METASURFACE LOADED CIRCULARLY POLARIZED BROADBAND ANTENNA FOR RCS REDUCTION

A project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY IN
ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC With 'A' Grade)
Sangivalasa, Bheemili Mandal, Visakhapatnam dist. (A.P)
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ANITS

CERTIFICATE

This is to certify that the project report entitled "**Metasurface Loaded Circularly Polarized Broadband Microstrip Patch Antenna For RCS Reduction**" submitted by **TEPPALA CHANDRIKA (319126512184), GANJI HARSHITH (319126512148), BANKURU GEETA SAI SNEHA (319126512133), MD MAHIN NOORE (319126512164)** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology in Electronics and Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision during the year **2022-2023.**

Project Guide

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CONTENTS

ABSTRACT

In this project, a circularly polarized patch antenna is proposed for broadband radar cross section (RCS) reduction over 4.95 to 15.73 GHz. The broadband RCS reduction (RCSR) can be achieved by two destructive interference principles to be applied in two regions, high frequency region and low frequency region. The design process involves two steps, first, designing a reference antenna, followed by, loading of the metasurfaces. The metasurface unit cell will be designed with the required reflection magnitude and phase difference along with realizing a polarization conversion as high as possible in the low band. The unit cells can be repeated in all directions, to the left, right, top and bottom, generating a larger unit. The combination of two artificial magnetic conductors (AMCs) will be used for RCS reduction. The proposed antenna is surrounded by chessboard arrangement of metasurface sections. RCSR can be achieved by redirecting the scattered wave away from the backscattered direction. The proposed design aims at gain enhancement using minimum number of metasurface unit cells.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 Introduction to Antennas

An antenna is typically defined as a metallic device (a rod or wire) used to transmit or receive radio waves. The aerial or aerial is defined as "a means of radiating or receiving radio waves" by the IEEE standard definition. In other words, the antenna serves as a bridge between free space and a directing device.

The guiding device or transmission line, which can be a coaxial line or a hollow pipe (waveguide), transports electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver.

In order to maximise or suppress radiation energy in certain directions, an advanced wireless system often requires an antenna in addition to the ability to receive or send energy. As a result, the antenna must perform both probing and guiding functions. It could be a conductor, an aperture, a patch, a collection of elements (array), a reflector, a lens, or something else. It has taken on various forms to meet the needs of the time.

1.2 Definition of Antenna

Antenna is defined in numerous ways. These are their names:
• An antenna is a device that effectively transfers electronic signals to electromagnetic waves and vice versa with little signal loss.
• An antenna is a transducer that converts radio frequency (RF) fields to alternating current (AC). For sending or receiving radio broadcasts, there are receiving and transmission antennas.

1.3 Types of Antennas

1.3.1 Wire Antennas

A wire antenna is a radio antenna that consists of a long wire hung above the ground. The wire of the antenna collects and radiates the signals. This antenna's wire antenna length is independent of its wavelength. To send or receive signals, the cable is simply linked to the transmitter or receiver via an antenna tuner. These antennas are well-known for being portable and simple to install. Wire antenna examples include

1- Linear wire antenna:
An antenna which are in form of straight wire are called as linear wire antennas. It is also called as dipole.

2- Loop antenna:
When wire is used to make a loop, it is referred to as a loop antenna. The loop does not have to be circular; it can have any shape. However, a square or circular loop is simple to analyse and build.

3- Helical antenna:
A helical antenna, or simply a helix, is formed when wire is bent to form a helical shape.
Wire antennas are used in structures, ships, cars, and spacecraft.

1.3.2 Aperture Antennas

Depending on the cross-section, rectangular or circular. When one end of the tube is caught in a large hole, the structure takes on the characteristics of an antenna. These antennas are known as aperture antennas. Because of their horn-like shape, they are also known as
as horn antennas. Because they may be flush-mounted into the skin of a spacecraft or aircraft, aperture antennas are highly suitable for aerospace applications. To protect the antenna from environmental conditions, their aperture opening can be covered with an electromagnetic (dielectric) window material that is transparent to RF energy.
Flush-mounted applications, air crafts, and spacecraft are examples of applications.

1.3.3 Microstrip Antennas

Microstrip antennas are made out of a metallic patch mounted on a grounded substrate. The metallic patch can be worn in a variety of ways. However, rectangular and circular patches are the most preferred due to their ease of analysis and manufacture, as well as their appealing radiation properties, particularly low cross-polarization radiation.
Microstrip antennas have a low profile, are conformable to planar and nonplanar surfaces, are simple and inexpensive to manufacture using modern printed-circuit technology, are mechanically robust when mounted on rigid surfaces, are compatible with MMIC designs, and are extremely versatile in terms of resonant frequency, polarization, pattern, and impedance. These antennas can be attached to the surfaces of high-performance aircraft, spacecraft, satellites, missiles, automobiles, and even handheld mobile phones.

1.3.4 Array Antennas

The desired radiation properties will be produced by a collection of radiating devices in an electrical and geometrical arrangement (an array). The array can be configured so that the radiation from the elements adds up to give a radiation maximum in one or more directions, a minimum in others, or otherwise as desired. The Yagi-Uda antenna, Microstrip patch array, Aperture array, and Slotted waveguide guide array are a few examples.
Array antennas are typically utilised for very high-gain applications, particularly when controlling the radiation pattern.

1.3.5 Reflector Antennas

These antennas are made up of a radiating element and a reflecting surface. To achieve high directivity, we can utilise a number of dipoles as radiating structures and a flat reflector in addition to the simplest form, which uses a dipole as a radiating element and a flat conductor as a reflector. The most common type is a parabolic reflector, which uses a parabolic reflector instead of a flat reflector. They are used to transform spherical waves into plane waves. Following demands for reflectors for use in radio astronomy, microwave communication, and satellite tracking resulted in spectacular progress in the development of sophisticated analytical and experimental techniques for shaping reflector surfaces and optimising illumination over their apertures to maximise gain.

1.3.6 Lens Antennas

Lenses are generally used to collimate incident divergent energy so that it does not spread in undesirable directions. Divergent energy of various forms can be turned into plane waves by properly creating the geometrical structure and selecting the appropriate material for the lenses. They can be used in many of the same ways, especially at higher frequencies.
As parabolic reflectors, they can be used. Their size and weight increase dramatically at lower frequencies. Lens antennas are classified according to the material they are constructed of or their geometrical design..

1.4 Basic Antenna Parameters

Antenna characteristics are often measured in two planes, known as the azimuthal and elevation planes, which can sometimes be referred to as the horizontal and vertical planes. The angle in the azimuthal plane is traditionally represented by the Greek letter phi, while the angle in the elevation plane is represented by the Greek letter theta.

1.4.1 Beamwidth

The angular gap between two identical locations on the opposite side of the pattern maximum is defined as the beamwidth of a pattern. There are several beamwidths in an antenna pattern. Half Power Beam Width (HPBW) and First Null Beam Width (FNBF) are the two major beamwidth issues.

Half Power Beam Width (HPBW): The angular distance from the centre of the main beam to the point where the radiation power is lowered by 3dB is defined as half power beam width. This measurement is made at two sites from the main beam's center, so that the angular distance is centred on the main beam. This measurement is useful for describing an antenna's radiation pattern and identifying how directional it is. IEEE defines it as a plane encompassing the greatest direction of a beam, as well as the angle between the two directions in which the radiation strength is one-half that of the beam. To find HPBW, we set power equal to 0.5 in the equation characterising the radiation pattern and solved for angles**.**

First Null Beam Width (FNBW): The first null beam width is the angular spacing between the first nulls on either side of the main lobe, and it is referred to as such. The pattern in the figure below shows both the HPBW and the FNBW**.**

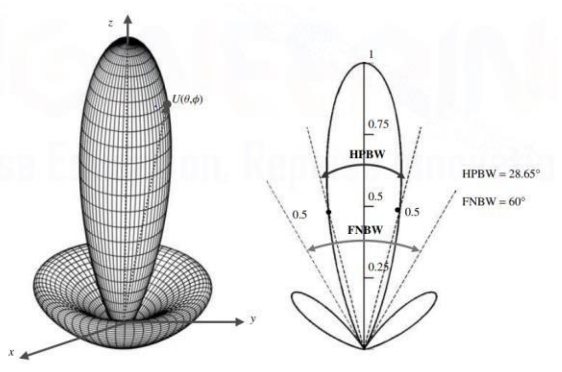


Fig 1.1: Representation of HPBW and FNBW

1.4.2 Antenna impedance

The ratio of input voltage to input current is defined as antenna impedance:

$$Za \equiv \frac{Vi}{Ii}\ \Omega \qquad (1.1)$$

Za is a complex number that can be expressed as Za = Ra + j Xa.
Ra = R_l + Rr, where R_l represents antenna losses and Rr represents radiation resistance.

1.4.3 Radiation pattern

An antenna radiation pattern, also known as an antenna pattern, is defined as "a mathematical function or graphical representation of the antenna's radiation properties as a function of space coordinates." The radiation pattern is typically determined in the far field region and expressed as a function of the directional coordinates. Power flux density, radiation intensity, field strength, directivity, phase, and polarisation are all examples of radiation qualities."
The most important radiation attribute is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a constant radius path or surface. The amplitude field pattern is a trace of the received electric (magnetic) field with a constant radius. An amplitude power pattern, on the other hand, is a graph showing the spatial fluctuation of the power density along a constant radius.

Field and power patterns are frequently normalised with regard to their maximum value, resulting in normalised field and power patterns. Furthermore, the power pattern is typically shown on a logarithmic scale or, more commonly, in decibels. (dB). Lobes are different sections of a radiation pattern that can be classed as main, minor, side, or back lobes. A major lobe is defined as the radiation lobe containing the highest radiation direction. Any lobe other than a major lobe is considered a minor lobe. Except for the major lobe, a side lobe is a radiation lobe. A side is any radiation lobe that is not the targeted lobe. A rear lobe is a radiation lobe with an axis that makes an angle of about 180o with respect to an antenna's beam. Figure 1.2 depicts the radiation pattern in the 3D plane.

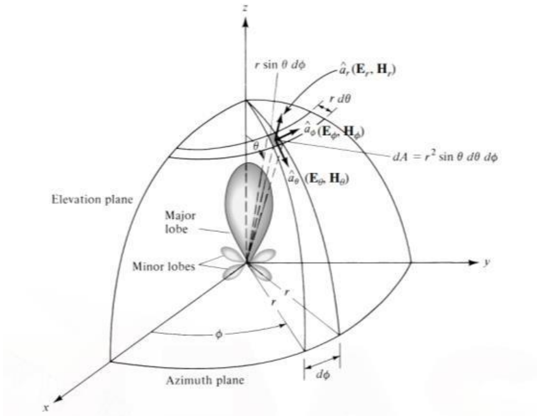


Fig 1.2: Radiation pattern in 3D plane of an antenna

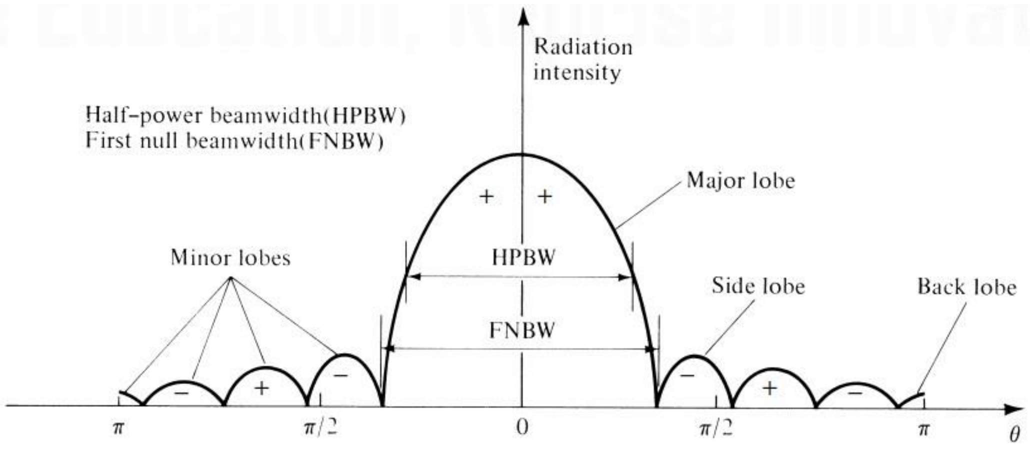


Fig 1.3: Linear plot of power pattern

1.4.4 Radiation Intensity

The power radiated from an antenna per unit solid angle is defined as radiation intensity in a particular direction. The radiation intensity is a far-field characteristic that can be calculated by multiplying the radiation density by the distance squared. It is expressed mathematically as

$$U = r^2 W_{rad} \qquad (1.2)$$

Where U is the radiation intensity (W/unit solid angle). W_{rad} is an abbreviation for radiation density (W/m2).

1.4.5 Directivity

It is defined as the ratio of the intensity of radiation in a given direction to the average intensity of radiation. The directivity of an antenna indicates how much energy the antenna can radiate in a specific direction. It is a must when the antenna is used as a receiver. If an antenna radiates equally in all directions, its directivity is one, or 0dB when measured with respect to an isotropic antenna. In its most basic form, directivity can be defined as the ratio of maximum radiation intensity to average radiation intensity.

$$\text{Directivity} = \frac{maximum\ radiation\ intensity}{average\ radiation\ intensity}$$

$$D = \frac{U}{U0} = \frac{4\pi U}{Prad} \qquad (1.3)$$

Where, D = Directionality U = Intensity of radiation (W/unit solid angle) Uo = Isotropic source radiation intensity (W/unit solid angle). P_{rad} stands for total radiated power. (W)

When discussing antennas at the transmitting end, the directivity of an antenna with a certain angle indicates that the antenna radiations are more focused in that given direction. In the event of a receiving antenna, it will receive the power efficiency from a specific direction.

1.4.6 Gain

Gain is similar to antenna directivity, but the difference is that directivity assumes a lossless antenna and disregards power reflected at the input port, whereas gain is the radiated power density relative to the power density of an isotropic antenna radiating not the total radiated power but rather the total forward power accepted by the antenna, which is greater than the total power radiated for a non-ideal antenna.

The antenna gain accounts for loss, hence the gain of an antenna is always smaller than the directivity. Knowing the antenna's directivity, total power radiated by the antenna, and received power after loss, you can determine the antenna gain using the equation

$$G = D \frac{Pa}{P\ accepted\ by\ the\ antenna} \leq D \quad (1.4)$$

In other words, gain is the efficiency multiplied by the directivity of the antenna, the maximum possible gain of an antenna.

Directive gain, g_d, is defined as the ratio of the radiation intensity in a specified direction to the average radiation intensity, given by,

$$g_d = \frac{4\pi\psi}{\omega r} \quad (1.5)$$

where ω_r is the radiated power.

1.4.7 Antenna Efficiency

Antenna efficiency is defined as the directivity to gain ratio. It takes into account all of the power lost before to radiation. The losses could be caused by an input terminal mismatch, conduction losses, dielectric losses, or spill over losses.

e_o is due to the combination of number of efficiencies:

$$e_o = e_r e_c e_d \quad (1.6)$$

e_o = total efficiency
e_r = reflection (mismatch) effciency
e_c = conduction efficiency
e_d = dielectric efficiency

1.4.8 Polarization

Depending on our needs, an antenna can be polarised. It can be polarised either linearly or cyclically. The beam pattern and polarisation during reception or transmission are determined by the type of antenna used.

Linear polarisation: A wave can travel in multiple directions when it is transmitted or received. The antenna's linear polarisation aids in keeping the wave moving in a specific direction while ignoring all other directions. The electric field vector remains in the same plane despite the usage of this linear polarisation. Therefore, we employ this linear polarisation to raise the antenna's directivity.
Circular polarisation: When an electric field vector is circularly polarized, all of its components lose direction and the electric field vector seems to be rotated. Additionally, the rotational mode may occasionally change. Circular polarization, on the other hand, lessens the impact of multi-path, which is why it is employed in satellite communications like GPS.

Horizontal polarisation: because it is more vulnerable to reflections from the earth's surface, weakens the wave. They frequently exhibit weakness at frequencies below 1GHz. TV signals are transmitted using horizontal polarisation to increase the signal-to-noise ratio.

Vertical polarization: For ground wave transmission, the low frequency vertically polarised waves are useful. Unlike the horizontally polarised ones, these are not impacted by surface reflections. As a result, mobile communications use vertical polarisation.

Each kind of polarisation has benefits and drawbacks of its own. According to the needs of the system, the type of polarisation can be chosen by the RF system designer.

1.4.9 Return Loss

The efficiency of power distribution from a transmission line to a load, like an antenna, is measured by return loss. The return loss can be determined if the power incident on the antenna-under-test (AUT) is Pin and the power reflected back to the source is Pref.
10 log10(Pin/Pref) dB Return Loss

1.4.10 Voltage Wave Standing Ratio (VSWR)

The amount of energy reflected from the antenna as a result of impedance mismatching is measured by VSWR. VSWR would be one for an antenna with ideal impedance. For the majority of wireless applications, VSWR less than 2:1 is regarded as acceptable because any reflections typically have a short time delay, resulting in minimal receiver error.

The voltage reflection coefficient at the antenna's input terminals is represented by the formula

$$\text{VSWR} = \frac{1+|c|}{1-|c|} \tag{1.7}$$

1.4.11 Bandwidth

The frequency range throughout which an antenna retains its properties and attributes, such as gain, front-to-back ratio, standing wave ratio, radiation pattern, polarization, impedance, and directivity, among many others, without noticeably changing is known as its bandwidth.

Fractional bandwidth equation for BW less than 100% = fu – fl / fc * 100
Fractional bandwidth equation for BW exceeding 100% = fu/fl

Bowtie, biconical, and blade dipole antennas are some typical forms of broadband antennas. Broadband antennas are defined as antennas with a bandwidth greater than 2:1.

1.4.12 Front-to-back ratio

Front-to-back ratio (FBR) is defined as the ratio of radiated power in the desired direction to the radiation power in the opposite direction.

1.5 Circular Polarization

If two orthogonal modes are excited with a 90° time-phase difference between them, circular polarisation can result. This can be done by modifying the patch's physical

parameters and applying one, two, or more feeds. Some recommendations have been made and documented in the literature using single patches.
The simplest technique to excite ideal circular polarisation in a square patch element is to feed it at two neighbouring edges, which will excite the two orthogonal modes, the TMx 010 at one edge and the TMx 001 at the other. A 90 power divider or 90 hybrid is used to feed the element in order to acquire the quadrature phase difference. The use of two feeds with the proper angular separation allows for circular polarisation for the TMz 110 mode on a circular patch. Using two orthogonal coax feeds separated by 90°, Both inside and outside the patch, fields are produced. Because one probe is constantly positioned at a location where the field generated by the other probe displays a null, there is also very minimal mutual coupling between the two probes in this two-probe setup. The two feeds must also be supplied with a 90° time-phase difference between their fields in order to create circular polarisation. The 90° hybrid is used to achieve this. In order to ground the patch to the ground plane, which is not necessary for circular polarisation but is used to suppress modes with no variations and may also enhance the quality of circular polarization, a shorting pin is inserted at the centre of the patch.

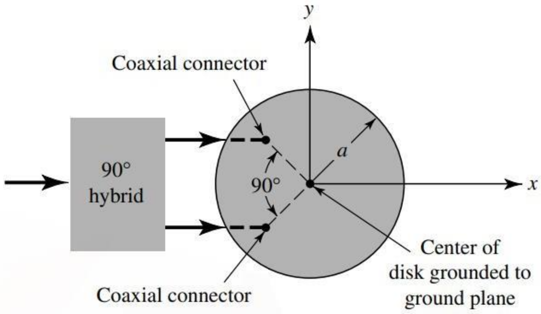


Figure 1.4: Circular Polarization

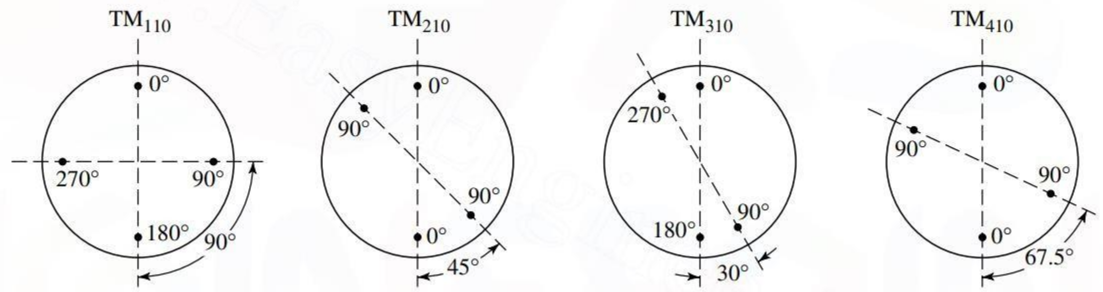


Figure 1.5: Different modes of circular polarization

For higher order modes, a different spacing between the two feeds is required to achieve circular polarisation. In order to maintain symmetry and minimise cross polarization, two additional feed probes placed opposite the original poles are often advocated, especially for relatively thick substrates. The additional probes suppress the neighbouring (adjacent) modes, which often have the next-highest magnitudes. regarding the even modes (TM10 and TM10). The four feed probes should have phases of 0.90.0 and 90, whereas the odd modes (TM10 and TM10) should have phases of 0.90", 180, and 270°.

1.6 Artificial Magnetic Conductor

1.6.1 Introduction

Investigating metamaterial constructions that display unique electromagnetic properties not found in nature has garnered more attention recently. The artificial magnetic conductor (AMC), known as a perfect magnetic conductor, is one of the metamaterial constructions. (PMC). In contrast to a perfect electric conductor (PEC), which has a reflectance of -1, it has a high impedance surface. The frequency or frequencies where the phase of the reflection coefficient is zero degrees define the AMC condition. The reflected wave from the AMC structure is in phase with the incident wave. Additionally, it has been demonstrated that these high impedance structures can smooth out radiation patterns, lessen surface waves, and lessen mutual coupling in array antennas.

1.6.2 Metamaterial

A substance that has been created to have a quality that is not present in naturally occurring materials is known as a metamaterial. They are constructed from composite materials, such as metals or polymers, that are assembled from various parts. On scales lower than the wavelengths of the phenomena they affect, the materials are typically organised in repeating patterns. Metamaterials' qualities come from their newly created structures rather than the attributes of the parent materials. They have smart qualities that allow them to manipulate electromagnetic waves by blocking, absorbing, amplifying, or bending waves to obtain benefits that are superior to those provided by traditional materials because of their precise shape, geometry, size, orientation, and arrangement.

properly constructed sound or radiation that isn't typical of bulk materials. Significant study has been conducted on materials that have an electromagnetic negative index of refraction for specific wavelengths. Negative-index metamaterials are the name for these substances.Optical filters, medical devices, remote aerospace applications, sensor detection and infrastructure monitoring, smart solar power management, crowd control, high-frequency battlefield communication, lenses for high-gain antennas, enhancing ultrasonic sensors, and even earthquake-shielding structures are just a few of the diverse potential uses for metamaterials. The creation of super lenses is a possibility using metamaterials. A lens of this type would enable imaging at resolutions lower than the diffraction limit, which is the lowest that regular glass lenses can produce. The use of gradient-index materials was used to exhibit a type of invisibility. Metamaterials for seismic and acoustic waves are also being studied.

The characteristics for microwave radiation are on the order of millimetres. The most common way to build microwave frequency metamaterials is as arrays of electrically conductive components with the appropriate inductive and capacitive properties. The split-ring resonator is used in one microwave metamaterial.

1.6.3 About AMC

AMCs are a sort of implemented metamaterials that are used in a number of microwave and antenna design applications. The performance of many microwave devices can be improved by utilising the special properties of metamaterials, which do not occur naturally. This article describes recent developments in AMC for antenna applications from a technical standpoint. The theoretical aspects, simulation design processes, and the measurement setup utilised to describe the AMC unit cell are all included in the technical perspective. The inclusion of AMC in different current antenna design works is afterwards found. An artificial, metallic, electromagnetic structure is known as the HIS or AMC. In contrast to traditional metallic conductors, the structure is made to sustain surface wave currents in a selective manner. It has uses for microwave antennas and circuitry.

CHAPTER 2

RADAR SYSTEM

RADAR SYSTEM

2.1 Working of Radar System

RADAR means Radio Detection And Ranging, detection refers to finding whether the target is present or not. The target is movable or stationary while ranging refers to the distance between the radar and the target.

Radars are applicable at various instances – on ground, in space and on sea as well. Few of the applications include sensing of remote places, military applications and controlling the air traffic.

Operation of Radar

- It operates by transmitting electromagnetic waves by directive antennas into a specified volume in space to search for targets.
- These targets reflect a fraction of incident energy back to radar that entails the radar to echo
- The reflected energy is processed by radar receiver to obtain information about the target.

Further, the operation can be understood through the radar block diagram.

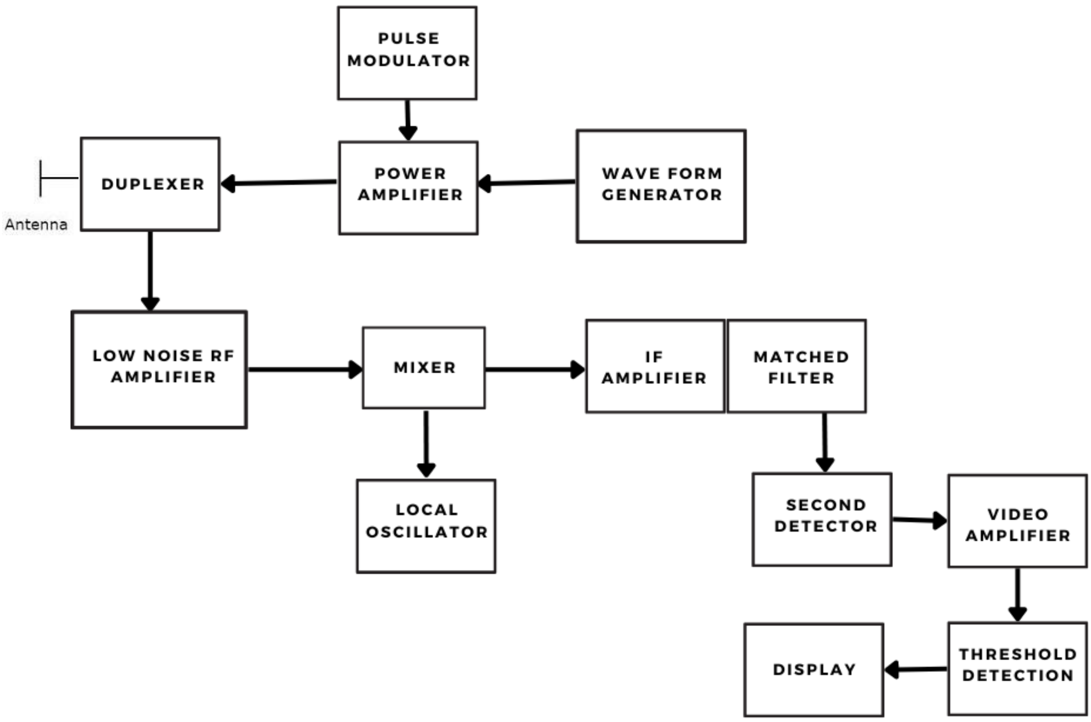


Fig 2.1: Radar Block Diagram

- The duplexer acts as a switch connecting the antenna to the transmitter section for transmission of the signal. It helps in bidirectional communication over a single path
- Low noise RF amplifier amplifies weak RF signal received by the antenna
- Local oscillator produces a signal having stable frequency
- A mixer can produce both sum and difference of the frequencies that are applied to it, among which the difference of the frequency will be of intermediate frequency (IF)

- IF amplifier amplifies the intermediate frequency signal. It allows only the IF obtained from the mixer and amplifies it, improves signal to noise ratio (SNR) at the output.
- Detector demodulates the signal obtained at the output of the IF amplifier
- Display helps us see the amplified video signals on CRT screen
- Pulse modulator is used to build synchronization between the waveform generator and transmitter
- Threshold detection unit makes the decision about existence of the target in space.

2.2 Basic Terminology

2.2.1 Range

The distance between the radar and the target is the range, denoted by R and is given by

$$R = CT/2$$

Where C – speed of the light and T is time taken by the signal to travel from radar to target and back to radar

2.2.2 Maximum Unambiguous Range

We know that Radar signals should be transmitted at every clock pulse. If we select a shorter duration between the two clock pulses, then the echo signal corresponding to present clock pulse will be received after the next clock pulse. Due to this, the range of the target seems to be smaller than the actual range.

So, we have to select the duration between the two clock pulses in such a way that the echo signal corresponding to present clock pulse will be received before the next clock pulse starts. Then, we will get the true range of the target and it is also called maximum unambiguous range of the target or simply, maximum unambiguous range.

Pulse repetition frequency can be determined by the maximum unambiguous range beyond which the targets are not expected.

$$R_{un} = C/2f_p = CT_p/2$$

Echoes arriving from ranges greater than $2R_{un}$ are called multiple time around echoes.

2.2.3 Pulse Repetition Frequency

Radar signals should be transmitted at every clock pulse. The duration between the two clock pulses should be properly chosen in such a way that the echo signal corresponding to present clock pulse should be received before the next clock pulse. A typical radar wave form is shown in the following figure.

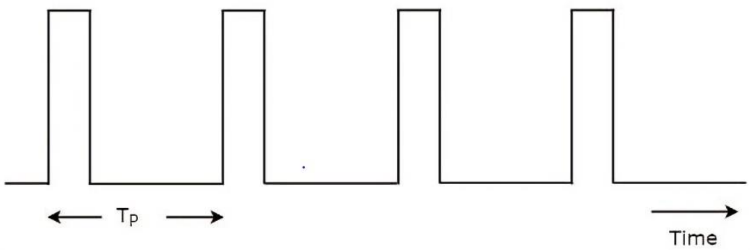


Figure 2.2: Pulse Repetition Frequency

Radar transmits a periodic signal and it is having a series of narrow rectangular-shaped pulses. The time interval between the successive clock pulses is called pulse repetition time, T_p .

The reciprocal of pulse repetition time is called pulse repetition frequency, f_p . It can be mathematically represented as

$$f_p = 1/T_p$$

2.2.4 Minimum range

We are aware that each clock pulse should result in the transmission of a radar signal. The echo signal corresponding to the current clock pulse will be received after the subsequent clock pulse if we choose a shorter time interval between the two clock pulses. As a result, the target's range appears to be shorter than it actually is.

Hence, we must choose the time interval between the two clock pulses so that the echo signal corresponding to the current clock pulse will be received before the beginning of the next clock pulse. The target's actual range, also known as the target's maximum unambiguous range or just maximum unambiguous range, will then be shown.

$$R_{min} = CT/2$$

2.3 Types of Radars

2.3.1 Pulse Radar

The radar which operates with pulse signal for detecting stationary targets, is called the Pulse Radar. With the aid of a duplexer, it employs a single antenna to transmit and receive signals.

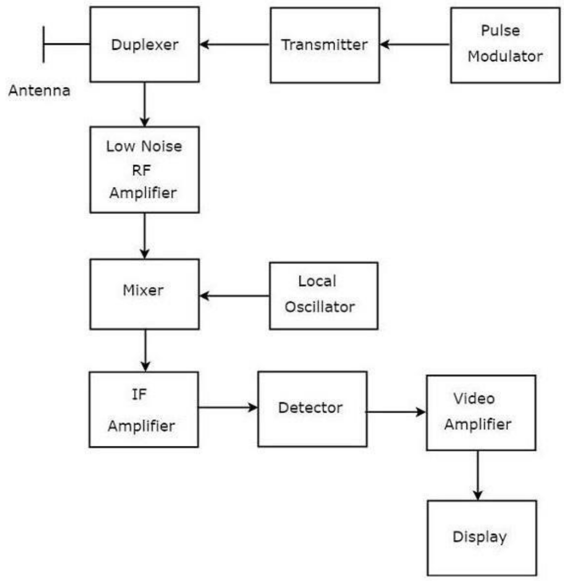


Fig 2.3: Pulse Radar Block Diagram

Every time the clock pulses, the antenna will send out a pulse signal. It is important to choose the time interval between the two clock pulses so that the echo signal corresponding to the current clock pulse is received before the next clock pulse.

2.3.2 Continuous Wave Radar

Simple radar transmits and receives signals using the same antenna. When the target is stationary and/or the radar can be operated with a pulse signal, we can use this sort of radar.

Continuous Wave Radar, or simply CW Radar, is a type of radar that uses a continuous signal (wave) to detect moving targets. Two antennas are needed for this radar. Wherein one antenna is used for signal transmission and the other antenna is used for signal reception.

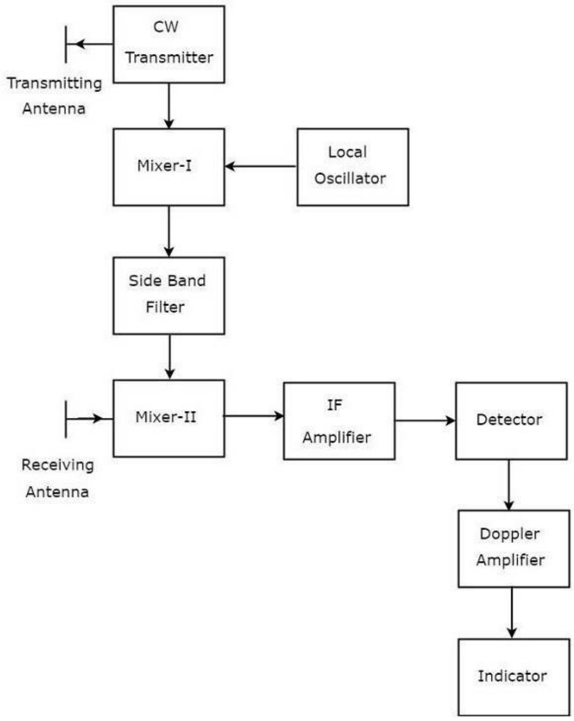


Fig 2.4: Block diagram of CW Radar

Continuous wave radars are classified into two types -:

- **Unmodulated Continuous Wave Radar -** Unmodulated Continuous Wave Radar is a type of radar that uses a continuous signal (wave) to find moving targets. It also goes by the name CW Doppler Radar. Two antennas are needed for this radar. One of these two antennas is used for signal transmission, and the other antenna is utilised for signal reception. Target distance from the radar is not measured; only the target's speed is.
- **Frequency Modulated Continuous Wave Radar -** If CW Doppler Radar uses the Frequency Modulation, then that Radar is called the Frequency Modulated Continuous Wave (FMCW)

2.3.3 FMCW Radar

FMCW Radar contains two antennas − transmitting Antenna and receiving antenna. The transmitting Antenna transmits the signal and the receiving Antenna receives the echo signal. Together with the target's speed, it also calculates how far away the target is from the radar.

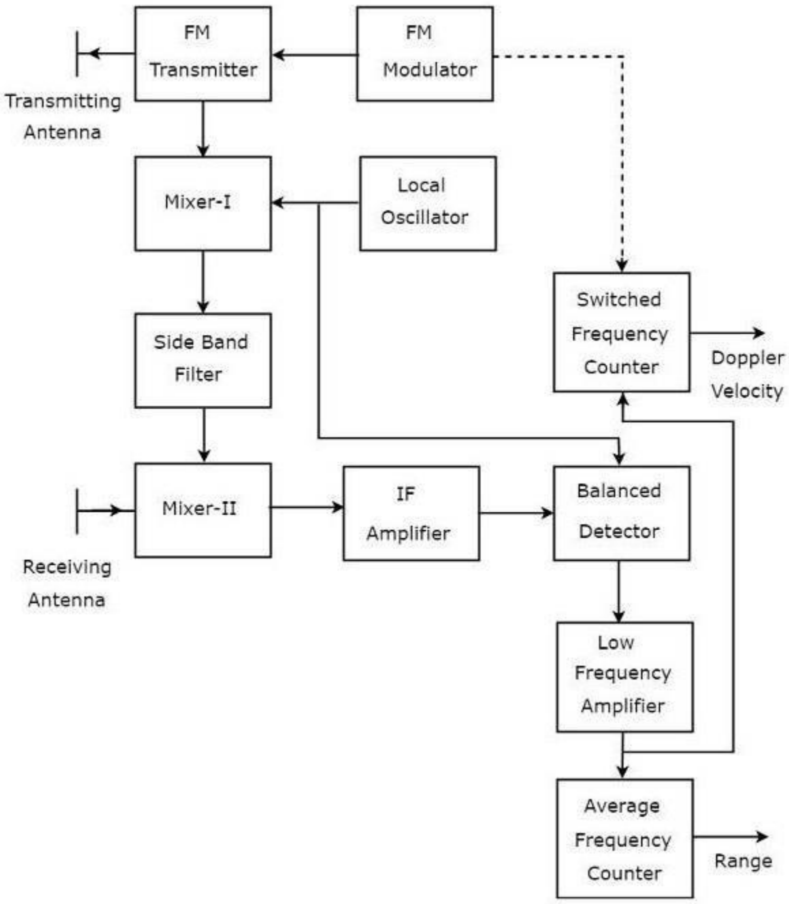


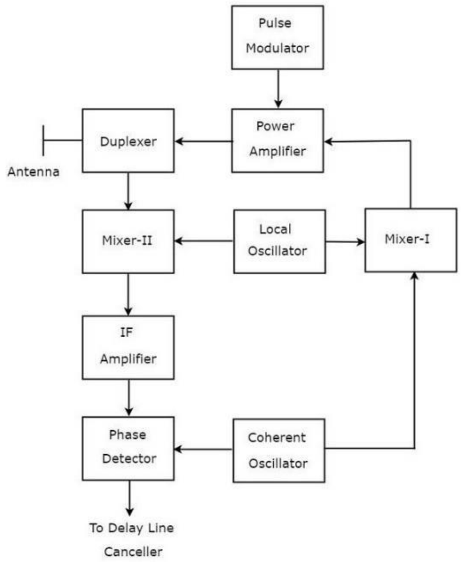
Fig 2.5: Block Diagram of FMCW Radar

2.3.4 MTI Radar

The radar which operates with pulse signal for detecting non-stationary targets, is called Moving Target Indication Radar (MTI Radar). It transmits and receives signals using a single antenna with the help of a duplexer. MTI Radar distinguishes between stationary and non-stationary targets using the Doppler effect hypothesis.

Radar should only pick up an echo signal from a moving object if one is being detected by it. This is the expected echo signal. In practice, radar detects both the echo signal from stationary objects and the echo signal from the moving target. The echo signals produced by immovable objects (locations) such as land and water are referred to as clutters since they are unwelcome signals. We must thus choose the radar in such a way that it only takes into account the echo signal caused by mobile targets and ignores clutters.

Radar uses the Doppler Effect concept to accomplish this by telling fixed objects and moving targets apart. Moving Target Indicator Radar, or simply MTI Radar, is the name of this kind of radar. The Doppler effect states that if a target is moving in the radar's direction, the frequency of the signal received will rise. In a similar vein, the frequency of the signal received will decrease if the object is moving away from the radar.



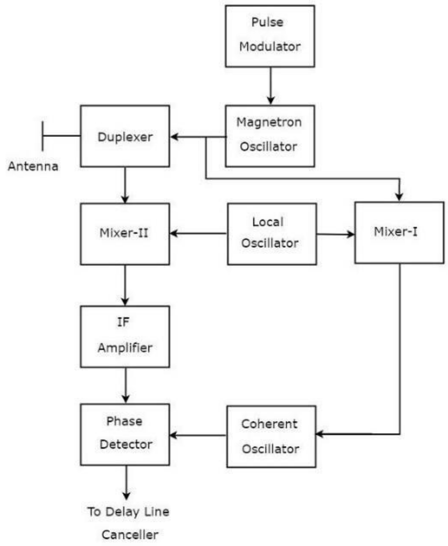


Fig 2.6: MTI Radar with Power Amplifier Transmitter

Fig 2.7: MTI Radar with Power Oscillator Transmitter

2.4 Radar Cross Section (RCS)

2.4.1 Introduction

Radar uses radio wave pulses that are reflected back to the source by objects to detect the existence, direction, distance, and speed of airplanes, ships, and other things. A short, intense burst of radio waves at high frequency is produced by a radar system and directed at an intended target. The waves then bounce off the target and return some of the reflected power to the radar system, where a special signal processing component calculates the precise distance to the target.

Radar cross section (RCS) refers to the estimation of the backscattered radar signals from target in the direction of the receiver and is given by the formula:

$$\sigma = 4\pi R^2 \lim_{\mathrm{R}\to\infty} \left(\frac{P_{\mathrm{Dr}}}{P_{\mathrm{Di}}}\right)$$

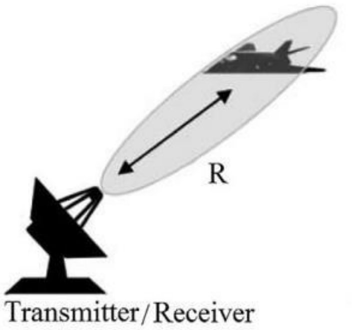
where at a distance of R from the target, PDi is the power density of the incident waves, and PDr is the power density of the reflected waves at the receiving antenna. It is assumed in this equation that the receiving antenna is in the far field (i.e., distant from the target), that the backscattered waves at the receiving antenna are planar, and that is expressed in square metres.

RCS is composed of three factors: the material from which the vehicle is made from, the size of the object and the angle of incidence.

Let us assume the directions of the incident and backscattered waves as the angles (θi, φi) and (θs, φs) respectively. Based on θs and θi, the target RCS is considered either as monostatic or bistatic.

- When θs = θi and φs = φi, the target RCS is said to be monostatic. Transmitter and receiver are located in the same place which is illustrated in Figure 1(a)

- When θs ≠ θi and/or φs ≠ φi, the target RCS is said to be bistatic. This means that the radar transmitter and receiver are located in a distance from each other which is illustrated in Figure 1(b).



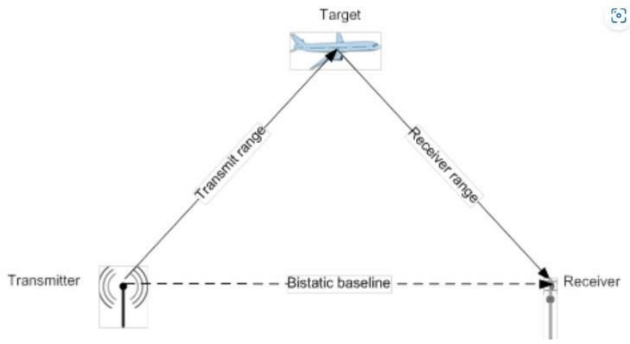


Figure (a)

Figure (b)

Figure 2.8(a) Monostatic RCS (b) Bistatic RCS

2.4.2 Radar Cross Section Reduction (RCSR)

The target RCS should be reduced to reduce detectability and visibility by reducing the backscattered EM energy. This is known as RCSR. This aids in increasing the surveillance security and increase the survivability by evading detection.

RCS reduction can be achieved using two basic mechanisms: scattering and absorption. Scattering deflects the incident signal wave form the wave from the radar while absorption dissipates all or part of the incident is an absorbing layer. Shaping works via scattering mechanism – it is a high frequency technique. Its main objective is designing the geometrical configuration of the target such that the backscattered wave toward the radar is minimized. Radar absorbing material works via absorption – it is specifically designed to absorb the incident signals hitting the object. Consider the example of an aircraft, as the radar waves hit the exterior of a plane, oscillations are induced within the coating that alternates the magnetic field of the RAM resulting in radar signals being converted into heat. This blocks the signals from being reflected back to the source, thus, ensuring low detectability.
A metasurface is a periodic or aperiodic array of subwavelength resonant scatterers that influence the electromagnetic response of the surface. These metasurfaces are arranged in multitude of arrangements to backscatter the incident waves. Metasurfaces are based on both scattering and absorption. Scattering based metasurfaces and absorption based metasurfaces are further discussed in section 4(a) and 4(b) respectively.

The RCSR methods are classified majorly into two fields:

i. Active RCSR
ii. Passive RCSR

Active RCSR -: The RCS measurement is influenced by the target's structure as well as the antennas and sensors placed there. This method measures and records the target's structural RCS, echo characteristics, and antenna RCS; however, the target must be capable of detecting the incident wave's amplitude, frequency, phase, and angle of arrival. The target is then rendered invisible to radar by the phased array put on it, which produces a new correct waveform that is coincident with the incoming wave and cancels the reflected wave in the array and sensor-based systems. Combining both software-based (signal processing) and hardware-based methods, this procedure is completed. (using control module of the phased-array and high-speed microelectronic system).This is most suitable technique for low frequencies that can be utilized for multiple target incidences from hostile sources. Its disadvantages include high fabrication complexity and cost and narrow bandwidth, and its difficulties increase with increasing the frequency

Passive RCSR -: These techniques are performed in three main ways to reduce the backscattered wave in the direction of radar receiver:
1. Absorbing the incoming wave energy so that no backscattered wave reaches the radar receiver
2. Redirecting or cancelation of the incident wave by altering the characteristics of the reflected wave (such as reflection phase, amplitude, and polarization) from different parts of the target

2.4.3 Applications of RCSR

Radars are used to are used to track aircraft and ships, detect insects and animals, measure automobiles' speed, and predict weather conditions. RCS reduction is vividly applicable in

- military operations, RCS reduction prevents them from being attacked
- aircraft hangars
- stealth technology
- Reducing the antennas mounted on aircrafts and ships, RCS reducing structures are designed without affecting the radiation characteristics of the antenna.

2.4.4 Classification

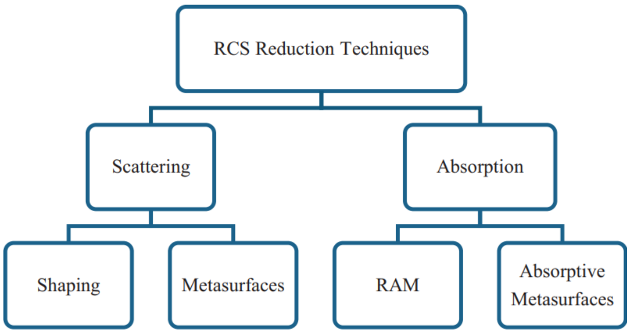


Fig 2.9: Classification of RCS Reduction Techniques

Shaping is most effective in monostatic radars. It can be implemented in two ways:

- By implementing a compact, smooth, blended external geometry to minimize glint.
- By employing a faceted configuration to minimize reflections back to the illuminating radar.

Limitations of shaping would be that it effects incident waves over a limited bandwidth and angles of incidence. This can be improved using sophiscated gradient shapes but this would affect the target's internal volume and stability.

Radar absorbing materials (RAM) can modelled based on impedance matching and resonance. Pyramidal, tapered, and matched impedance-matching RAMs are the three varieties. These substances generate heat from the incident radar energy. The transition layer's impedances and thickness must match those of the two impedances. The incident and absorbing media's impedances are mismatched in resonant RAMs. At the first interface, the arrangement causes reflection and transmission. Limitations include the fact that they are frequently thick, pricey, and only reduce RCS over a limited bandwidth. The bulkiness of the structure can be increased to increase bandwidth.

2.5 Types of RCS Reduction

2.5.1 RCS Reduction based on Scattering Metasurfaces

There are six different types of RCS reduction techniques based upon scattering metasurfaces that will be elaborated in the following sections:

- Phase Gradient Metasurfaces (PGMS)
- Checkerboard Metasurfaces (CMS)
- Polarization Conversion Metasurface (PCMS)
- Coding Based Metasurface
- Reconfigurable Metasurface
- Time Varying Metasurface

2.5.2 Phase Gradient Metasurfaces (PGMS)

The PGMS work on the principle of anomalous reflection and conversion of propagating wave to surface wave. The phase gradient metasurface is obtained by repeating a tile that is formed using elements with varying phases arranged in a gradient fashion. The working principle of PGMS is based on generalised Snell's law that states that a surface with phase discontinuity deflects the signal away from the specular direction. The basic element of PGM is a super cell that consists of six unit cells. Each unit cell is made up of a metal-substrate-metal configuration, with the bottom layer being a 0.5 mm thick dielectric substrate and the top layer consisting of a split-ring resonator (SRR) structure and a full metallic film. To achieve the anomalous reflection at two different frequencies, the six unit cells are positioned alternately along the y-axis. The outcomes of both simulations and trials show that the proposed PGM will stray from the waves' initial propagation route. Because of its high cost, graphene cannot be employed to achieve adjustable perfect absorption.

The working mechanism can be illustrated using ki – wavenumber of the incident signal and kr – wavenumber of the reflected signal.

- If ki > kr, surface wave coupling takes place, leading the reflected waves to lie along the PGMS plane.
- If ki < kr, anomalous reflection occurs.

Main challenge faced by PGMS is its dependency on size of the unit cell to that of the operating frequency range.

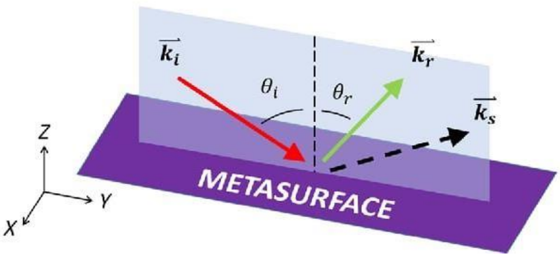


Figure 2.10: Performing anomalous and surface reflection under different scenarios

Table 1: PGMS Comparison Table

Sl. No	Ref.No	Working Type	Simulated	Measured	Array size
1	[3]	Anomalous reflection	a) monostatic b)8.9 GHz and 11.4 GHz	a) monostatic b)8.9 GHz and 11.4 GHz	10.4λ0 × 10.4 λ0
2	[4]	Anomalous reflection	a) monostatic b)9.85-19.37 GHz (65%)	a) monostatic b)9.85-19.37 GHz (65%)	8.25λ0 × 8.25 λ0
3	[5]	Anomalous reflection	a) monostatic/ bistatic b) 9GHz to 40.7GHz (128%)	a) monostatic/ bistatic b) 9 GHz to 40.7 GHz (128%)	19λ0 × 19λ0

2.5.3 Checkerboard Metasurface (CMS)

CMS works on the principle of destructive interference. A pair of sub arrays is alternated in a checkerboard like fashion where each subarray is made of a periodic arrangement of unit cells. The two-unit cells' reflection phases are intended to provide 0 and 180. An artificial magnetic conductor (AMC) and a perfect electric conductor (PEC) are arranged in a checkerboard pattern where the AMC and PEC, which reflect signals with 0° and 180° phase, respectively, cancel out the far-field fields and reduce RCS.

The AMC-AMC-based CMS had a broader bandwidth than the AMC-PEC pair, according to the authors' comparison of an AMC-PEC pair and an AMC-AMC pair [3]. By maintaining a 180 ± 30◦ phase difference between two AMCs, a 32% bandwidth was reported in [6].

In the design presented in this study [9], geometrical simplicity is advantageous while also reducing overall thickness (for the current design, /16). The design is likewise based on the arrangement of AMC and PEC cells in a manner akin to a chessboard. Since the AMC and PEC reflections cancel out for any typical incident plane wave in this situation because of their opposite phase, RCS is decreased.
RCS reduction bandwidth can be enhanced by appropriate choice of elements and surface wave suppression.

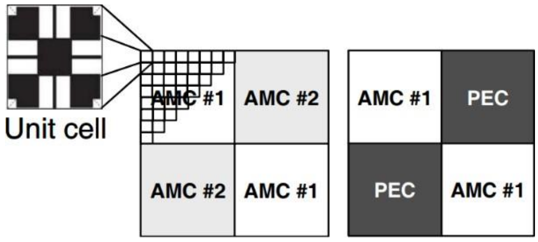


Figure 2.11: Unit combination in two different 2×2 chessboard-like geometrics: AMC#1,2 and AMC#1 PEC.

Table 2: Checkerboard Comparison Table

Sl. No	Ref.No	Simulated	Measured	Array size	Unit Cell
1	[6]	a) Monostatic/ bistatic b) 15.32 GHz	a) Monostatic/ bistatic b) 15.32 GHz	22λ0 × 14λ0	1λ0 × 1λ0
2	[7]	a) Monostatic b) 5.78 GHz	a) Monostatic b) 5.78 GHz	3.5λ0 × 3.5λ0	0.18λ0 × 0.18λ0
3	[8]	a) Monostatic/ bistatic b) 3.78–10.08 GHz (90.9%)	a) Monostatic b)3.77–10.14 GHz (91.5%)	2.98λ0 × 2.98λ0	0.37λ0 × 0.37λ0

2.5.4 Polarization Conversion Metasurface (PCMS)

The primary purpose of polarisation is to decrease a metal surface's monostatic radar cross section (RCS). In accordance with [8], the incident wave's polarisation is rotated at various angles, causing the reflected wave to become zero in the direction of incidence. Eight different polarisation rotation angles were devised, simulated, and then manufactured as a set. 60% RCS decrease bandwidth between 7.6 and 11.3 GHz was measured in [7]. Verifying the simulation and measurement results is the method used to arrive at the outcome.

The lowering of radar cross section (RCS) is accomplished via a polarisation conversion metasurface (PCM). The advantage of the suggested design is that it simultaneously reduces RCS over broadband while having simple geometry. A cut-wire resonator, which can change a linear polarisation state into its orthogonal, is combined with an oblique split ring resonator (SRR) to form the metasurface. In wideband from 9.4 to 19.2 GHz, the simulation results demonstrate that the 10 dB bandwidth of polarisation conversion is achieved with an average polarisation conversion ratio (PCR) of over 100%. Given an equal-sized PEC ground plane and a high PCR, a 10 dB reduction in RCS can result in a frequency bandwidth reduction of more than 60%. 32.8dB is the maximum reduction.

Table 3: PCMS Comparison Table

Sl No.	Ref No.	a) Monostatic/bistatic b) RCS reduction frequency range — Simulated	a) Monostatic/bistatic b) RCS reduction frequency range — Measured	Array size
1	9	a) Monostatic b) 10.2 to 19.3 GHz	a) Monostatic b) 10.2-19.3 GHz	3.4λ0 × 3.4λ0
2	10	a) Monostatic/bistatic b) 17 GHz–42 GHz c) 10–50 degree	a) Monostatic b) 17GHz–42 GHz	21λ0 × 21λ0

2.5.5 Coding Based Metasurface

To investigate the RCS reduction characteristic, a number of matrix-type random coding MSs are used. A proposed MS coding scheme using various "0" and "1" unit ratios is followed by a theoretical discussion of the various RCS reduction schemes. The designed MSs were simulated to get the scattering patterns under normal incidence and the RCS reduction curves in order to investigate the energy scattering characteristic of random coding sequences. When x- and y-polarized waves were incident on MS samples of coding a and b, the average reflectance was less than 10 dB; however, when normal waves were incident in the frequency range of 5.5–15 GHz, the average RCS reduction was essentially greater than 10 dB. A broadband RCS reduction characteristic is presented by the matrix-type coding MS. It is also possible to get an efficient RCS reduction feature at oblique incidence.

2.5.6 Reconfigurable Metasurface

The major drawback of passive metasurfaces is being operated only at particular fixed frequency bands. Metasurfaces that can be tuned with external triggering circuits were designed to overcome this limitation. Utilizing stimuli-responsive materials that can alter their physical characteristics in reaction to environmental factors, globally adjusted metasurfaces are created. These metasurfaces are made using graphene and liquid crystals. The RCS reduction level is dynamically controlled by the graphene layers, which also help to tune the surface resistance.

A locally tuned metasurface is one whose functional performance has been changed at the unit cell level. To ensure self-adaptability in real-time with respect to change in ambient environment conditions, a smart metasurface was designed. An online feedback algorithm is used to adaptively control and maintain synergy between all the dynamic reactions such as single beam, multi-beam steering.

2.5.7 Time Varying Metasurface

Time-varying metasurfaces are those that are used to manipulate electromagnetic scattering in the time domain. In this technique, to ensure non detectability of the target, an enhancement was made, that is, to spread the incident spectrum into a different frequency band. Momentum is controlled by space-gradient metasurfaces, while space-time-gradient metasurfaces are capable of controlling both the photonic energy and the tangential momentum are controlled by space-time-gradient metasurfaces. In [10], the construction of optical isolators was made possible by the demonstration that time-gradient metasurfaces can end Lorentz reciprocity. Additionally, a universal non-reciprocal variant of Snell's law was derived. When photons contact with a time-varying metasurface, they experience a Doppler-like wavelength shift that results in an energy exchange.

2.5.8 RCS Reduction based on Absorptive Metasurfaces

A phase cancellation and absorption are used to create a dual-mechanism absorptive metasurface with a 20 dB RCS reduction. We organically combine the absorbing and phase cancellation mechanisms to lessen the intensity of the backward echo in both the energy domain and the spatial domain by utilising the reflection phase difference between two absorbing unit cells. In order to execute RCS reduction above 20dB, an absorptive metasurface is constructed by optimising the number of two-unit cells. Experimental and numerical findings support the dual-mechanism absorptive metasurface's wideband, resilience, and significantly lower RCS properties.

CHAPTER 3

MICROSTRIP PATCH ANTENNA

MICROSTRIP PATCH ANTENNA

3.1 INTRODUCTION

In the early 1970s, the microstrip patch antenna initially emerged, and Deschamps' original 1953 idea for the first microstrip antenna was given fresh life. The ease with which microstrip antenna adhere to both planar and non-planar surfaces is one of its main advantages. This was the primary driver behind the microstrip antenna receiving significant research attention in the early 1970s, when high performance applications like those for aircraft, spacecraft, missiles, and satellite communication inspired scientists to examine the practicality of conformal microstrip antennas. Howell unveiled a fundamental rectangular-shaped microstrip antenna after around two years that was fed by microstrip transmission line. At the time, researchers' main area of interest was microstrip antenna.

Radio frequency identification (RFID), broadcast radio, mobile systems, global positioning systems (GPS), television, multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction finding, radar systems, remote sensing, missile guidance, and other applications have all made extensive use of microwave monolithic integrate circuits (MMICs).

A microstrip patch antenna's most basic design consists of a ground plane on one side of a dielectric substrate with a radiating patch on the other. The patch can be constructed in any shape and is made of conductive materials like copper or gold. The patch is chosen to be extremely thin, with a thickness of t and a wavelength in free space of. Researchers presented a wide range of designs. However, obtaining the improved radiation efficiency, which was only allowed to reach 90%, was challenging. Microstrip antennas had a serious issue with narrow bandwidth.

3.2 OVERVIEW OF MICROSTRIP ANTENNA

A transducer called an antenna is used to send or receive electromagnetic waves. Since microstrip antennas outperform traditional microwave antennas in many ways, they are frequently utilised in a variety of real-world settings. Microstrip antennas with simplest configuration are shown in the figure 3.1. It is composed of a ground lane on one side of the dielectric substrate and a radiating patch on the opposite side.

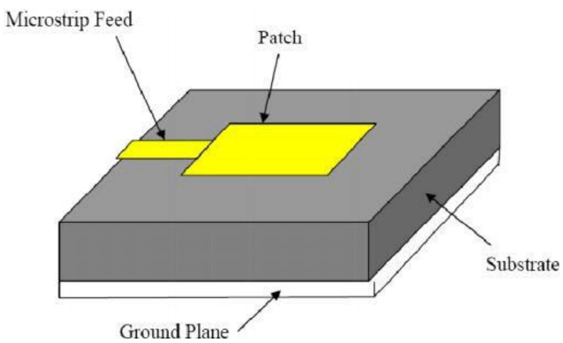


Figure 3.1: Structure of Microstrip Patch Antenna

All microstrip antennas can be divide into four basic categories:

- Micro-strip Patch Antennas

- Micro-strip Dipoles
- Printed Slot Antennas
- Micro-strip Travelling Wave Antennas

The fringing fields between the patch edge and the ground plane are principally responsible for the radiation of microstrip patch antennas. A thick dielectric substrate with a low dielectric constant is preferred for optimal antenna performance because it offers better efficiency, a wider bandwidth, and better radiation. However, this arrangement results in a higher antenna size. Higher dielectric constants must be employed, which is less effective and results in a narrower bandwidth, in order to design a small microstrip antenna. Therefore, a balance between antenna size and performance is required.

Similar criteria can be found in numerous other government and private applications, including wireless communication and mobile radio. Microstrip antennas can be utilised to satisfy these needs. When a specific patch shape and mode are chosen, these antennas are low profile, conformable to planar and non-planar surfaces, mechanically robust when placed on rigid surfaces, and exceedingly adaptable in terms of resonant frequency, polarization, pattern, and impedance. Additionally, adaptive elements with changeable resonant frequency, impedance, polarization, and pattern can be constructed by inserting the load between the patch and ground plane, such as pins.

A microstrip patch antenna consists of the following:

- A radiating patch
- Substrate
- Ground (perfect electric conductor)

An example of microstrip patch antenna with rectangular shaped patch and feed from coaxial feed is shown in the figure below 3.2. The following factors are crucial for designing microstrip patch antennas:

- Shape of the metallic patch
- Substrate thickness
- Substrate dielectric constant and tangent loss
- Type of feed used

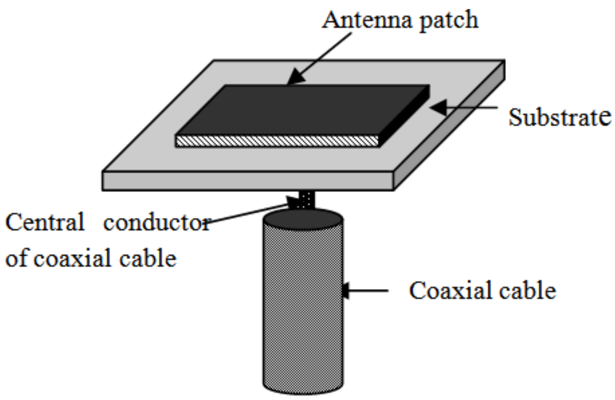


Figure 3.2: Microstrip antenna with coaxial feed

The change of substrate characteristics like height and dielectric constant is the focus of structural technique. We can improve the bandwidth by raising the height. However, it will also introduce surface waves, which worsen performance and characteristics by increasing power loss.

Researchers have developed a variety of techniques, including stacking, ground planes with defects, parasitic patches, and increasing the bandwidth of microstrip antennas. This is still a fascinating area for research. One can easily create an antenna with the necessary frequency radiation pattern and polarisation by selecting a specific form.

3.3 CONFIGURATION

The fringing fields between the patch edge and the ground plane are the main cause of micro-strip patch antennas' radiative properties. A thick dielectric substrate with a low dielectric constant is preferred for optimal antenna performance because it offers better efficiency, a wider bandwidth, and better radiation. However, this arrangement results in a higher antenna size. to create a small design. It is necessary to employ dielectric constants, which are less effective and cause a smaller bandwidth. Therefore, a balance between antenna size and performance is required. On a dielectric substrate, the radiating patch and feed lines are typically photo etched. The patch is typically square, rectangular, circular, triangular, elliptical, or some other common shapes as depicted in fig. 3.3 to facilitate analysis and performance prediction.

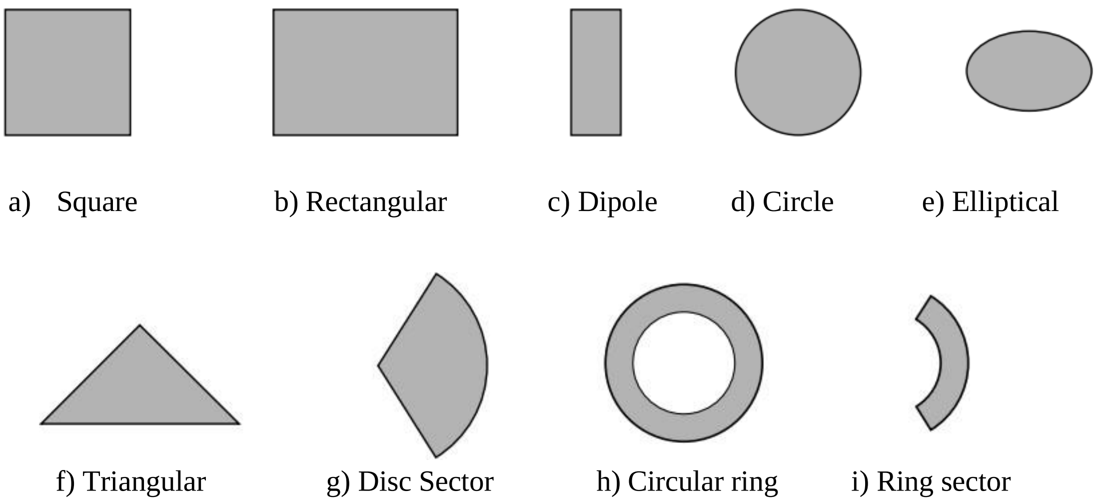


Figure 3.3: Different shapes of microstrip patch antennas

3.4 ADVANTAGES AND DISADVANTAGES

Due to its low-profile design, microstrip patch antennas are becoming more and more common for usage in wireless applications. As a result, they are quite compatible with embedded antennas in hand-held wireless devices including cell phones, pagers, and numerous others. In order to be thin and conformal, the telemetry and communication antennas on missiles are frequently microstrip patch antennas. They have also been effectively applied in satellite communication. Some of their principle advantages are:

- Light weight and low fabrication cost
- Inexpensive and easy to fabricate
- Can be planted easily on any surface
- Easily integrated with microwave integrated circuits
- Suitable to microwave integrated circuits (MICs)
- Capable of dual and triple frequency operations
- Mechanically robust, resistant against vibration and shock

- Low cost
- For high gain and directivity, array of antennas can be easily formed
- Supports both, linear as well as circular polarization.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas that are given below:

- Low efficiency
- Low gain
- Narrow bandwidth and associated tolerance problems
- Extraneous radiation from feeds and junctions
- Poor end fire radiated except tapered slot antennas
- Surface wave excitation
- Low power handling capacity
- Low RF power (not suited for high power applications)
- Complex feed structure for arrays
- High quality factor

The antenna quality factor (Q) of microstrip patch antennas is quite high. A big Q results in a limited bandwidth and poor efficiency since Q stands for the antenna's related losses. By increasing the thickness of the surface wave formed by the total power given by the source, Q can be decreased. Since the surface wave contribution finally scatters at the dielectric bends and degrades the antenna properties, it might be considered an undesired power loss.

3.5 FEEDING TECHNIQUES

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories:

- Contacting
- Non-contacting

  In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such a micro-strip line.

  i. Microstrip line
  ii. Co-axial probe

In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch.

i. Aperture Coupling
ii. Proximity Coupling

3.5.1 Micro-strip Line Feed:

As demonstrated in Figure 3.4, this form of feed approach connects a conducting strip directly to the edge of the microstrip patch. The advantage of this type of feed arrangement is that the feed can be the same substrate to give a planar structure, even though the conducting strip is narrower than the patch.

Without the use of any extra matching components, the inset cut in the patch is intended to match the impedance of the feed line to the patch. By correctly managing the inset position, this is accomplished. As a result, it is a simple feeding scheme since it offers simplicity in modeling, ease of fabrication, and impedance matching. However, this feed has some flaws, including limited bandwidth, surface wave losses, and erroneous feed radiation. Also, surface waves and spurious feed radiation also rise with the thickness of the dielectric substrate being employed, which reduces the antenna's bandwidth. Unwanted cross-polarized radiation is also produced by the feed radiation.

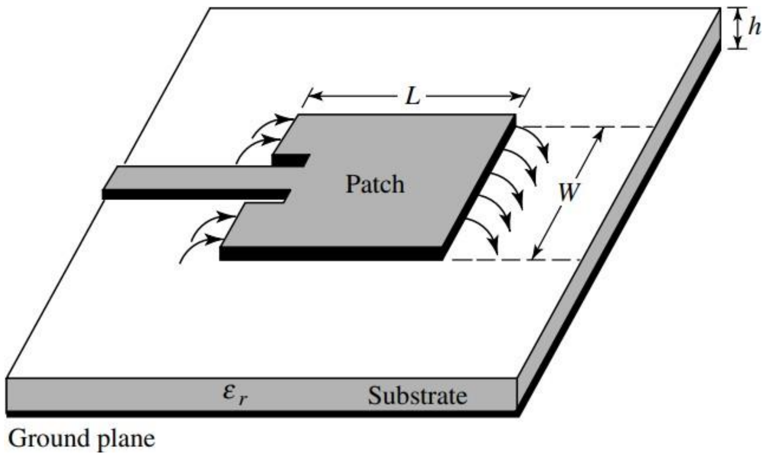


Figure 3.4: Microstrip line feed

3.5.2 Co-axial Feed or Probe:

One of the most popular microstrip antenna feedings. Using solder, the coaxial cable's core is attached to the patch in this method of feeding while the outer cables are connected to the ground. The primary benefit of this kind of feeding arrangement is the flexibility with which the feed can be positioned inside the patch to best match the input impedance. This feed system has little spurious radiation and is simple to manufacture. However, its main drawback is that it has a limited bandwidth and is challenging to model.

To modify the input impedance, the feed's location can be changed. If the height h increases, the inductance introduced by the coaxial feed may need to be taken into consideration. Additionally, the probe will radiate, which could result in radiation coming from unfavourable angles.

Since a hole must be bored in the substrate and the connector sticks out beyond the ground plane, thick substrates (h > 0.02 o) are not entirely flat. Additionally, for thicker substrates, the longer probe causes the input impedance to become more inductive, which causes a matching issue.

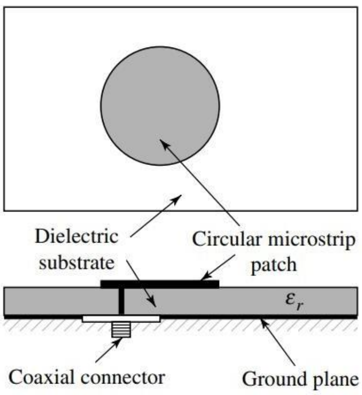


Figure 3.5: Probe Feed

3.5.3 Aperture Coupled Feed

The aperture feed is a further technique of feeding microstrip antennas. In this method, a conducting plane with a hole (aperture) to transmit energy to the antenna shields the feed circuitry (transmission line) from the antenna..

Through an aperture or slit cut out of the ground plane, the energy is electromagnetically connected to the patch. There are many different sorts of aperture shapes, but generally speaking, rectangular and circular shapes are most common. Slots with cross or annular shapes are utilised to excite circular polarisation. To enhance the characteristics of the antenna, slots' parameters are used. In order to achieve superior radiation and bandwidth, substrates for proximity coupled feeding are chosen based on their dielectric constant. For the upper substrate, a thick substrate with a low dielectric constant is employed to obtain good radiation and bandwidth. The upper substrate is made of a thin, highly dielectric substance to provide effective energy transfer from the feed line to the patch. The patch slot should be placed where the magnetic field is strongest in order to get the greatest coupling between the feed structure and the patch slot. We may infer that the magnetic field is strongest in the patch's centre and that the electric field is strongest at the patch's ends based on the current and voltage distribution throughout the length of the patch. A length of extra microstrip feed line is added and used as a stub. Stub admittance is parallel to slot admittance and functions as an open circuit transmission line. The reactive components of the slot can be cancelled out to that of the stub by optimising the length of the extended feed line (stab), which will improve impedance matching.

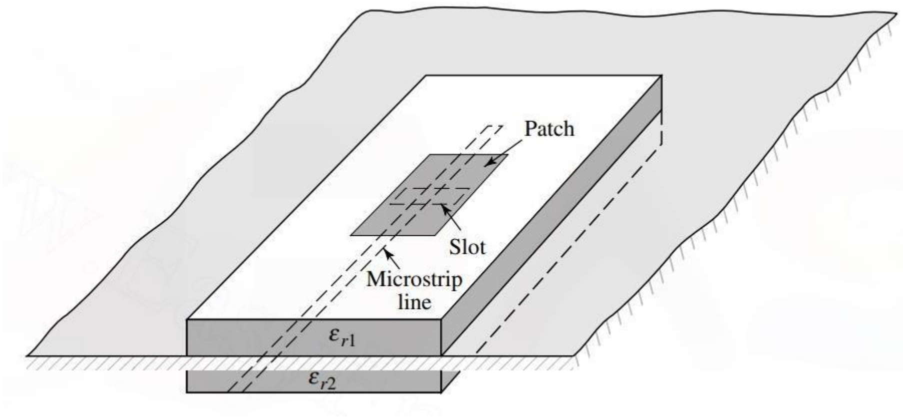


Figure 3.6: Aperture Coupled Feed

3.5.4 Proximity Coupled Feed

This method of feeding employs two different types of dielectric substrates. Microstrip line is sandwiched between the substrates and is not directly attached to the patch; it is left open-ended. The radiating patch receives energy from the feed line via electromagnetic coupling. To enhance bandwidth, a microstrip can be stretched as a stub. The selection of the substrate's dielectric constants plays a key role in increasing bandwidth and reducing spurious feed radiations from the feed line.

Thin substrates with high dielectric constants are chosen for lower substrates while thick materials with low dielectric constants are chosen for upper substrates because the lower the dielectric constant, the greater the fringing field and the greater the radiation from the patch. Although it is simple to model and has no spurious feed radiation, its production is more challenging since the feed line must be precisely aligned. The width to line ratio of the patch and the length of the extended stub can both be optimised to affect the antenna characteristics.

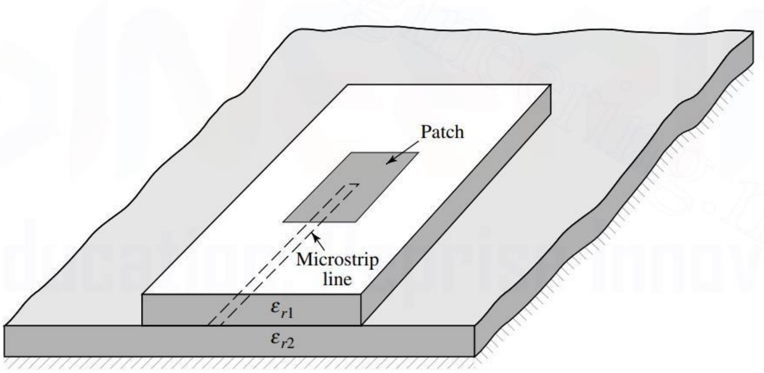


Figure 3.7: Proximity-coupled feed

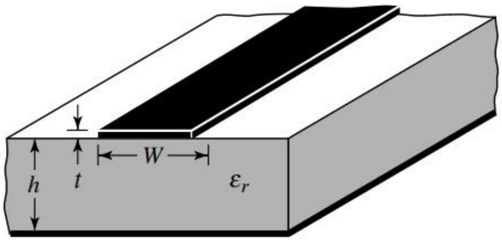
Table 4: Characteristics of Various Feeding Techniques

Characteristics	Micro-strip line feed	Co-axial Probe	Aperture Coupling	Proximity Coupling
Spurious feed Radiation	More	More	Less	Minimum
Reliability	Better	Poor to soldering	Good	Good
Ease of Fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	(2-5)%	(2-5)%	(2-5)%	13%

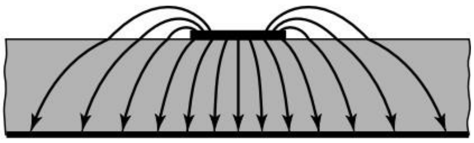
3.6 METHODS OF ANALYSIS

3.6.1 Transmission Line Model

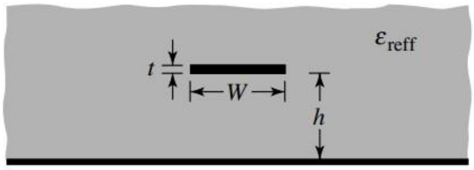
This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non-homogenous line of two dielectrics, typically the substrate and air.



(a) Microstrip line



(b) Electric field lines



(c) Effective dielectric constant

Figure 3.8: Transmission line model

Figure (b) shows that the majority of the electric field lines are located in the substrate, with some lines having portions in the air. Since the phase velocities in the air and the substrate would differ, this transmission line cannot support pure transverse electric-magnetic (TEM) mode of transmission. Instead, the quasi-TEM mode would be the predominant mode of propagation. Consequently, in order to take into account the fringing and wave propagation in the line, an effective dielectric constant (r) must be determined. The expression for & reff is given as:

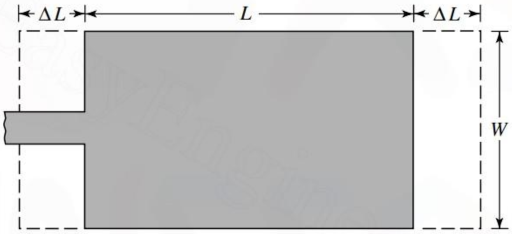
$$\varepsilon_{reff} = \frac{sr+1}{2} + \frac{sr-1}{2}\left[1+12\frac{h}{w}\right] \qquad (3.1)$$

where ε_{reff} = effective dielectric constant

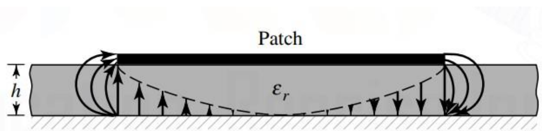
ε_r = dielectric constant of substrate

h = height of dielectric substrate

w = width of the patch



(a) Top view



(b) Side view

Figure 3.9: Top and side view of microstrip antenna

It is seen from figure (b) that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase.

They balance each other out in the broadside direction because the patch is only half as long. Because the tangential components (shown in Figure (b)) are in phase, the combined fields produce the largest radiated field normal to the structure's surface. Since they are 2 apart, excited in phase, and radiate in the half space above the ground plane, the edges along the breadth can be visualised as two radiating slots. The radiating slots along the breadth of the fringing fields can be used to mimic the microstrip antenna's patch, which electrically appears larger than its actual size. The dimensions of the patch along its length have now been extended on tach end by a distance Δ_L, which is given as:

$$\Delta L = 0.412h\frac{(sreff+0.3)(\frac{w}{h}+0.264)}{(sreff-0.258)(\frac{w}{h}+0.8)}$$

3.6.2 Cavity Model

Higher order resonances are displayed by microstrip antennas, which mimic dielectric-loaded cavities. By treating the area as a cavity surrounded by magnetic walls (to simulate an open circuit) around the patch's perimeter and by electric conductors (above and below it), it is possible to find the normalised fields inside the dielectric substrate (between the patch and the ground plane) more precisely. This is an approximation, and it does not radiate any power, leading in theory to a reactive input impedance (of zero or infinite resonance value).

The transmission line model covered in the preceding part is simple to use, but it also has a few drawbacks. It is particularly helpful for rectangular-shaped patches and ignores field changes along radiating borders. The cavity model can be used to get around these drawbacks. Below is a quick description of this model.

In this model, the interior region of the dielectric substrate is modelled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption the following observations for thin substrates ($h \ll \lambda$).

- Due to the thinness of the substrate, there is little variation in the fields in the inner region while looking normal to the patch.
- In the area enclosed by the patch metallization and the ground plane, the magnetic field only has the transverse components, H and H, and the electric field only has z-direction. This finding explains why there are electric walls at the top and bottom.

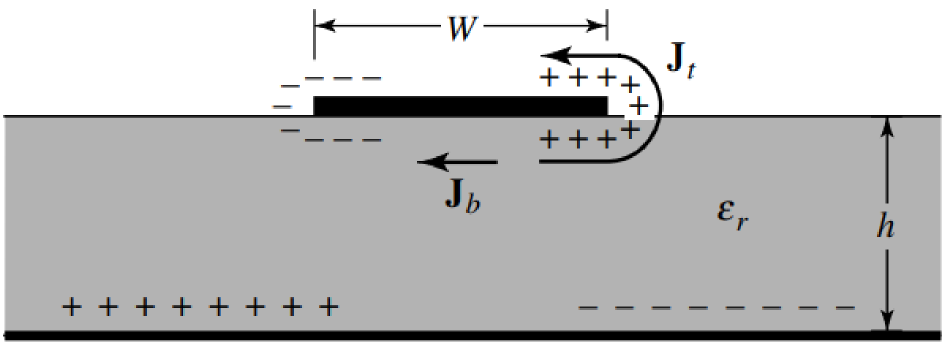


Figure 3.10: Charge distribution and current density creation on microstrip patch

A charge distribution is seen on the upper and lower surfaces of the microstrip patch as well as at the base of the ground plane when the patch is powered. Two mechanisms—an attracting mechanism and a repulsive mechanism—control the distribution of charges. The ground plane and the opposing charges on the bottom side of the patch form an attractive mechanism that aids in maintaining the charge concentration at the bottom of the patch. Similar charges repel each other on the patch's bottom surface, which results in certain charges being pushed up to the patch's top surface. This charge movement causes currents to flow at the patch's top and bottom surfaces.

The attractive process prevails because of the very small height to width ratio in the cavity model, which causes the majority of the charge concentration and current to lie below the patch surface. The top surface of the patch would see much reduced current flow, and when the height to width ratio fell further, nearly no current would be flowing there. This would prevent any tangential magnetic field components from developing at the patch edges. Thus, the four sides might be represented in a model as absolutely magnetic conducting surfaces. This implies that the distribution of the magnetic and electric fields beneath the patch wouldn't be altered. The tangential magnetic fields would not be fully zero in practise due to the finite width to height ratio, but because to their extreme smallness, the side walls might be approximated to be perfectly magnetic conducting.

3.7 APPLICATIONS OF MICRSTRIP ANTENNA

The performance, reliable design, fabrication, and wide use of microstrip patch antennas are widely recognised. The advantages of this microstrip patch antenna outweigh its drawbacks, which include its simplicity in design and light weight, among others. It can be used in a variety of settings, including satellites, rockets, aircraft, missiles, and even military systems. Due to the inexpensive cost of the substrate material and the fabrication, microstrip antennas are becoming more and more common in all kinds of disciplines and industries nowadays.

3.7.1 Mobile and satellite communication application:

Small, inexpensive, low-profile antennas are necessary for mobile communication. All specifications are met by microstrip patch antennas, and numerous varieties of microstrip antennas have been developed for use in mobile communication systems. Circularly polarised radiation patterns are necessary for satellite communication and can be achieved using either a square or circular patch with one or two feed points.

3.7.2 Global Positioning System applications:

These antennas are circularly polarized, small, and highly expensive as a result of their placement. Millions of GPS receivers are anticipated to be utilised by the general public to accurately locate land vehicles, aircraft, and maritime vessels.

3.7.3 Radio Frequency Identification (RFID):

RFID is used in a variety of industries, including manufacturing, transportation, logistics, and health care. Depending on the requirements, RFID systems typically operate from 30 Hz and 5.8 GHz in frequency. A tag or transponder and a transceiver or reader are the basic components of an RFID system.

3.7.4 Worldwide Interoperability for Microwave Access (WiMax):

WiMax is the trade name for the IEEE 802.16 protocol. Theoretically, it has a 30 mile range and a 70 Mbps data rate. Due to the fact that MPA produces three resonant modes at 2.7, 3.3, and 5.3 GHz, it can be employed in WiMax-compliant communication devices.

3.7.5 Radar Application:

Radar can be used to find moving objects, including people and cars. The microstrip antennas are the perfect option because it calls for a low profile, lightweight antenna subsystem. In comparison to conventional antennas, the fabrication process based on photolithography enables the mass manufacture of microstrip antennas with reproducible performance at a cheaper cost in a shorter amount of time.

3.7.6 Rectenna Application:

A rectifying antenna, or rectenna, is a unique kind of antenna that transforms microwave energy directly into DC electricity. An antenna is made up of four separate systems: an antenna, an ore rectification filter, a rectifier, and a post rectification filter. To address the needs of long-distance communications, it is important to build antennas for rectenna applications with extremely high directional qualities. The rectenna's electrical size must be increased in order to achieve the goal of transferring DC power over great distances over wireless networks.

3.7.7 Telemedicine Application:

Antennas used in telemedicine applications operate at 2.45 GHz. Wireless Body Area Network applications are suited for a worn microstrip antenna. (WBAN). The proposed antenna outperformed the other antennas in terms of gain and front-to-back ratio. It also has a semi-directional radiation pattern, which is preferable to an omni-directional pattern for preventing unnecessary radiation from reaching the body of the user, and it meets the requirements for both on-body and off-body applications. Telemedicine applications can benefit from an antenna that resonates at 2.45GHz, with a gain of 6.7 dB, and an F/B ratio of 11.7 dB.

3.7.8 Medicinal applications of patch:

It is found that in the treatment of malignant tumours the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should possess light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the microstrip radiator for inducing hyperthermia was based on the printed dip holes and annular rings which were designed on S-band. And later on the design was based on the circular microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body. A flexible patch applicator can be seen in the figure below which operates at 430 MHz.

CHAPTER 4

ANTENNA DESIGN AND SIMULATION RESULTS

ANTENNA DESIGN AND SIMULATION RESULTS

4.1 HFSS Software

For modelling arbitrary 3D devices, HFSS uses a full-wave high electromagnetic (EM) field simulator and benefits from the well-known Microsoft Windows graphical user interface. Solutions to 3D EM problems are acquired quickly and precisely because to the integration of simulation, visualization, solid modeling, and automation in this environment that is simple to understand. Ansoft HFSS uses graphics, the adaptive meshing approach, and the finite element method (FEM) to solve all 3D EM issues with greater performance and understanding. Parameters like S parameters, resonant frequency, and fields can be calculated using Ansoft HFSS.

There are multiple applications of the HFSS Software. The major applications can be divided into Antenna design and simulation, sensor development, PCB modelling and simulation, electromagnetic interference and compatibility and RF and microwave modelling.

The advanced functionalities of HFSS software can be utilized to model the radar signatures of huge targets and scenes. Fast radar cross section (RCS) calculations can be performed quickly that helps in detecting objects such as vehicles and airplanes, also to minimise the radar detection. In order to promote a seamless and unified workflow for solving these challenging electromagnetic issues, Ansys now offers a single framework for all high-frequency EM solvers. In addition, HFSS offers capabilities for monostatic and bistatic RCS modelling with the use of plane wave excitations for radar signature investigations.

4.1.1 In antennas / mobile communications – Patches, horns, dipoles, conformal cell phone antennas, Helix, specific absorption rate (SAR), infinite arrays, Radar Cross Section (RCS), frequency selective surfaces

- HFSS is an interactive simulation system. This allows us to solve any 3D geometry, especially those with complex curves and shapes, within a short time.
- The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the FEM for EM simulation by implementing techniques such as finite element, adaptive meshing

4.1.2 Electromagnetic Interference and Compatibility – Electronic systems are frequently crucial for safety or mission. They are the foundation of technological advancements around the world, including the Internet of Things, driverless vehicles, and 5G-connected products. The potential of interference resulting in subpar performance, unforeseen consequences, or even failure rises rapidly as performance requirements rise and the number of devices multiplies.

High-performance, safe, and compliant designs can be produced with decreased physical testing thanks to simulation's ability to address EMI/EMC problems beforehand. Installed antenna radiation patterns can be identified for the best positioning to reduce co-site interference using full wave electromagnetic field solvers and a toolbox for electromagnetic interference. Examining the performance of electronic subsystems in electrically expansive surroundings is made possible by cable and circuit simulations, which include shooting and bouncing ray plus techniques and full wave field electromagnetic solvers.

4.2 Antenna Design

For designing a rectangular microstrip patch antenna, we have to select the resonant frequency and a dielectric medium for which antenna is to be designed. The parameters to be calculated are as follows:

Width(W) –

$$W = \frac{V0}{2f0}\sqrt{\frac{2}{\varepsilon_{r+1}}} \qquad (4.1)$$

Length (L) of the patch can be calculated using

$$L = \frac{v0}{2f_r\sqrt{\varepsilon reff}} - 2\Delta L \qquad (4.2)$$

Actual Length (ΔL) – Due to fringing, electrically the size of the antenna is increased by an amount of ΔL

$$\Delta L = 0.412h\,\frac{(\varepsilon+0.3)\,(\frac{w}{h}+0{\cdot}264)}{(\varepsilon-0{\cdot}258)\,(\frac{w}{h}+0.8)} \qquad (4.3)$$

Length (L_g) and width (W_g) of the ground plane can be calculated now as the dimensions of the patch are known. The length and width of a substrate is equal to that of ground plane. The length of a ground plane (L_g) and the width of a ground plane (W_g) are calculated using:

$$L_g = 6h + L \qquad (4.4)$$
$$W_g = 6h + W \qquad (4.5)$$

For feeding the microstrip patch antenna, there are different methods for example, feed line method, coaxial probe feeding method, etc. Mostly coaxial probe method is used.

4.2.1 Design of a rectangular microstrip patch antenna with strip line feed

The geometry of the patch antenna is shown in the figure 4.1 which is a mm x mm. The antenna is fabricated on a substrate of FR4 epoxy with dielectric constant (ε_r) = 4.4 and substrate height = 1.6 mm at an operating frequency of 5.5 GHz

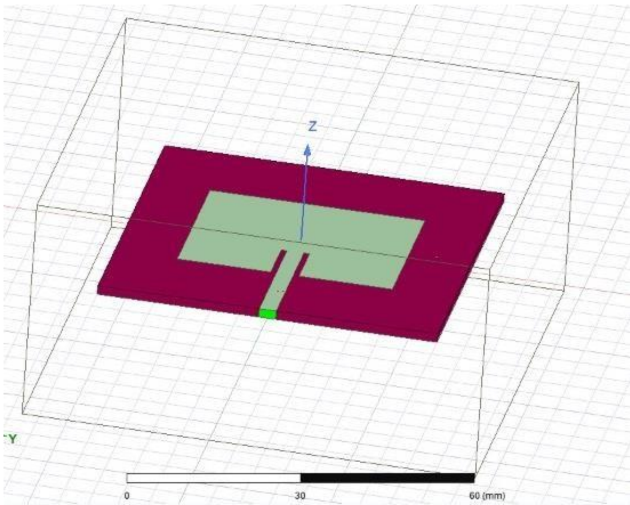


Fig 4.1 Rectangular microstrip patch antenna with strip line feed

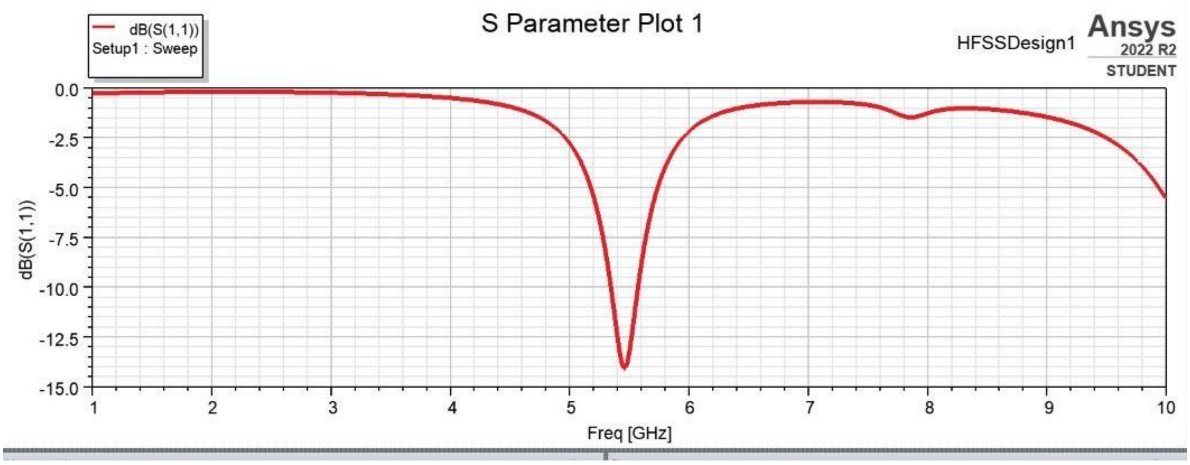


Fig 4.2 S_{11} (dB) of a Rectangular Microstrip Patch Antenna with Stripline Feed

4.2.2 Design of microstrip patch antenna with coaxial feed (reference antenna)

The geometry of the patch antenna is shown in the figure 4.3 which is a 95 mm x 95 mm. The antenna is fabricated on a substrate of FR4 epoxy with dielectric constant (ε_r) = 4.4 and substrate height = 1.6 mm. Coaxial feed of radius 0.5 mm.

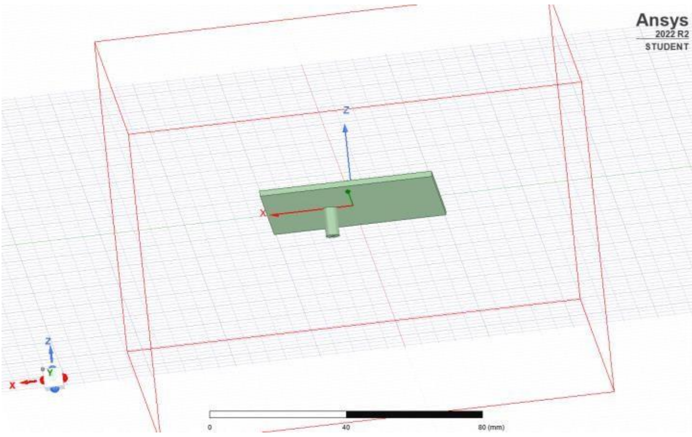


Fig 4.3 Rectangular microstrip patch antenna with coaxial feed

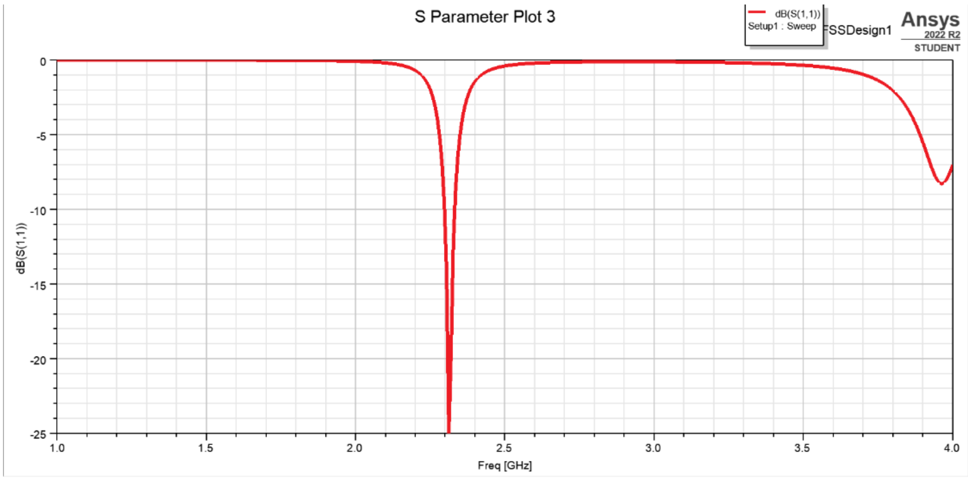


Fig 4.4 S_{11} (dB) of a Rectangular Microstrip Patch Antenna with Coaxial Feed

4.2.3 Design of metasurface unit cell

In order to get around the challenges that metamaterials face, thin-films called metasurfaces were first created. To observe and compare the efficiency and performance of the metasurface unit cell, we designed it in two ways – metasurface unit cell without truncated corners and with truncated corners. The dimensions and the simulated results are illustrated below.

a) **Without truncated corners –** The dimensions of the metasurface unti cell without truncated corners as shown in Figure 4.5 are

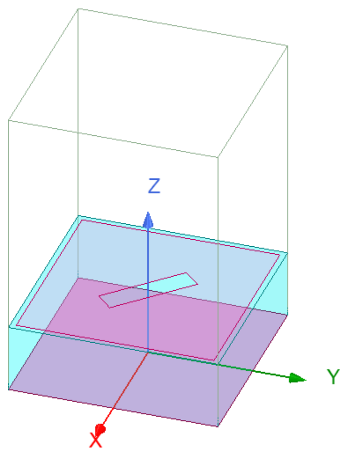
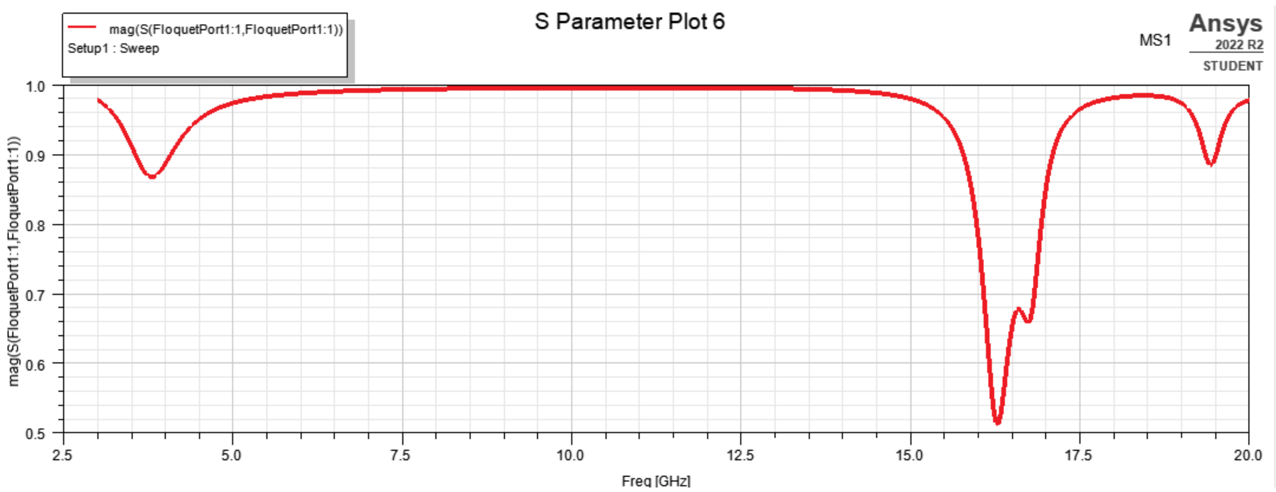
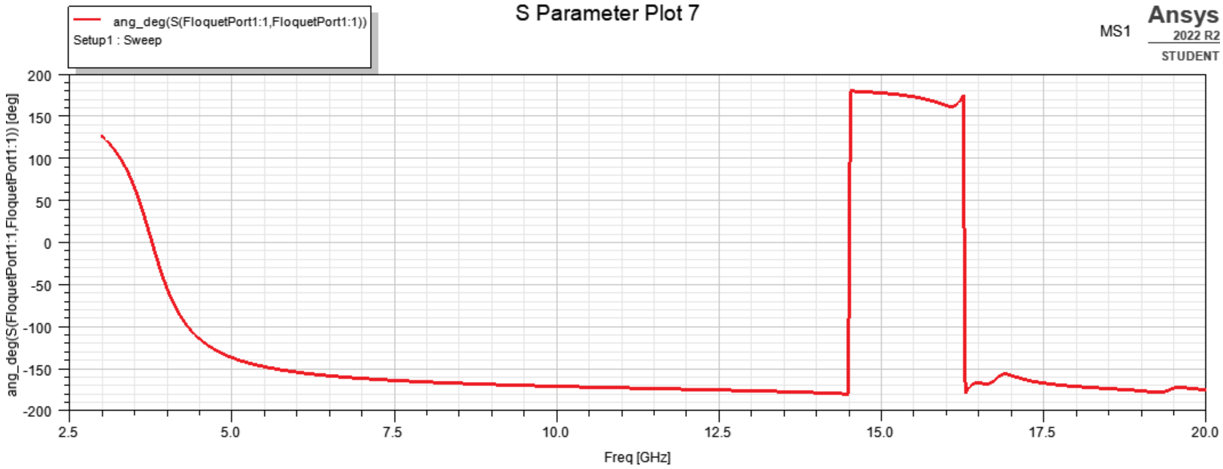


Fig 4.5 Metasurface unit cell without truncated corners



(a)



(b)

Fig 4.6 Simulated results of MS unit cell without truncated corners (a) Reflection magnitudes (b) Reflection phases

The reflection magnitude must be approximately around 1 GHz in order to obtain circular polarization.

b) With truncated corners

For designing the corner-truncated square slotted patch, refer to figure 4.7 where the parameters are p = 9 mm, a = 8.5 mm, b = 3 mm, l_s=4 mm, w_s = 1 mm, h = 3 mm.

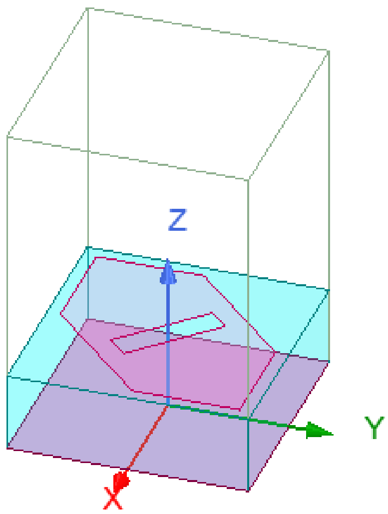
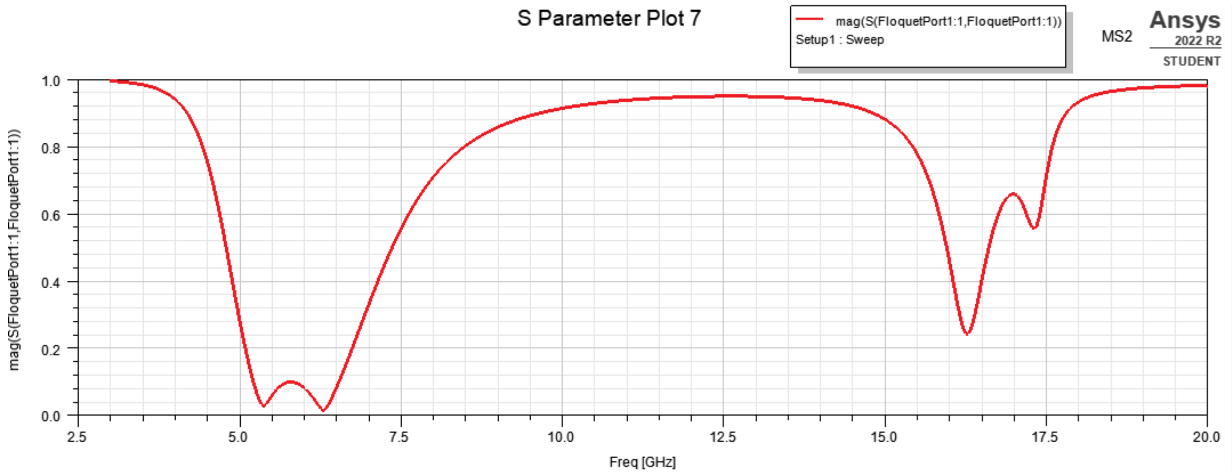
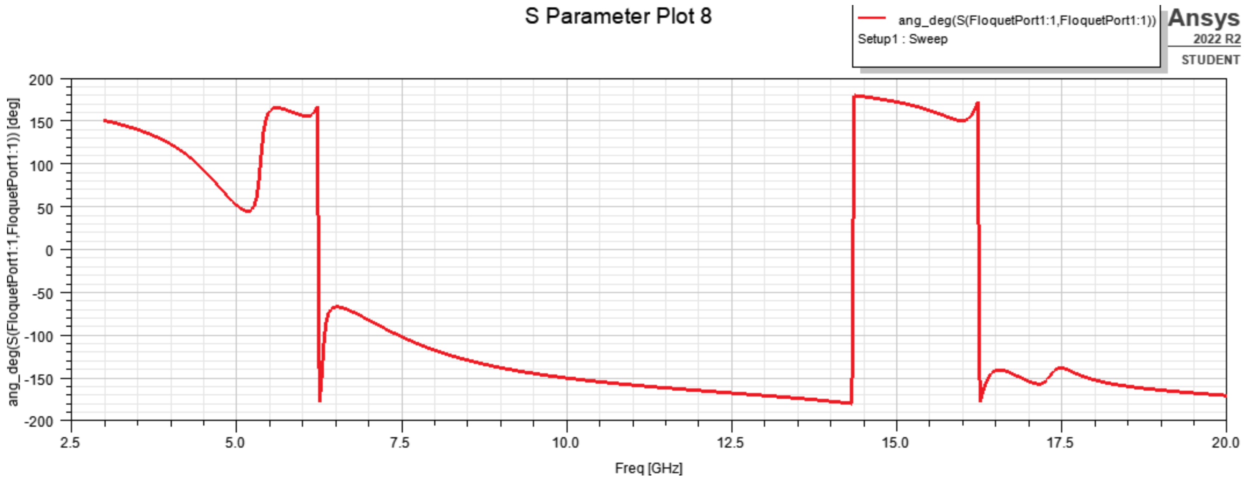


Fig 4.7 Metasurface unit cell with truncated corners

The reflection magnitude and reflection phase plots were simulated and the results are illustrated in the figure 4.8.



(a)



(b)

Fig 4.8 Simulated results of MS unit cell with truncated corners (a) Reflection magnitudes (b) Reflection phases

As mentioned previously, the reflection magnitude is observed to be more compared to that of the MS unit cell without truncated corners. Thus, we use the unit cell with truncated corners to obtain better circular polarization.

4.2.4 Design of the reference antenna

The combination of unit cells are mounted on the substrate of dimensions 95 mm x 95 mm along with the microstrip patch antenna with coaxial feed along with a truncated patch in the center. The dimensions of the truncated patch are: p = 9 mm, a = 8.5 mm, b = 3 mm. The top view of the reference antenna is shown in the figure 4.10.

The simulated results for the reference antenna are illustrated in the figure 4.11. A bandwidth of approximately 1.2 GHz is obtained.

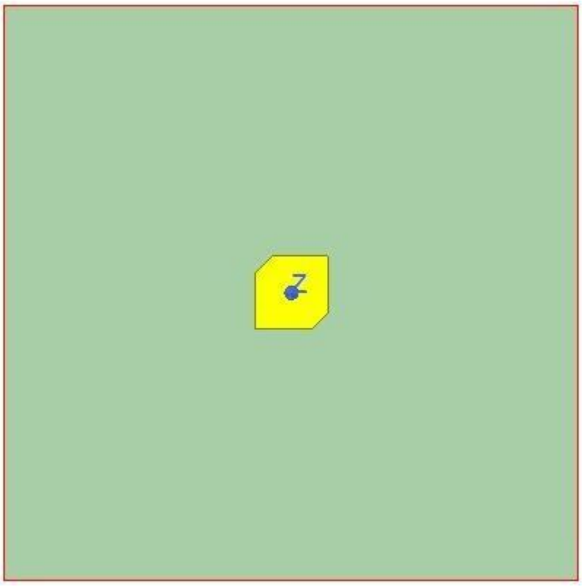


Fig 4.10 Top view of the reference antenna

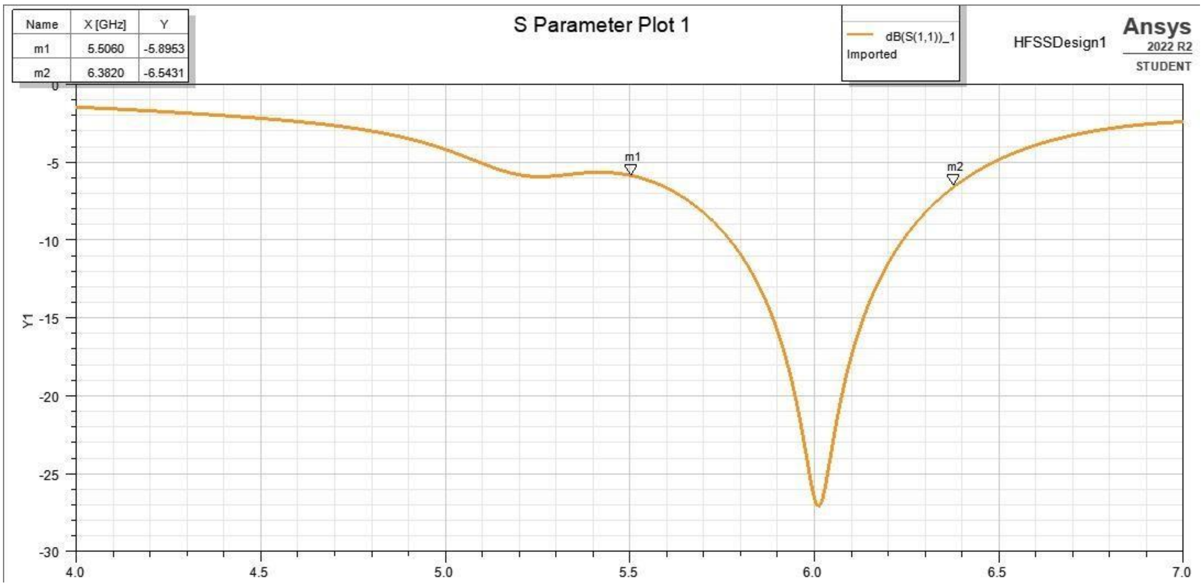


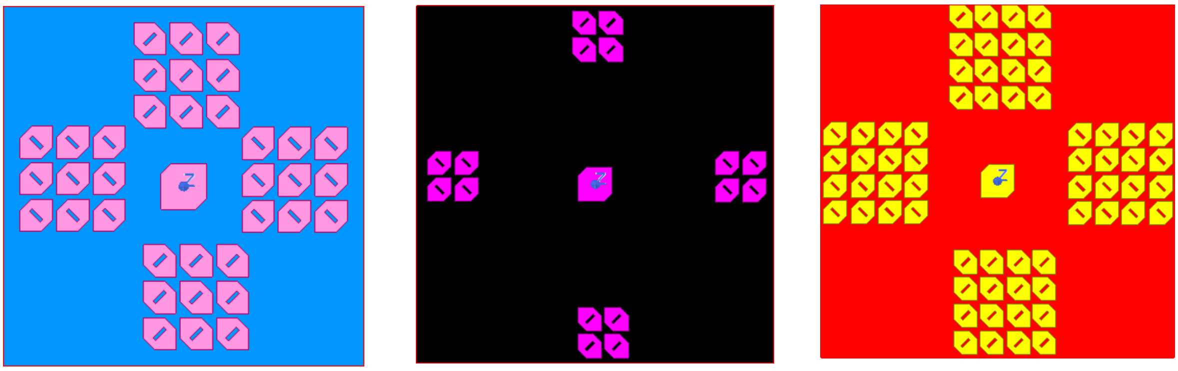
Fig 4.11 S_{11} (dB) parameter plot of the reference antenna

4.2.5 Design of the proposed antenna

The combination of unit cells are mounted on the substrate of dimensions 95 mm x 95 mm along with the microstrip patch antenna with coaxial feed. Parametric analysis has been performed based upon the number of unit cells (n) and the variation in the length of the truncated corners (b). The simulated results are illustrated and explained in the further sections.

(a) Parametric analysis with the variation of n

The parametric analysis of the proposed antenna has been performed with variation in the number of unit cells as shown in Figure 4.9. The simulated results are shown in figure 4.10. As per the simulated results, the antenna with n = 3, has a slightly larger bandwidth (5.52 GHz – 6.22 GHz) compared to other two, it is taken as the proposed antenna.



(a) (b) (c)

Fig 4.9 Layout of Proposed Antenna with n Variation (a) n = 3, (b) n = 2 (c) n = 4

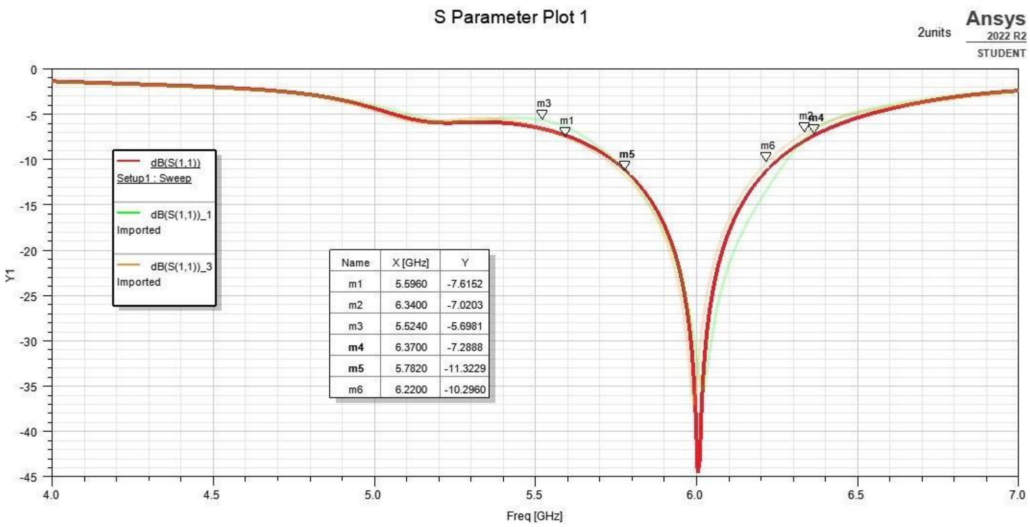


Fig 4.10 S parameter variation with respect to n = 2,3,4

(b) Parametric analysis with the variation of b

The variations were observed when the size of the truncated corners (b) is varied. The designed and the simulated results are shown below in figure 4.15 and 4.16.

A change in the magnitude of resonant frequency is observed along with the variations in the size of the truncated corners.

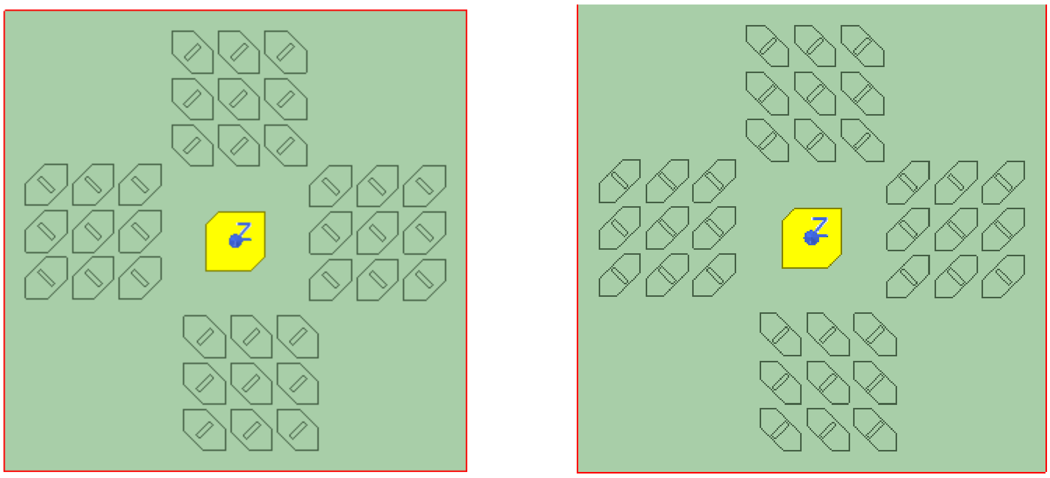


Fig 4.15 Proposed antenna with (a) b = 4 mm (b) b = 5 mm

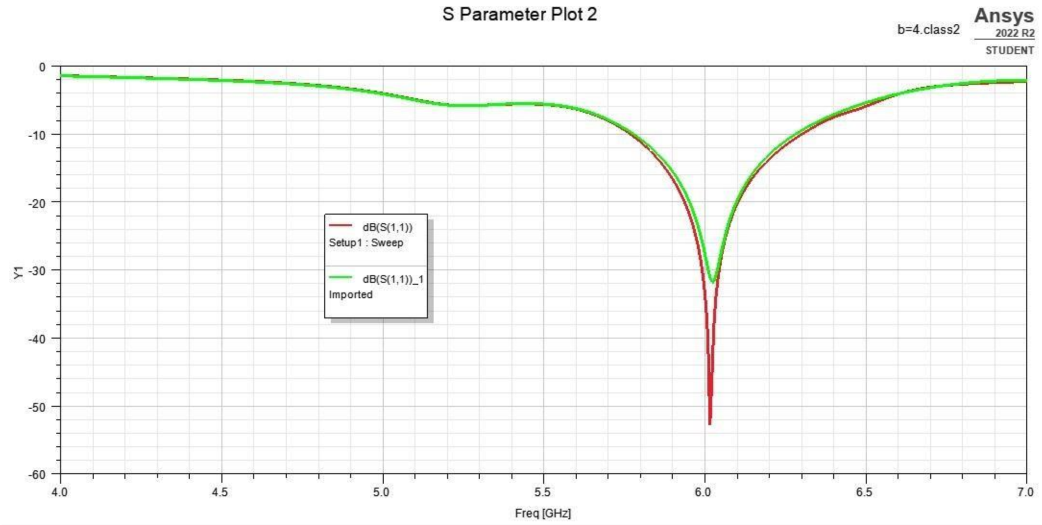


Fig 4.16 Reflection coefficient plot for b = 4 mm and b = 5 mm

(c) Axial Ratio plots

Axial ratio depicts the extent of circular polarization of an antenna. The closer the value of axial ratio towards 0dB the antenna will be much circular polarized. AR=0 dB means perfect CP. AR is the ratio of the magnitudes of the major and minor axis defined by E field vector. The AR (axial ratio) vs frequency (in GHz) was compared by plotting an AR plot. The effect of b (size of truncated corners) on axial ratio is depicted through the plots.

From the simulated results as shown in figure 4.19, the parametric analysis based on b = 3 mm and b = 4 mm has been done. It can be inferred that at b = 3 mm, the green curve in the figure, the value of axial ratio is closer to 0 dB, thus showing that circular polarization is much effective in the design where b = 3 mm.

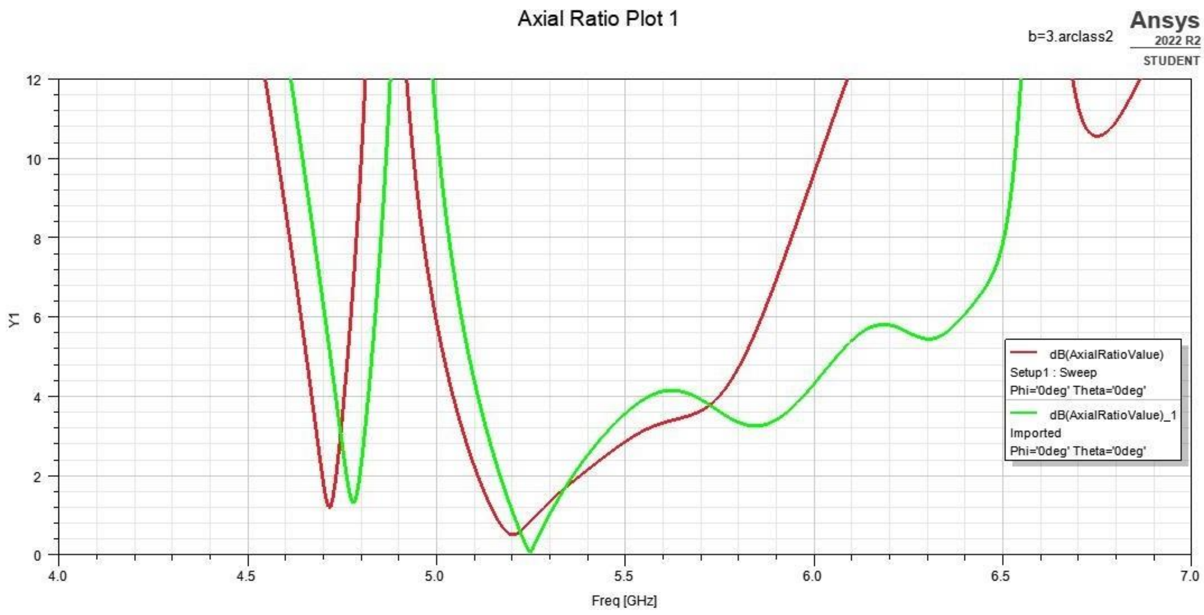


Fig 4.19 Axial Ratio plot for b = 3, 4 mm

(d) Monostatic RCS plot

To get monostatic RCS, an incident wave has been used. The monostatic RCS configuration is characterized by a radar system that transmits a signal and receives the backscattered signal from the object being interrogated at the same site.

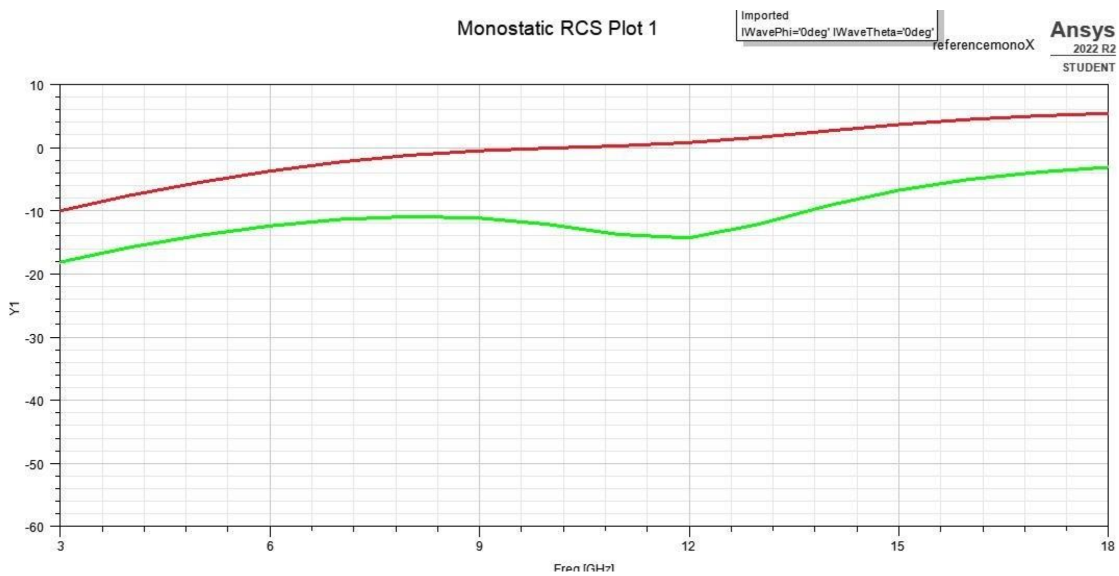


Fig 4.20 Monostatic RCS Plot

From the above figure 4.20, the monostatic RCS is above -10 dB which is not feasible for RCS reduction. For the reference antenna while for the proposed antenna it is below -10 dB.

CONCLUSION

This project reports the design and performance of a metasurface loaded circularly polarized microstrip patch antenna. Two destructive interference principles are combined and implemented in a checkerboard patterned combination of metasurface unit cells. Combining this checkerboard construction with a low-RCS CP patch antenna results in an enhanced 3-dB AR bandwidth and improved gain. In this structure, the proposed antenna can be mounted on desired platform as the structural RCS of an antenna depends on both the antenna as well the platform. The proposed antenna is combined with MS and patch antenna to reduce the overall RCS of the system. A parametric study of the antenna has also been completed to examine the RCS as well as the radiation performance. The designed antenna is quite suitable for its usage in space arrays, where the array elements can be placed in the grounded substrate regions.

References

1. Akila Murugesan, Krishnasamy T. Selvan, *, Ashwin K. Iyer, Kumar V. Srivatsav, and Arokiaswami Alphones, “A Review of Metasurface-Assisted RCS Reduction Techniques”, *Progress In Electromagnetics Research B*, Vol. 94, 75–103, 2021
2. De Cos, M. E., Y. Alvarez-Lopez, and F. L. H. Andres, “A novel approach for RCS reduction using a combination of artificial magnetic conductors,” *Progress In Electromagnetics Research*, Vol. 107, 147–159, 2010.
3. Cheng, Y., C. Wu, J. Yang, X. Peii, F. Jia, and R. Gong, “An ultra-thin dual-band phase-gradient metasurface using hybrid resonant structures for backward RCS reduction,” *Applied Physics B*, Vol. 143, Apr. 18, 2017.
4. Zheng, Q., Y. Li, J. Zhang, J. Wang, H. Ma, Y. Pang, Y. Han, S. Sui, Y. Shen, H. Chen, and S. Qu, “Wideband, wide-angle coding phase gradient metasurfaces based on Pancharatnam-Berry phase,” *Scientific Reports*, Vol. 7, 43543, 2017.
5. Azizi, Y., M. Soleimani, and S. H. Sedighy, “Ultra-wideband radar cross section reduction using amplitude and phase gradient modulated surface,” *Journal of Applied Physics*, Vol. 128, No. 20, 2020.
6. Fu, Y., Y. Li, and N. Yuan, “Wideband composite AMC surfaces for RCS reduction,” *Microwave and Optical Technology Letters*, Vol. 53, No. 4, 712–715, 2011.
7. Jiang, W., Y. Xue, and S.-X. Gong, “Polarization conversion meta surface for broadband radar cross section reduction,” *Progress In Electromagnetics Research Letters*, Vol. 62, 9–15, 2016.
8. Pfeiffer, C. and A. Grbic, “Bianisotropic meta surfaces for optimal polarization control: Analysis and synthesis,” *Physical Review Applied*, 2014
9. Paquay, M., J.-C. Iriarte, I. Ederra, R. Gonzalo, and P. D. Maagt, “Thin AMC structure for radar cross-section reduction,” *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 12, 3630–3638, Dec. 2007.
10. Amr Shaltout, Alexander Kildishev, and Vladimir Shalaev, "Time-varying metasurfaces and Lorentz non-reciprocity," *Opt. Mater. Express 5*, 2459-2467 (2015)
11. Yang, J. J., Y. Z. Cheng, D. Qi, and R. Z. Gong, “Study of energy scattering relation and RCS reduction characteristic of matrix-type coding metasurface,” *Applied Sciences*, Vol. 8, No. 8, 2018.

About Department

The Department of Electronics and Communication Engineering, established during the Academic Year 2001-02 with UG program, M.Tech programme (PG) in VLSI and Embedded Systems with an intake of 18 commenced from 2021-2022. The Department has National and International affiliations with professional bodies like IETE, IEEE etc. The Department has highly qualified and experienced faculty with specializations in Wireless & Mobile Communications, Signal Processing, Radar & Microwave Engineering, Antennas, VLSI Design, Embedded systems and IOT. The department has good infrastructural facilities like spacious labs with adequate hardware and software. The Department has successfully completed one Research Promotion Scheme (RPS) project and one Faculty Development Program (FDP) funded by AICTE. The faculty members are actively involved in research and are publishing papers in reputed national and International Conferences / Journals

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A Review of RCS Reduction Techniques Using Metasurface

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***Abstract*— This paper reviews the techniques of RCS reduction of a target incorporating metasurfaces.** The **existing RCS reduction techniques are classified and described** in this paper**. In this comparative review, RCS reduction methods are categorized based on their electromagnetic behavior and its shape. The traditional methods, shaping and radar absorbing material (RAM) are described in section 3. A separate section is allocated for various RCS reduction techniques based on scattering and absorptive metasurfaces. Moreover, the techniques, phase gradient metasurfaces (PGMS), checkerboard metasurfaces (CMS), polarization conversion metasurfaces (PCMS), coding based metasurfaces(COM) and reconfigurable metasurfaces (RMS) are explained and analyzed based on bandwidth and profile.**

Keywords—RCS, Metasurfaces, shaping, radar absorbing material

I. INTRODUCTION

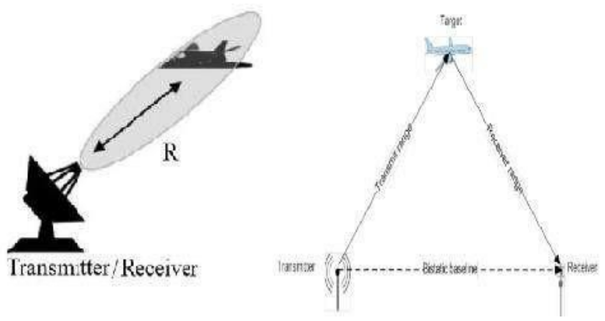
Radar uses radio wave pulses that are reflected back to the source by objects to detect the existence, direction, distance, and speed of aeroplanes, ships, and other things. Radar system will generate a short high intensity burst of high frequency radio waves towards an intended target, these waves will then bounce off an object and return some amount of reflected power to the radar system where special signal processing element will determine exactly how far away the object is.

Radar cross section (RCS), [1] refers to the estimation of the backscattered radar signals from target in the direction of the receiver and is given by the formula (1)

$$\sigma = 4\pi R^2 \lim_{R\to\infty}\left(\frac{P_{Dr}}{P_{Di}}\right) \qquad (1)$$

Where P_{Di} is the power destiny of the incident waves at a distance of ‗R' from the target and P_{Dr} is the power density of the reflected waves at the receiving antenna. The receiving antenna is assumed to be far away in this equation. The backscattered waves at the receiving antenna are planar and measured in m 2 from the target (ie, far field). RCS is composed of three factors: the material from which the vehicle is made from, the size of the object and the angle of incidence. Let us assume the directions of the incident and backscattered waves as the angles (θi, φi) and (θs, φs) respectively as presented in [2] based on θs and θi, the target RCS is considered either as monostatic or bistatic.

- When θs = θi and φs = φi, the target RCS is said to be monostatic. Transmitter and receiver are located in the same place which is illustrated in Figure 1(a)
- When θs ≠ θi and/or φs ≠ φi, the target RCS is said to be bistatic. This means that the radar transmitter and receiver are located in a distance from each other which is illustrated in Figure 1(b).



(a) (b)
Fig.1. (a) Monostatic RCS (b) Bistatic RCS

The target RCS should be reduced to reduce detectability and visibility by reducing the backscattered EM energy. This is known as RCSR. This aids in increasing the surveillance security and increase the survivability by evading detection.

Scattering and absorption are the two main ways that might reduce RCS. While absorption destroys all or part of the incident signal wave, scattering deflects the incident signal wave from the radar beam. Shaping is a high frequency technique that operates by a scattering process. Its major goal is to create a geometrical configuration for the target that minimises the backscattered wave toward the radar. Radar absorbing material works via absorption – it is specifically designed to absorb the incident signals hitting the object. Consider the example of an aircraft, as the radar waves hit the exterior of a plane, oscillations are induced within the coating that alternates the magnetic field of the RAM resulting in radar signals being converted into heat. This blocks the signals from being reflected back to the source, thus, ensuring low detectability.

A metasurface is a periodic or aperiodic arrangement of subwavelength resonant scatterers that affects the surface's electromagnetic response. To disperse the incident waves, these metasurfaces are organised in a variety of ways. Both scattering and absorption are the foundation of metasurfaces. Section 2 expands on scattering-based metasurfaces and absorption-based metasurfaces.

The RCSR methods are classified majorly into two fields: active RCSR and passive RCSR.

There are two basic ways that absorption and scattering could both lower RCS. The incident signal wave is deflected from the radar beam by scattering as opposed to being completely or partially destroyed by absorption. High frequency shaping uses a scattering process to function. Its main objective is to shape the target in a way that minimises the backscattered wave toward the radar. This is accomplished through a combination of software-based (signal processing) and hardware-based approaches (using control module of the phased-array and high-speed microelectronic system). This is most suitable technique for low frequencies that can be utilized for multiple target incidences from hostile sources. Its disadvantages include high fabrication complexity and cost and narrow bandwidth, and its difficulties increase with increasing the frequency

In passive RCSR, these techniques are performed in two ways to reduce the backscattered wave in the direction of radar receiver:

- Absorbing the incoming wave energy so that no backscattered wave reaches the radar receiver.
- Modifying the properties of the reflected wave (such as reflection phase, amplitude, and polarisation) from various sections of the target to redirect or cancel the incident wave.

A. *Applications of RCS Reduction:*

Radars are used to track aeroplanes and ships, identify insects and animals, estimate the speed of autos, and anticipate weather conditions, among other things. RCS reduction is immediately relevant in

- military operations, RCS reduction prevents them from being attacked
- aircraft hangars
- stealth technology
- Reducing the antennas mounted on aircrafts and ships, RCS reducing structures are designed without affecting the radiation characteristics of the antenna.

B. *Classification of RCS Reduction:*

The classification of Radars Cross Section Reduction is represented in Fig .2 based on scattering and absorbing. The importance of RCS reduction in stealth technology for aeroplanes, missiles, ships, and other military vehicles cannot be overstated. Vehicles with reduced RCS are better able to avoid radar detection from other vehicles, guided missiles, and land-based systems. A platform's overall survivability is further increased by a reduced signature design thanks to the platform's better radar counter measures.

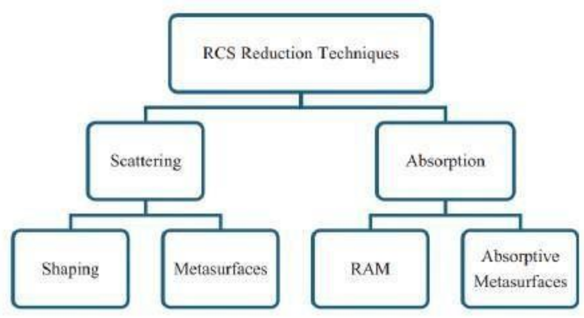


Fig.2. Classification of RCS Reduction techniques

Shaping

Shaping is most effective in monostatic radars. It can be implemented in two ways:

- By using a small, rounded, blended exterior shape to reduce glint.
- By using a faceted shape to reduce reflections back to the radar that is lighting the area.

Shaped waves are only affected by incident waves within a certain bandwidth and at certain incidence angles. The target's interior volume and stability might be modified by applying complex gradient forms to improve this.

Radar absorbing materials (RAM)

RAM may be represented using resonance and impedance matching. Pyramidal, tapered, and matched impedance-matching RAMs are the three varieties. These materials convert the heat from the incident radar radiation. The transition layer's impedances and thickness must match those of the two impedances. The incident and absorbing media's impedances are mismatched in resonant RAMs. At the first interface, the arrangement causes reflection and transmission. Salisbury screen absorbers and Jaumann absorbers are two different varieties of resonant RAM. Limitations include the RAMs are usually thick, expensive, and RCS reduction is provided only over a narrow bandwidth. Bandwidth enhancement can be accomplished by making the structure larger.

II. RCS Reduction based on Scattering and Absorptive Metasurfaces

A. *Phase Gradient Metasurfaces (PGMS):*

The PGMS work on the principle of anomalous reflection and conversion of propagating wave to surface wave, as presented in [3]. The phase gradient metasurface is obtained by repeating a tile that is formed using elements with varying phases arranged in a gradient fashion in[4]. The PGMS operates on the generalised Snell's law, which states that a surface with a phase discontinuity deflects the signal away from the specular direction. Super cells, which are made up of six unit cells, are the fundamental component of PGM. Each unit cell is made up of a metal-substrate-metal arrangement, with the bottom layer being a 0.5 mm thick dielectric substrate and the top layer consisting of a split-ring resonator (SRR) structure and a complete metallic film. The six unit cells are arranged together in an alternating fashion along the y-axis to realize the anomalous refection at two distinct frequencies. The outcomes of both simulations and trials show that the proposed PGM will stray from the waves' initial propagation route. Because of its high cost, graphene cannot be employed to achieve adjustable perfect absorption.

The working mechanism can be illustrated using k_i – wave number of the incident signal and k_r – wave number of the reflected signal.

- If $k_i > k_r$, surface wave coupling takes place, leading the reflected waves to lie along the PGMS plane.
- If $k_i < k_r$, anomalous reflection occurs in [5].

Main challenge faced by PGMS is its dependency on size of the unit cell to that of the operating frequency range.

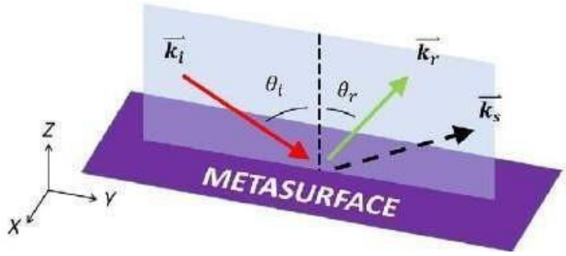


Fig.3. Performing anomalous and surface reflection under different scenario

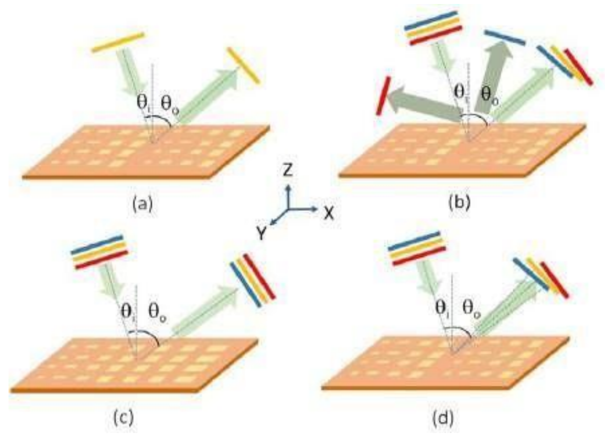


Fig.4.Metasurface performing anomalous reflection under different scenarios: (a) narrowband design with narrowband illumination (b) narrowband design with broadband illumination (c) broadband achromatic design (constant angle responses) (d) broadband dispersive design (frequency dependent angle).

TABLE 1: PGMS COMPARISON TABLE

SI. No	Ref. No	Working Type	Simulated	Measured	Array size
1	[3]	Anomalous reflection	a) monostatic b)8.9 GHz and 11.4 GHz	a) monostatic b)8.9 GHz and 11.4 GHz	10.4λ0 × 10.4 λ0
2	[4]	Anomalous reflection	a) monostatic b)9.85-19.37 GHz (65%)	a) monostatic b)9.85-19.37 GHz (65%)	8.25λ0 × 8.25 λ0
3	[5]	Anomalous reflection	a)monostatic/ bistatic b) 9GHz to 40.7GHz (128%)	a) monostatic/ bistatic b) 9 GHz to 40.7 GHz (128%)	19λ0 × 19λ0

B. Checkerboard Metasurfaces:

CMS works on the principle of destructive interference. A pair of sub arrays is alternated in a checkerboard like fashion where each sub array is made of a periodic arrangement of unit cells. In checkerboard the ―black‖ cells and ―white‖ cells are fully metalized parts and filled with AMC structure are having the same square area. The reflection phases of the two-unit cells are designed to provide 0^0 and 180^0. An artificial magnetic conductor (AMC) and a perfect electric conductor (PEC) are arranged in a checkerboard pattern, reflecting signals with 00 and 1800 phase, respectively. This cancels the far-field fields and lowers the RCS. The AMC-AMC-based CMS had a broader bandwidth than the AMC-PEC pair, according to the authors' comparison of an AMC-PEC pair and an AMC-AMC pair. By maintaining a 180–30 phase difference between two AMCs, a 32% bandwidth was reported.

The design in the publication [6] demonstrates the benefit of geometrical simplicity while also lowering overall thickness (for the present design, /16). The design is likewise based on the arrangement of AMC and PEC cells in a manner akin to a chessboard. Since the AMC and PEC reflections cancel out for any typical incident plane wave in this situation because of their opposite phase, RCS is decreased.

Increased RCS reduction bandwidth may be achieved with the proper component selection and surface wave suppression. The proposed prototype in [7, 8] combines two-unit cell metallization sizes and exhibits at two resonant frequencies. It is not necessary for there to be a 180° phase shift between reflected waves in order to reduce RCS with the suggested AMCs combination. A comparison of the two designs—the previously described one, which combines AMCs with overlapping frequency bands, and the other, which combines measurements from anechoic chambers with Perfect Electric Conductor (PEC) and AMC surfaces. The basic goal is to reduce the electromagnetic field that scatters when an incident wave illuminates an item of interest. It uses an Arlon 25N dielectric substrate with a relative dielectric permittivity of 3.28, a loss tangent of less than 0.0025, and a thickness of h = 0.762 mm (30 mils). W W = 9.60 mm 9.60 mm is the size of a unit cell, and there are four symmetry planes in its geometry. The metallization is 18 m thick. operating at 5.87 GHz and has a 2.5% (150 MHz) AMC frequency bandwidth. Both multilayer substrates and through holes are not necessary. This unit cell's metallization has been scaled to produce another unit cell with a different resonance frequency (5.96 GHz), known as AMC #2. Since there is less than a 180 degree phase difference between AMC #1 and AMC #2, the reflected waves in these two AMC surfaces won't entirely cancel one another out. In groups of 8 8 cells, unit cells are merged once again to create a geometry resembling a chessboard (2 2), which is designated as AMC #1, 2 (see Fig. 4). In order to accomplish a 180° phase-shift when the AMC #1 reflection phase is zero, a second design is created by swapping out the AMC #2 for a PEC surface.

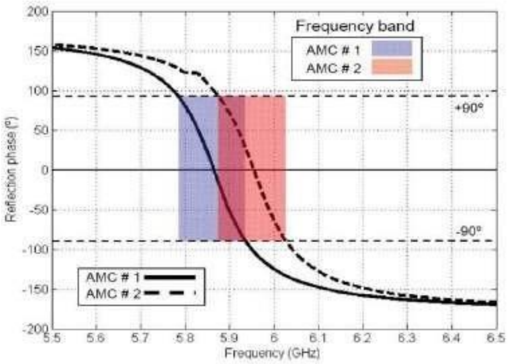


Fig.5. Simulated AMC reflection phase vs.frequency of AMC designs #1,2.

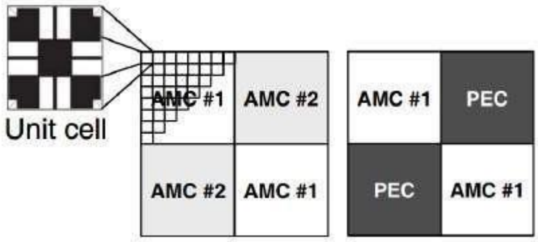


Fig.6. Unit combination in two different 2×2 chessboard-like geometrics: AMC#1,2 and AMC#1 PEC.

TABLE 2: CHECKERBOARD COMPARISON TABLE

SI. No	Ref. No	Simulated	Measured	Array size	Unit Cell
1	[6]	a) Monostatic/ bistatic b) 15.32 GHz	a) Monostatic/ bistatic b) 15.32 GHz	22λ0 × 14λ0	1λ0 × 1λ0
2	[7]	a) Monostatic b) 5.78 GHz	a) Monostatic b) 5.78 GHz	3.5λ0 × 3.5λ0	0.18λ0 × 0.18λ0
3	[8]	a)Monostatic/ bistatic b) 3.78–10.08 GHz (90.9%)	a) Monostatic b)3.77–10.14 GHz (91.5%)	2.98λ0 × 2.98λ0	0.37λ0 × 0.37λ0

C. Polarization Conversion Metasurfaces:

The main purpose of polarisation is to decrease the monostatic radar cross section (RCS) of a metal surface. To do this, the incoming wave's polarisation is rotated by a number of degrees, making the reflected wave zero in the direction of incidence. As shown in [9], a set of eight angles of polarisation rotations was created, then it was simulated and manufactured. Within the frequency range of 7.6 to 11.3 GHz, a 60% RCS reduction bandwidth was recorded. Verifying the simulation and measurement findings is the method used to arrive at the outcome.

The lowering of radar cross section (RCS) is accomplished using a polarisation conversion metasurface (PCM). The advantage of the suggested design is that it simultaneously reduces RCS over broadband, as shown in [10], while maintaining a basic geometry. A cut-wire resonator, which can change a linear polarisation state into its orthogonal, is combined with an oblique split ring resonator (SRR) to form the metasurface. According to the simulation results, a polarisation conversion ratio (PCR) of around 100% is required to achieve the 10 dB bandwidth of polarisation conversion in wideband from 7 to 14 GHz.

Given an equal-sized PEC ground plane and a high PCR, a 10 dB reduction in RCS can result in a frequency bandwidth reduction of more than 60%. 32.8dB is the highest decrease. The PCM's components are manufactured and measured to evaluate how the simulation performed.

TABLE 1: PCMS COMPARISON TABLE

Sl No.	Ref No.	a) Monostatic/bistatic b) RCS reduction frequency range		Array size
		Simulated	Measured	
1	9	a) Monostatic b) 10.2 to 19.3 GHz	a) Monostatic b) 10.2-19.3 GHz	3.4λ0 × 3.4λ0
2	10	a) Monostatic/bistatic b) 17 GHz–42 GHz c) 10–50 degree	a) Monostatic b) 17GHz–42 GHz	21λ0 × 21λ0

D. Coding Based Metasurfaces:

To investigate the RCS reduction feature, a number of random coding metasurfaces of the matrix type [11] have been developed. Theoretically, the RCS reduction mechanism of various arrangements is examined after the suggested coding technique for metasurfaces with various ratios of "0" and "1" units. Binary coding metasurfaces are made up of unit cells allocated the digits 0 and 1, and they have a phase response range of 0 and 180. Similar to this, 2-bit coding metasurfaces employ four elements with phases 0, 90, 180, and 270. Metasurfaces for N-bit coding require 2/N elements. The developed metasurfaces were simulated to get the scattering patterns under normal incidence and the RCS reduction curves in order to analyse the energy scattering characteristic of random coding sequences. For metasurface samples of coding a and b, the average reflectance was less than 10 dB under x- and y-polarized wave incidence in the range of 5.8-15.5 GHz, and the average RCS reduction is essentially bigger than 10 dB under normal incidence in the region of 5.5-15 GHz Broadband RCS reduction is presented using matrix-type coding metasurfaces. An efficient RCS reduction feature may also be attained at oblique incidence.

E. Reconfigurable Metasurfaces:

The main flaw with passive metasurfaces is that they can only be used in certain set frequency ranges. To get around this restriction, it was briefly mentioned that metasurfaces that can be tweaked using external triggering circuits were created. Utilizing stimuli-responsive materials that may alter their physical characteristics in reaction to environmental factors, globally adjusted metasurfaces are created. These metasurfaces are made using graphene and liquid crystals. The RCS reduction level is dynamically controlled by the graphene layers, which also help to tune the surface resistance.

A locally tuned metasurface is one whose functional performance has been changed at the unit cell level. A smart metasurface was created to guarantee self-adaptability in response to changes in the ambient environment circumstances. To adaptively control and maintain synergy between all the dynamic reactions, such as single beam and multi-beam steering, an online feedback algorithm is utilised [12].

F. Time-Varrying Metasurfaces:

Electromagnetic scattering in the time domain is controlled by time-varying metasurfaces. This technology was improved by spreading the incident spectrum across multiple frequency bands, which ensures the target is undetectable. Space-gradient metasurfaces are in charge of managing momentum, whereas space-time-gradient metasurfaces have the ability to control both photonic energy and tangential momentum. In [13], a universal non-reciprocal variant of Snell's law was obtained, and it was shown how time-gradient metasurfaces can dismantle Lorentz reciprocity, allowing the creation of optical isolators. A Doppler-like wavelength shift caused by an energy exchange is seen in [14] when photons contact with a time-varying metasurface.

G. Absorptive Metasurfaces:

Phase cancellation and absorption mechanisms are combined to create a dual-mechanism absorptive metasurface [15] with a 20 dB RCS reduction. Using the reflection phase difference between two absorbing unit cells to naturally combine the absorption and phase cancellation techniques to reduce the intensity of the backward echo in both the energy domain and the spatial domain. In order to implement RCS reduction above 20dB, an absorptive metasurface is constructed by optimising the number of two-unit cells [16]. Experimental and numerical findings support the dual-mechanism absorptive metasurface's wideband, robustness, and significantly lower RCS properties.

CONCLUSION

With a focus on metasurfaces, this research explored several RCS reduction strategies. The traditional methods, shaping and RAM were briefly reviewed. Active and passive configurations of the metasurfaces were also discussed and the RCS reduction techniques were compared based on profile and bandwidth and tabulated. A detailed review of RCS reduction techniques was done and explained based on their principle, working mechanism, challenges involved and further improvements.

REFERENCES

[1] Akila Murugesan, Krishnasamy T. Selvan, Ashwin K. Iyer, Kumar V. Srivatsav, and Arokiaswami Alphones, ―A Review of Metasurface-Assisted RCS Reduction Techniques‖, Progress In Electromagnetics Research B, Vol. 94, 75–103, 2021

[2] Zaker, R., & Sadeghzadeh, A. (2020). ―Passive techniques for target radar cross section reduction: A comprehensive review‖. International Journal of RF and Microwave Computer-Aided Engineering, 30(11), e22411.

[3] Cheng, Y., C. Wu, J. Yang, X. Peii, F. Jia, and R. Gong, ―An ultra-thin dual-band phase-gradient metasurface using hybrid resonant structures for backward RCS reduction,‖ Applied Physics B, Vol. 143, Apr. 18, 2017.

[4] Zheng, Q., Y. Li, J. Zhang, J. Wang, H. Ma, Y. Pang, Y. Han, S. Sui, Y. Shen, H. Chen, and S. Qu, ―Wideband, wide-angle coding phase gradient metasurfaces based on Pancharatnam-Berry phase,‖ Scientific Reports, Vol. 7, 43543, 2017.

[5] Azizi, Y., M. Soleimani, and S. H. Sedighy, ―Ultra-wideband radar cross section reduction using amplitude and phase gradient modulated surface,‖ Journal of Applied Physics, Vol. 128, No. 20, 2020.

[6] Paquay, M., J.-C. Iriarte, I. Ederra, R. Gonzalo, and P. D. Maagt, ―Thin AMC structure for radar cross-section reduction,‖ IEEE Transactions on Antennas and Propagation, Vol. 55, No. 12, 3630–3638, Dec. 2007.

[7] De Cos, M. E., Y. Alvarez-Lopez, and F. L. H. Andres, ―A novel approach for RCS reduction using a combination of artificial magnetic conductors,‖ Progress In Electromagnetics Research, Vol. 107, 147–159, 2010.

[8] Fu, Y., Y. Li, and N. Yuan, ―Wideband composite AMC surfaces for RCS reduction,‖ Microwave and Optical Technology Letters, Vol. 53, No. 4, 712–715, 2011.

[9] Jiang, W., Y. Xue, and S.-X. Gong, ―Polarization conversion meta surface for broadband radar cross section reduction,‖ Progress In Electromagnetics Research Letters, Vol. 62, 9–15, 2016.

[10] Sun, H., C. Gu, X. Chen, L. Liu, B. Xu, and Z. Zhou, ―Broadband and broad-angle polarization independent metasurface for radar cross section reduction,‖ Scientific Reports, Vol. 7, Jan. 20, 2017

[11] Yang, J. J., Y. Z. Cheng, D. Qi, and R. Z. Gong, ―Study of energy scattering relation and RCS

[12] reduction characteristic of matrix-type coding metasurface,‖ Applied Sciences, Vol. 8, No. 8, 2018.

[13] Liu, S. and T. J. Cui, ―Flexible controls of terahertz waves using coding and programmable metasurfaces,‖ IEEE Journal of Selected Topics in Quatum Electronics, Vol. 23, No. 4, 1–12, 2017.

[14] Amr Shaltout, Alexander Kildishev, and Vladimir Shalaev, "Time-varying metasurfaces and Lorentz non-reciprocity," Opt. Mater. Express 5, 2459-2467 (2015)

[15] Shaltout, A., A. Kildishev, and V. Shalaev, ―Time-varying metasurfaces and Lorentz non reciprocity,‖ Optical Materials Express, Vol. 5, No. 11, 2459–2467, 2015.

[16] Yuan, Fang, Qiang Chen, Yuejun Zheng, and Yunqi Fu. "Dual-Mechanism Absorptive Metasurface with Wideband 20 dB RCS Reduction." Crystals 12, no. 4 (2022): 493.