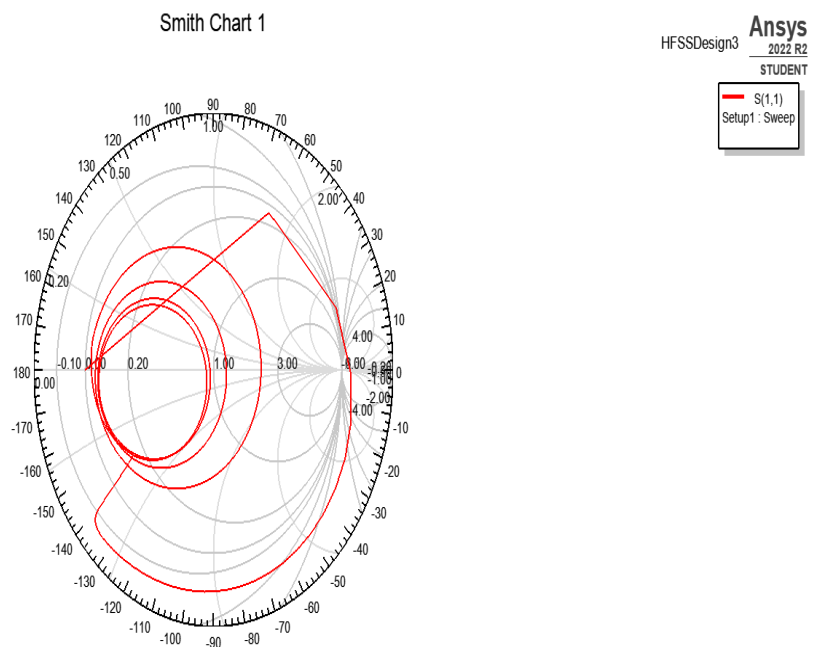


Fig 5.4: Smith chart of the antenna

The above Fig 5.4 is the Smith chart of the designed antenna. A Smith chart is a circular plot with a lot of interlaced circles on it. When used correctly, matching impedances, with apparently complicated structures, can be made without any computation. The only effort required is the reading and following of values along the circles. The Smith chart is a polar plot of the complex reflection coefficient (also called gamma and symbolized by Γ). Or, it is defined mathematically as the 1-port scattering parameter s or s_{11} .

The Smith Chart, as it has been presented up to this point, is a plot of reflection coefficient for magnitudes either equal to or less than 1, thereby encompassing all real, positive values of resistance. A Smith chart is developed by examining the load where the impedance must be matched. Instead of considering its impedance directly, you express its reflection coefficient Γ_L , which is used to characterize a load (such as admittance, gain, and transconductance). The Γ_L is more useful when dealing with RF frequencies.

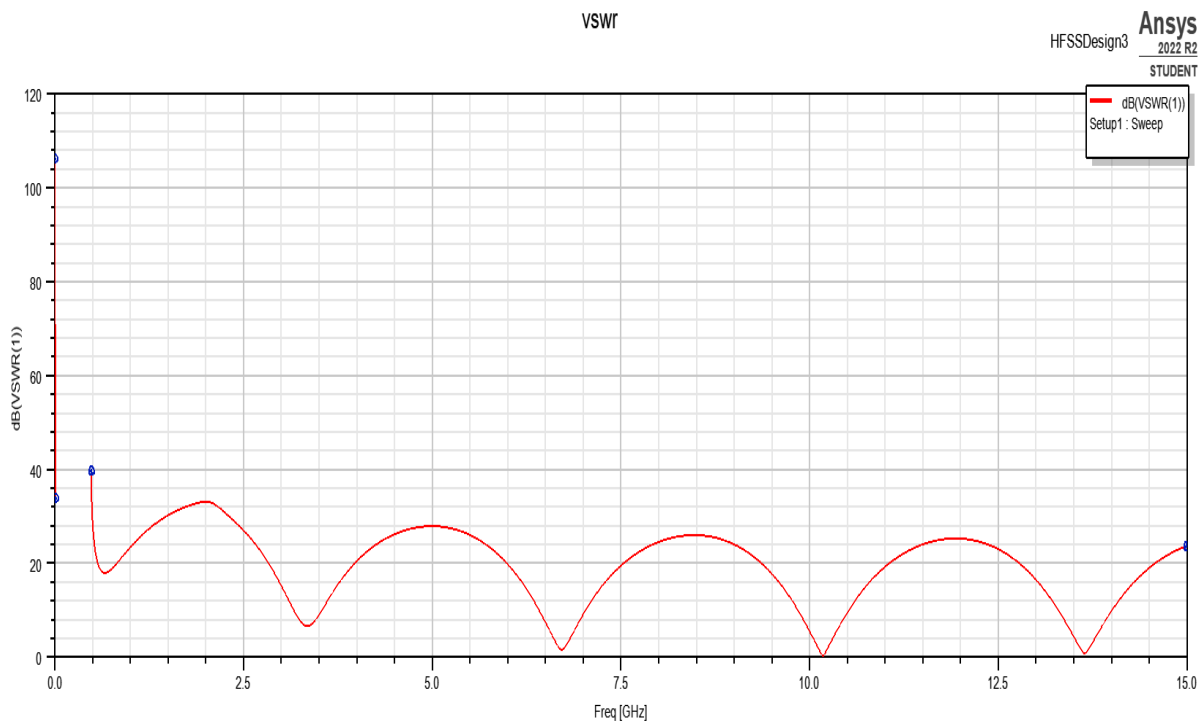


Fig 5.5: VSWR

The ratio of the scattering aperture to the effective aperture is defined as the scattering ratio. In Fig 5.5 the scattering ratio may assume values between zero and infinity. For conditions of maximum power transfer and zero antenna losses, the scattering ratio is unity.

When a transmission line (cable) is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected down the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a

When a transmission line (cable) is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back the transmission line. The ratio of the maximum to minimum voltage is known as VSWR or the Voltage Standing Wave Ratio. The scattering ratio may assume values between zero and infinity. For conditions of maximum power transfer and zero antenna losses, the scattering ratio is unity. Part of the power is reflected back the transmission line.

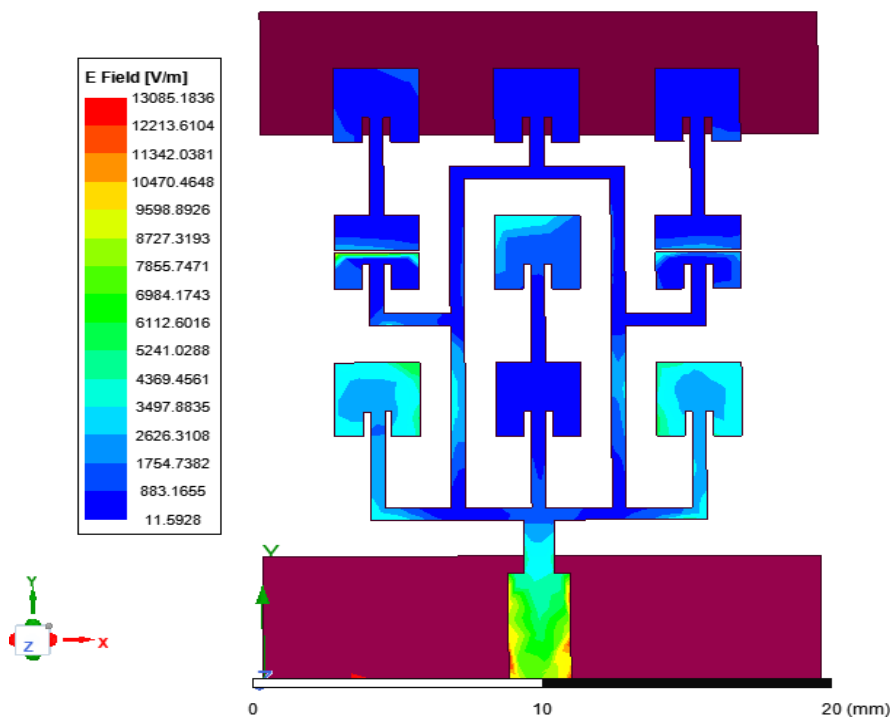


Fig 5.6: Electrical field of the antenna

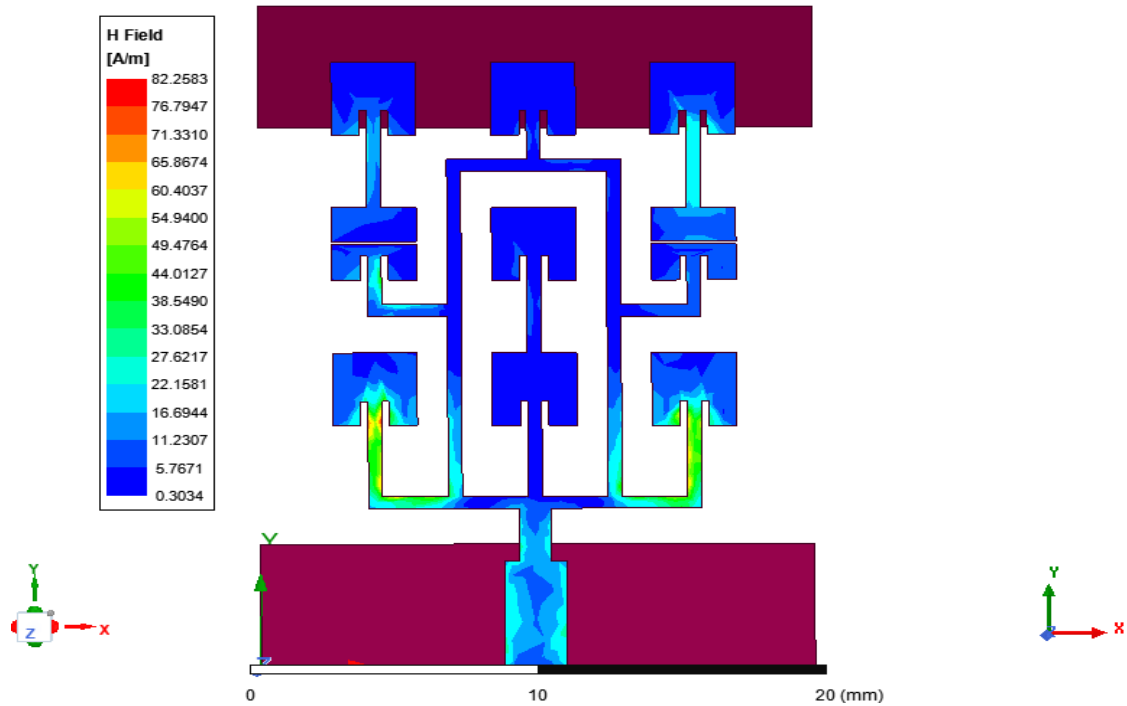


Fig 5.7: Magnetic field of the antenna

The above figures Fig 5.6 and Fig 5.7 display the electric and magnetic field flow on the patch of the antenna. So, from the above figures, it is clearly shown that the flow of both the electric and magnetic fields in the patch is very good. Part of the power is reflected down the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a When a transmission line (cable) is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back the transmission line. The ratio of the maximum to minimum voltage is known as VSWR or the Voltage Standing Wave Ratio. The scattering ratio may assume values between zero and infinity. For conditions of maximum power transfer and zero antenna losses, the scattering ratio is unity.

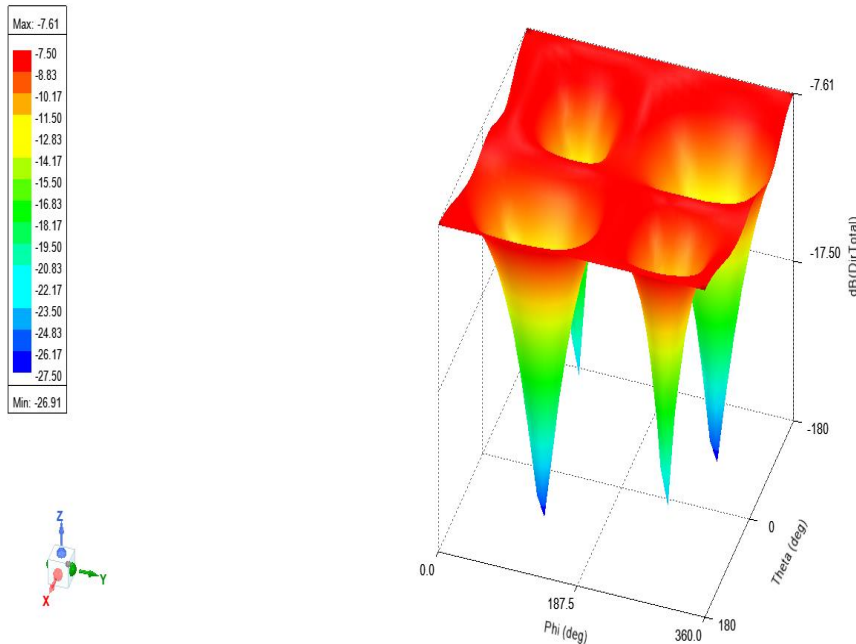


Fig 5.8: 3D Rectangular Plot of the magnitude of impedance

A 3D rectangular plot is a three-dimensional space that can be represented by a rectangular prism, also known as a rectangular cuboid. The rectangular cuboid is defined by three dimensions: length, width, and, height. In Fig 5.8 to visualize a 3D rectangular plot, imagine a rectangular box that has a length(L), width(W), and height(H). The three dimensions can be represented as axes, where the x-axis represents the width, and the z-axis represents the height.

The rectangular plot can be used to represent various physical quantities such as the volume of the box, the surface area of the box, or the total length of the edges of the box. It can also use to represent a mathematical function of the data in a 3D space. To represent a point in a 3D rectangular plot, we need three coordinates (x, y, z) that correspond to the three dimensions of the rectangular cuboid. For example, point (2, 3, 4) represents a point that is 2 units away in the x-direction, 3 units away in the y-direction, and 4 units away in the z-direction.

Overall, a 3D rectangular plot is a useful tool for visualizing three-dimensional data and can be used in a wide range of applications, from engineering and architecture to mathematics and data science.

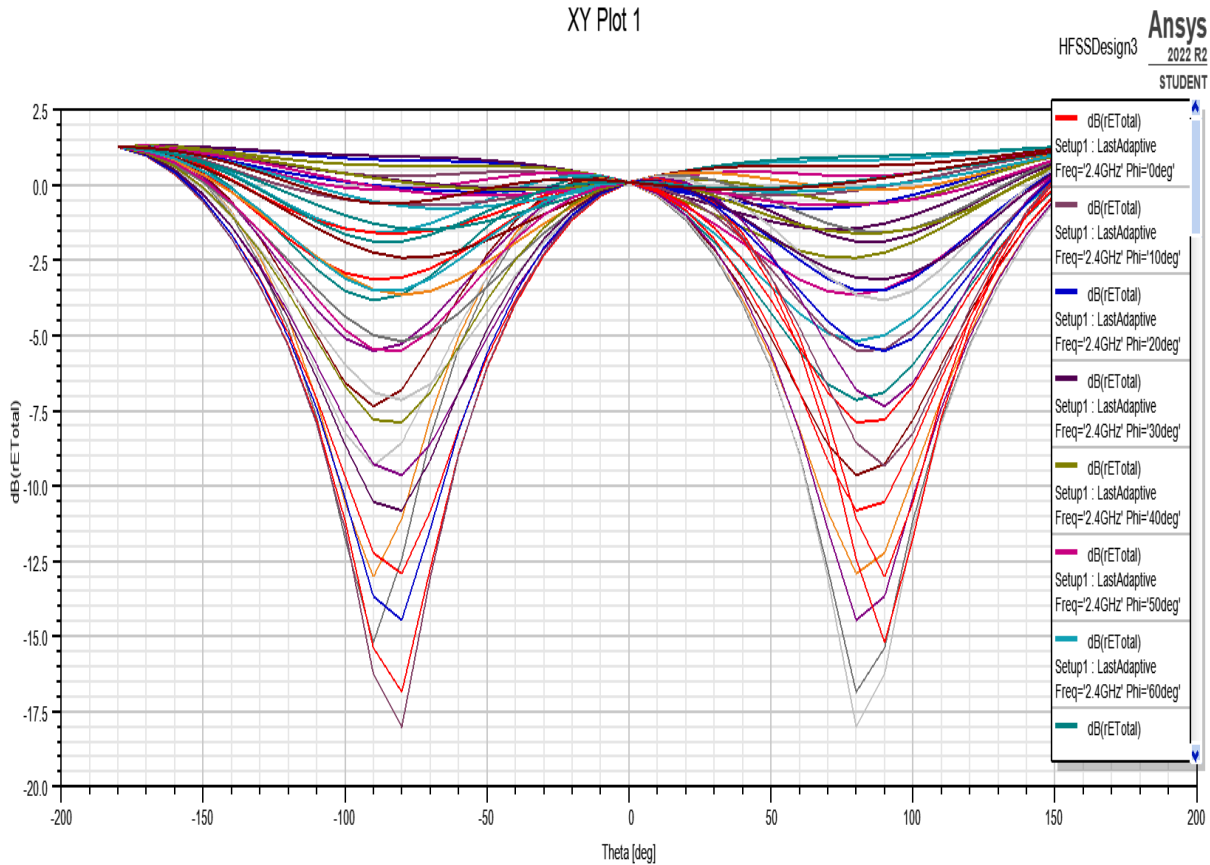


Fig 5.9: Bending effect of Antenna

In Fig 5.9 the bending of flexible antennas is different for the different ranges of frequencies and becomes crucial at higher frequencies because of the small size of the antenna, impedance mismatching, and the narrow bandwidth. The tested frequency ranges were divided into three groups to analyze the stable response in each range of frequencies. the small size of the antenna, impedance mismatching, and the narrow bandwidth. For this purpose, the effects of bending levels on the PET, Teflon, and PVC substrate antennas for the bending levels of 14 and 27 mm were analyzed for the flexible polymer antennas with an operating frequency of 2.45, 4.25, and 7.45 GHz, which lie within the three frequency ranges of

- (i) 2.2–2.5 GHz,
- (ii) 2.5 to 5.0 GHz, and
- (iii) greater than 5 GHz.

To establish a consistent bend in the flexible antenna, polystyrene foam cylinders were used with radial curvatures of 27 and then 14 mm, as demonstrated in Fig 5.9. In this figure, the bending of the flexible antenna on the foam at 27 mm, then 14 mm, and the connection with the VNA are exhibited.

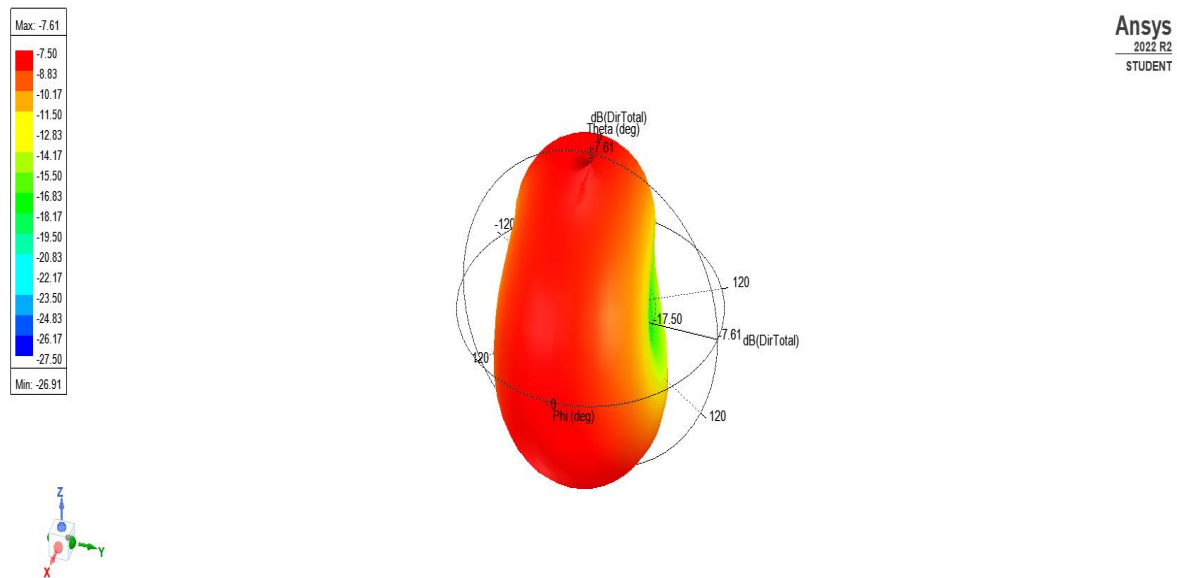


Fig 5.10 Directivity of the antenna

The directivity of an antenna is a measure of its radiation pattern in a certain direction. In Fig 5.10 the top of the patches will be cut into triangular shapes with sharp edges to achieve or produce a directivity plot positive, which will naturally increase the antenna's radiation pattern. This is what we will put into practice over the next several days to get the right gain and directivity, which will allow the aerial design to function without any loss and achieve the highest power transfer. Fig 5.10 shows the directivity of the antenna. Directivity is a measure of how well the array directs energy toward a particular direction. Directivity is a fundamental antenna parameter. It is a measure of how 'directional' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB). This is what we will put into practice over the next several days to get the right gain and directivity.

Gain is the product of directivity and efficiency. Where efficiency accounts for the losses on the antenna such as manufacturing faults, surface coating losses, dielectric, resistance, VSWR, or any other factor. The directivity of patch antennas is approximately 3.2 maximum. Here for this antenna's design, the directivity is given as 3.2 maximum. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π . If the direction is not strictly specified, the direction of maximum radiation intensity is implied.

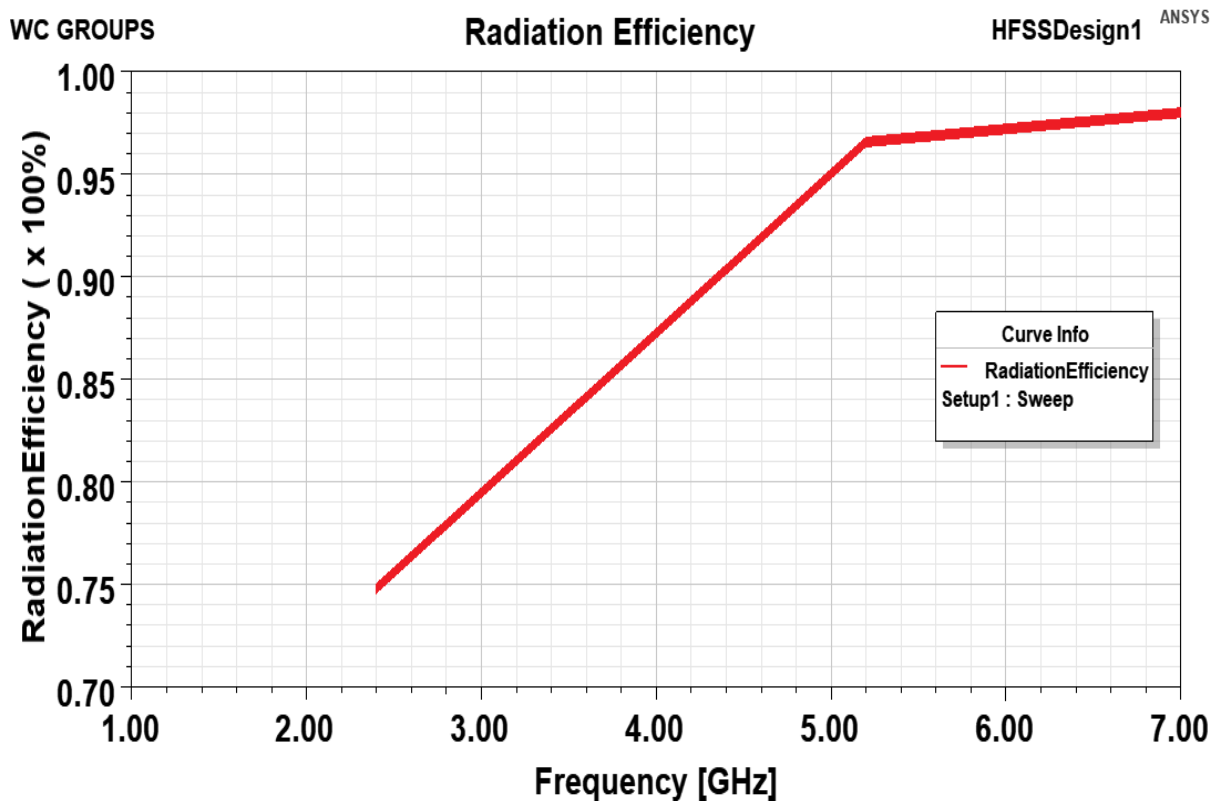


Fig 5.11: Radiation Efficiency Plot of the Microstrip antenna

The above graph Fig 5.11 shows the Radiation Efficiency of the antenna. The radiation efficiency of an antenna is defined as the ratio of the power radiated by an antenna to the power fed to the excitation port of the antenna. The power loss due to port impedance mismatch is not considered here. For wire antennas that have a defined radiation resistance the radiation efficiency is the ratio of the radiation

resistance to the total resistance of the antenna including ground loss (see below) and conductor resistance. In practical cases, the resistive loss in any tuning and/or matching network is often included, although network loss is strictly not a property of the antenna. For other types of antennas, the radiation efficiency is less easy to calculate and is usually determined by measurements.

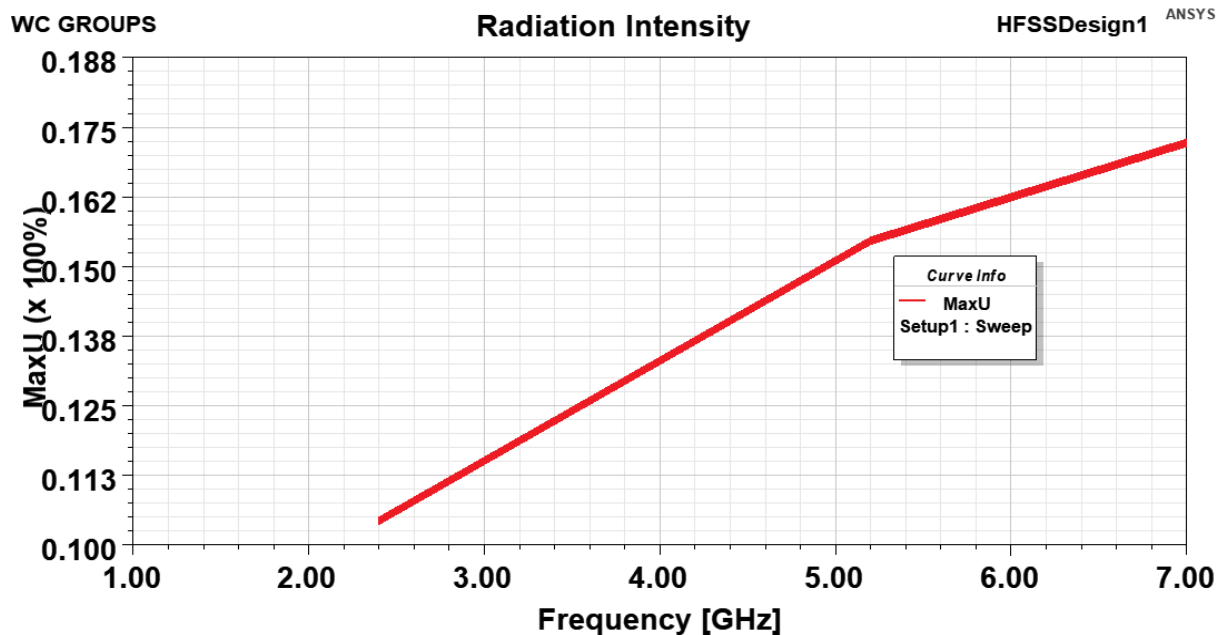


Fig 5.12: Radiation Intensity Plot of the Microstrip Antenna

The above plot Fig 5.12 shows the Radiation Intensity of the microstrip patch array antenna. Radiation intensity, or the antenna power pattern, in each direction, is defined as the power radiated from an antenna per unit solid angle. The radiation intensity is a far-field parameter that can be obtained by simply multiplying the radiation power density by the square distance. An Antenna radiates power, but the direction in which it radiates matters much. The antenna, whose performance is being observed, is termed the subject antenna. Its radiation intensity is focused in a particular direction, while it is transmitting or receiving. Hence, the antenna is said to have its directivity in that particular direction.

The ratio of radiation intensity in each direction from an antenna to the radiation intensity averaged over all directions, is termed as directivity. If that particular direction is not specified, then the direction in which maximum intensity is observed can be taken as the directivity of that antenna.

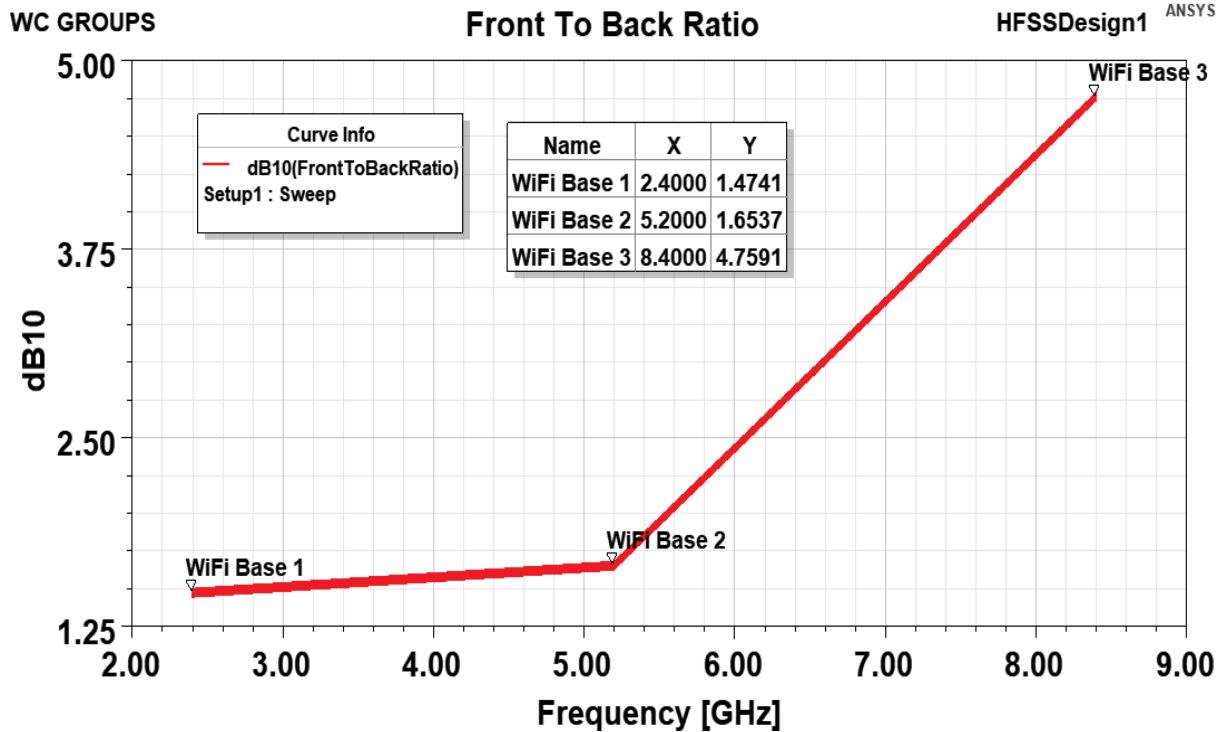


Fig 5.13: Front to Back Ratio Plot of the Microstrip antenna

The above plot Fig 5.13 displays the Front to Back Ratio Plot of the antenna. The Front Back Ratio (F/B Ratio) of an antenna is the ratio of power radiated in the front/main radiation lobe and the power radiated in the opposite direction (180 degrees from the main beam). This ratio tells us the extent of backward radiation and is normally expressed in dB. This parameter is important in circumstances where interference or coverage in the reverse direction needs to be minimized. In another electrical engineering, the front-to-back ratio is a ratio of parameters used to characterize rectifiers or other devices, in which electric current, signal strength, resistance, or other parameters, in one direction, is compared with that in the opposite direction. The minimum value in db. It is subject to statistical validation for a single-sided parameter. This parameter is to be defined for the nominal sub bands in a broadband antenna.

Unless otherwise noted it will be assumed the specification is for the full electrical down-tilt range, and all the ports associated with each frequency sub band of the antenna.

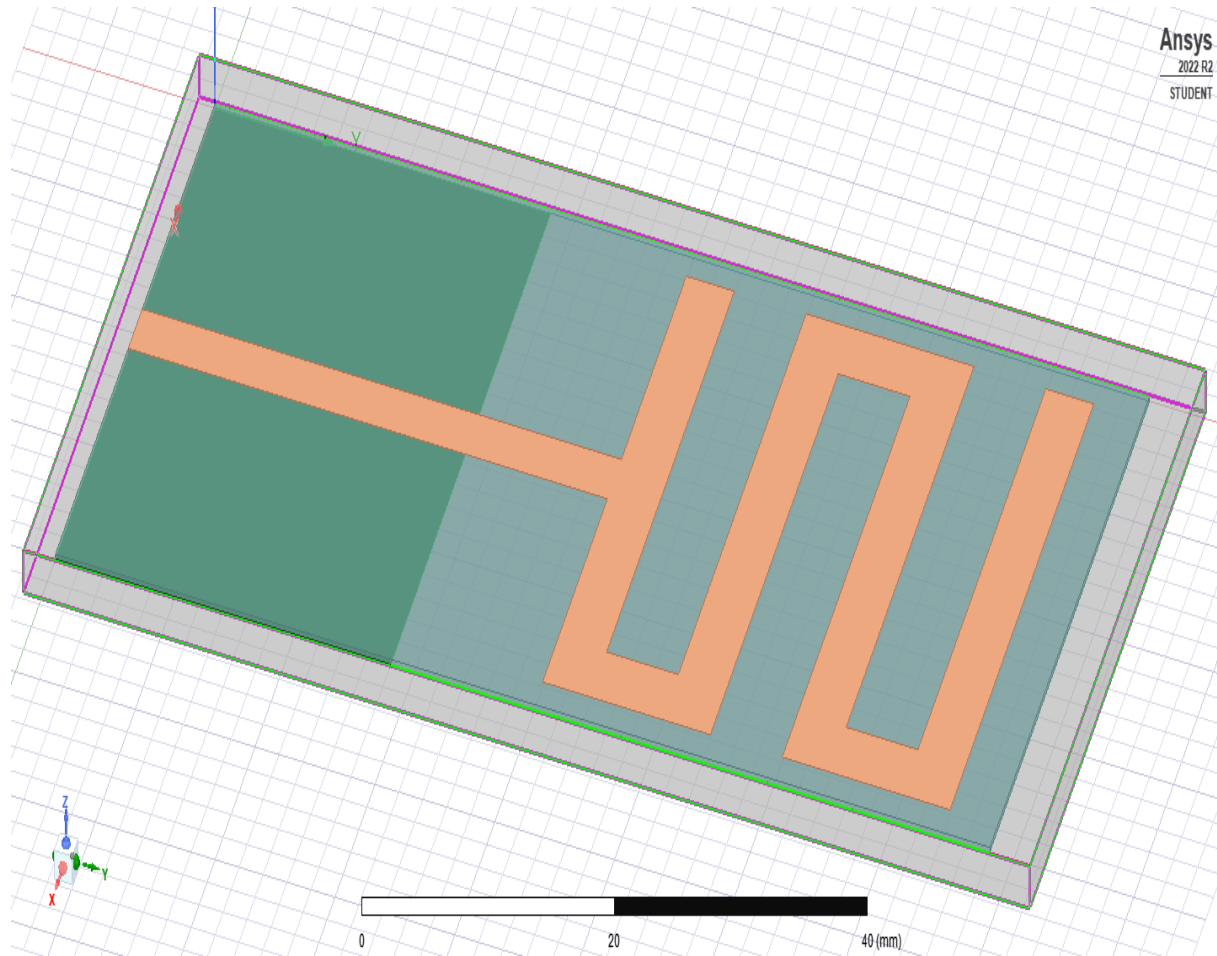


Fig 5.14: A soft HFSS E Antenna design

In Fig 5.14 designing an antenna using the High-Frequency Structure Simulator (HFSS) software involves several steps:

1. Define the geometry of the antenna: This involves creating a 3D model of an antenna using the HFSS software. The antenna's shape, size, and materials used should be considered.

2. Specify the material properties: The software requires specifying the material properties of each component of the antenna.
3. Assign boundary conditions: HFSS requires specifying the boundary conditions of the antenna model. This includes defining the type of boundaries such as metallic or radiation boundaries.
4. Set up the simulation parameters: After the simulation is complete, analyze the result to see the antenna's performance. The results can be viewed as S-parameters, radiation patterns, and other parameters.
5. Run the simulation: After defining the simulation parameters, run the simulation and wait for it to complete. This process can take several hours, depending on the complexity of the antenna model.
6. Analyze the results: After the simulation is complete, analyze the result to see the antenna's performance. The result can be viewed as S-parameters, radiation patterns, and other parameters.
7. Optimize the design: If the antenna's performance is not satisfactory, the design parameters can be adjusted and the simulation run again. This process of tweaking the design and simulating it is repeated until the antenna's performance meets the requirements.

In conclusion, designing an antenna using HFSS requires knowledge of the software's features and the antenna's design requirements. A well-designed antenna should have a good performance which can be achieved through simulation and optimization.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

A dual-band flexible patch antenna presented for WLAN and X-band applications with truncated rectangular patch and defected ground structure polyethylene terephthalate (PET) substrate is going to be used in this design with relative permittivity value 3, loss tangent 0.008, and thickness is 0.14mm. The antenna design and simulation are carried out by Ansys HFSS which is based on the Finite Element Method (FEM). The proposed dual-band flexible antenna operates at 2.45 GHz and 11.3 GHz. The proposed thin and flexible antenna shows stable characteristics and is suitable for WLAN and X-band applications. The parametric study is performed to understand the characteristics of the proposed antenna. The return loss radiation pattern and gain are studied too. The simulation return loss indicates the suitability of this antenna for WLAN applications.

Three microstrip patch antennas are designed for dual-band operation, which operates at WLAN and WiMAX applications. The T-shaped dual band operates at two resonating frequencies, the first band operates at 3.4GHz with a return loss of -18.53, and the second band operates at 5.2GHz with a return loss of -21.62. The achieved values of VSWR are 2.05 and 1.73 respectively. The H-shaped dual band operates at 3.2GHz and 5.45GHz with a return loss of -19.41 and -19.28 and the simulated values of VSWR are 1.92 and 1.89 respectively. And the F-shaped dual-band antenna operates on two frequencies such as 2.4GHz and 5.4GHz. The first band operates with a return loss of -21.46 and a VSWR of 1.47 and the second band appears at 5.4GHz with a simulated return loss of -22.46 and a VSWR of 1.3. By comparing the above three dual band antennas we can conclude that F shaped dual band antenna has good return loss, VSWR, and bandwidth and has less patch size compared to other dual band antennas. This proposed antenna has a promising performance such as dual-band, low profile, simple feed network, easy fabrication, and low cost. As F shaped dual band antenna covers two operating bands of 2.40GHz-2.48GHz and 5.4GHz-5.8GHz it is flexible to use in WLAN/WiMAX applications. Consequently, it is also suitable for multi-frequency applications of wireless communication systems.

6.1 FUTURE SCOPE

6.1.1 Optimization of antenna performance:

The project could be further developed by optimizing the performance of the substrate waveguide antenna, such as by increasing the bandwidth, gain, and radiation efficiency of the antenna. This could involve using advanced simulation and optimization tools to fine-tune the antenna design.

6.1.2 Integration with other wireless technologies:

The substrate waveguide antenna could be integrated with other wireless technologies, such as Bluetooth, and Wi-Fi to provide a more comprehensive wireless communication system. This would require developing the necessary hardware and software interfaces to enable seamless integration.

6.1.3 Miniaturization of the antenna:

The substrate waveguide antenna could be further miniaturized to enable its use in smaller devices, such as wearables or Internet of Things (IoT) devices. This would require developing new fabrication techniques and optimizing the antenna design for smaller form factors.

6.1.4 Power efficiency:

Power efficiency is an important consideration for wireless applications, particularly for battery-powered devices. Future research could focus on improving the power efficiency of the substrate waveguide antenna, such as by reducing the antenna's power consumption or optimizing the antenna's impedance matching.

6.1.5 Real-world testing:

The performance of the substrate waveguide antenna could be tested in real-world environments to determine how it performs in various conditions, such as indoors, outdoors, or the presence of obstacles. This would require developing testing methodologies and conducting field trials.

REFERENCES

- [1] Khaleel, Haider R., Hussain M. Al-Rizzo, Daniel G. Rucker, and Yahiea Al-Naiemy. "Flexible printed monopole antennas for WLAN applications." In 2011 IEEE International Symposium on Antennas and Propagation (APSURSI), pp. 1334-1337. IEEE, 2011.
- [2] Zhang, Ying, Shandong Li, Zhi-Qun Yang, Xiao- Yun Qu, and Wei-Hua Zong. "A coplanar waveguide-fed flexible antenna for ultra-wideband applications." International Journal of RF and Microwave Computer-Aided Engineering 30, no. 8(2020): e22258. 2021 JETIR June 2021, Volume 8, Issue 6 www.jetir.org (ISSN- 2349-5162) JETIR2106164 Journal of Emerging Technologies and Innovative Research (JETIR) www.jetir.org b160.
- [3] Prabhakar, D., M. Akhil Poor Vika, M. Venkata Krishna Sai, and M. Suba Naidu. "Flexible Patch Antenna using Different Substrates for WBAN Applications."
- [4] Zhang, Ying, Shandong Li, Zhi-Quan Yang, Xiao- Yun Qu, and Wei-Hua Zhong. "A coplanar waveguide-fed flexible antenna for ultra-wideband applications." International Journal of RF and Microwave Computer-Aided Engineering 30, no. 8(2020): e22258. 2021 JETIR June 2021, Volume 8, Issue 6 www.jetir.org (ISSN- 2349-5162) JETIR2106164 Journal of Emerging Technologies and Innovative Research (JETIR) www.jetir.org b160
- [5] Adachi Choogle, J. S., and D. U. V. Wail. "Design of Flexible Microstrip Antenna for wearable application." International Journal for Research in Emerging Science and Technology 2, no. 6 (2015).
- [6] Ramadan, M., and R. Dale. "A flexible 2.4 GHz microstrip patch antenna using 3-Dprinted tile array design." In 2017 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), pp. 1-3. IEEE, 2017.
- [7] Moksha, Shiva, Shubham Jangir, Shreyas Pimple, and Sumeet Bhandarkar. "Design of flexible microstrip patch antenna of 2.4 GHz operation frequency using HFSS." Department of Electronics Engineering, Shri radiobe college of Engineering and Management, Nagpur, Maharashtra India (2016).

- [8] Kirani, Sharadindu Gopal, Alan Wesley Elger, Md Hasan, Anna Wisniewska, Karthik Sekhar, Tutku Karacolak, and Praveen Kumar Sekhar. "Flexible Antennas: A Review." *Micromachines* 11, no. 9 (2020): 847.
- [9] Sakib, Nazmus, Siti Noorjannah Ibrahim, Muhammad Ibn Ibrahimy, Md Shazzadul Islam, and MM Hasan Mahfuz. "Design of Microstrip Patch Antenna on Rubber Substrate with DGS for WBAN Applications." In *2020 IEEE Region 10 Symposium (TENSymp)*, pp.1050-1053. IEEE, 2020.
- [10] Pradeep, Pendle, and K. N. S. Ganesh. "Rectangular Slot Patch Antenna Design for S-Band Applications."
- [11] Pradeep, Pendle, and S. K. Satyanarayana. "Design and Analysis of Dual-Band Circular Patch Antenna for X-Band Applications with Enhanced Bandwidth."
- [12] M. Arrebola, L. de Haro, J.A. Encinar, "Analysis of Dual-Reflector Antennas with Reflectarray as Subreflector", *IEEE Antennas and Propagation Magazine*. Dec. 2008, vol 50,
- [13] W. Hu, M. Arrebola, R. Cahill, J.A Encinar V. Fusco, H. Gamble, Y. Alvarez, F. Las-Heras, "94 GHz Dual-reflector", *IEEE Trans. Antenna with reflectarray sub-reflector*".
- [14] R.J. Martin and D. H. Martin, "Quasi-optical antennas for radiometric remote-sensing," *IEEE Electron & Comm. Eng.*
- [15] L. Marcaccioli, B. Men cage, R. Vincenti Gatti, T. Feger, T. Purtova, H. Schumacher, R. Sorrentino, "Beam steering MEMS mm-wave reflectarrays", *MEMSWAVE* 2006.
- [16] S. Ebadi, R. Vincenti Gatti, and R. Sorrentino, "Linear Reflectarray antenna Design Using 1-bit Digital Phase Shifters," *3rd European Conference on Antennas and Propagation*.
- [17] R. Sorrentino, R. Vincenti Gatti, L. Marcaccioli, "Recent Advances in Millimetre Wave Reconfigurable Reflect arrays", *3rd European on the conference on Antenna and Propagation EuCAP 2009*, Berlin, Germany, March 2009.
- [18] W.Menzel, M. Al-Tikriti, R. Leberer, "A 76 GHz multiple-beam planar reflector antenna", *EuMC*, Milano, Italy, Sept 2002.
- [19] Rob Lewis, "Wideband antenna technology in military applications", in *International Workshop on Antenna Technology (iWAT)*, 2010.

- [20] Khalil H. Sayidmarie, Neil J. McEwan, Peter S. Excell, Raed A. Abd-Alhameed and Chan H. See, "Antennas for emerging 5G systems", International Journal of antennas and Propagation.
- [21] A. Babar, L. Ukkonen, M. Soini, and L. Sydanheimo, "Miniaturized MHz antenna for card size wireless systems", in 2009 IEEE Antennas Propagation Society International Symposium.
- [22] Cheuk Yin Cheung, Joseph S.M. Yuen, and Steve W.Y. Mung, "Miniaturized printed inverted-F antenna for Internet of things: A design on PCB meandering line and shorting strip", International Journal of Antennas and Propagation.