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DESIGN OF TRI-BAND ANTENNA LOADED WITH HEXAGONAL METAMATERIAL FOR UWB APPLICATIONS

A MINOR PROJECT - IV REPORT

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in

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M.KUMARASAMY COLLEGE OF ENGINEERING

(Autonomous)

KARUR – 639 113

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Certified that this **18ECP106L - Minor Project IV** report "**DESIGN OF TRI-BAND ANTENNA LOADED WITH HEXAGONAL METAMATERIAL FOR UWB APPLICATIONS**" is the bonafide work of "**SHREE SUBHA M(20BEC4175), SUJITHAA R(20BEC4190), THANYA K (20BEC4201)**" who carried out the project work under my supervision in the academic year 2022-2023.

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This Minor project-III report has been submitted for the **18ECP106L – Minor Project-IV**

Review held at M. Kumarasamy College of Engineering, Karur on _____________ .

PROJECT COORDINATOR

INSTITUTION VISION AND MISSION

Vision

To emerge as a leader among the top institutions in the field of technical education.

Mission

M1: Produce smart technocrats with empirical knowledge who can surmount the global challenges.

M2: Create a diverse, fully -engaged, learner -centric campus environment to provide quality education to the students.

M3: Maintain mutually beneficial partnerships with our alumni, industry and professional associations

DEPARTMENT VISION, MISSION, PEO, PO AND PSO

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M2: Inculcate the students in problem solving and lifelong learning ability.

M3: Provide entrepreneurial skills and leadership qualities.

M4: Render the technical knowledge and skills of faculty members.

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PEO1: **Core Competence:** Graduates will have a successful career in academia or industry associated with Electronics and Communication Engineering

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PO 4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

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Abstract	**Matching with POs, PSOs**
Compact Tri-band Antenna, Rectangular Patch	PO1,PO2,PO3,PO4,PO5, PO6,PO7, PO8, PO9,PO10, PO11 PO12, PSO1, PSO2

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ABSTRACT

A compact and novel multiband antenna operating in three different bands is proposed in this work. The rectangular patch antenna of dimension 25x25mm is integrated on the top of FR4 Substrate material. The unique feature of the suggested antenna is that the tri band is achieved with deployment of metamaterial and slot. The designed rectangular patch offers return loss of -25.5 dB, -19.5 dB, -38.5 dB over the tri bands. The voltage standing wave ratio of all the tri-bands is less than 2. The Band 1 ranges from 11.21GHz to 11.75GHz finds application in X-band, the Band 2 ranges from 12.55GHz to 13.56GHz finds application in KU-band, the Band 3 ranges between 14.58GHz to 15.45GHz and is applicable for KU-band.

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LIST OF ABBREVIATIONS

ACRONYM		ABBREVIATION
CWP	-	Coplanar Wave Guide
CSRR	-	complementary split-ring resonator
CST	-	Computer Simulation Technology
DBS	-	Direct Board Cast Service
GPS	-	Global Positioning System
MM	-	Metamaterial
SRR	-	Split Ring Resonator
UWB	-	Ultra-Wide Band

CHAPTER 1

INTRODUCTION

A transducer known as an antenna transforms radio frequency (RF) signals into alternating current or the other way around. For transmitting or receiving radio broadcasts, there are both receiving and transmission antennas. All radio equipment depends on antennas to function properly. They are utilized in satellite communication, mobile telephony, and wireless local area networks. The technological advancement on the field of communication the necessity for having an antenna which is very efficient enough to operate in multiple frequency bands is highly required. Antenna operating in multiple frequencies and satisfying the necessary operational requirements is gaining more attention in the recent days. An antenna that is formed by etching out a patch of conductive material on a dielectric surface is known as a patch antenna. A metallic object called an antenna is used to receive and/or broadcast radio waves. Antennas exist in a variety of sizes and designs, ranging from tiny ones used to watch TV on your roof to enormous ones used to receive signals from satellites located millions of kilometers away. Mobile devices are required to cover various communication services (Wi- Fi, Bluetooth, GPS, LTE). Long term evolution (LTE) is one of the widelyused communication systems as a fourth-generation wireless service.

1.1 ANTENNA PARAMETERS

An electrical conductor or network of conductors is an antenna.

Transmitter: Radiates electromagnetic energy into space.
Receiver: Gathers cosmic electromagnetic energy.

According to Stutzman and Thiele, an antenna is "that component of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves," according to the IEEE definition. The following sections define the key parameters connected to an antenna.

1.1.1 ANTENNA GAIN

Gain is evaluated at the radiation's peak intensity and describes how well an antenna can convert input power into radiation in a certain direction. Think about the power density emitted by an isotropic antenna at a distance R that is S = $P_0/4R^2$ yields the value. By dividing the radiated power by the surface area of the sphere $4R^2$, one may determine the radiated power density S of an isotropic antenna, which radiates equally in all directions. The efficiency of an isotropic radiator is 100 percent. The ability of an antenna to emit more or less in any directionas compared to a theoretical antenna is known as antenna gain.

$$G_{dB} = 10 \log_{10} (4\pi\eta A/\lambda^2)$$

An antenna would radiate evenly in all directions if it could be constructed as a perfect sphere. Theoretically known as an isotropicantenna, such an antenna doesn't actually exist.

1.1.2 ANTENNA EFFICENCY

The ratio of the antenna's output power to its input power is known as antenna efficiency. The ratio of an antenna's output power to the power input into its excitation port is known as the radiation efficiency of the antenna. Here, the power loss resulting from port impedance mismatch is not taken into account. The radiation efficiency (r) of a lossless antennain a perfect world is 1. The relative power radiated by the antenna, also known as the antenna efficiency, is calculated as the surface integral of the radiation intensity over the radiation sphere divided by the input power P_0.

$$\text{Antenna Efficiency} = \frac{P_{RAD}\,\%}{P_T}$$

To account for losses at the input terminals and within the antenna'structure, the overall antenna efficiency, or e^0, is utilized.

1. reflections because of the mismatch between the transmission lineand the antenna.
2. I^2R losses (conduction and dielectric).

1.1.3 EFFECTIVE AREA

A portion of the power that antennas harvest from passing waves is sent to the terminals. The power provided to the terminals is the result of the incident wave's power density and the antenna's effective area. The effective area of an aperture antenna, like a horn, parabolic reflector, or flat-plate array, is calculated by multiplying the physical area by the aperture efficiency. Losses resulting from distribution, material, and mismatch generally cause the effective area to physical area ratio to decrease. A parabolic reflector's estimated average aperture efficiency is 55%. Due to the fact that they drain energy from passing waves, even antennas with incredibly small physical surfaces, like dipoles, have effective areas.

1.1.4 DIRECTIVITY

The concentration of radiation in the direction of the maximumis measured by directivity. The array's directivity is a measurement of how well it focuses energy in a certain direction. If the antenna elements are isotropic, the AGF alone determines the directivity, D.

$$D = \frac{\text{Maximum radiation intensity of test antenna}}{\text{Average radiation intensity of test antenna}}$$

Gain and directivity merely differ in their efficiency, although directivity may be readily inferred from patterns. Gain must be calculated as directivity times efficiency. Since the coordinate angles are unknown, we calculate directivity at Umax. Directivity can alternatively be defined for an arbitrary direction D, as radiation intensity divided by the average radiation intensity.

1.1.5 PATH LOSS

The primary factor in the design of wireless networks is path loss, which quantifies the energy lost when a wave travels between a transmitter and a receiver. To calculate delivered power and route loss,we integrate the gain of the transmitting antenna with the effective area of the receiving antenna. Combining the received power and the power density at the receiving antenna. When antenna 2 receives, antenna 1 sends. The transmission and receiving patterns are identical if the materials used to construct the antennas are linear and isotropic. Taking into account antenna 1 as the receiving antenna and antenna 2 as the transmitting antenna.

$$\text{Path loss(dB)} = K_U + 20\log(f\,R) - G_1(\text{dB}) - G_2(\text{dB})$$

1.1.6 INPUT IMPEDANCE

As stated in Za=Ra+jXa, where Ra is the resistance at antenna terminals and Xa is the reactance at antenna terminals, input impedance is defined as the ratio of the voltage and current at the pair of input antenna terminals. The impedance exhibited by an antenna at its terminals, the voltage to current ratio at a pair of terminals, or the ratioof the relevant components of the electric to magnetic fields at a pointare all examples of input impedance.

$$Z_{in} = R_{in} + jX_{in}$$

Where, Zin is the antenna impedance at the terminals,Rin
is the antenna resistance at the terminals

Xinis the antenna reactance at the terminals

1.2 TYPES OF ANTENNA

Many categories exist for dividing up antennas. The frequency band of operation is one method. Others include electromagnetic design and physical structure. Simple dipoles or monopoles are the most common types of non-directional antennas. more intricate and directional Antennas are made up of arrays of elements, like dipoles, or they can use a combination of active and passive elements, like the Yagi antenna. When new antenna technologies are created, an antenna will be able to quickly alter its pattern in response to changes in the signal's arrival direction. Future applications for these antennas in the higher frequency bands may include adaptive or "smart" antenna technology. The sections that follow include descriptions of a fewpopular antenna types.

1.2.1 DIPOLE AND MONOPOLE

The dipole is the prototypical antenna on which a large classof antennas are based. A basic dipole antenna consists of two conductors (usually metal rods or wires) arranged symmetrically, with one side of the balanced feedline from the transmitter or receiver attached to each. The most common type, the half-wave dipole consists of two resonant elements just under a quarter wavelength long.This antenna radiates maximally in directions perpendicular to theantenna's axis, giving it a small directive gain of 2.15 dB. Although half-wave dipoles are used alone as omnidirectional antennas, they are also a building block of many other more complicated directional antennas. A monopole antenna consists of a single conductor such as a metal rod, usually mounted over the ground or an artificial

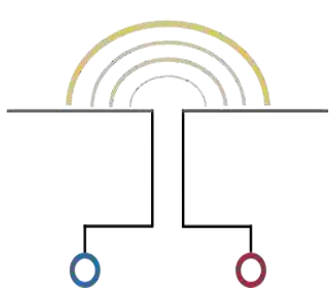

Fig 1.2 a) Dipole

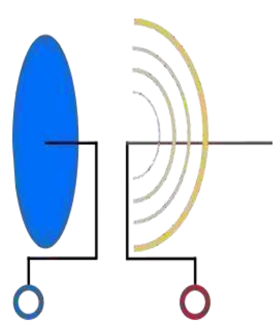

Fig 1.2 b) Monopole

conducting surface (a so-called ground plane) is shown in fig 1.2(b). One side of the feedline from the receiver or transmitter is connectedto the conductor, and the other side to ground or the artificial ground plane. The radio waves reflected from the ground plane seem to come from an image antenna below the ground, with the monopole and its image forming a dipole, so the monopole antenna has a radiation pattern identical to the top half of the pattern of a similar dipole antenna which is shown in fig 1.2(a). Since all of the equivalent dipole's radiation is concentrated in a half-space, the antenna has twice 3 dB increase of the gain of a similar dipole, not considering losses in the ground plane.

1.2.2 MICROSTRIP ANTENNA

A microstrip antenna in the context of communications isoften an antenna made on a printed circuit board using photolithographic methods (PCB). A sort of inside antenna, that is. The majority of their usage is in microwave frequencies. In the 1970s, space-borne applications accounted for a large portion of the popularity of microstrip antennas. Currently, they are employed in both government and private sectors. A metallic patch on a grounded substrate makes up these antennas. There are numerous configurations for the metallic patch. However, Due to their simplicity in analysis and fabrication as well as their appealing radiation properties, particularly low cross-polarization radiation, the rectangular and circular patches are shown in the fig 1.2.2 and 1.2.3 depicted are the most widely used. Using today's printed-circuittechnology, the microstrip antennas are low profile, conformable to both planar and nonplanar surfaces, easy and inexpensive to manufacture,physically robust when mounted on stiff surfaces.

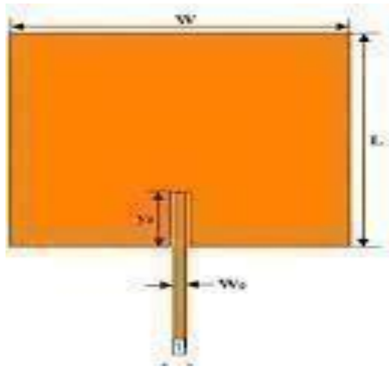 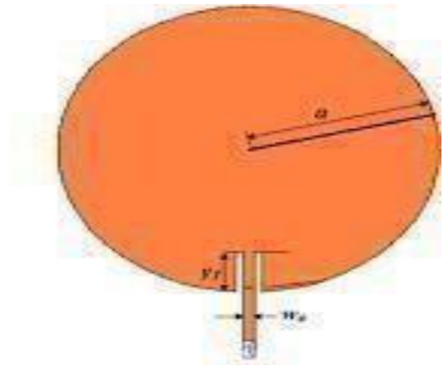

Fig 1.2.2 Rectangular Patch **Fig 1.2.3** Circular Patch

1.2.3 YAGI-UDA ANTENNA

For communications over a medium distance of three to five miles between two places, a Yagi antenna is employed. In order to link clients to an access point, it can also be utilized as a bridge antenna. This phrase is sometimes referred to as a patch antenna or a Yagi-Uda array. The Yagi antenna is an additional passive element-based antenna design. Antenna with three element is shown in fig 1.2.4 and with multi-element is shown in fig 1.2.5. Both are affordable and efficient. It can be built witha single or multiple (often a single or two) reflector elements and a single or multiple (usually two or more) director's tools. a horizontally polarized Yagi antenna with one reflector, a folded-dipole active element, and seven directors.

Fig 1.2.4 Three element

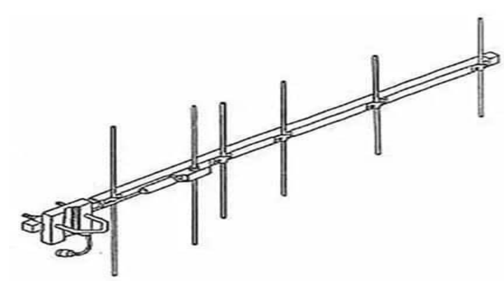

Fig 1.2.5 Multi element

1.2.4 CORNER REFLECTOR

Radio waves can be passively reflected back directly towards the emission source using a corner reflector. Corner reflectors are hencea handy tool for calibrating radar systems. There are different types of corner reflector antenna they are solid reflector which is shown in fig 1.2.6(a) and the wire reflector which is shown in fig 1.2.6(b). The corner reflector typically consists of perpendicular plates that cross one another. The corner- reflector antenna, a type of antenna with one or more dipole elements in front of a corner reflector.

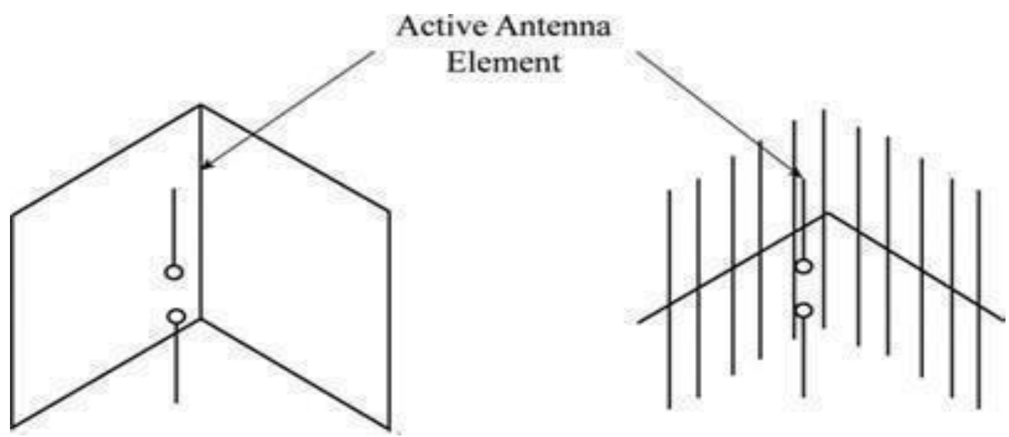

Fig 1.2.6 a) Solid Reflector **Fig 1.2.6 b)** Wire Reflector

1.2.5 ARRAY ANTENNA

Array antennas consist of multiple antennas working as a single antenna. Typically, they consist of arrays of driven elements, usually dipoles fed in phase, giving increased gain over that of a single dipole.

1.2.6 LOOP ANTENNA

Loop antennas consist of a loop (or coil) of wire. Loop antennas interact directly with the magnetic field of the radio wave, rather thanits electric field, making them relatively insensitive electrical noise within about a quarter-wavelength of the antenna. There are essentially two broad categories of loop antennas: large loops (or full loops) and small loops. Loops with circumference of a full wavelength, or an integer multiple of a full-wavelength, are naturally resonant and act somewhat similarly to the full-wave or multi-wave dipole. When it is necessary to distinguish them from small loops, they are called “full- wave” loops. Full loops have the highest radiation resistance, and hence the highest efficiency of all antennas: their radiation resistances are several hundreds of Ohms, whereas dipoles and monopoles are tens of Ohms, and small loops are a few Ohms, or even fractions of an Ohm. Loops that are a half-wavelength in circumference – with a small gap cut in the loop – are called halo antennas and are intermediate in form and function between small and large loops.

1.3 FR4 SUBSTRATE

FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant (self-extinguishing). "FR" stands for flame retardant, and denotes that the material complies with the standard UL94V-0. The designation FR-4 was created by NEMA in 1968.

FR-4 glass epoxy is a popular and versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios. With near zero water absorption, FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength. The material is known to retain its high mechanical values and electrical insulating qualities in both dry and humid conditions. These attributes, along with good fabrication characteristics, lend utility to this grade for a wide variety of electrical and mechanical applications.

FR-4 is a common material for printed circuit boards (PCBs). A thin Layer of copper foil is laminated to one or both sides of an FR-4 glass of epoxy panel. These are commonly referred to as copper clad laminates.

When ordering a copper clad laminate board, the FR-4 and the copper thickness can both vary and so are specified separately.

CHAPTER 2

LITERATURE SURVEY

2.1 TITLE: Design of Multi-Band Octagonal Shape Patch Antenna For WLAN/WiMAX Applications

AUTHORS: Ritesh Kumar Saraswat, Swasti Dubey, Kunal jeet Singh,Neeraj Sharma, Vishal Kachhawa

YEAR: 2018

DESCRIPTION:

The antenna design on FR-4 substrate with relative dielectric constant 4.4. With the dimension of 30x26x0.8mm^3. Proposed design consists octagonal split ring resonator facing each other as a radiating element. The octagonal shape of SRR ring and the gap between them are responsible to create the multiple band characteristics to obtain the WLAN and WiMAX wireless applications. The variation in radiation efficiency is achieved up to 89.56% to 60.89%. The high average antenna gains of 3.31 dBi is observed during simulation for WLAN and WiMAX standards. The operating bandwidth for first band is (2.4 to 2.48) GHzfor second band is (5.15 to 5.35) GHz and for last third band is (5.75 to 5.825) GHz of WLAN and for WiMAX operating bandwidth (3.4– 3.69) GHz A triple-band octagonal shape patch antenna covering WLAN 2.4GHz, WiMAX 3.5-GHz, and WLAN 5.5-GHz bands are evaluated with high gain and stable patterns presented in this paper.

2.2 TITLE: Design of a compact Quad-band radiating element MIMO Antenna for LTE/WIFI Applications

AUTHORS: Abubeker A.Yussuf , Selcuk Paker

YEAR: 2019

DESCRIPTION:

In this paper, the dimension of the designed antenna MIMO antenna is 66x66x1.6mm^{3}. The antenna is designed using FR-4substrate with the thickness of 1.6mm. This antenna design comprises of the tapered radiating slot, the microstrip feed line and the partial ground plane. The tapered radiating slot is fed by 50 0hm microstrip line. The design and stimulation of this antenna were designed using CST software. The cross-shaped and ring-shaped stripes were added to enhance the isolation between the adjacent and diagonal antenna elements for its MIMO antenna configuration. A prototype MIMO antenna was fabricated and S-parameters were measured in order to characterize the performance parameters of the MIMO antenna. The mutual coupling is reduced by more than 17db between adjacent antenna elements and 21db between diagonal antenna elements. This design of MIMO antenna supports Wi-Fi and LTE applications.

2.3 TITLE: Slot and EBG Loaded Compact Quad-band Notched UWB Antenna

AUTHOR: Samineni Peddakrishna,Vamshi Kollipara, Jayendra Kumar, Taimoor Khan

YEAR: 2021

DESCRIPTION:

In this antenna design, the dimensions of the antenna is $28x30mm^2$. There are four bands to achieve this antenna, 3.5GHZ 4.2GHZ, 5.7GHZ, and 9.1GHZ bands are used, the impedance bandwidth of 3-11.4GHZ for VSWR less than 2. An ultra-wideband monopole antenna with four band notches is suggested in this research. By etching two pi-shaped slots on the radiating patch and coupling two EBG cells on either side of the feed line, the quad band-notch design is made possible. The notch frequencies for WIMAX 3.5GHZ frequency is used and WLAN 5.7GHZ frequency is used. The substrate used to design thisantenna is RT duroid substrate with permittivity of 2.2 and with the thickness of 0.762mm. It is a rectangular radiating element, the dual pi shaped slots is used. The antenna exhibits a broad impedance bandwidth from 3-11.4GHZ.

CHAPTER 3

EXISTING SYSTEM

The design for achieving Tri-band antenna is achieved previously by various techniques but it makes complex in designing the antenna. They have used varactors, diodes, MEMS, slots, metamaterial etc.., Also, they have used different shapes for designing patch like hexagon, rectangular, circular, decagon etc.,

CHAPTER 4

PROPOSED SYSTEM

From the literature papers reviewed, we have formulated the design challenges to achieve. The main consideration is the size and number of operating band ratio. The suggested design has the novel features of achieving the tri-band with the implementation of metamaterial structure in rectangular patch.

4.1 DESIGN FLOW

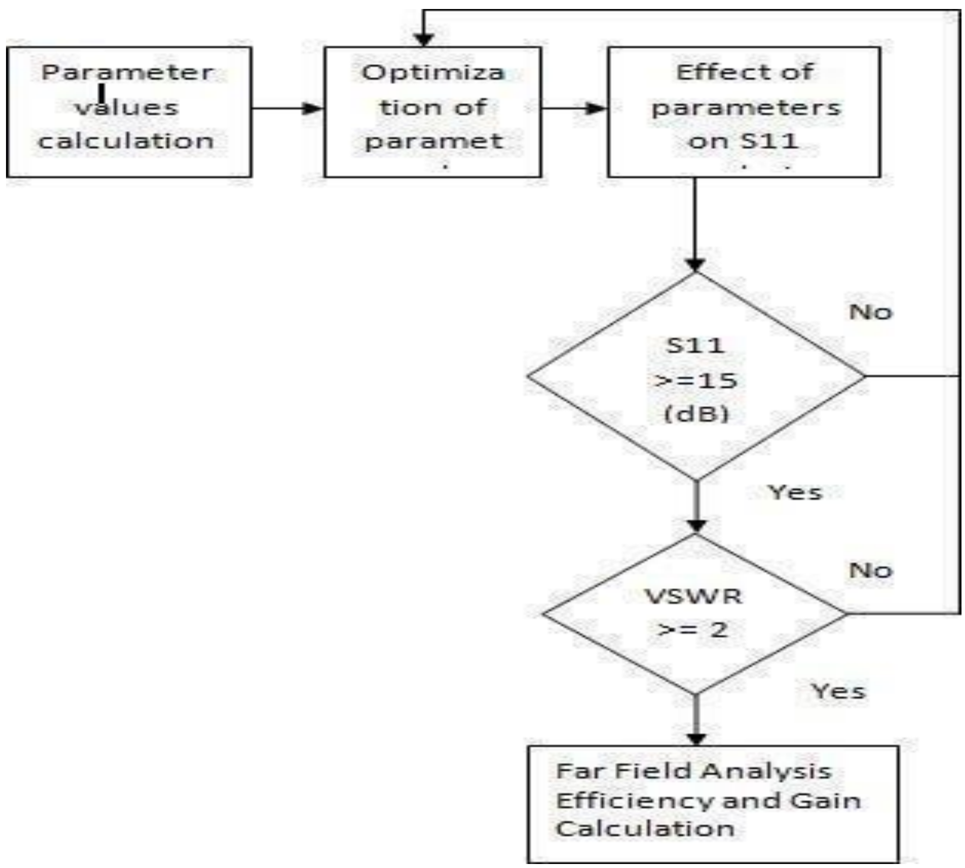

Fig 4.1 Antenna design flow chart

4.2 PROPOSED QUAD BAND OPERATING ANTENNA

The proposed antenna is compact and is very flexible to use, it is designed with the dimension of 25 x 25 x 1.6 mm^3. FR4 substrate is deployed to design the antenna with effective permittivity of 4.4 and value of the loss tangent is 0.009. The shape of the patch antenna is rectangular, and dimension is about 25x25mm. Microstrip feed line is used as the feed line for the antenna design. We have introduced Hexagonal Metamaterial Structure of radius ring1 is 1.8 and ring 2 is 4 and also a rectangular slot of length 9mm and width 1mm is implemented. The designed rectangular patch has front view is shown in fig 4.2.

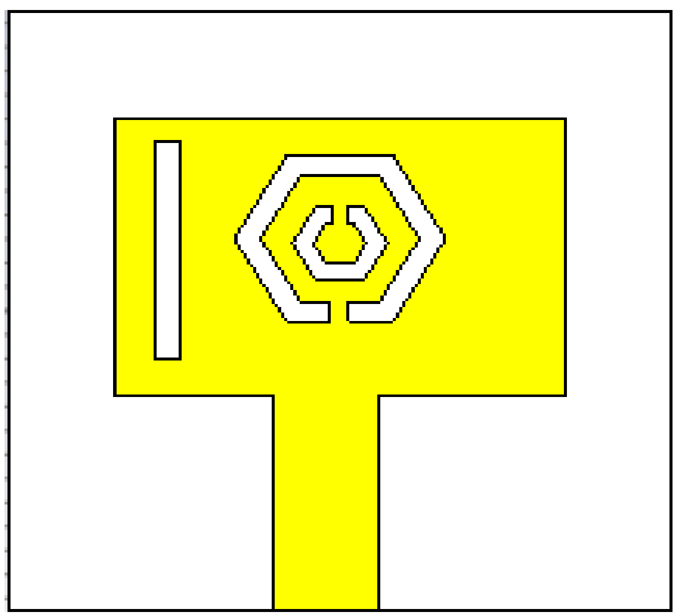

Fig 4.2 Proposed Structure

PARAMETER NAME	VALUE
Ground Length	25.00 mm
Ground Width	25.00 mm
Patch Length	11.50 mm
Patch Width	17.00 mm
Feed Length	9.00 mm
Feed Width	4.00 mm
Hexagon Ring1(Radius)	1.8
Hexagon Ring2(Radius)	4
Split Gap1	0.5 mm
Split Gap2	0.7 mm
Slot Length	9.00 mm
Slot Width	1.00 mm

Table 1: Rectangular Tri-Band Antenna Dimensions

CHAPTER 5

SOFTWARE DETAILS

5.1 SOFTWARE USED

In this antenna design, we use CST software to design a compact octagonal quad-band antenna for UWB application. In this CST software, we used 2019 Version to stimulate this compact antenna. CST stands for Computer Stimulation Technology. We use CST Studio Suite which is a high-performance 3D EM analysis software package for designing, analyzing, and optimizing electromagnetic components and systems. CST stimulation enables the use of visual prototyping. Device performance can be optimized, potential compliance issues identified and mitigated early in the design process, the number of physical prototypes required can be reduced, and the risk of test failures can be minimized. CST Studio Suite contains electromagnetic field solutions for applications across the EM spectrum in a single user interface. Engineers have the freedom to quickly and effectively analyze entire systems made up of numerous components thanks to the solvers' ability to be coupled to perform hybrid simulations. EM simulation may be integrated into the design flow and drives the development process from the very beginning by co-designing with other SIMULIA products. Leading engineering and technology firms all over the world use CST Studio Suite.

CHAPTER 6

RESULT AND DISCUSSION

6.1 RETURN LOSS

S11 is used to measure the amount of power that is reflected back into the antenna and its value has to less than -10dB. The proposed rectangular patch operates in tri band. Band 1 ranges from 11.21GHz to 11.75GHz resonates at the frequency of 11.5 GHz with -25.5 dB return loss value. Band 2 ranges from 12.55GHz to 13.56GHz resonates at 13.09 GHz frequency with -19.5 dB return loss value. Band 3 ranges from 14.58GHz to 15.45GHz resonates at frequency of 15.12 GHz with -38.5 dB as return loss value. From the graphical representation of the S11 values it is evident that all the tri bands have the S11 values less -20 is shown in fig 6.1.1.

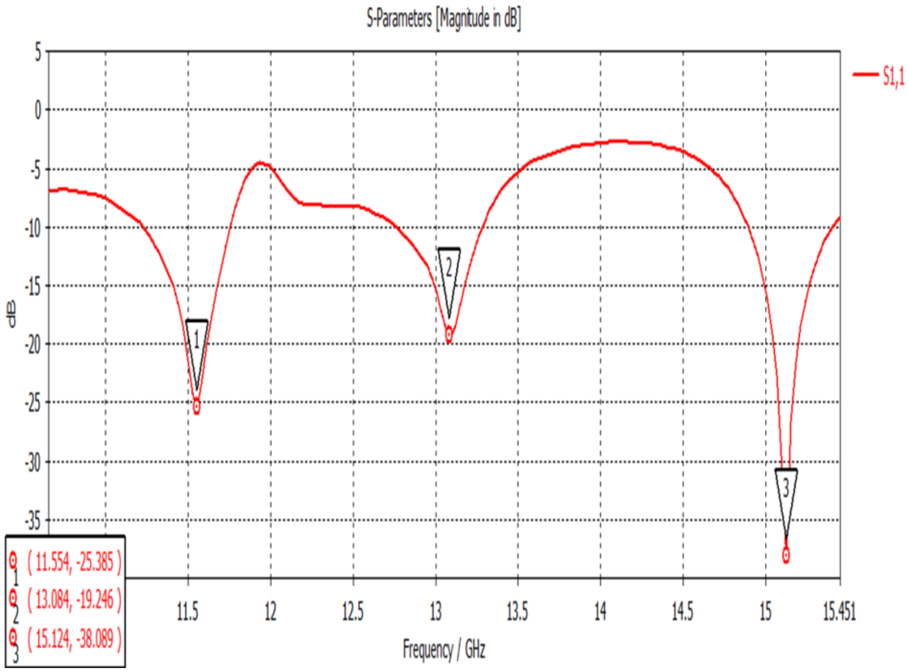

Fig 6.1.1 S11 of Tri-Band antenna design

6.2 VSWR

The Voltage Standing Wave Ratio for the antenna should be generally less than 2. The rectangular Tri – band antenna design attains a VSWR value of 1.2 at 11.5 GHz band, VSWR value for band 2 is 1.24 and at 15.12 GHz band, VSWR value is 1.15. Figure 6.2.1 shows the evidence for the VSWR values for all the operating bands.

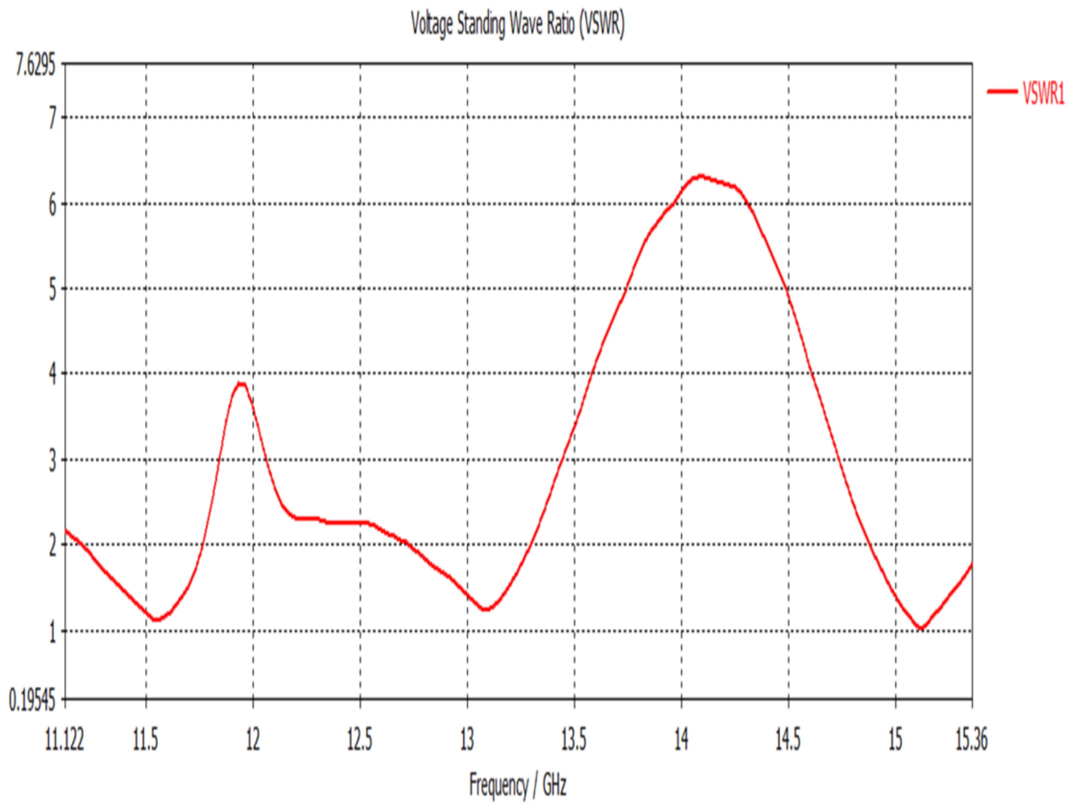

Fig 6.2.1 Voltage Standing Wave Ratio Graph

6.3 GAIN

Maximum gain attained over frequency is given in figure 6.3.1.

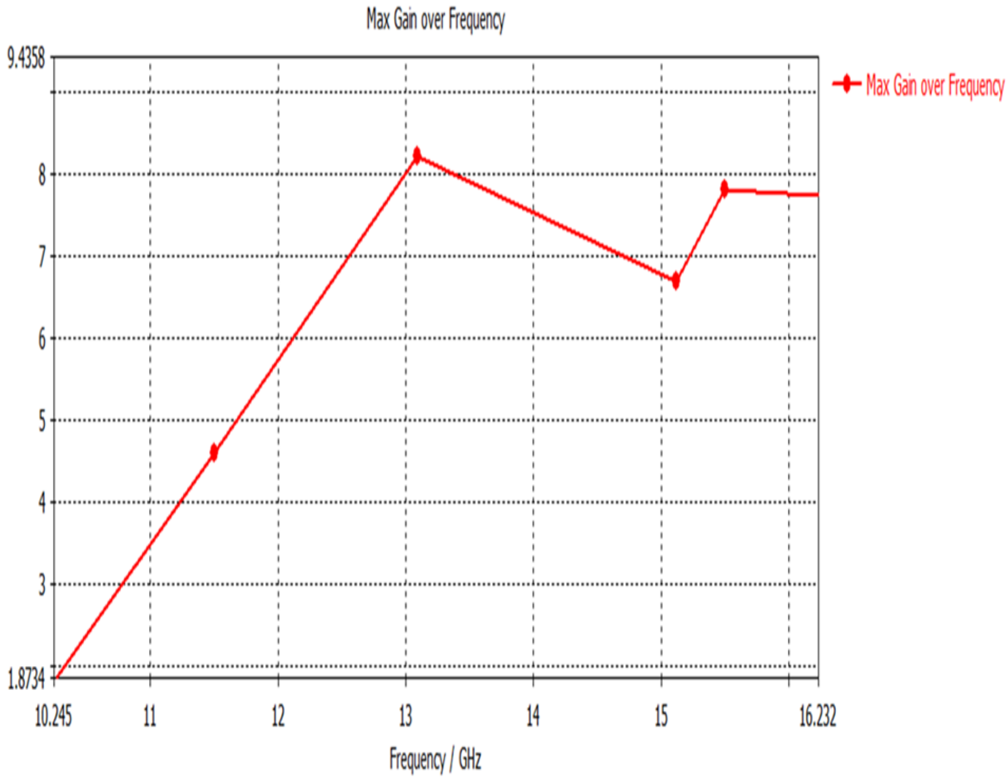

Fig 6.3.1 Gain of Tri-band Antenna

CHAPTER 7

CONCLUSION AND FUTURE WORK

The main goal is to design the compact antenna with less complexity. This tri - band antenna with rectangular patch is well suited for DBS (Direct Broad Cast Service) application weather monitoring, air traffic control, defense, radar applications, and many more in the frequency range of X and Ku bands. The antenna has an efficiency of 75 percent, flexible and performs good in terms of return loss, VSWR, Radiation pattern. The antenna proposed will be fabricated and measured in future to analyze the real time operation of the simulated quad-band structure.

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DESIGN OF TRI-BAND ANTENNA LOADED WITH HEXAGONAL METAMATERIAL FOR UWB APPLICATIONS

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Abstract: Over the last decade, numerous techniques are proposed to improve the performance of the antenna. One such technique is the use of metamaterials (MTMs) in antenna design. Metamaterial antennas are a class of antennas which use metamaterials to increase performance of miniaturized (electrically small) antenna systems. "Meta" a Greek word defines "beyond" the materials provide properties beyond conventional materials. A multiband antenna with the incorporating complementary split-ring resonator (CSRR) metamaterial unit cell and slots to achieve triband operational characteristics for application in wireless standards is proposed. The type of feed preferred is Coplanar waveguide (CPW). The triband coplanar waveguide fed metamaterial antenna is proposed. The proposed antenna serves the criteria for multiband applications with an additional feature of increased bandwidth at the zeroth mode. The average efficiency of the proposed design is more than 70% for all resonant modes. The radiation characteristics (gain/efficiency/patterns/impedance matching) are shown in the stable and improved form at achieved wireless modes.

Keywords: CST Software, Triband, VSWR, Return Loss, Gain.

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