A Beam Split Metasurface Antenna For 5G Applications

PROJECT REPORT

Submitted in the fulfilment of the requirements for

the award of the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

SHAIK.AHMAD ALISHA [201FA05048]

SHAIK.BAJI [201FA05057]

Under the Esteemed guidance of

Dr. N. Ananda Rao

Assistant Professor

Department of ECE

(ACCREDITED BY **NAAC** WITH **'A+'**GRADE)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

(ACCREDITED BY **NBA**)

VIGNAN'S FOUNDATION FOR SCIENCE, TECHNOLOGY AND RESEARCH

(Deemed to be University)

Vadlamudi, Guntur, Andhra Pradesh, INDIA-522213

MAY- 2024

CERTIFICATE

This is to certify that the project report entitled **"A Beam Split METASURFACE ANTENNA FOR 5G APPLICATIONS"** that is being submitted by SK. Ahmed Alisha and SK. Baji bearing Regd. No. 201FA05048, 201FA05057 in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering to Vignan's Foundation for Science Technology and Research, is a record of bonafide work carried out by them under the guidance of Dr. N. Ananda Rao of ECE Department.

N. A Rao

Signature of the guide

Dr. N. Ananda Rao

Assistant Professor

24/5/24.

Signature of Head of the Department

Dr. T. Pitchaiah, M.E, Ph.D.,MIEEE, FIETE

Professor & HoD ECE.

DECLARATION

We hereby declare that the project work entitled **"A BEAM SPLIT METASURFACE ANTENNA FOR 5G APPLICATIONS"** is being submitted to Vignan's Foundation for Science, Technology and Research (Deemed to be University) in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering. The work was originally designed and executed by us under the guidance of Dr .N. Ananda Rao at Department of Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research (Deemed to be University) and was not a duplication of work done by someone else. We hold the responsibility of the originality of the work incorporated into this thesis.

Signature of the candidates

Sk. Ahmad Alisha

Shaik. Ahmad Alisha [201FA05048]

Sk. Baji

Shaik. Baji [201FA05057]

ACKNOWLEDGEMENT

The satisfaction that comes from successfully completing any task would be incomplete without acknowledging the people who made it possible, whose ongoing guidance and encouragement have been essential to the achievement.

We are greatly indebted to **Dr. N. Ananda Rao**, my revered guide and Professor in the Department of Electronics and Communication Engineering, VFSTR (Deemed to be University), Vadlamudi, Guntur, for his valuable guidance in the preparation of this project report. He has been a source of great inspiration and encouragement to us. He has been kind enough to devote considerable amount of his valuable time in guiding us at every stage. This is our debut, but we are sure that we are able to do many more such studies, under the lasting inspiration and guidance given by respectable guide.

We would also like to thank to **Dr. T. Pitchaiah**, Head of the Department, ECE for his valuable suggestion.

We would like to specially thank, **Dr. N. Usha Rani**, Dean, School of Electrical, Electronics and Communication Engineering for her help and support during the project work.

We thank our project coordinators **Dr. Satyajeet Sahoo, Dr. Arka Bhattacharyya, Mr. Abhishek Kumar** and **Mr. M. Vamsi Krishna** for continuous support and suggestions in scheduling project reviews and verification of the report. Also, thank to supporting staff of ECE Department for their technical support for timely completion of project.

We would like to express our gratitude to **Dr. P. Nagabhusan,** Vice-Chancellor, VFSTR (Deemed to be University) for providing us the greatest opportunity to have a great exposure and to carry out the project. Finally, we would like to thank our parents and friends for the moral support throughout the project work.

Name of the Students

Sk. Ahmad Alisha [201FA05048]

Sk. Baji [201FA05057]

ABSTRACT

A hybrid meta surface split beam antenna operating at 3.5 GHz is presented in this paper for use in fifth generation (5G) mobile applications. For a 5G mobile network, multi-beam antennas with excellent directivity are necessary. An array antenna can help achieve that. When a low-frequency antenna array is used, the overall network's complexity and size grow. In order to direct surface current and have high gain and multibeam properties, a metasurface (MS) is therefore suggested. To do that, a single square patch antenna is superposed with a square split ring resonator (SSRR) and a U-shaped unit cell metasurface. By adjusting this hybrid metasurface arrangement, the beam can be separated by producing opposing current flows on the unit cell. On FR-4 ($\varepsilon r = 4.4$, $\tan\delta = 0.02$), the hybrid metasurface superstrate and antenna are constructed. The antenna has a reflection coefficient of less than −10 dB at 3.5 GHz, indicating good resonance, according to the results. The radiation pattern beam is split into two beams in the E-plane at ± 45° due to the unit cell arrangement on the superstrate metasurface's ability to split current. With its high capacity and low interference, this antenna is a viable option for 5G Pico cell base stations in urban or suburban locations in the future.

Major Design (Final Year Project Work) Experience Information

Student Group	SK. AHMAD ALISHA (201FA05048)	SK. BAJI (201FA05057)
Project Title	A Beam split Metasurface antenna for 5G applications	
Program Concentration Area	Antennas, Electromagnetic Field Theory, Beam split Antennas	
Program Concentration Area	Metasurface, 5G, SRR, Beam split, Unit cell, Metamaterial	
Constraints – Examples		
Economic	Cost-effective implementation	
Environmental	Hardware with minimal ecological impact	
Sustainability	Eco-friendly development methods	
Manufacturability	Yes	
Ethical	Adhere to ethical standards	
Health and Safety	Ensure the system poses no harm to users' health and safety	
Social	In align with societal norms	
Political	None	
Other	Technical constraints, resource availability	
Standards		
1. IEEE145-1973,2023 2. IEEE 51-1955 3. IEEE C95 1-2019	1. IEEE Standard definitions of terms for antennas 2. IEEE Guiding Principles for di-electric tests 3. IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.	
PreviousCourse Required for the Major Design Experience	1.Analog communications 2.Digital communications 3. Antenna and wave propagation 4.Cellular mobile communications	

N. A [signature] Arka Bhattacharya 24/5/24.

Supervisor **Project co-ordinator** **Head of the department ECE**

CONTENTS

Chapter 5

Chapter 6

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABREVATIONS

HFSS	High Frequency Structure Simulator
5G	5^{th} Generation
SRR	Split Ring Resonator
dBm	decibel Milli watts
dB	decibel
MS	MetaSurface
AMMs	Artificially magnetic materials
MPA	Microstrip patch antenna
ENG	Epsilon-negative metamaterial
PCR	polarization conversion ratio

CHAPTER-1

1.1 INTRODUCTION

The current generation of telecommunication systems is growing at a faster rate than the previous one due to the increasing needs of wireless communication for more capacity and faster speed. A larger throughput of demands is supported by the introduction of the fifth generation (5G). In order to have a higher gain performance system with the capacity to switch the beam and prevent interferences, array architectures were proposed in numerous studies. This is because a higher gain antenna is required. In the realm of wireless communications, where 5G base stations are combined with numerous antennas that would be compatible for high capacity, high gain, and high efficiency, antenna arrays and multi-beam antennas are frequently employed [1-3]. In particular, multi-beam and antenna arrays boost capacity. and extend their coverage to more areas, therefore enhancing the overall base station systems [4]. Further more, lowering the overall cost of the 5G base stations is achieved by improving the infrastructure.

These benefits will therefore be especially welcome for lower band 5G applications in the future [5].In order to reach the target, several beams with high gain and capacity must be provided by fifth-generation (5G) systems. As a result, 5G technology recommends using the 3.5 GHz lower band for 5G mobile applications [6]. Nonetheless, the antenna array is large and rigid at this 3.5 GHz frequency. As a result, metamaterial structures are suggested as a way to guide multiple beams, reshape radiation patterns, and have a small, miniaturized wideband antenna [4]–[7]. Artificially magnetic materials, or metamaterials, are materials constructed to exhibit electromagnetic properties that are not achievable with regular materials at the needed sidelobes. When this technology is upgraded to include more than two beams, the coding and structure become extremely intricate.Among the modern materials is AMM.comprised of metal structures that are positioned on the dielectric substrate interface.

As a result, the structures of metamaterials determine their physical properties more so than the constituent parts [9], [10]. Veselago was the first specialist to characterize the crucial characteristics, permittivity (ε) and permeability (μ), in 1968, which helped to build the metamaterials' architectures [11], [12].One of the most important little parts of metamaterials for creating artificial magnetism at microwave frequencies is the split-ring resonator (SRR) [13].

The optically thin subwavelength resonators known as metasurfaces (MS) are built from a compact of two-dimensional metamaterials, or unit cells [14]. By implementing metamaterial and metasurface on the feed lines, patch lines, superstrate, and backdrop of the microstrip substrate,one can decrease the antenna size while increasing bandwidth, gain, and directivity. As a result, that will provide more functionality by fulfilling the needs of the communication devices for 5G apps. The metasurface-based antenna has garnered attention recently because of its small size, low profile, and capacity to generate numerous beams in different directions [15]. Metasurface performance can be optimized for gain by configuring the metasurfaces for near-field alteration, as previously mentioned in [16]. As covered in [17], radiation patterns have also been altered by the use of this kind of technology, known as near-field transformation. A double split ring metasurface was used to create a monopole antenna with wideband, which is another modern technique that shows increasing gain [18].

In order to improve the gain, bandwidth, polarization, and steering of the antenna beams, the metasurface is frequently employed in antenna design [19]–[23]. It may generate multiple beam antennas with good gain and polarization properties or steer beams [24], [25]. Its vast size is a problem, though, as it sources many beams from an antenna array [26]–[28]. The air gap between the radiating antenna and the metasurface is mostly to blame for this [29], [30]. For instance, the metasurface in [24] has good beam steering properties, but because of the antenna beam characteristics, it can only scan a narrow beam and cannot be employed in the 5G spectrum.Therefore, the 5G mobile application requires a metasurface that can split and steer the beam in multiple directions. Metasurface antennas for controlling and splitting antenna beams have been the subject of numerous recent studies. An antenna beam is split using a digital coding metasurface, same like in [31]. This method, however, simply splits a single beam into two beams with significant sidelobes when using digital coding. When this technology is upgraded to include more than two beams, the coding and structure become extremely intricate. Additionally, programmable metasurface antennas based on PIN diodes are . One of the modern materials is AMM. depending on the diode bias states, offered for split beam with dual operations and beam switching applications [32], [33]. The recommended antenna performs somewhat better across the frequency range in terms of gain and has acceptable impedance matching. The main disadvantage of these methods is that they require a significant number of PIN diodes to build a reconfigurable metasurface. An arrangement coding in a metasurface proposes a reshaping multibeam in [34].

1.2 MOTIVATION

The main motivation to design the high gain metasurface antenna for 5G applications that resonates well at 3.5 GHZ was actually Multi-beam antennas with high directivity are required for a 5G mobile network. It can be achieved by having an array antenna. Using an antenna array at low frequency increases the complexity and size of the whole network. Therefore, a metasurface (MS) is proposed to direct surface current and to have high gain and multibeam properties. To achieve that, a square split ring resonator (SSRR) and U-shaped unit cell metasurface is implemented as a superstrate to a single square patch antenna and we can design different antennas with less complexity by exploring different metamaterial properties.

1.3 OBJECTIVES

1.3.1 BROAD OBJECTIVE

The main objective is to design the high gain metasurface antenna for 5G applications that operates at 3.5 GHZ

1.3.2 SPECIFIC OBJECTIVE

Designing metasurface antenna that resonates well at 3.5 GHZ with

1.less complexity

2.Good impedance matching

3.Bandwidth optimization

4.Radiation pattern and Gain.

1.4 TOOLS AND STANDARDS

Tools and standards are:

- IEEE 149-2021 is for The recommended practices for the measurement of antenna transmitting and receiving properties are presented. Throughout this standard it is assumed that the antenna to be measured can be treated as a passive, linear, and reciprocal device.
- IEEE 149-1977 it is a standard of test procedures for antennas.
- IEEE 145-1973 is standard definition of terms for antennas.
- IEEE 802.5-1998-Telecommunication and information exchange between the systems-local area and metropolitan area networks.
- HFSS [High frequency structure simulator] was used to design and simulate the Antenna.

1.6 5G FREQUENCIES AND BANDS

1.6.1 5G FREQUENCIES

1.6.1.1 Fr-1: 0.4-7.125GHz

FR1 (Frequency Range 1) consists of Sub-6 GHz frequency bands allocated to 5G. Ever since the introduction of GSM, there has been an increasing demand for additional frequency bands. GSM/UMTS mostly utilized 900 and 1800 MHz frequency bands while 4G LTE utilized frequencies of up to 6 GHz. With 5G, even higher frequency bands have been allocated for operation with bands going up to 39 GHz and higher.

However, not every frequency in between is being utilized for 5G deployment. Sub-6 GHz frequencies (low/mid-band) have been classified as Frequency Range 1 (FR1) and frequencies higher than 24 GHz (mm Wave) are classified as Frequency Range 2 (FR2). Networks operating on FR1 may not provide the absolute best 5G performance, but they provide a decent balance between range and performance.

1.6.1.2 Fr-2: 24.25-71.0GHz

FR2 (Frequency Range 2) consists of the operational frequencies that have been allocated to 5G in the mmWave region (above 24 GHz). These bands aim to provide high performance 5G as large amounts of bandwidths are available for use. Networks operating on FR2 bands can achieve gigabit data rates or even higher with extremely low latency. Most 5G networks use a combination of both FR1 and FR2 bands. FR1 Band provide better range and indoor propagation whereas FR2 bands provide higher data rates and lower latency. FR2 bands experience significant atmospheric attenuation and path loss during propagation. With the reduced penetration power, mass mmWave 5G deployments pose a challenge for telecom operators and engineers

Table 1.6 Frequency Ranges and Bands

Band	Frequency range
HF Band	3 to 30 MHz
VHF Band	30 to 300 MHz
UHF Band	300 to 1000 MHz
L Band	1 to 2 GHz
S Band	2 to 4 GHz
C Band	4 to 8 GHz
X Band	8 to 12 GHz
Ku Band	12 to 18 GHz
K Band	18 to 27 GHz
Ka Band	27 to 40 GHz
V Band	40 to 75 GHz
W Band	75 to 110 GHz
mm Band	110 to 300 GHz

The High gain Metasurface antenna operates in FR-1 band.

IEEE C95.1-2019 is a standard titled "IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz." This standard provides guidelines for evaluating human exposure to electric, magnetic, and electromagnetic fields across a wide frequency range, from static fields (0 Hz) up to radiofrequency fields (300 GHz). It establishes limits on exposure to these fields to ensure the safety of individuals in various environments, including workplaces, residential areas, and public spaces.

1.6.2 5G APPLICATIONS

- It will make unified global standard for all.
- Network availability will be everywhere and will facilitate people to use their computer and such kind of mobile devices anywhere anytime.
- Because of the IPv6 technology, visiting care of mobile IP address will be assigned as per the connected network and geographical position.
- Its application will make world real Wi Fi zone.
- Its cognitive radio technology will facilitate different version of radio technologies to share the same spectrum efficiently.
- Its application will facilitate people to avail radio signal at higher altitude as well.

1.6.3 5G ADVANTAGES

There are several advantages of 5G technology, some of the advantages have been described below

- High resolution and bi-directional large bandwidth shaping.
- Technology to gather all networks on one platform.
- More effective and efficient.
- Technology to facilitate subscriber supervision tools for the quick action.
- Most likely, will provide a huge broadcasting data (in Gigabit), which will support more than 60,000 connections.
- Easily manageable with the previous generations.
- Technological sound to support heterogeneous services (including private network).
- Possible to provide uniform, uninterrupted, and consistent connectivity across the world.

1.6.3.1 5G DISADVANTAGES

Though, 5G technology is researched and conceptualized to solve all radio signal problems and hardship of mobile world, but because of some security reason and lack of technological advancement in most of the geographic regions, it has following shortcomings.

- Technology is still under process and research on its viability is going on.
- The speed, this technology is claiming seems difficult to achieve (in future, it might be) because of the incompetent technological support in most parts of the world.
- Many of the old devices would not be competent to 5G, hence, all of them need to be replaced with new one — expensive deal.
- Developing infrastructure needs high cost.
- Security and privacy issue yet to be solved.

CHAPTER-2

2.1 LITERATURE REVIEW

S.NO	Title	Authors	Year	Content
1	Metamaterial based antennas	Tatsuo itoh Yuandan dong	2012	Metamaterial characteristics and small antennas based on metamaterial loadings
2	A Beam split metasurface antenna for 5G applications	Atamara z.fadhil Noor asniza murad Mohammad kamal A. rahim	2021	Antenna with hybrid metasurface and beam splitting properties
3	programmable metasurface with dynamic polarization, scattering and focusing control	Huanhuan Yang,Xiangyu Cao, Fan Yang	2016	Controlling programmable metasurface unit cells
4	Design of a PIN diode-based reconfigurable Metasurface antenna for beam switching applications	S. Chaimool, T. Hongnara, C. Rakluea	2019	Metasurface antenna with reconfigurable properties and beam switching applications

5	Single-layer polarization insensitive frequency selective surface for beam reconfigurability of monopole antennas	P. Das, K. Mandal, and A. Lalbakhsh	2019	Polarization with single layer for frequency selective surface of monopole antennas
6	A multi-functional polarization transforming Metasurface for *C*, *X* and *K* band applications	F. Ahmed, M. I. Khan, and F. A. Tahir	2021	Different band applications with multi functional polarization to metasurface
7	study on 5G technology and it applications in telecommunications	Deepender, Manoj, Utpal Srivastava	2021	Brief study about 5G applications and various applications

CHAPTER-3

3.1 ANTENNA THEORY

An antenna is a specialized transducer that converts electric current into electromagnetic (EM) waves or vice versa. Antennas are used to transmit and receive nonionizing EM fields, which include radio waves, microwaves, infrared radiation (IR) and visible light. Radio wave antennas and microwave antennas are used extensively throughout most industries and in our day-to-day lives. Infrared and visible light antennas are less common. They're still deployed in a variety of settings, although their use tends to be more specialized.

Antennas are often categorized as either transmitting or receiving. However, many antennas can do both through a transceiver. A transmitting antenna receives current from a transmitting device. From this current, the antenna generates EM waves at a specific frequency that radiate out through the air, where they can then be received by one or more other antennas.

A receiving antenna intercepts EM waves transmitted through the air. From these waves, the antenna generates a small amount of current, which varies depending on the strength of the signal. The current is passed to the receiving device, where it is transformed for its specific environment. For example, a car's antenna might pick up the FM signal from the radio station. The antenna converts the signal's radio waves to current, which is fed to the car's radio. The radio amplifies the current and in other ways transforms it and delivers it as music to the speakers.

IEEE 145-1973 is a standard for recommended practices in electric power systems for industrial plants. It covers topics such as the generation, transmission, distribution, and utilization of electric power within industrial settings. However, there seems to be no record of an update to this standard in 2023. It's possible that it may have been revised or replaced by a newer standard, but without further information, it's hard to provide specifics. If you need information on a particular update or revision, you may want to check the latest editions or revisions of the IEEE 145 series or consult the IEEE website for the most up-to-date information.

3.2 TYPES OF ANTENNAS

Antennas support different use cases, depending on their design. To help distinguish between the different types, they are often grouped into specific categories, although there is no industry-wide agreement on what constitutes each group. Even so, several common categories are often used in describing and distinguishing one antenna type from another.

- **Aperture:**An antenna with an opening in its surface that helps direct EM transmission or reception to achieve larger gain. The antenna's size and shape depend on how the antenna is used. Aperture antennas are often deployed in situations that require a flush mounting, such as aircraft or spacecraft.
- **Array:**An antenna made up of smaller connected antennas that work together to produce a single radiation pattern. Array antennas can increase gain and reduce interference, while providing greater control over its directionality. Array antennas are used in a variety of settings, including wireless communications, 5G networks and military radar systems.
- **Reflector:**An antenna that includes one or more components that reflect the EM waves in order to better focus or direct them. Reflector antennas are often used in microwave and satellite communications. Many include a parabolic structure that reflects EM waves, such as those used in satellite dishes.
- **Lens:**An antenna that includes an embedded lens made up of glass, metal or a dielectric material. The antenna uses the convergence and divergence properties of the lens to transmit or receive EM waves, typically at higher frequencies. Lens antennas are often used for radar systems and microwave communications.
- **Log periodic:**A directional antenna with multiple elements that can support a broad range of frequencies. The supported range depends on the size of the elements and how they're arranged, which is based on a logarithmic function of frequency. Log periodic antennas can be useful in situations that require variable bandwidth or that support high-frequency communications, such as analog televisions, cellular communications or shortwave radios.
- **Microstrip:**A small antenna printed into a circuit board. The antenna itself is a patch made out of a conductive material that is mounted on a dielectric substrate, which itself sits on a ground plate. Microstrip antennas are used extensively in wireless communication and mobile devices including cell phones.

- **Traveling-wave:**A directional antenna in which the EM waves travel through the antenna in one direction, unlike many other types of antennas in which the waves travel in multiple directions. The unidirectional waves make it possible to support a wider range of frequencies. Traveling-wave antennas are used for analog televisions, amateur radios, telecommunications and other use cases.
- **Wire:**An antenna that is nothing more than a length of wire, connected at one end to a transmitter or receiver. Wire antennas are the simplest and most portable type of antenna. They're used extensively with radios, automobiles, ships, aircraft, buildings and a variety of other devices and structures.

3.3 ANTENNA PARAMETERS

3.3.1 Directivity:

The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the Directivity. An Antenna radiates power, but the direction in which it radiates matters much.

Mathematical expression for Directivity

$$D=\phi(\theta,\phi)max(\text{from subject antenna})/\phi0(\text{from an isotropic antenna})$$

3.3.2 Aperture Efficiency:

Aperture efficiency of an antenna, is the ratio of the effective radiating area (or effective area)to the physical area of the aperture.An antenna has an aperture through which the power is radiated. This radiation should be effective with minimum losses. The physical area of the aperture should also be taken into consideration, as the effectiveness of the radiation depends upon the area of the aperture, physically on the antenna.

The mathematical expression for aperture efficiency is as follows −

$$\varepsilon A=Aeff/Ap$$

3.3.3 Antenna Efficiency:

Antenna Efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna.Simply, an Antenna is meant to radiate power given at its input, with minimum losses. The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line.

The mathematical expression for antenna efficiency is given below −

$$\eta e=Prad/Pinput$$

3.3.4 Gain:

Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically

The equation of gain, G is as shown below.

$$G=\eta eD$$

3.3.5 Impedance matching:

The approximate value of impedance of a transmitter, when equals the approximate value of the impedance of a receiver, or vice versa, it is termed as Impedance matching.Impedance matching is necessary between the antenna and the circuitry.

3.3.6 VSWR:

The ratio of the maximum voltage to the minimum voltage in a standing wave is known as Voltage Standing Wave Ratio.If the impedance of the antenna, the transmission line and the circuitry do not match with each other, then the power will not be radiated effectively. Instead, some of the power is reflected back.

3.3.7 Radiation intensity:

Radiation intensity is defined as the power per unit solid angle.Radiation emitted from an antenna which is more intense in a particular direction, indicates the maximum intensity of that antenna. The emission of radiation to a maximum possible extent is nothing but the radiation intensity.

Radiation Intensity is obtained by multiplying the power radiated with the square of the radial distance.

$$U=r2\times Wrad$$

3.3.8 Radiation pattern:

It is a graphical representation of the radiation properties of the antenna as a function of space. It has three patterns : isotropic, omnidirectional and directional.

3.3.9 Return loss:

The amount of power returned or reflected due to discontinuity in the path of transmission or impedance mismatch.

3.3.10 Dielectric constant or relative permittivity (εr):

It is a material property describing how a substance affects electric fields. In microstrip antennas, this value characterizes the substrate used.

3.4 Microstrip patch antenna

The Metasurface antenna uses Microstrip patch antenna as a base generally a microstrip antenna is a type of planar antenna that consists of a radiating patch on a dielectric substrate, which is backed by a ground plane. The patch is typically made of copper or aluminium, and the substrate is made of a material with a high dielectric constant, such as FR-4 or Rogers RO4003C.Microstrip antennas are popular for a number of reasons, including their low profile, ease of fabrication, and good performance. They are widely used in a variety of applications, such as wireless communications, radar systems, and satellite communications.

3.4.1 The equations to calculate the length (L) and width (W) of a Microstrip antenna are as follows:

Width (W) : $W=C/2\ f_0*(\sqrt{\varepsilon r}+1)/2$

Length (L): $L = L0 - 2\Delta L$

$L0 = C/2\ f_0*(\sqrt{\varepsilon r})$

$$\Delta L= (0.412h * (\varepsilon reff + 0.3) * (W / h + 0.264)) \ /(\varepsilon reff - 0.258)$$

Effective dielectric constant (εreff) :

$$\varepsilon_{reff} = (\varepsilon_r + 1) / 2 + (\varepsilon_r - 1) / 2 * (1 + 12h / W) \wedge (-1/2)$$

3.5 Antenna Feeding Techniques

3.5.1 Microstrip Line Feed:

(This antenna follows) This technique involves using a microstrip transmission line to feed energy into a circuit or component. Microstrip lines are commonly used in microwave integrated circuits and PCB designs.

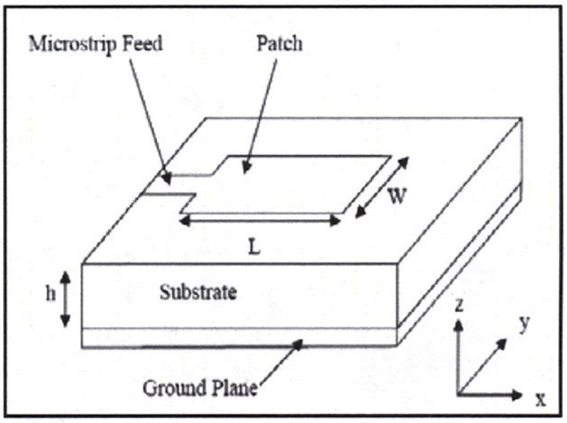


Fig-3.5.1: Microstrip Line Feed

3.5.2 Coaxial Feed:

Coaxial feeding involves using a coaxial cable to transmit signals to a component. This method is widely used in RF applications due to its ability to provide excellent shielding and impedance matching.

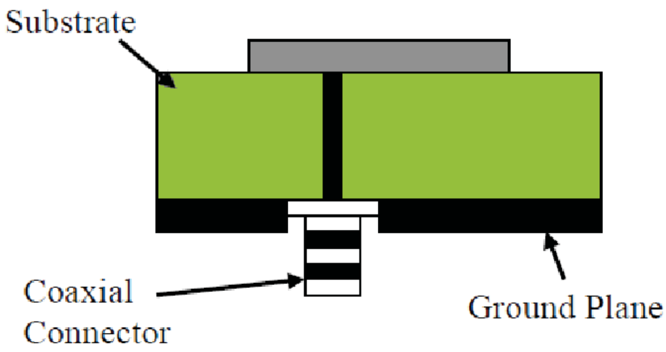


Fig-:3.5.2 Coaxial Feed

3.5.3 Waveguide Feed:

Waveguide feeding utilizes a waveguide structure to transfer electromagnetic energy to antennas, RF components, or other devices. Waveguides are often used in high-frequency and microwave systems.

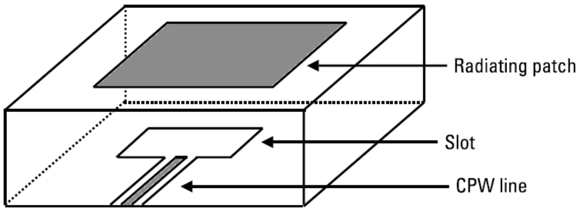


Fig-3.5.3 Waveguide Feed

3.5.4 Aperture coupled feeding:

The input signal couples to the radiating patch through the aperture (slot) that appears on the ground plane of the feed line and with their feeding structure of the radiating patch element it is different from other micro strip patch antenna.

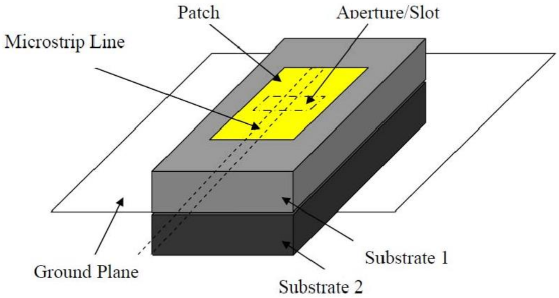


Fig- 3.5.4: Aperture coupled feeding

3.6 METAMATERIALS

Metamaterials are artificial, usually periodic structures which exhibit advantageous and unusual electromagnetic properties. A metamaterial is defined as: “An object that gains its electromagnetic material properties from its structure rather than inheriting them directly from the material it is composed of ”. The term metamaterial was also defined as “macroscopic composites having a synthetic, three-dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation.

Metamaterials are generally implemented in a periodic configuration although this is not a requirement. From a fabrication point of view it is easier to design and build by repeating a cell than by using different cells. Also, making metamaterials periodic allows one to use wellestablished theory of periodic structures, where a nonuniform structure would be much more difficult to analyze

IEEE 51-1955 is a standard titled "IEEE Standard American National Standard for Transformers and Reactors for Use in Nuclear Power Generating Stations." This standard provides guidelines for the design, testing, and operation of transformers and reactors specifically intended for use in nuclear power generating stations. It covers various aspects including construction, insulation, testing procedures, and safety considerations.

It's worth noting that standards often undergo revisions and updates over time to incorporate new technologies, best practices, and safety requirements. Therefore, while IEEE 51-1955 provides valuable guidance, it's essential to check for any revisions or newer editions to ensure compliance with the latest industry standards and regulations.

3.6.1 METAMATERIAL CHARACTERSTICS

Metamaterials are artificially structured materials engineered to have properties that are not found in naturally occurring materials. Their unique characteristics arise from their structure rather than their composition. Here are some key characteristics of metamaterials:

1.Negative Refractive Index:

Metamaterials can be designed to have a negative refractive index, meaning they bend light in the opposite direction compared to conventional materials. This property can be used to create perfect lenses that can focus light beyond the diffraction limit.

2.Electromagnetic Properties:

Metamaterials can manipulate electromagnetic waves in novel ways. They can exhibit unusual responses to electric and magnetic fields, leading to applications in cloaking and invisibility.

3.Band Gaps:

Similar to photonic crystals, some metamaterials can create band gaps for electromagnetic waves, preventing propagation at certain frequencies. This is useful for waveguides and filters.

4.Chirality:

Some metamaterials can be chiral, meaning they respond differently to left-handed and right-handed circularly polarized light. This can be exploited in polarization control and circular dichroism.

5.Acoustic and Elastic Properties:

Metamaterials can also be designed to control sound and vibrations. They can have negative density and modulus, leading to applications in soundproofing and vibration isolation.

6.Superlensing and Subwavelength Imaging:

Due to their negative refractive index, metamaterials can be used to create superlenses that achieve imaging resolution beyond the diffraction limit, allowing for subwavelength imaging.

7.Nonlinearity and Tunability:

Metamaterials can be engineered to exhibit nonlinear optical properties, enabling control over the intensity of light passing through them. They can also be made tunable by changing their structural parameters or applying external stimuli such as electric or magnetic fields.

8.Cloaking and Invisibility:

Metamaterials can be used to design cloaking devices that can render objects invisible or less detectable by redirecting light around them.

9.Hyperbolic Dispersion:

Some metamaterials exhibit hyperbolic dispersion, where the permittivity tensor components have opposite signs. This leads to unique propagation characteristics and applications in hyperlensing and thermal emission control.

10.High Permeability and Permittivity:

Metamaterials can achieve high values of permittivity (ε) and permeability (μ), which are difficult to find in natural materials. This enhances their ability to control electromagnetic waves. These characteristics enable a wide range of applications in fields such as telecommunications, medical imaging, defense, and consumer electronics.

CHAPTER-4

4.1 HFSS (High-Frequency Structure Simulator)

High Frequency Structure Simulator (HFSS) is a 3D electromagnetic (EM) simulation tool used to design a broad range of high frequency products such as antennas, filters, and IC packages. HFSS has advanced 3D electromagnetic field solvers based on finite elements and other integral equation methods supported by high performance computing technology that enable engineers to perform rapid and accurate design of high-frequency and high speed electronic components.

There are six main steps to creating and solving a proper HFSS simulation**.**

1.Create Model.
2.Assign boundaries.
3.Assign excitations.
4.Set up the solutions.
5.Solve
6.Analysis of the results

4.2 Mathematical Method Used in HFSS

The numerical technique used in HFSS™ is the Finite Element Method (FEM). In this method a structure is subdivided into many small subsections called finite elements. In HFSS these finite elements are in the form of tetrahedra. The entire collection of tetrahedra constitutes the finite element mesh. A solution is found for the fields within these tetrahedra. These fields are interrelated so that Maxwell's Equations are satisfied across inter-element boundaries yielding a field solution for the entire original structure. Once the field solution is found, the generalized S-matrix solution is determined. The figure below shows the geometry, mesh, field results, and the S-matrix results of a bandpass cavity filter in HFSS.

ANSYS is pleased to provide a great number of new and advanced features in HFSS. The new features have been developed with guidance fromour most innovative customers. These advancements deliver solutions to amplify your engineering effectiveness, simulateyour most complex electronic design challenges, and accelerate your time to market.

1.Improved lower frequency port solving

2.Improved performance for solutions with dielectric IE regions

3.N-port circuit element/S-parameter model

4.TAU mesh support for IE regions. Improves mesh quality for canonical geometries

5.Feedback highlighting of problem areas in 3D modeler reported by mesher

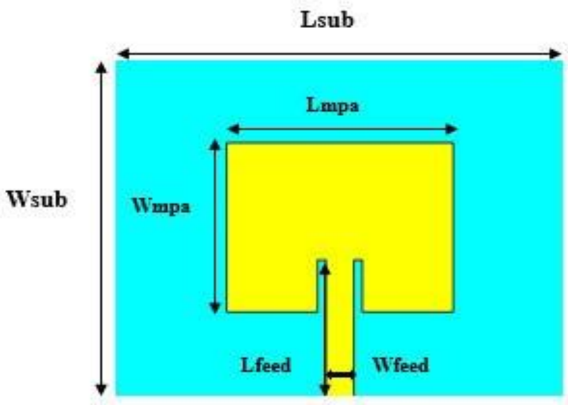
6.Animated modeler zoom. Real-time zoom in and out to selected objects and views

7.3D modeler and fields animation from parametric setup

8.3D uniformspherefar fieldplotswithcolor scaling

CHAPTER-5

5.1 PATCH ANTENNA DESIGN



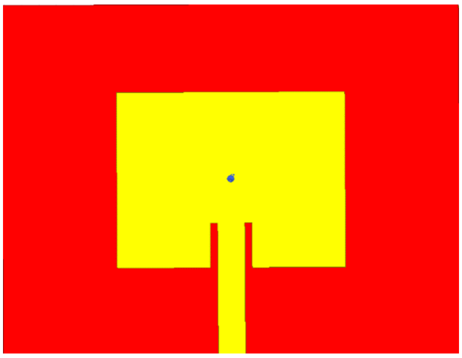


Fig5.1:Patch antenna dimensions layout **Fig5.1.1:Basic Patch antenna design**

5.1.2 PATCH ANTENNA DIMENSIONS

Table 5.1.2: Patch Antenna dimensions

Parameter	Description	Dimensions(mm)
Lmpa, Wmpa	Length of patch & width of patch	26.31 X 20.20
Lgnd,Wgnd	Length of Ground plane&width of Ground Plane	52.62 X 40.40
Lfeed	Length of Feed Line	15.25
Wfeed	Width of Feed line	3.127

5.1.3 PATCH ANTENNA WITH METASUEFACE

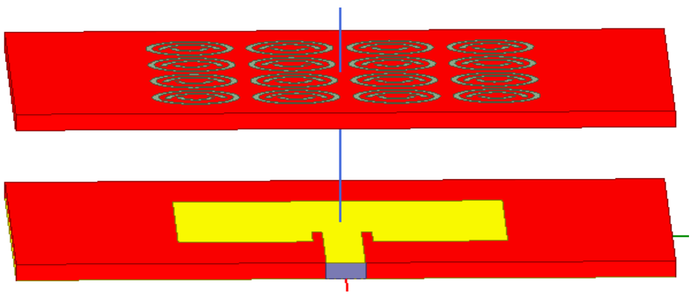


Fig-5.1.3: PATCH ANTENNA WITH METASUEFACE

5.1.4 DIMENSIONS OF PATCH ANTENNA WITH METASUEFACE

Table 5.1.4: Patch Antenna dimensions

Parameter	Description	Dimensions(mm)
Lmeta	Length of metasurface	52.62
Wmeta	Width of metasurface	40.40
d	Air gap distance	15

5.2 ANTENNA UNIT CELL

An antenna unit cell is a fundamental component in the design and analysis of antenna arrays, particularly for phased array systems and metamaterials. Understanding the theory behind an antenna unit cell involves several key concepts:

1.Resonance and Radiation Mechanism:

- Each unit cell is designed to resonate at a specific frequency, efficiently radiating electromagnetic waves.
- The resonance frequency depends on the geometry, size, and materials of the unit cell.

2.Electromagnetic Simulation and Analysis:

- The performance of a unit cell is typically analyzed using electromagnetic simulation tools, such as HFSS (High-Frequency Structure Simulator) or CST Microwave Studio.
- Parameters like return loss, radiation pattern, and impedance are evaluated to ensure proper functioning.

3.Periodic Structures and Floquet Modes:

- When multiple unit cells are arranged in a periodic manner, the array exhibits certain electromagnetic behaviors that can be described using Floquet modes.
- Floquet theory helps in understanding how waves propagate through the periodic structure, affecting the overall array performance.

4.**Mutual Coupling:**

- In an array, each unit cell interacts with its neighbors, leading to mutual coupling effects.

- These interactions can affect the impedance, radiation pattern, and overall efficiency of the array.

5.Antenna Array Factor:

- The array factor is a mathematical representation of the combined radiation pattern of all the unit cells in the array.
- It depends on the number of unit cells, their spacing, and the phase difference between them.

6.Metamaterials and Metasurfaces:

- In advanced designs, unit cells can be engineered to exhibit properties not found in natural materials, such as negative refractive index or cloaking.
- Metamaterial unit cells are often sub-wavelength in size and rely on resonant structures to achieve these exotic properties.

7.Fabrication and Material Considerations:

- Practical implementation of unit cells involves considerations of the materials used (e.g., substrates, conductors) and the fabrication processes.
- The choice of materials impacts the losses, bandwidth, and durability of the antenna.

5.2.1 UNIT CELL APPLICATIONS:

- Antenna unit cells are crucial in various applications, including satellite communications, radar systems, wireless networks, and emerging technologies like 5G and IoT.
- Specific designs are tailored for different applications, considering factors like frequency range,bandwidth, and polarization.

In summary, the theory of an antenna unit cell encompasses its resonance and radiation properties,the impact of periodic structures, mutual coupling, array factors, and the practical aspects of material selection and fabrication. Understanding these elements is essential for designing efficient and effective antenna arrays for various applications.

5.2.2 UNIT CELL DESIGN

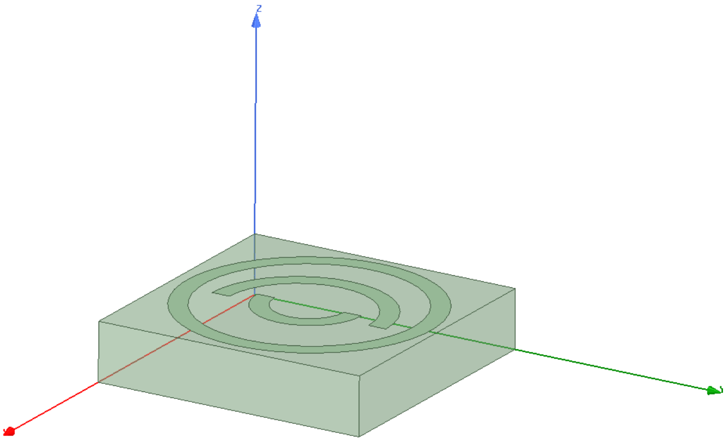


Fig-5.6.1: Unit Cell

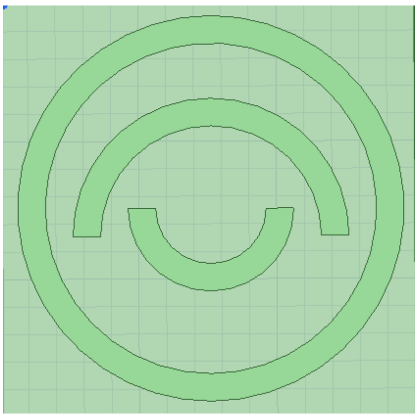


Fig-5.6.2: Unit Cell Shape

Tableno 5.2.2 Dimensions of unit cell

Parameter	Distance	Units
Length of unit cell	7.5	mm
Width of unit cell	7.5	mm
Height of unit cell	1.6	mm

5.7 RESULTS AND DISCUSSIONS

5.7.1 Basic patch results

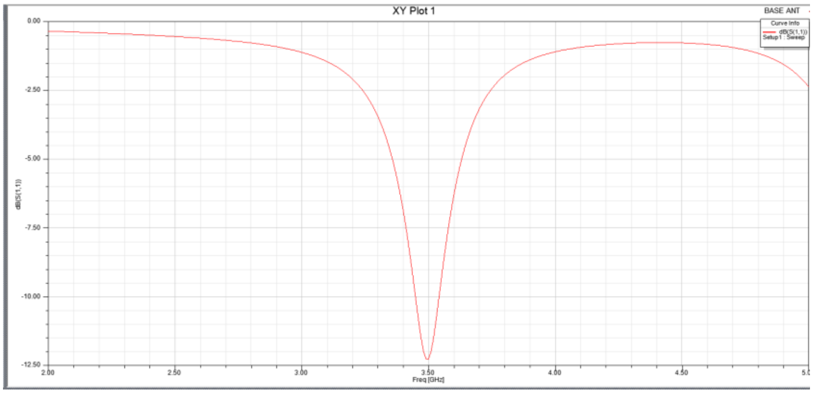


Fig-5.7.1.1: S parameter plot

The basic Patch antenna is operating at 3.5 GHz with the return loss of -12.50 to increase the performance of antenna the metasurface is placed.

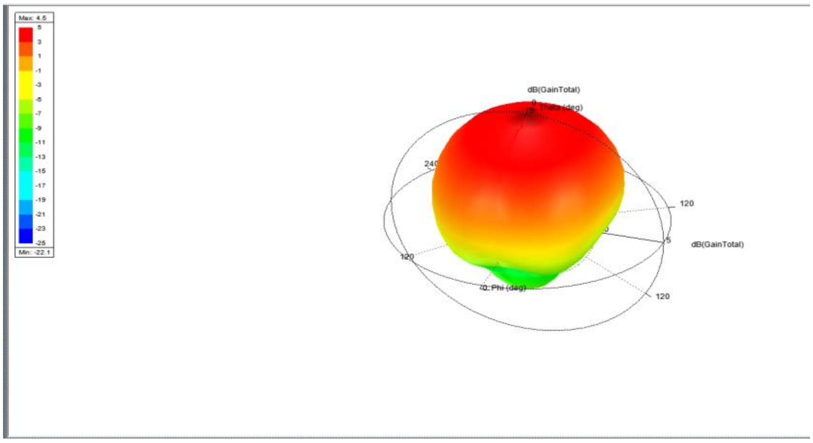


Fig- 5.7.1.2: Gain plot

For the Basic patch Antenna the gain is 4.5 db

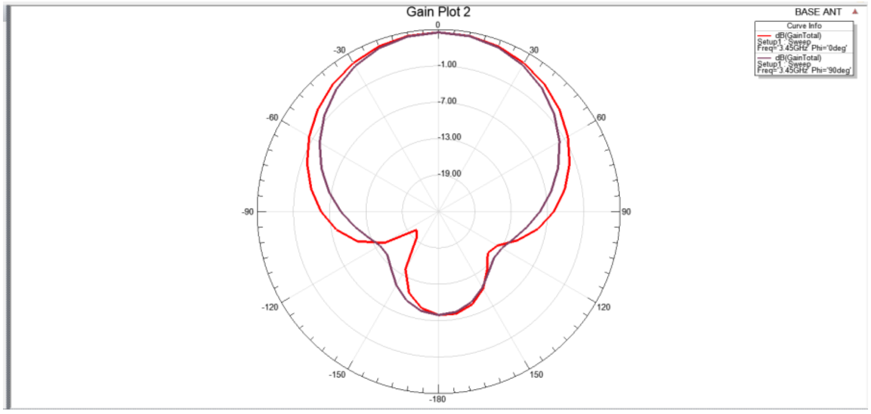


Fig-5.7.1.3: RADIATION PATTERN PLOT

The fig:5.7.3 shows the radiation plot of the patch antenna.

5.7.2 Patch antenna with Metasurface result

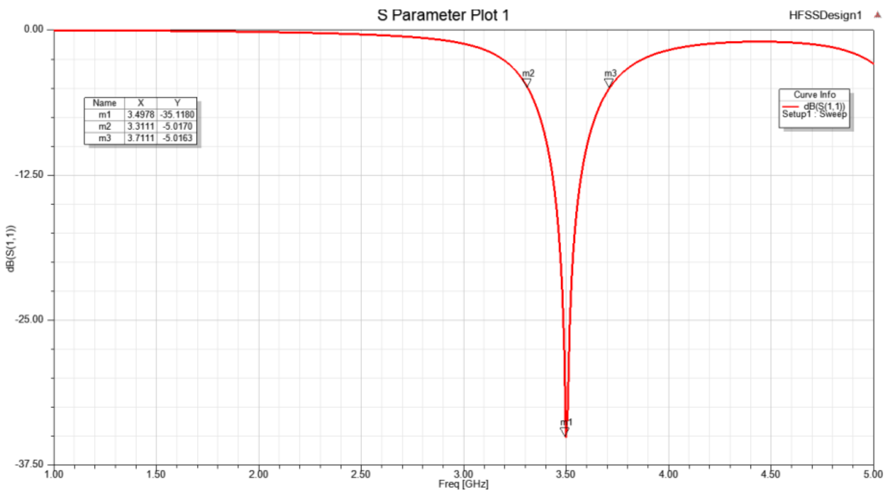


Fig-5.7.2: S parameter plot

After placing the Metasurface on the patch antenna the antenna is operating at 3.5 GHZ with the return loss of -35.11

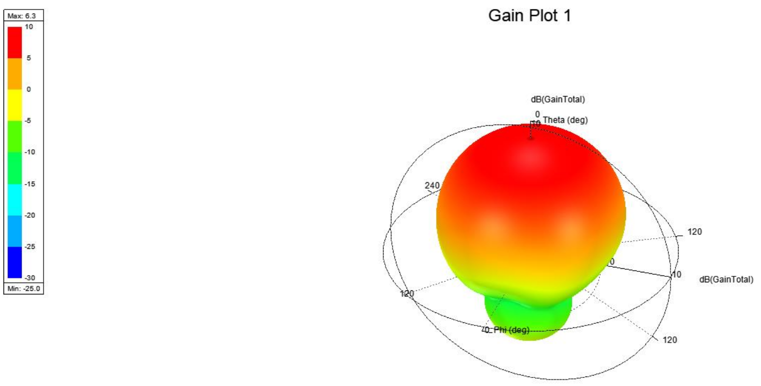


Fig- 5.7.3: Gain plot

The gain of the beam split metasurface antenna is 6.3 db as compared to the gain of patch antenna the gain increases

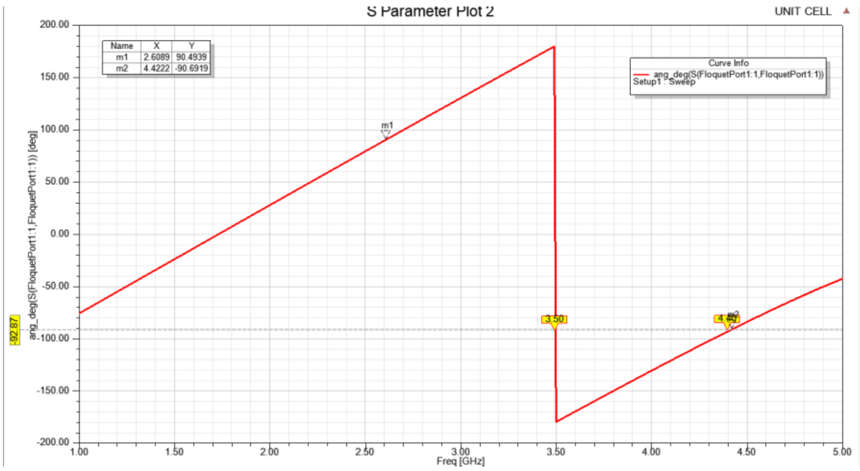
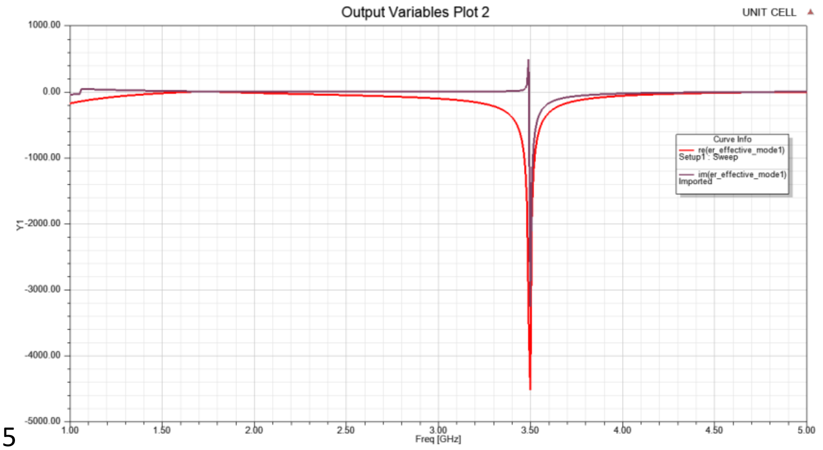


Fig-5.7.4 Unit cell reflection phase plot

Fig-5.7.4 shows the reflection phase of the unit cell that is operating from 2.6 to 4.4 that means this unit cell 3.5 GHz frequency is covering



5

Fig-5.7.5 Permitivity plot

Fig-5.7.5 shows the permittivity plotof the unit cell the permittivity should be in negitive

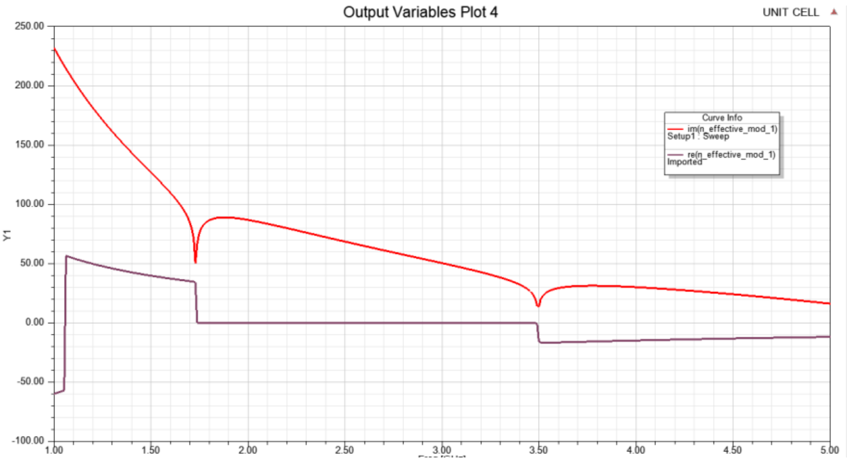


Fig-5.7.6 Refractive index

Fig-5.7.6 shows the Refractive index of the unit cell the refractive index for metamaterial unit cell should be in negitive

CHAPTER-6

6.1 CONCLUSION

The successful design and fabrication of a Beam split metasurface utilising smiley-shaped unit cells and SRR to split the antenna beam has been achieved. Once the metasurface prototype is positioned over a microstrip patch antenna operating at 3.5 GHz, measurements are taken. At the target frequency, the measured reflection coefficient is less than -10 dB, which is in good agreement with the simulated reflection coefficient. At the necessary impedance bandwidth, a 3.5 dB gain boost is achieved at the broad side of the antenna direction. The E-plane effectively observes a split beam with 2.65 dB gain for each beam. There are two beam tilt angles in the split direction, which are -45° and 45°, respectively. This kind of metasurface can be applied to 3.5 GHz Pico cell beam guiding technology, which is needed for 5G mobile applications.

6.2 FUTURE SCOPE

As further advancements in wireless communication technologies continue, future work will focus on optimizing the antenna design for higher frequency bands, exploring different metamaterial configurations, and investigating the integration of other advanced functionalities into the antenna system. Metasurface antennas, leveraging engineered surfaces with subwavelength structures, hold significant promise for future technological advancements. Their potential scope includes:

5G and Beyond: Metasurface antennas can enhance the performance of 5G networks and future 6G technologies by enabling higher data rates, improved beamforming capabilities, and reduced interference.

- Internet of Things (IoT): These antennas can be integrated into IoT devices, providing compact, efficient, and cost-effective communication solutions for smart homes, cities, and industrial applications.
- Satellite and Space Communications: Metasurface antennas can offer lightweight and compact solutions for satellite communication systems, improving bandwidth and signal quality for space missions.

- Wearable Technology: Their flexibility and compactness make metasurface antennas ideal for integration into wearable devices, enhancing connectivity for health monitoring, fitness tracking, and augmented reality applications.
- Military and Defense: These antennas can be used in radar and communication systems, offering stealth capabilities, improved signal processing, and better resistance to jamming and interference.
- Medical Applications: Metasurface antennas can be used in medical imaging and diagnostic tools, providing high-resolution imaging and non-invasive monitoring techniques.
- Autonomous Vehicles: Enhanced communication and radar systems in autonomous vehicles can benefit from metasurface antennas, improving safety and navigation capabilities.
- Energy Harvesting: These antennas can be used to develop efficient energy harvesting systems, capturing ambient RF energy to power low-consumption devices.
- Wireless Power Transfer: Metasurface antennas can facilitate efficient wireless power transfer systems, enabling new ways to charge devices without physical connections.
- Smart Environments: Integration into smart buildings and environments can improve indoor communication networks, supporting advanced automation and connectivity.
- Continued research and development in metasurface antenna technology are likely to unlock new applications and improve existing systems, driving innovation across multiple industries.

6.3 REFERENCES

1. M. F. Imani, J. N. Gollub, O. Yurduseven, A. V. Diebold, M. Boyarsky, T. Fromenteze, L. Pulido-Mancera, T. Sleasman, and D. R. Smith, ‘‘Review of metasurface antennas for computational microwave imaging,’’ *IEEE Trans. Antennas Propag.*, vol. 68, no. 3, pp. 1860–1875, Mar. 2020.
2. M. Faenzi, G. Minatti, D. González-Ovejero, F. Caminita, E. Martini, C. D. Giovampaola, and S. Maci, ‘‘Metasurface antennas: New models, applications and realizations,’’ *Sci. Rep.*, vol. 9, no. 1, pp. 1–14, Dec. 2019.
3. X. Tong, Z. H. Jiang, C. Yu, F. Wu, X. Xu, and W. Hong, ‘‘Lowprofile, broadband, dual-linearly polarized, and wide-angle millimeterwave antenna arrays for *ka*-band 5G applications,’’ *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 10, pp. 2038–2042, Oct. 2021.
4. I.-J. Nam, S. Lee, and D. Kim, ‘‘Miniaturized beam reconfigurable reflectarray antenna with wide three-dimensional beam coverage,’’

IEEE Trans. Antennas Propag., early access, Jun. 2, 2021, doi: 10.1109/TAP.2021.3083732.

5. S. J. Yang, Y. Yang, and X. Y. Zhang, ‘‘Low scattering element-based aperture-shared array for multiband base stations,’’ *IEEE Trans. Antennas Propag.*, vol. 69, no. 12, pp. 8315–8324, Dec. 2021.
6. M. Abdullah, A. Altaf, M. R. Anjum, Z. A. Arain, A. A. Jamali, M. Alibakhshikenari, F. Falcone, and E. Limiti, ‘‘Future smartphone: MIMO antenna system for 5G mobile terminals,’’ *IEEE Access*, vol. 9, pp. 91593–91603, 2021.
7. S. Li, Z. N. Chen, T. Li, F. H. Lin, and X. Yin, ‘‘Characterization of metasurface lens antenna for sub-6 GHz dual-polarization full-dimension massive MIMO and multibeam systems,’’ *IEEE Trans. Antennas Propag.*, vol. 68, no. 3, pp. 1366–1377, Mar. 2020.
8. C. Milias, R. B. Andersen, P. I. Lazaridis, Z. D. Zaharis, B. Muhammad, J. T. B. Kristensen, A. Mihovska, and D. D. S. Hermansen, ‘‘Metamaterialinspired antennas: A review of the state of the art and future design challenges,’’ *IEEE Access*, vol. 9, pp. 89846–89865, 2021.
9. A. Pander, H. Hamada, and H. Nosaka, ‘‘Excitation of resonances in planar metamaterials at a two-layer dielectric interface for substrate integrated electronics,’’ *Phys. Lett. A*, vol. 409, Sep. 2021, Art. no. 127523.
10. T. Hayat, M. U. Afzal, A. Lalbakhsh, and K. P. Esselle, ‘‘Additively manufactured perforated superstrate to improve directive radiation characteristics of electromagnetic source,’’ *IEEE Access*, vol. 7, pp. 153445–153452, 2019.
11. J. J. de Oliveira, L. D. Ribeiro, E. J. da Silva, and R. M. de Souza Batalha, ‘‘Design of a free space metamaterial lens based on LC parameters at S-band,’’ *J. Electromagn. Waves Appl.*, vol. 35, no. 16, pp. 1–14, Jun. 2021.
12. S. Abdullah, G. Xiao, and R. E. Amaya, ‘‘A review on the history and current literature of metamaterials and its applications to antennas & radio frequency identification (RFID) devices,’’ *IEEE J. Radio Freq. Identificat.*, vol. 5, no. 4, pp. 427–445, Dec. 2021.
13. S. L. Madsen and J. S. Bobowski, ‘‘The complex permeability of splitring resonator arrays measured at microwave frequencies,’’ *IEEE Trans. Microw. Theory Techn.*, vol. 68, no. 8, pp. 3547–3557, Aug. 2020.
14. S. Sithara and Z. N. Chen, ‘‘Low-profile broadband dual-polarization dou-ble-layer metasurface antenna for 2G/3G/LTE cellular base-stations,’’ *IEEE Trans. Antennas Propag.*, early access, Jul. 26, 2021, doi: 10.1109/TAP.2021.3098554.
15. L. Bao, R. Y. Wu, X. Fu, Q. Ma, G. D. Bai, J. Mu, R. Jiang, and
T. J. Cui, ‘‘Multi-beam forming and controls by metasurface with phase and amplitude modulations,’’ *IEEE Trans. Antennas Propag.*, vol. 67, no. 10, pp. 6680–6685, Oct. 2019.

16. A. Lalbakhsh, M. U. Afzal, T. Hayat, K. P. Esselle, and K. Mandal, ‘‘Allmetal wideband metasurface for near-field transformation of medium-tohigh gain electromagnetic sources,’’ *Sci. Rep.*, vol. 11, no. 1, pp. 1–9, Dec. 2021.
17. M. U. Afzal, L. Matekovits, K. P. Esselle, and A. Lalbakhsh, ‘‘Beamscanning antenna based on near-electric field phase transformation and refraction of electromagnetic wave through dielectric structures,’’ *IEEE Access*, vol. 8, pp. 199242–199253, 2020.
18. S. Adibi, M. A. Honarvar, and A. Lalbakhsh, ‘‘Gain enhancement of wideband circularly polarized UWB antenna using FSS,’’ *Radio Sci.*, vol. 56, no. 1, pp. 1–8, Jan. 2021.
19. X. Chen, H. Zou, M. Su, L. Tang, C. Wang, S. Chen, C. Su, and Y. Li, ‘‘Alldielectric metasurface-based beam splitter with arbitrary splitting ratio,’’ *Nanomaterials*, vol. 11, no. 5, p. 1137, Apr. 2021.

20. M. Ameen, A. Mishra, and R. K. Chaudhary, ‘‘Dual-band CRLH-TL inspired antenna loaded with metasurface for airborne applications,’’ *Microw. Opt. Technol. Lett.*, vol. 63, no. 4, pp. 1249–1256, Apr. 2021.