

TWO-WAY MULTI-ANTENNA RELAYING WITH SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER

A Project Report Phase – II

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

by

**AAKASH C (39130003)
ANGELO ALEXANDER (39130025)**



**DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS**

SATHYABAMA

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

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

APRIL - 2023



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with "A" grade by NAAC
Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119
www.sathyabama.ac.in

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Aakash C (39130003)**, **Angelo Alexander (39130025)** who carried out the project entitled **"Two-Way Multi-Antenna Relaying with Simultaneous Wireless Information and Power Transfer"** under our supervision from November 2022 to April 2023.

Internal Guide

Ms. R. Sakthi Prabha, M.E., (Ph.D)

Head of the Department

Dr. T. RAVI, M.E., Ph.D.,

Submitted for Viva voce Examination held on 26.04.2023

Internal Examiner

EXTERNAL EXAMINER

DECLARATION

We **Aakash C (39130003)** and **Angelo Alexander (39130025)** hereby declare that the Project Report entitled “**Two-Way Multi-Antenna Relaying with Simultaneous Wireless Information and Power Transfer**” done by us under the guidance of **Ms. R. Sakthi Prabha, M.E., (Ph.D)** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering Degree in Electronics and Communication Engineering.

DATE: 26.04.2023

PLACE: chennai

SIGNATURE OF THE CANDIDATES

1.



2.



ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to **Board of Management of SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. N. M. NANDHITHA, M.E., Ph.D., Professor & Dean, School of Electrical and Electronics** and **Dr. T. RAVI, M.E., Ph.D., Professor & Head, Department of Electronics and Communication Engineering** for providing us necessary support and details at the right time during the progressive reviews.

We would like to express my sincere and deep sense of gratitude to our **Project Guide Ms. R. SAKTHI PRABHA, M.E., (Ph.D)**, for her valuable guidance, suggestions and constant encouragement paved way for the successful completion of our project work.

We wish to express our thanks to all Panel members, Year coordinator, Teaching and Non-teaching staff members of the Department of Electronics and Communication Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The state of art of UWB antennas together with feed networks and other microwave associated components for UWB applications has been presented. It started by describing the UWB technology and its advantages for future wireless communication systems. In this project it is investigated several relevant works related to UWB antenna element designs and antenna arrays. Several UWB feed networks and other associated UWB microwave components such as vertical transitions, 90° hybrid couplers and phase shifters. Then background information about UWB beamforming techniques will be addressed with a focus on the architecture of a Butler matrix as a suggested beamforming network for generating multiple fixed orthogonal beams.

TABLE OF CONTENTS

Chapter No	TITLE	Page No.
	ABSTRACT	v
	LIST OF ABBREVIATIONS	vii
	LIST OF FIGURES	viii
	LIST OF TABLES	x
1	INTRODUCTION	1
	1.1 Types of Antennas	1
	1.2 Antenna parameters	4
	1.3 Introduction to V2X	11
	1.4 Application of V2X	15
	1.5 Microstrip patch array antenna	16
2	LITERATURE SURVEY	20
	2.1 Inference from literature survey	24
	2.2 Problem Statement	24
3	AIM AND SCOPE OF THE INVESTIGATION	25
	3.1 Objective of V2X	25
	3.2 Benefits of V2X	26
4	PROPOSED METHODOLOGY	27
	4.1 Microstrip Patch Antenna Design Formulas	27
	4.2 Simulating Software for the antenna	30
5	SIMULATION RESULTS AND DISCUSSIONS	32
6	CONCLUSION	50
	6.1 Future Work	50
	STANDARDS AND CONSTRAINTS	51
	REFERENCES	52

LIST OF ABBREVIATION

SWR	Standing Wave Ratio
UWB	Ultra-Wideband
NB	Narrow Band
EIRP	Effective Isotropic Radiated Power
SNR	Signal-to-Noise Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks
WMAN	Wireless Metropolitan Area Networks
MBA	Multi-Beam Antennas
SBA	Switched-Beam Antenna
SIR	Signal-to-Interference Ratio
BFN	Beam Forming Network
WPT	Wireless Power Transfer
MIMO	Multiple Input Multiple Output
IOT	Internet of Things
PCB	Printed Circuit Board
MED	Magneto-Electric Dipoles
RCA	Resonant Cavity Antenna
CPW	Coplanar Waveguide
UE	User Equipment
MAV	Micro Aerial Vehicles

LIST OF FIGURES

Fig no.	Figure Name	Page no.
1.1	Representation of the Dipole Antenna	2
1.2	Representation of the Horn Antenna	2
1.3	Representation of the Reflector Antenna	3
1.4	Representation of the Lens Antenna	3
1.5	Representation of Yagi-uda Antenna	4
1.6	Graphical representation between SWR and return loss	4
1.7	Plots of radiation pattern of antennas with higher directivity	6
1.8	Gain pattern of an antenna	7
1.9	Rectangular plot representation of radiation pattern	8
1.10	Polar plot representation of radiation pattern	9
1.11	Polarizational representation of an antenna	10
1.12	Four types of V2X application	14
1.13	Microstrip line feeding technique	17
1.14	Coaxial Probe Feeding technique	18
1.15	Proximity Coupling Feeding technique	18
1.16	Aperture Coupling Feeding technique	19
5.1	Design of the Microstrip Patch Array Antenna	32
5.2	Ground Structure of the Microstrip antenna	33
5.3	Patch of the Antenna	34
5.4	S-Parameter Plot of the Microstrip antenna	35
5.5	Gain of the Microstrip antenna	36
5.6	Directivity of the Microstrip patch antenna	36
5.7	VSWR Plot of the Microstrip antenna	37
5.8	Frequency Vs Power Plot of the Microstrip antenna	38

Fig no.	Figure Name	Page no.
5.9	Radiation Efficiency Plot of the Microstrip antenna	38
5.10	Radiation Intensity Plot of the Microstrip antenna	39
5.11	Front To Back Ratio Plot of the Microstrip antenna	40
5.12	Radiation Pattern of the Microstrip Antenna	41
5.13	Radiation Pattern of the Microstrip Antenna	41
5.14	Smith Chart of the Microstrip antenna	42
5.15	Electric Field Flow on The Patch	43
5.16	Magnetic Field Flow on The Patch	43
5.17	Front Side of the Microstrip Antenna	44
5.18	Back Side of the Microstrip Antenna	44
5.19	Log Mag plot of the fabricated microstrip antenna	45
5.20	SWR plot of the fabricated microstrip antenna	45
5.21	Smith chart plot of the fabricated microstrip antenna	46

LIST OF TABLES

Table No.	Table Name	Page no.
5.1	Dimensions and positions of the Microstrip Patch array antenna	47
5.2	Comparison between existing and proposed methodology	49

CHAPTER 1

INTRODUCTION

Antennas are a major part of any wireless communication system. In today's scenario, although, antenna as a device is not new to the common man, the level of understanding the background concept involved in the working of this device will certainly help in designing new types of antennas, in order to meet the necessary requirements in the wireless domain. In any wireless communication system, after a radio frequency (rf) signal has been generated in a transmitter, some means must be used to radiate this signal through space to a receiver[1]. The device that does this job is the antenna. The transmitter signal energy is sent into space by a transmitting antenna, the rf signal is then picked up from space by a receiving antenna.

The Rf energy is transmitted into space in the form of an electromagnetic field. As the traveling electromagnetic field arrives at the receiving antenna, a voltage is induced into the antenna (usually a conductor). The rf voltages induced into the receiving antenna are then passed into the receiver and converted back into the transmitted rf information. So, antennas can be thought of as a "transducer" that converts radio waves into electrical currents and voltages and vice versa. More specifically, these are devices designed to radiate or receive electromagnetic energy efficiently in a prescribed manner.

1.1 TYPES OF ANTENNAS

Antennas have to be classified to understand their physical structure and functionality more clearly. There are many types of antennas depending upon the applications. There are several types of antennas and each literature work has its own classification of antennas.

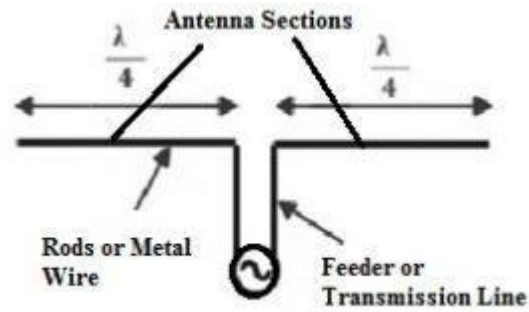


Fig: 1.1 Representation of the Dipole Antenna

The above Fig 1.1 shows the circuit diagram of the Dipole antenna. Wire antennas are Dipole, monopole, loop antenna, helix. Usually used in personal applications, automobiles, buildings, ships, aircrafts and spacecrafts.

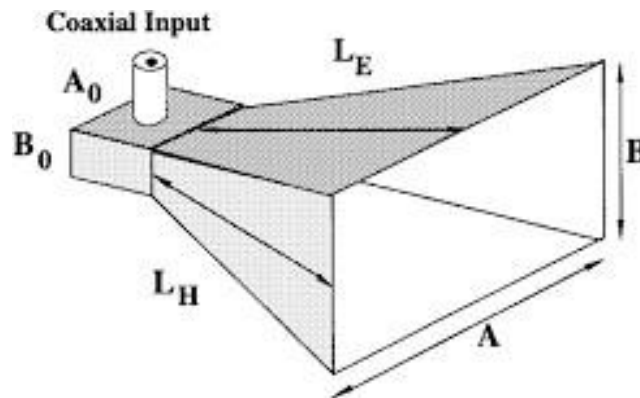


Fig: 1.2 Representation of the Horn Antenna

The above Fig 1.2 is the diagram of Horn antenna. Aperture antennas are Horn antennas, waveguide opening. Usually used in aircraft and spacecrafts because these antennas can be flush mounted. Reflector Antennas Parabolic, corner reflectors. These are high gain antennas usually used in Radio astronomy, Microwave communication and Satellite Tracking[3].

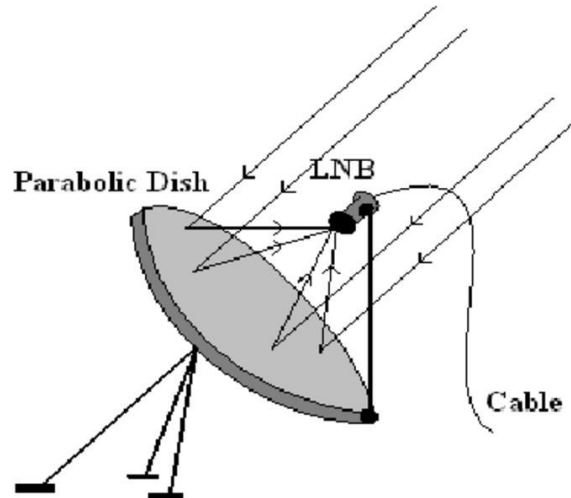


Fig: 1.3 Representation of the Reflector Antenna

The above Fig 1.3 is the diagram of the reflector antenna. Reflector Antennas Parabolic, corner reflectors. These are high gain antennas usually used in Radio astronomy, Microwave communication and Satellite Tracking.

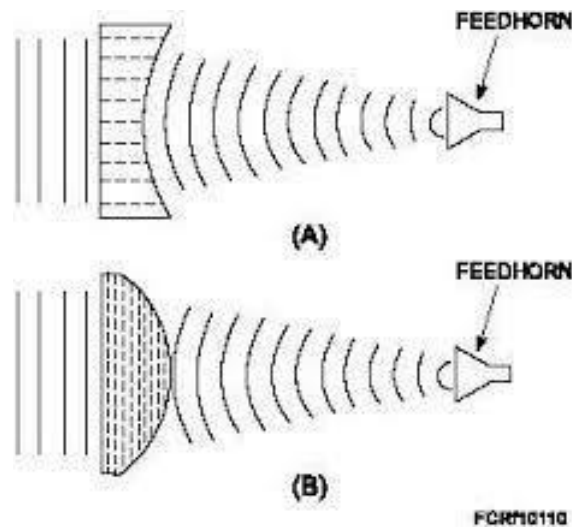


Fig: 1.4 Representation of the Lens Antenna

The above Fig 1.4 shows the diagram of lens antenna. Lens Antennas are Convex plane, convex-convex, concave-convex and concave plane lenses. These antennas are usually used for very high frequency applications.

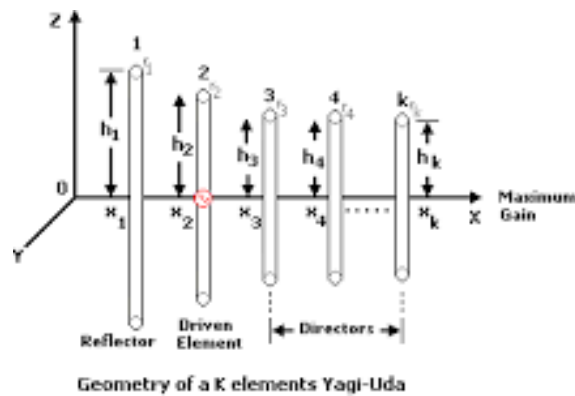


Fig: 1.5 Representation of Yagi-uda Antenna

The above Fig 1.5 shows the diagram of Yagi-uda antenna. Microstrip Antennas are rectangular, Circular etc. shaped metallic patches above a ground plane. Used in aircraft, spacecraft, satellites, cars, mobile phones etc. Yagi antenna, Microstrip patch array, Aperture array, Slotted waveguide array. Used for high gain applications with added advantage such as controllable radiation.

1.2 ANTENNA PARAMETERS

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following,

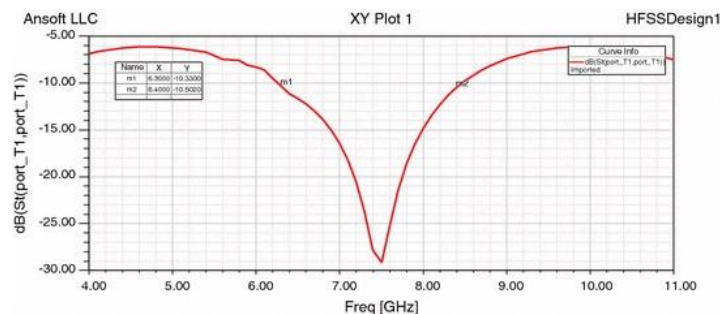


Fig: 1.6 Graphical representation between SWR and return loss

The above Fig 1.6 shows the return loss plot. The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However, in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an omnidirectional antenna. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dB.

The directivity of patch antennas is approximately 5-7 dB. Here for this antenna's design the directivity is given as 6.3 dB. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π . If the direction is not strictly specified, the direction of maximum radiation intensity is implied. Minimum value in dB. It is subject to statistical validation for a single-sided parameter. This parameter is to be defined for the nominal subbands in a broadband antenna. Unless otherwise noted it will be assumed the specification is for the full electrical downtilt range, and for all the ports associated with each frequency subband of the antenna. An antenna's directivity is greater than its gain by an efficiency factor, radiation efficiency. Directivity is an important measure because many antennas and optical systems are designed to radiate electromagnetic waves in a single direction or over a narrow-angle. By the principle of reciprocity, the directivity of an antenna when receiving is equal to its directivity when transmitting.

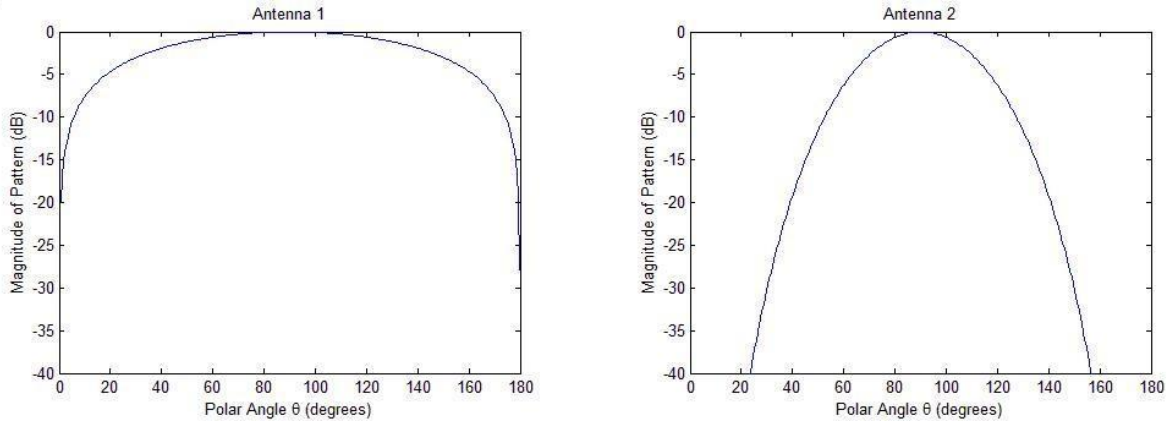


Fig: 1.7 Plots of radiation pattern of antennas with higher directivity

The above Fig 1.7 shows the diagram radiation pattern of antennas with higher directivity. Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna[4].

The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. This design is focused on enhancement in gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dB. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dB.

The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the 3 antennas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

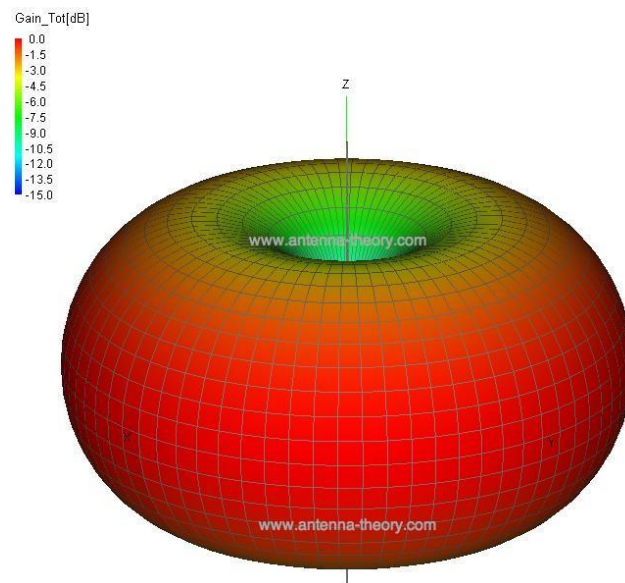


Fig: 1.8 Gain pattern of an antenna

The above fig 1.8 shows the gain pattern of an antenna. The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured [5]. In electromagnetics, an antenna's power gain or simply gain is a key performance number that combines the antenna's directivity and electrical efficiency. As a transmitting antenna, the gain describes how well the antenna converts input power into radio waves headed in a specified direction. As a receiving antenna, the gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power. When no direction is specified, "gain" refers to the peak value of the gain. The radiation pattern is a plot of the gain as a function of direction.

Radiation patterns are a two-dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format. Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles.

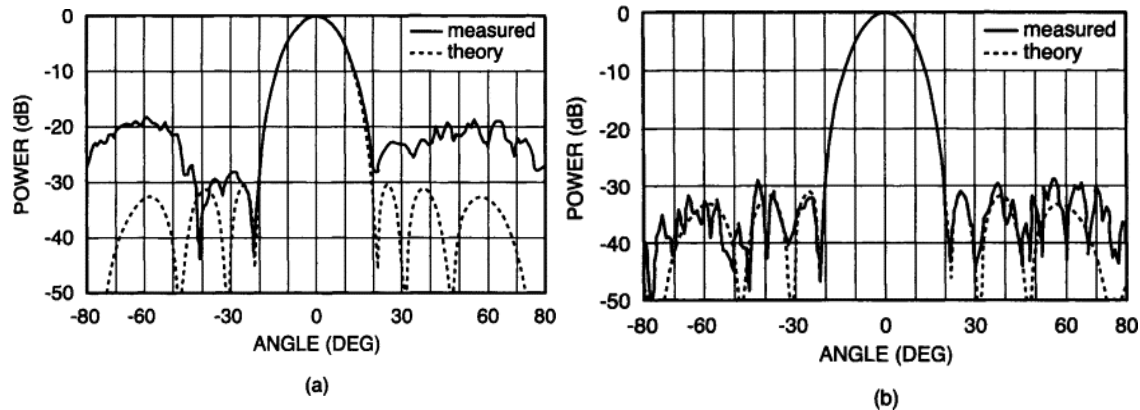


Fig: 1.9 Rectangular plot representation of radiation pattern

The above Fig 1.9 shows the rectangular plot representation of radiation pattern. The far-field pattern of an antenna may be determined experimentally at an antenna range, or alternatively, the near-field pattern may be found using a near-field scanner, and the radiation pattern deduced from it by computation. The far-field radiation pattern can also be calculated from the antenna shape by computer programs such as NEC. Other software, like HFSS can also compute the near field. The far field radiation pattern may be represented graphically as a plot of one of a number of related variables, including; the field strength at a constant (large) radius (an amplitude pattern or field pattern), the power per unit solid angle (power pattern) and the directive gain. The radiation form of the antenna is an electromagnetic wave, by calculating and measuring the strength of this electromagnetic wave at a distant point. This far point is where the wave is considered a plane wave and is perpendicular to the direction of the antenna.

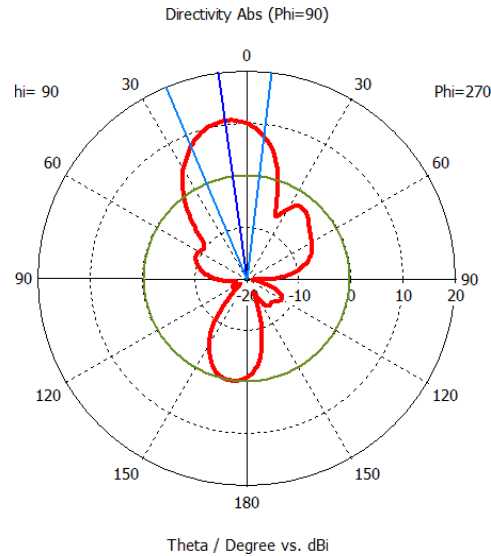


Fig: 1.10 Polar plot representation of radiation pattern

The above plot Fig 1.10 shows the polar representation of radiation pattern. Polar coordinate systems are divided generally in two classes: Line and Logarithmic

In the linear coordinate system, the concentric circles are equally spaced and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. In the logarithmic polar coordinate system the concentric grid lines are spaced periodically according to the logarithm of the voltage in the signal. Different values may be used for the logarithmic constant of periodicity, and this choice will have an effect on the appearance of the plotted patterns.

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna. In linear polarization the electric field vector stays in the same plane all the time but in circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right hand or left hand. Choice of polarization is one of the design choices available to the RF system designer.

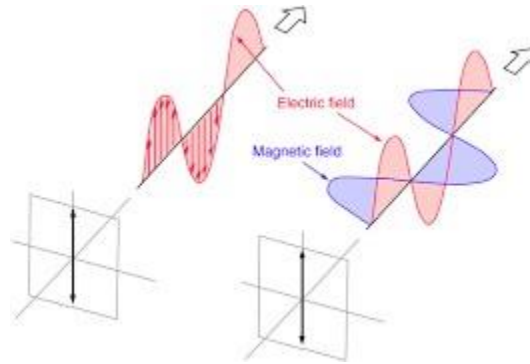


Fig: 1.11 Polarization representation of the antenna

The above Fig 1.11 shows the polarization of the antenna. In order to transfer maximum power between a transmit and a receive antenna, both antennas must have the same spatial orientation, the same polarization, the same polarization sense and the same axial ratio. When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance. When the transmitter and receiver antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss.

Metamaterial antennas are a class of antennas which use metamaterials to increase performance of miniaturized (electrically small) antenna systems. Their purpose, as with any electromagnetic antenna, is to launch energy into free space. In the proposed design, the contribution of substrate FR4 plays an important role in increasing the bandwidth of the antenna. The structure and shape of the substrate in the design of the antenna is the main parameter such as the dielectric constant and loss tangent. The main limitation of microstrip patch antennas is the lower bandwidth, which affects wireless communication applications. Bandwidth of microstrip antenna can be improved by increasing the height of substrate by using the transmission line model. At the same time, increasing height of the substrate also increases the surface waves, which move

from end to end around the substrate and spread at the curves of the radiating patch, which adopts a part of the energy of the signal; thus, declining the antenna's performance. In order to avoid this problem, different techniques are used such as air gap technique in which surface waves are not produced. Further, length of patch plays an important role in bandwidth of antenna. Antennas having the minimum possible size are considered efficient. Vehicle to Everything (V2X) is a new generation of information and communication technology that connects vehicles to everything. V represents vehicles and X represents any object interacting with the vehicle. At present, X mainly includes vehicles, people, roadside infrastructure, and network. The information modes of V2X interaction include Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Pedestrian (V2P), Vehicle to Network (V2N).

1.3 INTRODUCTION TO V2X (VEHICLE-TO-EVERYTHING)

Vehicle to Everything (V2X) is a new generation of information and communication technology that connects vehicles to everything. V represents vehicles and X represents any object interacting with the vehicle. At present, X mainly includes vehicles, people, roadside infrastructure, and network. The information modes of V2X interaction include Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Pedestrian (V2P), Vehicle to Network (V2N). V2X technologies defined by 3GPP include V2V, V2I, V2P, V2N/ V2C and other communication scenarios. Autonomous driving security leader, AUTOCRYPT, announced that its V2X security solution, Auto Crypt V2X, now implements YD/T 3957-2021, the newest standard for LTE-based V2N communications and credential management [6].

V2X uses various wireless communication technologies to connect traffic participation factors such as vehicle, road, people, cloud, etc. V2X can not only enable vehicles to obtain more perceptual information, but also promotes the innovation and application of autonomous driving technology. It is also beneficial to the construct the intelligent traffic system. It can promote the development of new models and new formats of vehicles and traffic services. And it is significant in improving traffic efficiency, saving resources, reducing pollution, reducing the frequency of accidents, and improving traffic management.

V2X communication is nothing but Vehicle-to-Everything Communication. Vehicle-to-everything (V2X), referring to Vehicle-to-vehicle (V2V) and vehicle-to-Infrastructure (V2I) communications, is a wireless technology aimed at enabling data exchanges between a vehicle and its surroundings. V2X technology is based on 5.9 GHz dedicated short-range communications, a Wi-Fi derivative specifically defined for fast-moving objects and enabling the establishment of a reliable radio link, even in non-line-of-sight conditions.

By sharing data, such as their position and speed, to surrounding vehicles and infrastructures, V2X communication systems improve driver awareness of upcoming potential dangers and dramatically improve collision avoidance, resulting in heavily reduced fatalities and injury severity. In addition, V2X technology will enhance traffic efficiency by providing warnings for upcoming traffic congestions, proposing alternative routes and ensuring eco-friendly driving, reducing CO2 emissions through adaptive cruise control and a smarter transportation management.

C-V2X allows to communicate via the LTE network using the 3GPP Release 14, and in future, the 5G mobile network. Cellular V2X is also designed to directly connect vehicles with each other as well as with the infrastructure and further road users.

1.3.1 TYPES OF V2X

1.3.2 Vehicle to Vehicle (V2V)

Vehicle to Vehicle (V2V) is used for vehicle-mounted communication. The most common application scenario is in urban streets and expressways. Vehicles communicate with each other, send data, realize information and data sharing in that case.

The intelligent vehicle computing platform can send or receive the following data: speed, the relative position, braking, orientation, and all data related to safety. It can even take pictures, audio, or video of things around. Then, it analyzes and forecasts other vehicles' driving behavior. Doing so can achieve active security strategy, improve road safety, and provide data points for semi-automatic and automatic driving.

V2V technology allows vehicles to prevent accidents by relaying real-time information about themselves and the road ahead. It can reduce commuting time, and ultimately improve the traffic environment and reduce traffic congestion.

V2V vehicle communication can achieve vehicle-to-vehicle communication through D2D protocol in C-V2X. It brings another operation and maintenance mode for OEMs. Namely, it can effectively establish intelligent fleets, plan route, reduce fuel consumption, and improve operating income.

1.3.3 Vehicle to Infrastructure (V2I)

Vehicle to Infrastructure (V2I) refers to the communication between the vehicle-end unit and the roadside infrastructure, such as traffic lights, traffic cameras, and roadside units. Roadside infrastructure captures information about the surrounding area and publishes all kinds of real-time information. V2I is mainly used in real-time information service, vehicle monitoring and management, paying tolls without stopping, etc.

The intelligent vehicle computing platform needs the analysis of the warning information received from roadside infrastructure, such as blind spot collision at crossroads, road hazard, road construction, emergency vehicles, traffic jam and accident warning, as well as the traffic signal or sign recognition in blind area. The analysis can provide users with information about corresponding dangerous situation, recommendation of optimized driving behavior.

V2I enables wireless data exchange between vehicles and roadside traffic facilities. Its main applications include intersection safety management, vehicle speed control, electronic toll collection, transportation safety management, and road construction and height limit warning. This technology will make transportation facilities smarter, including no entry lights and weather information systems. It can evolve into intelligent transportation facilities which can recognize high-risk situations and automatically take alerting measures through various algorithms.

1.3.4 Vehicle to Pedestrian (V2P)

Vehicle to People (V2P) refers to the communication between vehicle-end units in vehicles and vulnerable traffic groups (including pedestrians and cyclists) through user devices (such as smart phones, wearable devices, bicycle GPS signalers, etc.). V2P is mainly used in traffic safety, smart keys, location information services, car sharing, etc.

The intelligent vehicle computing platform enables keyless entry and remote startup by supporting powerful secure communication and using smart keys. At the same time, the powerful computing ability can calculate the movement track of pedestrians or cyclists in real time. It can provide drivers with driving prediction and help them avoid traffic accidents.

V2P allows pedestrians and cyclists to become a node in the V2X communication environment through their smartphones. It can send or receive warning signals, such as telling on-line connected traffic lights in advance to determine whether it will take longer to cross the road. It can also prompt pedestrians to cross the road at the intersection in front of nearby vehicles, or prompt vehicles that there are bicycles riding in the adjacent lanes.

1.3.5 Vehicle to Network/Cloud (V2N/ V2C)

Vehicle to Network/Cloud (V2N/ V2C) refers to the connection between the on-board device in a vehicle and the cloud platform through network.

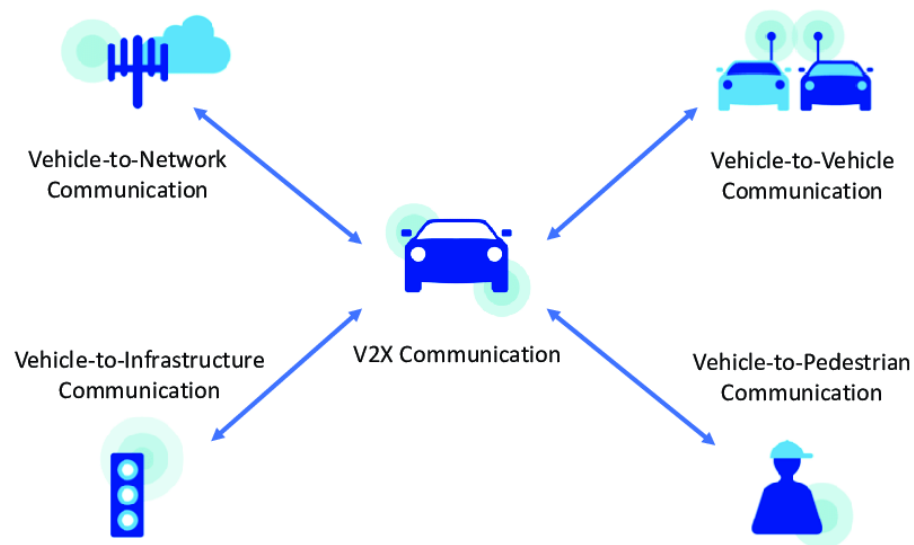


Fig:1.12 Four types of V2X application

Fig 1.12 show types of V2X. The cloud platform interacts with the vehicle. It also stores and processes the acquired data, and provides remote traffic information, entertainment, business services and vehicle management. V2N/ V2C is mainly applied to vehicle navigation, vehicle remote monitoring, emergency rescue, information entertainment services, etc.

1.4 APPLICATIONS OF V2X

V2X currently covers three typical application scenarios: traffic active safety, traffic efficiency and information services. And it's developing to support the implementation of autonomous driving applications. In The Basic Application of Intelligent Connected Vehicles jointly issued by Future Mobile Communication Forum and Vehicle-mounted Information Service Industry Application Alliance, 72 kinds of intelligent connected vehicle application scenarios are defined [9].

Active traffic safety: Forward collision warning, left turn assist/alarm, incoming main road assist/collision alarm, intersection collision alarm (with signal light/no signal light/no visual range, etc. with roadside unit), intersection collision alarm (with signal light/no signal light/no visual range, etc. without road units), overtaking auxiliary/reverse overtaking remind/through overtaking, blind spot alerting/auxiliary lane changing, emergency brake alerting (emergency electronic brake lights), vehicle safety function is out of control alarm, abnormal vehicle alarm (including static/slow vehicles ahead), stationary vehicles remind (such as traffic accident, vehicle failure cause), non-motor vehicles (electric cars, Bicycle, etc.) crossing alerting /pedestrian crossing alerting, emergency vehicle alerting, slippery/dangerous road alerting (wind, fog, ice, etc.), red light (yellow light) alarm).

Traffic efficiency: deceleration zone/speed limit reminder (tunnel speed limit, general speed limit, curve speed limit, etc.), speed guidance, car signs, electronic charging without parking.

Information services: entrance payment, automatic parking guidance and control, SOS/eCALL service, vehicle theft/damage (including whole vehicles and parts) alarm, remote vehicle diagnosis, maintenance tips.

V2V Use Case for Emergency Vehicle Warning: The emergency vehicle warning service allows the emergency vehicle (e.g., an ambulance) to share its location, speed, and direction information with surrounding vehicles, which helps the vehicles to choose a safe course of action, such as to vacate the ambulance path.

Wrong Way Driving Warning: This use case describes V2V communication used between two vehicles driving in opposite directions, to warn of wrong way driving and trigger safer behavior for cars in the area.

Warning to Pedestrian against Pedestrian Collision: This service is to share vehicle information with vulnerable road users, e.g., pedestrian or cyclist, to avoid dangerous situations, e.g., alerts are sent to vulnerable road users to avoid collision with a moving vehicle.

V2N Traffic Flow Optimization: V2N traffic flow optimization focuses on managing the speed of the vehicle for smooth driving and avoiding unnecessary stopping when the vehicle approaches an intersection. This involves the situation when the vehicle must slow down because there are explicit traffic light signals or has to stop even though no other vehicles are around at an intersection. Based on traffic conditions, the traffic lights can be adapted to reduce congestion at intersections.

1.5 MICROSTRIP PATCH ARRAY ANTENNA (MSP)

The Microstrip Patch Antenna is a single-layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part). Patch antenna can be classified as single – element resonant antenna. Once the frequency is given, everything (such as radiation pattern input impedance, etc.) is fixed. The patch is a very thin radiating metal strip (or array of strips) located on one side of a thin non-conducting substrate, the ground plane is the same metal located on the other side of the substrate. The metallic patch is normally made of thin copper foil plated with a corrosion resistive metal, such as gold, tin, or nickel. the most popular shape is the rectangular and circular patch.

The substrate layer thickness is 0.01–0.05 of free-space wavelength. It is used primarily to provide proper spacing and mechanical support between the patch and its ground plane. It is also often used with high dielectric-constant material to load the patch and reduce its size.

The advantages of the microstrip antennas are small size, low profile, and lightweight, conformable to planar and non-planar surfaces. It demands a very little volume of the structure when mounting. They are simple and cheap to manufacture using modern printed circuit technology. However, patch antennas have disadvantages. The main disadvantages of the microstrip antennas are low efficiency, narrow bandwidth of less than 5%, low RF power due to the small separation between the radiation patch and the ground plane (not suitable for high-power applications).

1.5.1 TYPES OF FEEDING IN MSP ARRAY ANTENNA

There are many methods of feeding a microstrip antenna. The most popular methods are:

- 1) Microstrip Line Feed.
- 2) Coaxial Probe (coplanar feed) Feed.
- 3) Proximity Coupling.
- 4) Aperture Coupling.

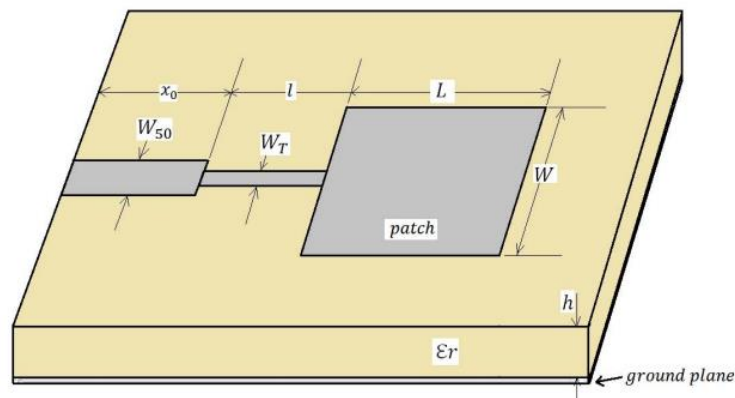


Fig 1.13: Microstrip Line Feeding technique

The above Fig 1.13 shows the diagram of Microstrip line feed technique. It is a feeding technique, in which the microstrip patch is directly connected with the conducting microstrip feed line. The dimensions of the feed line are different than microstrip patch. It is easy to fabricate and match. In this feeding method, inner conductor of coaxial cable is connected to the microstrip patch of an antenna and outer one is connected with ground plane. Mostly, the feed networks are isolated from the microstrip patch, but in this mechanism, it is not like that Spurious radiation minimization, easy fabrication and efficient feeding are the advantages of coaxial feeding method.

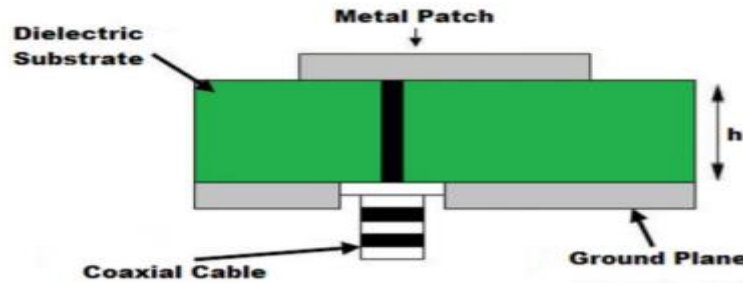


Fig 1.14: Coaxial Probe Feeding technique

The above Fig 1.14 shows the diagram of coaxial probe feed. In this feeding method, the inner conductor of coaxial cable is connected to the microstrip patch of an antenna and outer one relates to ground plane. Mostly, the feed networks are isolated from the microstrip patch, but in this mechanism. Spurious radiation minimization, easy fabrication and efficient feeding are the advantages of coaxial feeding method. The coaxial connector is coupled to the back side of the microstrip antenna (the ground plane) and the center connector of the coaxial will be passed through the substrate and soldered to the patch.[10].

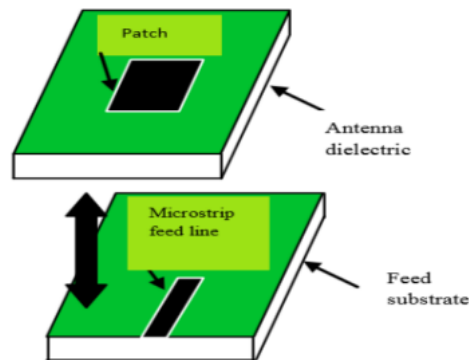


Fig 1.15: Proximity Coupling feeding technique

The above Fig 1.15 shows the diagram of proximity coupling. The fabrication of this feeding method is a bit complicated comparatively. Two dielectric substrates are used in this technique. The microstrip patch is there at the upper surface of the upper dielectric substrate and the feed line is there between two substrates. It provides the highest bandwidth and avoids spurious radiation.

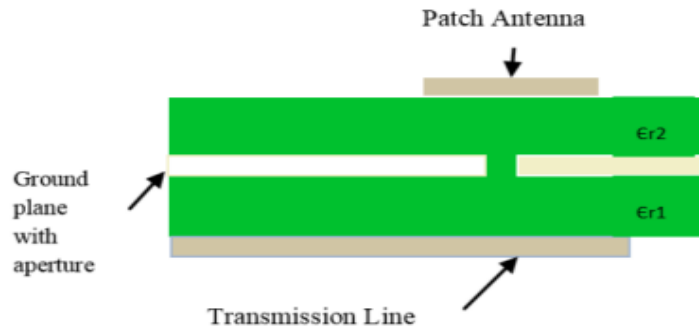


Fig 1.16: Aperture Coupling Feeding technique

The above Fig 1.16 shows the diagram of aperture coupling. This feed has two substrates, which are different from each other and are separated by a ground plane. In this method, the microstrip patch and feed line are coupled through a slot in the ground plane. Minimization in interference and pure polarization are the advantages of aperture coupled feeding method. The aperture feed technique consists of two dielectric substrates, namely antenna dielectric substrate, and feed dielectric substrate. These dielectric substrates are separated by a ground plane, which has a slot at its center. The metal patch is placed on top of the antenna substrate. The ground plane is placed on the other side of the antenna dielectric.

The feed dielectric and feed line are placed on the other side of the ground plane to provide isolation. Aperture feed provides excellent polarization purity, which is something unattainable with other feed techniques. Aperture fed antenna offers higher bandwidth. It is very useful in applications in which we don't want to use wires from one layer to another. The disadvantage with this feed is that it requires multilayer fabrication.

CHAPTER 2

LITERATURE SURVEY

Adnan Basir Patwary, Ifana Mahbub, [1] Microwave beam radiation-based far-field Wireless power transfer (WPT) provides power at a higher distance with a smaller attenuation. This can be used to power unmanned micro aerial vehicles (MAVs) thus not requiring them to come to the ground for recharging. Such WPT systems require antenna arrays with a high gain and a unidirectional beam for the most efficient power transfer. In this paper, a 4×4 phased array antenna design is proposed where it is divided into four quadrants of 2×2 array antennas and the total dimension is 17×14.3 cm². The antenna is modeled on a 1.53 mm thick FR4 substrate with 0.035 mm thick Copper (Cu) for the patch and ground. Every single antenna is individually fed where the antennas in each quadrant are fed the same phased signal. By controlling the input signal phase of each quadrant, the radiation beam can be steered within -140° to $+60^{\circ}$ along the phi (ϕ) axis. The overall beam steering angle is 200° with a beam angle of 43° . The antenna also operates within the UWB frequency range of 7.6–8.75 GHz making it suitable for pulsed-based WPT systems. The proposed phased array antenna achieves a high gain of 34 dBi, which is ~2x higher compared to the other state-of-the-art works while achieving a 1.15 GHz of bandwidth.

A. U. Bhohe, C. L. Holloway, et.al., [2] In this paper, they have presented novel designs of CPW-fed wideband slot antennas using the moment method technique. The validity of the design procedure has been illustrated by two design examples of the HSA structure, obtaining impedance bandwidths up to 57%.

Fallgren, M., Dillinger, M, et.al., [3] In this paper identifies relevant future 5G enhancements, specifically those specified by Third-Generation Partnership Project (3GPP) releases beyond Release 15, and outlines how they will support the ambitions of highly automated driving in cross-border corridors. In order to conduct this study, a set of representative use cases and the related communication requirements were identified. Then, for each use case, the most relevant 5G features were proposed.

Hasan U. Zaman; Touhidul Islam, et.al., [4] In this paper, Wireless power transfer (WPT) or wireless energy transmission is the transmission of electrical power from a power source to a consuming device without using solid wires or conductors. In this paper they have described the implementation of the concept of wireless power transfer to transmit power from mobile phones to mobile phones. In their design they use simple inductive coupling and basic electrical circuits to implement this technology.

Y. Huo, X. Dong, et.al., [5] In this paper, they first investigate contemporary wireless user equipment (UE) hardware design and unveil the critical 5G UE hardware design constraints on circuits and systems. On top of the said investigation and design tradeoff analysis, a new, highly reconfigurable system architecture for 5G cellular user equipment, namely distributed phased arrays-based MIMO (DPA-MIMO) is proposed.

Y.-W. Hsu, T.-C. Huang, et.al., [6] In this palimpsest, an uncomplicated design technique of dual-polarized antenna array is suggested for the fifth-generation (5G) mobile terminal. Its structure contains a pair of conventional slot antenna arrays arranged with a 90° difference on the top portion of the smartphone printed circuit board (PCB). The proposed design is designed to work at 28 GHz. The essential characteristics of the design in terms of S-parameters, radiation patterns, efficiency, and antenna gain are investigated. The obtained results show good features of the antenna array for non-identical polarizations.

K. Kanjanasit, C. Wang, [7] This paper reports the development of a wideband resonant cavity antenna (RCA). The RCA device was obtained by using an optimized aperture coupled CPW (coplanar waveguide) fed wideband patch antenna and a metamaterial based superstrate design. The wideband behavior is based on the effects of the Fabry-Perot cavity on either side of the resonant frequency of the metamaterial superstrate and the finite size of the superstrate to obtain enhanced gain around this frequency.

A. Li, K.-M. Luk, et.al., [8] A dual linearly polarized antenna array with end-fire radiation of the 60-GHz band is proposed by combining two types of magneto-electric dipoles (ME-dipole), which operate in vertical polarization (V-pol) and horizontal polarization (H-pol), respectively.

A.Li and K. M. Luk, et.al., [9]. They used by combining two kinds of magneto-electric (ME) dipole which operate in vertical polarization (v-pol) and horizontal polarization (H-pol) respectively and then the array achieved a good performance with larger bandwidths of 19.3% and 21.5% for V-pol and H-pol and radiation efficiency is around 80%.

Omar. H, Khadige Abboud, et.al., [10] This paper surveys potential DSRC and cellular interworking solutions for efficient V2X communications. First, we highlight the limitations of each technology in supporting V2X applications. Then, we review potential DSRC-cellular hybrid architectures, together with the main interworking challenges resulting from vehicle mobility, such as vertical handover and network selection issues. In addition, we provide an overview of the global DSRC standards, the existing V2X research and development platforms, and the V2X products already adopted and deployed in vehicles by car manufactures, as an attempt to align academic research with automotive industrial activities. Finally, we suggest some open research issues for future V2X communications based on the interworking of DSRC and cellular network technologies.

J. Park, D. Choi, et.al., [11] In this paper, an end-fire antenna for 28 GHz broadband communications is proposed with its multiple-input-multiple-output (MIMO) configuration for pattern diversity applications in 5G communication systems and the Internet of Things (IoT). The antenna comprises a simple geometrical structure inspired by a conventional planar helical antenna without utilizing any vias. Its MIMO configuration is characterized by reasonable gain, high isolation, good envelope correlation coefficient, broad bandwidth, and high diversitygain. To verify the performance of the proposed antenna, it was fabricated and verified by experimental measurements. Notably, the antenna offers a wide -10 dB measured impedance ranging from 26.25 GHz to 30.14 GHz, covering the frequency band allocated for 5G communication systems with a measured peak gain of 5.83 dB.

Shi. Y, Chen. S, Hu. J, et.al., [12] In this paper it is said that the LTE-V-direct is a new decentralized architecture which modifies TD-LTE physical layer and try to keep commonality as possible to provide short range direct communication, low latency, and high reliability improvements. By leveraging the centralized architecture with native features of TD-LTE, LTE-V-cell optimizes radio resource management for better supporting V2I. LTE-V-direct and LTE-V-cell coordinate with each other to provide an integrated V2X solution. Performance simulations based on sufficient scenarios and the prototype system with typical cases are presented.

J. Wang, Y. Li, L. Ge, et.al., [13] They used SIW feed horizontally polarized end fire magnetoelectric (ME) dipole antenna composed of an open-ended SIW with broad walls vertical to substrates and a pair of electric dipoles realized by four metallic patched and due to that a wide impedance bandwidth of 22.1% gain varying from 10 to 13 dBi and stable radiation beams can be obtained.

Kawasaki, R.; Onishi, H., et.al., [14] This paper investigates two methods of LTE-based V2X, - Uu-based LTEV2X which uses infrastructure and PC5-based LTE-V2X which uses D2D communication. We summarize pros and cons of these two methods for CWA, then, show quantitative performance evaluation results in terms of end-to-end latency. The results show that PC5-based LTE has much better performance than Uu-based LTE although PC5-based LTE requires additional functions to the current LTE.

Kawser, M., Sajjad. S, et.al., [15] This paper aims to clearly depict the most important aspects of V2X communication, namely, modes of operation, network architecture, spectrum used, specifications, applications, system requirements, security, and privacy. It also derives a detailed comparison among competitive standards for V2X communication, namely, CellularV2X (C-V2X), Dedicated Short Range Communication (DSRC), Cooperative Intelligent Transport Systems (C-ITS), Advanced ITS, and Association of Radio Industries and Businesses (ARIB) development.

2.1 INFERENCE FROM LITERATURE SURVEY

The given papers cover a range of topics in the field of wireless communication and technology. The first paper proposes a 4x4 phased array antenna design for microwave beam radiation-based wireless power transfer (WPT), which achieves high gain and efficient power transfer. The second paper presents designs of CPW-fed wideband slot antennas using the moment method technique. The third paper identifies future 5G enhancements and how they will support highly automated driving in cross-border corridors. The fourth paper describes the implementation of wireless power transfer between mobile phones using inductive coupling and basic electrical circuits. The fifth paper proposes a new, highly reconfigurable system architecture for 5G cellular user equipment. The sixth paper suggests a design technique of dual-polarized antenna array for 5G mobile terminals. The seventh paper reports the development of a wideband resonant cavity antenna (RCA). The eighth and ninth papers propose a dual linearly polarized antenna array with end-fire radiation for the 60-GHz band. The tenth paper surveys potential DSRC and cellular interworking solutions for efficient V2X communications. Overall, the papers demonstrate ongoing research in the field of wireless communication, particularly in the areas of 5G technology, wireless power transfer, and antenna design.

2.2 PROBLEM STATEMENT

Despite the potential benefits of V2X technology in enhancing vehicular safety and improving transportation infrastructure, there remain significant challenges to its widespread adoption. These challenges include issues related to data security and privacy, economic risk, internationalization, legal regulation and responsibility, and acceptance. Given the critical nature of this infrastructure, it is crucial to address these challenges and ensure that V2X technology can be deployed in a safe, secure, and effective manner. Therefore, the research problem is to identify solutions to these challenges and develop a framework for the successful implementation of V2X technology in the transportation industry. This framework should take into consideration the different communication technologies and platforms available, as well as the potential deployment challenges that may arise. In addition, the framework should also explore the economic and societal implications of V2X technology and identify strategies to ensure its acceptance and adoption by different stakeholders.

CHAPTER 3

AIM AND SCOPE OF THE INVESTIGATION

3.1 OBJECTIVE OF V2X

The fifth generation (5G) network is the current emerging technology that meets the increasing need for higher throughput and greater system capacities. It is expected that 5G technology will enable many new applications and services. Vehicle-to-everything (V2X) communication is an example of an application that is supported by 5G technology and beyond. A V2X communication system allows a vehicle to be connected to an entity, such as a pedestrian, another vehicle, infrastructure, and a network, to provide a robust transportation solution. The fifth generation is the current generation of cellular networks and aims to make significant improvements in service quality to enhance reliability, throughput, delay, and connectivity. Some examples of 5G emerging applications are smart houses, intelligent transportation, health monitoring, and the Internet of Things (IoT).

The algorithm analyses the individual behavior of all traffic participants (as long as they have a smart device activated) in the immediate surroundings and then decides if it is necessary to take action. For example, if a pedestrian is crossing the street in front of an approaching vehicle (even if this vehicle is around a corner), a warning message is sent to the driver and the pedestrian's smart device alike. With rising percentage of connected safety systems in cars and with increasing autonomy of driver assistance systems, the warning message can trigger automated countermeasures in the vehicle including evasive maneuvers or applying the brake.

The interactivity of this system exceeds well the possibilities of pure Car-to-X or X-to-Car communication. The context of the motion data is also included – these data can not only be used to determine the motion vector and speed of the traffic participants but can assess and identify danger zones such as bus stops or confusing street courses.

3.2 BENEFITS OF V2X

The system permanently gathers motion data from the systems connected. Therefore, smartphone users (and likewise users of wearables) can potentially benefit from the technology – at least as long as they are online. The algorithm leverages the motion data to calculate the probability of a crash between any of the participants. The collision warning is issued before a visual contact is established and also before the vehicle sensors – radar, lidar, cameras – are able to identify the hazard situation. This significantly increases the safety because according to studies, car drivers at the wheel are actually distracted for more than 50% of their driving time.

V2X technology helps with improving transportation management efficiency and reducing congestion. It notifies drivers for upcoming traffic congestions and offers them alternative routes. It enables communication between vehicles and traffic lights, road signs or other smart traffic systems. In addition, V2X communication ensures eco-friendly driving that leads to reducing fuel consumption and air pollution. As a result, there is better congestion control and traffic flows are normalized, especially in hot spots. V2X also provides information for road accidents. If an accident happens, the V2V communication system will notify the approaching vehicles. That way, V2X improves the quality and efficiency of the overall Smart Mobility.

V2X and especially vehicle-to-infrastructure system (V2I) have a big importance for Smart Parking Management in Smart Cities. Thanks to the V2X technology, vehicles and parking lots will be connected, so drivers will know which parking spaces are available. This smart solution makes parking occupancy tracking easier for parking lot owners and operators.

Here are some of the benefits of V2X and V2I for smart parking management: Better parking experience for parking users and parking operators, Real-time information about parking occupancy and availability, Automated vehicle identification and online payment for parking stay in order to reduce a vehicle's idling, Easier empty parking space finding and booking, Reducing the time of circling for a parking space, Monitoring air quality and congestion control and Improved parking enforcement.

CHAPTER 4

PROPOSED METHODOLOGY

4.1 MICROSTRIP PATCH ANTENNA DESIGN FORMULAS

Wavelength

All you have to do is divide the speed of light by the product of frequency and 1,000,000. And as a result, you have the wavelength of the dipole antenna.

$$\lambda = \frac{c}{f} \text{ mm/sec} \quad (4.1)$$

Width

$$W = \frac{\lambda}{2} \sqrt{\frac{2}{\epsilon_r + 1}} \text{ mm} \quad (4.2)$$

Where, W = Width of the patch, C = Speed of light, ϵ_r = value of the dielectric substrate and λ = Wavelength and f = frequency.

Fringing effect

Calculation of the Effective Dielectric Constant (ϵ_{reff}). This is based on the height, dielectric constant of the dielectric and the calculated width of the patch antenna.

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{w}\right)^{-1} \quad (4.3)$$

Calculation of the length extension ΔL Formula is mentioned below:

$$\Delta L = 0.412h \left\{ \frac{(\epsilon_{reff} + 0.3) \left(\frac{w}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258) \left(\frac{w}{h} + 0.8\right)} \right\} \quad (4.4)$$

Calculation of the Effective length (L_{eff}) formula is mentioned below:

$$L_{eff} = \frac{\lambda}{2\sqrt{\epsilon_{reff}}} \quad (4.5)$$

Length

Calculation of actual length of the patch (L) formula is given below:

$$L = L_{eff} - 2\Delta L \quad (4.6)$$

Ground and Substrate Dimensions

The length of a ground plane (L_g) and the width of a ground plane (W_g) are calculated using the following equations:

$$L_g = L + 6h \text{ mm} \quad (4.7)$$

$$W_g = W + 6h \text{ mm} \quad (4.8)$$

SRR and CSRR Metamaterial

Split ring resonators (SRRs) consist of a pair of concentric metallic rings, etched on a dielectric substrate, with slits etched on opposite sides. SRRs can produce an effect of being electrically smaller when responding to an oscillating electromagnetic field. These resonators have been used for the synthesis of left-handed and negative refractive index media, where the necessary value of the negative effective permeability is due to the presence of the SRRs.

$$L_1 = 4 \times l_1 - S - 4 \times W \quad (4.9)$$

$$L_2 = 4 \times l_2 - S - 4 \times W \quad (4.10)$$

$$f_1 = \frac{c}{2L_1 \sqrt{\epsilon_{\text{reff}}}} \quad (4.11)$$

$$f_2 = \frac{c}{2L_2 \sqrt{\epsilon_{\text{reff}}}} \quad (4.12)$$

$$L = 0.00508l(2.303 \log_{10} \frac{4l}{d} - \gamma) \quad (4.13)$$

$$C_1 = (\pi - \theta)r_0 C_{\text{pul}} \quad (4.14)$$

$$C_2 = (\pi + \theta)r_0 C_{\text{pul}} \quad (4.15)$$

$$f'_0 = \frac{1}{\sqrt{2r_0 L \frac{(\pi+k)^2 - \theta^2}{2(\pi+k)} C_{pul}}} \quad (4.16)$$

Substrate Position:

$$(x, y, z) = (0, 0, 0) \quad (4.17)$$

$$x = L_g$$

$$y = W_g$$

$$z = h$$

Ground Position:

$$(x, y, z) = (0, 0, 0) \quad (4.18)$$

$$x = L_g$$

$$y = W_g$$

Patch Position:

$$(x, y, z) = (L_g - L/2, W_g - W/2, h) \quad (4.19)$$

$$x = L$$

$$y = W$$

Feed Position:

$$(x, y, z) = ((L_g / 2 - W_f/2), 0, h) \quad (4.20)$$

$$x = W_f$$

$$y = L_f$$

Port Position:

$$(x, y, z) = ((L_g / 2 - W_f/2), 0, 0) \quad (4.21)$$

$$x = W_f$$

$$z = h$$

4.2 SIMULATING SOFTWARE FOR THE ANTENNA

Ansys HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, RF or microwave components, high-speed interconnects, filters, connectors, IC packages and printed circuit boards. Engineers worldwide use Ansys HFSS software to design high-frequency, high-speed electronics found in communications systems, advanced driver assistance systems (ADAS), satellites, and internet-of-things (IoT) products.

Ansys HFSS combines the highly accurate finite element method (FEM), the large-scale method of moments (MoM) technique, the ultra-large-scale asymptotic methods of physical optics (PO) and shooting and bouncing rays (SBR).

Engineers use Ansys HFSS primarily to design and simulate high-speed, high-frequency electronics in radar systems, communication systems, satellites, ADAS, microchips, printed circuit boards, IoT products, and other digital devices and RF devices. The solver has also been used to simulate the electromagnetic behaviour of objects such as automobiles and aircraft. ANSYS HFSS allows system and circuit designers to simulate EM issues such as losses due to attenuation, coupling, radiation and reflection.

The benefits of simulating a circuit's high frequency behavior with high accuracy on a computer reduces the final testing and verification effort of the system as well as mitigating the necessity of building costly multiple prototypes, saving both time and money in product development.

HFSS captures and simulates objects in 3D, accounting for materials composition and shapes/geometries of each object. HFSS is one of several commercial tools used for an antenna design, and the design of complex radio frequency electronic circuit elements including filters, transmission lines, and packaging.

The full-featured 3-D solid modeler and layout interface enables you to work in a layout design flow, or to import and edit 3-D CAD geometry.

HFSS 3-D Modeler: The 3-D interface enables you to model complex 3-D geometry or import CAD geometry for simulation of high-frequency components, such as antennas, RF/microwave components and biomedical devices. You can extract scattering matrix parameters (S, Y, Z parameters), visualize 3-D electromagnetic fields (near- and far-field), and generate ANSYS Full-Wave SPICE models that link to circuit simulations.

HFSS 3-D Layout: HFSS 3-D Layout is an optimized interface for layered geometry of PCBs, IC packages or on-chip embedded passives. Geometry is assembled and rendered in a 2-D design environment; however, all effects are rigorously simulated, including 3-D features such as trace thickness and etching, bond wires, solder bumps and solder balls. Layout primitives such as stack-up dimensions, anti-pad radius, trace widths or thicknesses can be easily parameterized in the design environment. HFSS 3-D Layout includes advanced phi meshing technology that is optimized for meshing silicon substrates, redistribution layers, electronic packages, and PCBs.

ANSYS HFSS can simulate phased-array antennas with all electromagnetic effects, including element-to-element coupling, embedded element patterns, scan input impedance and near- or far-field radiation. Infinitely large and finite-sized arrays can be simulated efficiently by exploiting the periodic nature of the geometry. For infinite arrays, one or more antenna elements are placed within a unit cell with periodic boundary conditions on the surrounding walls to mirror fields creating an infinite number of elements in two directions. Per-element scan impedance and embedded element radiation patterns can be computed, including all mutual coupling effects. The method is especially useful for predicting array blind zones that can occur under certain scan conditions. The finite-sized array simulation technology leverages HPC domain decomposition to obtain a fast solution for large finite-sized arrays. This technology makes it possible to perform complete array analysis to predict all mutual coupling, scan impedance, element patterns, array patterns and array edge effects.

CHAPTER 5

SIMULATION RESULTS AND DISCUSSIONS

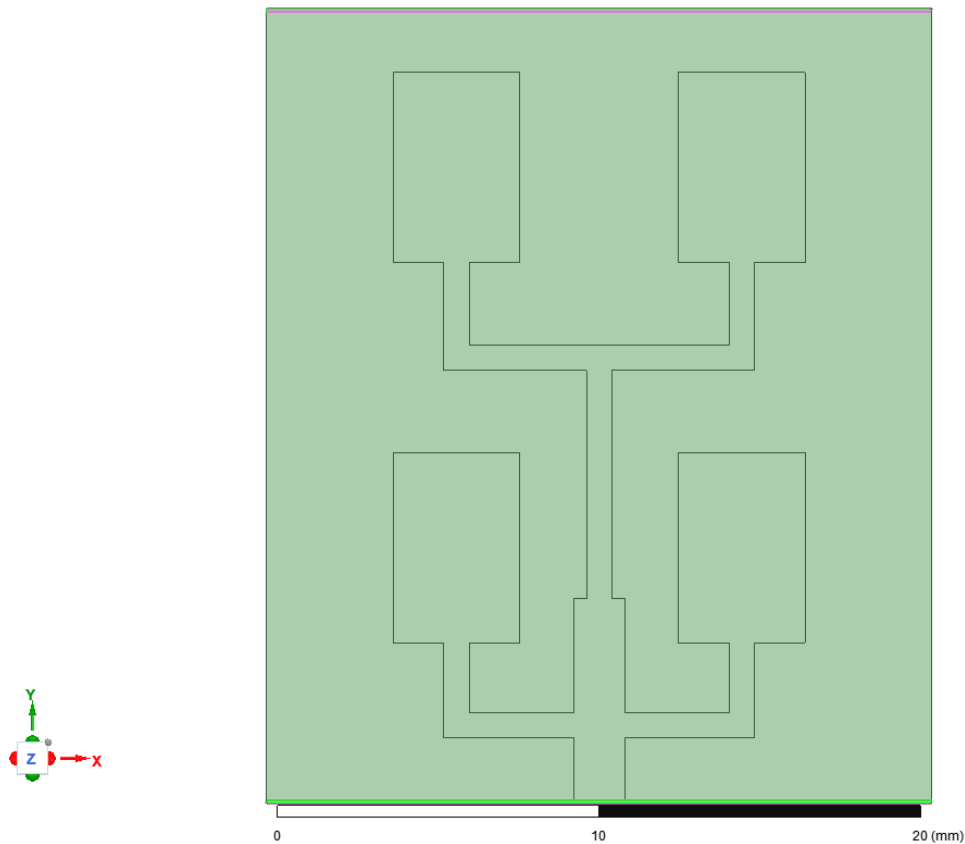


Fig 5.1: Design of the Microstrip Patch Array Antenna

The above Fig 5.1 displays the design of the antenna from the front view. The Microstrip patch antenna is a low-profile antenna consisting of multiple patches in a two-dimensional array. It is easy to design and manufacture due to its suitable design, relatively low cost and very narrow bandwidth, making it the ideal choice for many operations due to its advantages of small size, low cost, lightness, and has good mechanical strength.

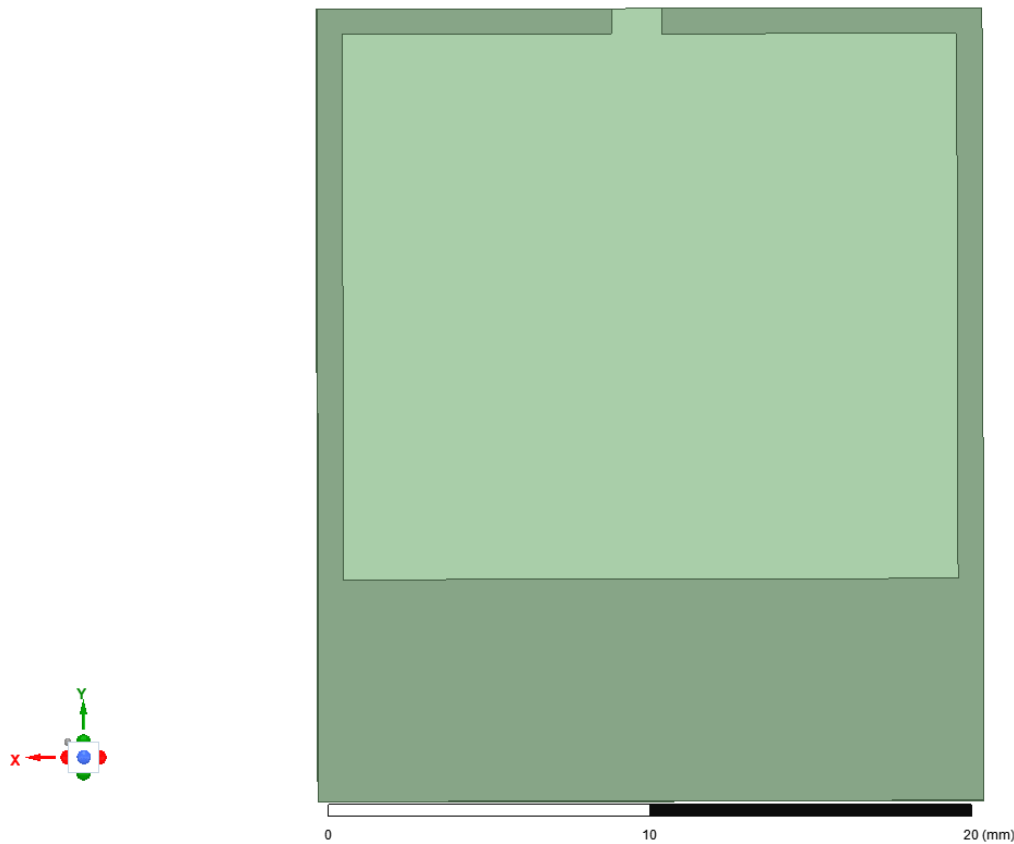


Fig 5.2: Ground Structure of the Microstrip patch Antenna

The above Fig 5.2 is the ground structure of the microstrip patch antenna. A ground-plane antenna is a form of dipole antenna designed to work with an unbalanced feed line. A ground-plane antenna is more or less one half of the dipole and mounted above the ground plane. Ease of fabrication and cost makes the ground-plane antenna one of the popular antennas in communication systems. If an antenna is grounded, the earth still acts as a mirror and becomes part of the radiating system. The ungrounded antenna with its image forms a dipole array, but the bottom of the grounded antenna is joined to the top of the image. The system acts as an antenna of double size. A grounded quarter-wave vertical radiator effectively has a quarter-wavelength added to it by its image. The voltage and current distributions on such a grounded $\lambda/4$ antenna are the same as those of the half-wave dipole in space.

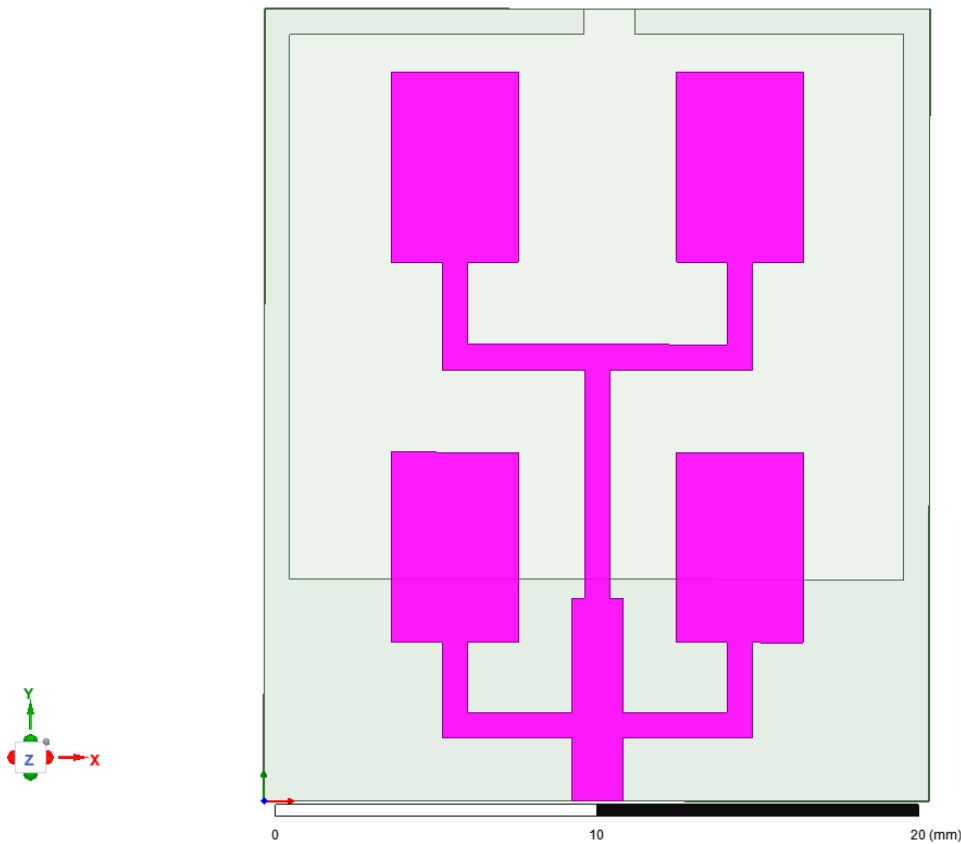


Fig 5.3: Patch of the Antenna

The above given Fig 5.3 is the structure of the patch in the antenna designed. A Patch antenna is a type of antenna with a low profile, which can be mounted on a surface. It consists of a planar rectangular, circular, triangular, or any geometrical sheet or "patch" of metal, mounted over a larger sheet of metal called ground plane. An antenna that is formed by etching out a patch of conductive material on a dielectric surface is known as a patch antenna. The dielectric material is mounted on a ground plane, where the ground plane supports the whole structure. Also, the excitation to the antenna is provided using feed lines connected through the patch. As it is formed using a microstrip technique by fabricating on a printed circuit board thus is also known as Microstrip antenna or printed antenna.

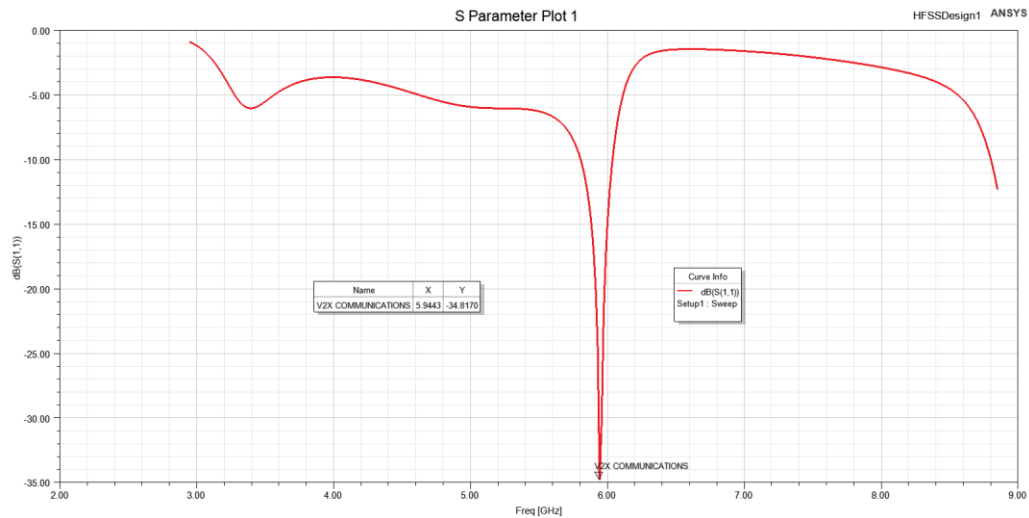


Fig 5.4: S-Parameter Plot of the Microstrip patch antenna

The above plot Fig 5.4 describes the S-Parameter of the antenna. Scattering parameters or S-parameters describe the electrical behavior of linear electrical networks when undergoing various steady state stimuli by electrical signals. S-parameters are used to describe how energy can propagate through an electric network, when it becomes especially important to describe a network in terms of amplitude and phase versus frequencies, rather than voltages and currents. Various optimizations are done to get the return loss at the required frequency (5.85-5.95 GHz), which is also used in the antenna design. This is achieved by varying patch size and the feedline size, and in the ground layer by applying half ground, a quarter ground, and SRR in the ground (Split Ring Resonator). Impedance matching is done between the patches to get the maximum power transfer. The above graph shows the required frequency output at nearly -35dB exactly at 5.92 GHz.

Before receiving the required output on the plot, front- to-back ratio is observed, which is the primary thing to get this output. The front-to-Back ratio is nothing, but the gain is 180 degrees more in the forward and 90 degrees less in the back from the required frequency. With this, the required frequency is obtained.

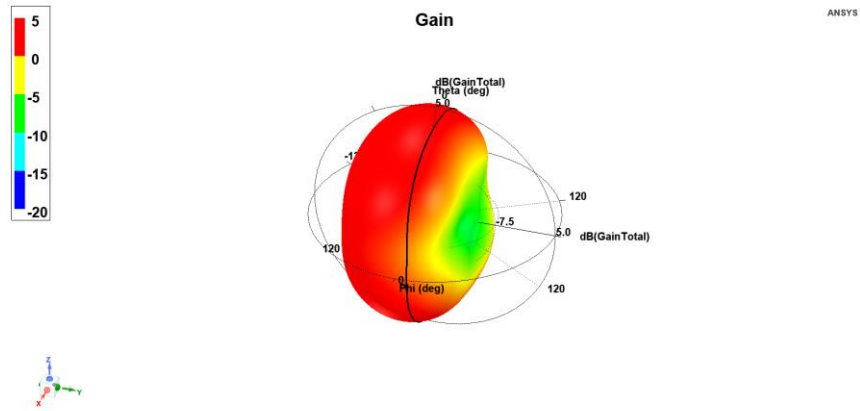


Fig 5.5: Gain of the Microstrip patch Antenna

The above Fig 5.5 shows the gain of the antenna. As we know, Antenna Gain is the measure of how strong the signal of an antenna can transmit or receive direction. Here the gain is -7.5dB which is strong enough to transfer power and information. The EBG Structure consists basically of periodic structure arrangements of a high and low dielectric substrate and metallic conductors. Here we are using mushroom PGB (Photonic-crystals and Band Gaps). The EBG structure has attracted much attention recently due to their unique electromagnetic features. Applications of microstrip antennas on high dielectric constant substrates are of growing interest due to their compact size and conformability with monolithic microwave integrated circuit. By this we can get the proper gain plot what we needed.

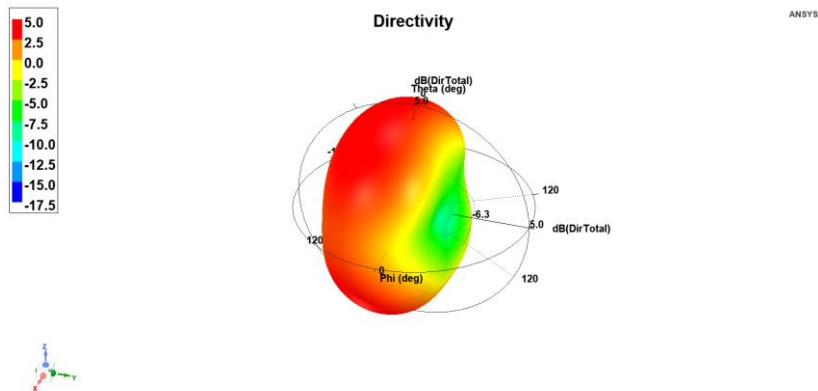


Fig 5.6: Directivity of the Microstrip patch Antenna

The above Fig 5.6 shows the directivity of the antenna. Directivity is a measure of how well the array directs energy toward a particular direction. Directivity is a fundamental antenna parameter. It is a measure of how 'directional' an antenna's radiation pattern is. An antenna

that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB). Gain is the product of directivity and efficiency. Where efficiency accounts for the losses on the antenna such as manufacturing faults, surface coating losses, dielectric, resistance, VSWR, or any other factor.

The directivity of patch antennas is approximately 5-7 dB. Here for this antenna's design the directivity is given as 6.3 dB. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π . If the direction is not strictly specified, the direction of maximum radiation intensity is implied.

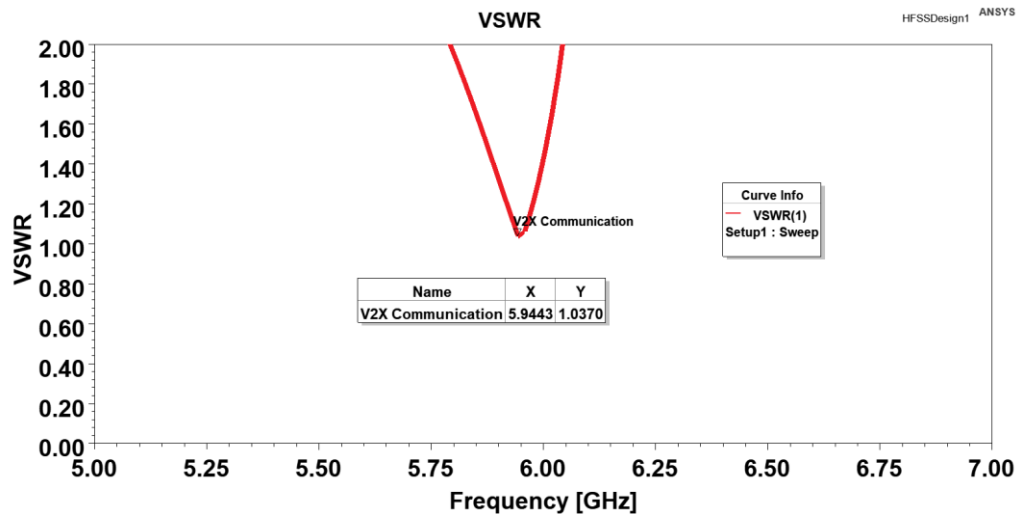


Fig 5.7: VSWR plot of the Microstrip antenna

The above plot Fig 5.7 shows the VSWR plot of the antenna. The Voltage Standing Wave Ratio (VSWR) is an indication of the amount of mismatch between an antenna and the feed line connecting to it. This is also known as the Standing Wave Ratio (SWR). The range of values for VSWR is from 1 to ∞ . A VSWR value under 2 is considered suitable for most antenna applications. The antenna can be described as having a “Good Match”. So, when someone says that the antenna is poorly matched, very often it means that the VSWR value exceeds 2 for a frequency of interest. Return loss is another specification of interest and is covered in more detail in the Antenna Theory section. A commonly required conversion is between return loss and VSWR, and some values are tabulated in chart, along with a graph of these values for quick reference.

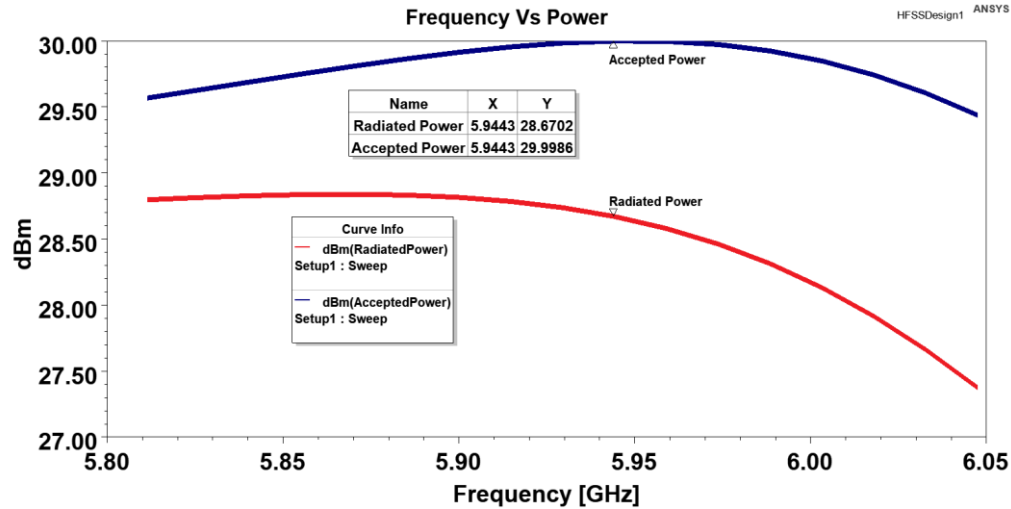


Fig 5.8: Frequency Vs Power Plot of the Microstrip antenna

The above Fig 5.8 shows the Frequency Vs Power plot of the designed microstrip patch antenna. This shows both accepted power and radiated power. According to this plot that this antenna will transmit maximum power. Power is the rate at which energy is being transferred and is measured in watts (W). Frequency is the number of times that the voltage or current in an AC circuit changes direction in one second and is measured in hertz (Hz).

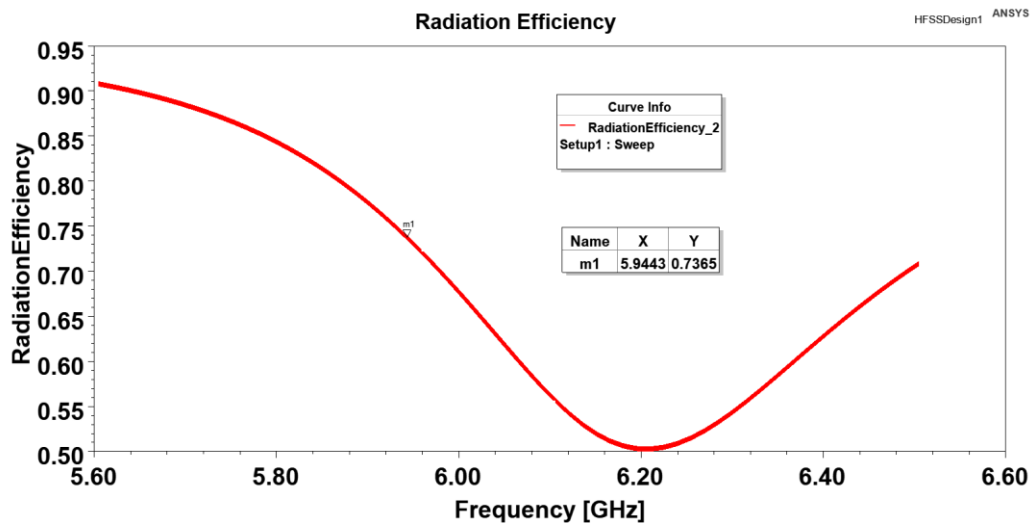


Fig 5.9: Radiation Efficiency Plot of the Microstrip antenna

The above graph Fig 5.9 shows the Radiation Efficiency of the antenna. The radiation efficiency of an antenna is defined as the ratio of the power radiated by an antenna to the power fed to the excitation port of the antenna. The power loss due to port impedance

mismatch is not considered here. For wire antennas which have a defined radiation resistance the radiation efficiency is the ratio of the radiation resistance to the total resistance of the antenna including ground loss and conductor resistance. In practical cases the resistive loss in any tuning and/or matching network is often included, although network loss is strictly not a property of the antenna. For other types of antennas, the radiation efficiency is less easy to calculate and is usually determined by measurements.

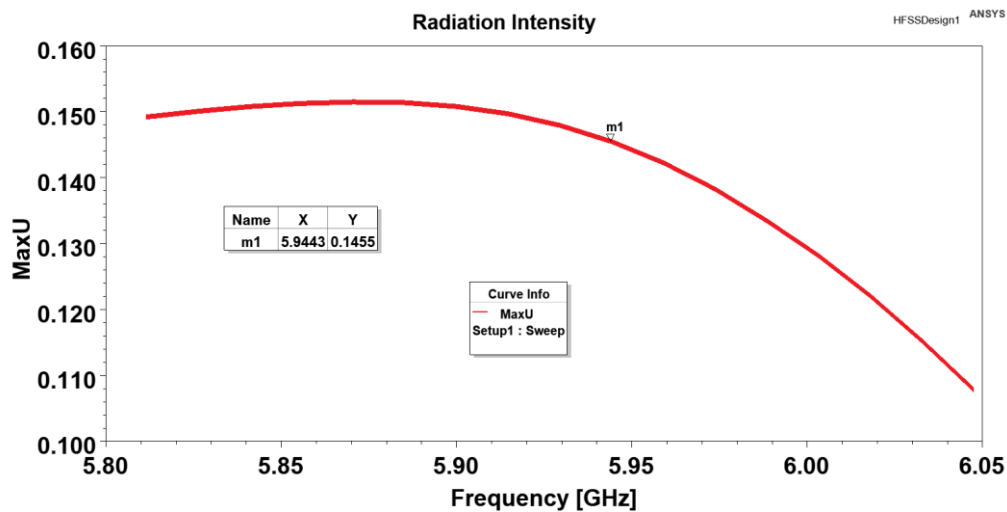


Fig 5.10: Radiation Intensity Plot of the Microstrip antenna

The above plot Fig 5.10 shows the Radiation Intensity of the microstrip patch array antenna. Radiation intensity, or the antenna power pattern, in each direction is defined as the power radiated from an antenna per unit solid angle. The radiation intensity is a far field parameter which can be obtained by simply multiplying the radiation power density by the square distance. An Antenna radiates power, but the direction in which it radiates matters a lot. The antenna, whose performance is being observed, is termed as subject antenna. Its radiation intensity is focused in a particular direction, while it is transmitting or receiving. Hence, the antenna is said to have its directivity in that direction.

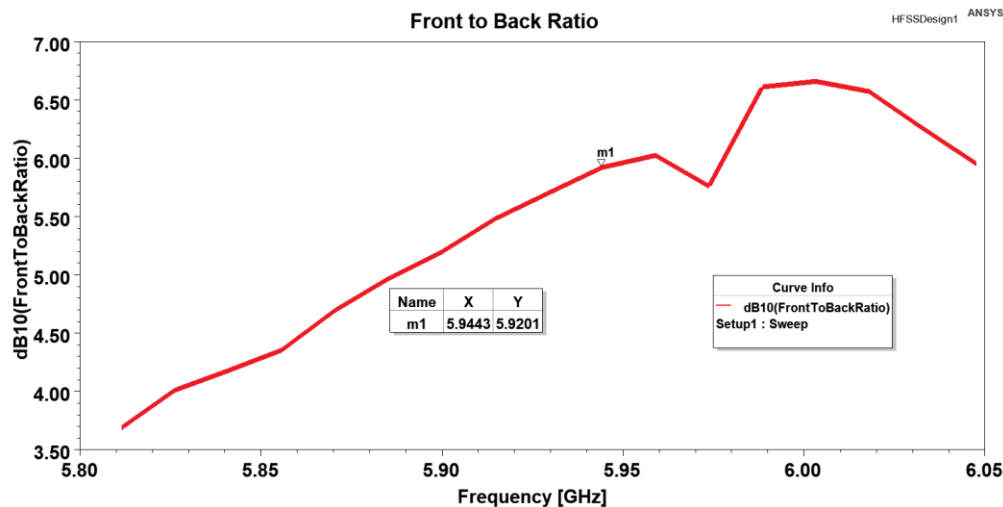


Fig 5.11: Front to Back Ratio Plot of the Microstrip antenna

The above plot Fig 5.11 displays the Front to Back Ratio Plot of the antenna. The Front to Back Ratio (F/B Ratio) of an antenna is the ratio of power radiated in the front/main radiation lobe and the power radiated in the opposite direction (180 degrees from the main beam). This ratio tells us the extent of backward radiation and is normally expressed in dB. This parameter is important in circumstances where interference or coverage in the reverse direction needs to be minimized. In other electrical engineering the front to back ratio is a ratio of parameters used to characterize rectifiers or other devices, in which electric current, signal strength, resistance, or other parameters, in one direction is compared with that in the opposite direction. Minimum value in dB. It is subject to a statistical validation for a single-sided parameter. This parameter is to be defined for the nominal subbands in a broadband antenna. Unless otherwise noted it will be assumed the specification is for the full electrical downtilt range, and for all the ports associated with each frequency subband of the antenna.

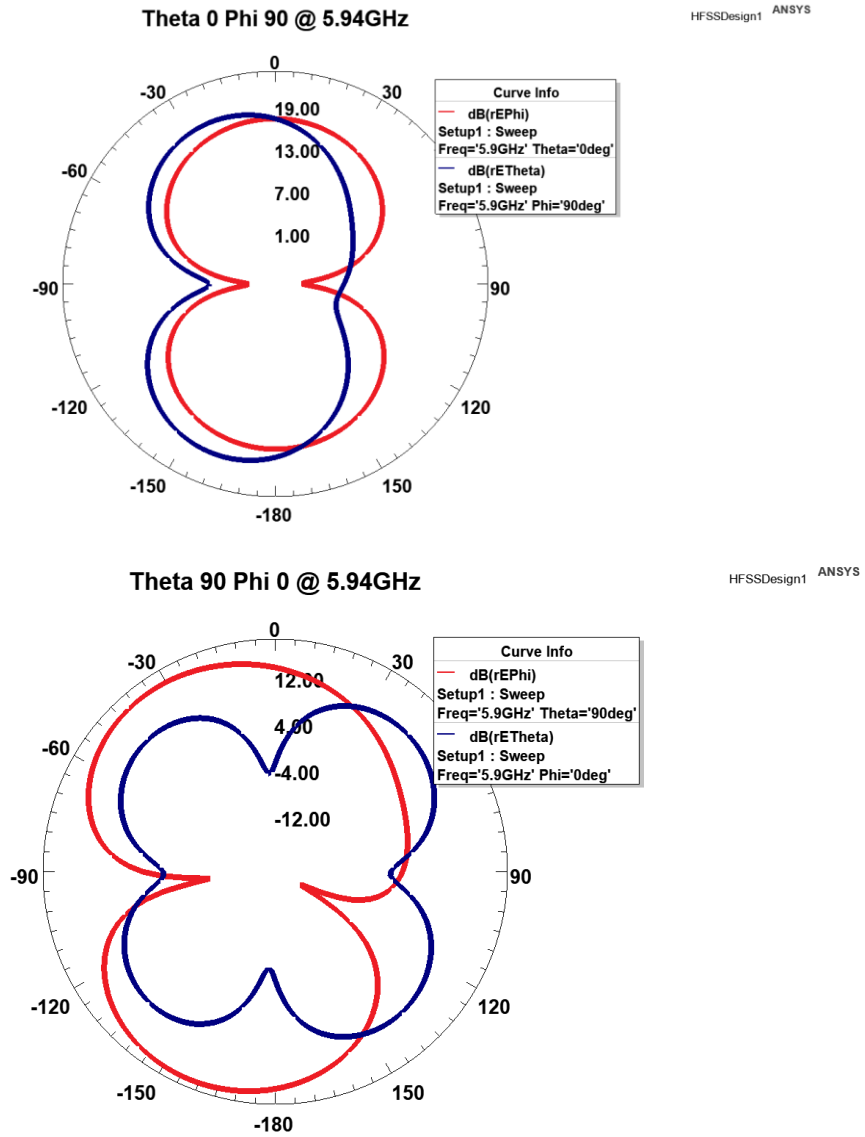


Fig 5.12 and Fig 5.13: Radiation Pattern of the Microstrip Antenna

The above Fig 5.12 and Fig 5.13 show the Radiation pattern of the microstrip patch array antenna. Fig .12 shows the pattern when theta is zero and phi is 90-degree value for 5.94Ghz and similarly the Fig 5.13 shows for theta 90 degree and phi zero degree at 5.94Ghz. The radiation form of the antenna is an electromagnetic wave, by calculating and measuring the strength of this electromagnetic wave at a distant point. This far point is where the wave is considered a plane wave and is perpendicular to the direction of the antenna.

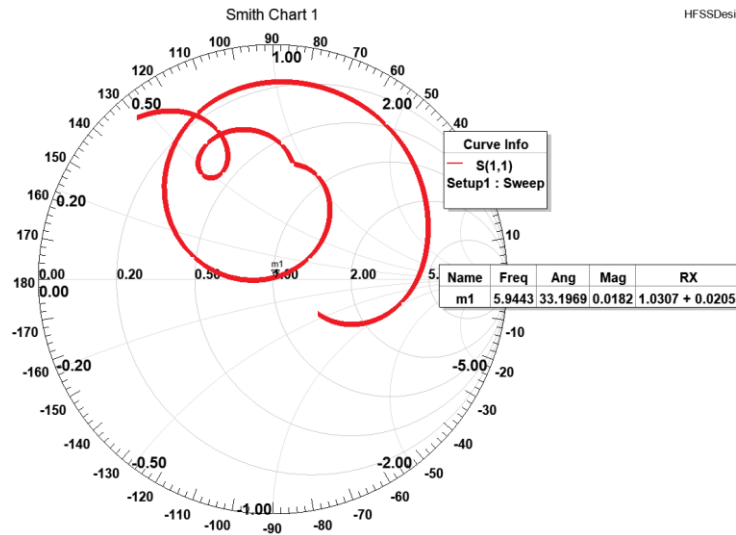


Fig 5.14: Smith chart of the Microstrip patch Antenna

The above Chart Fig 5.14 is the Smith chart of the designed antenna. A Smith chart is a circular plot with a lot of interlaced circles on it. When used correctly, matching impedances, with apparent complicated structures, can be made without any computation. The only effort required is the reading and following of values along the circles.

The Smith chart is a polar plot of the complex reflection coefficient (also called gamma and symbolized by Γ). Or, it is defined mathematically as the 1-port scattering parameter s or s_{11} . The Smith Chart, as it has been presented up to this point, is a plot of reflection coefficient for magnitudes either equal to or less than 1, thereby encompassing all real, positive values of resistance. A Smith chart is developed by examining the load where the impedance must be matched. Instead of considering its impedance directly, you express its reflection coefficient Γ_L , which is used to characterize a load (such as admittance, gain, and transconductance). The Γ_L is more useful when dealing with RF frequencies.

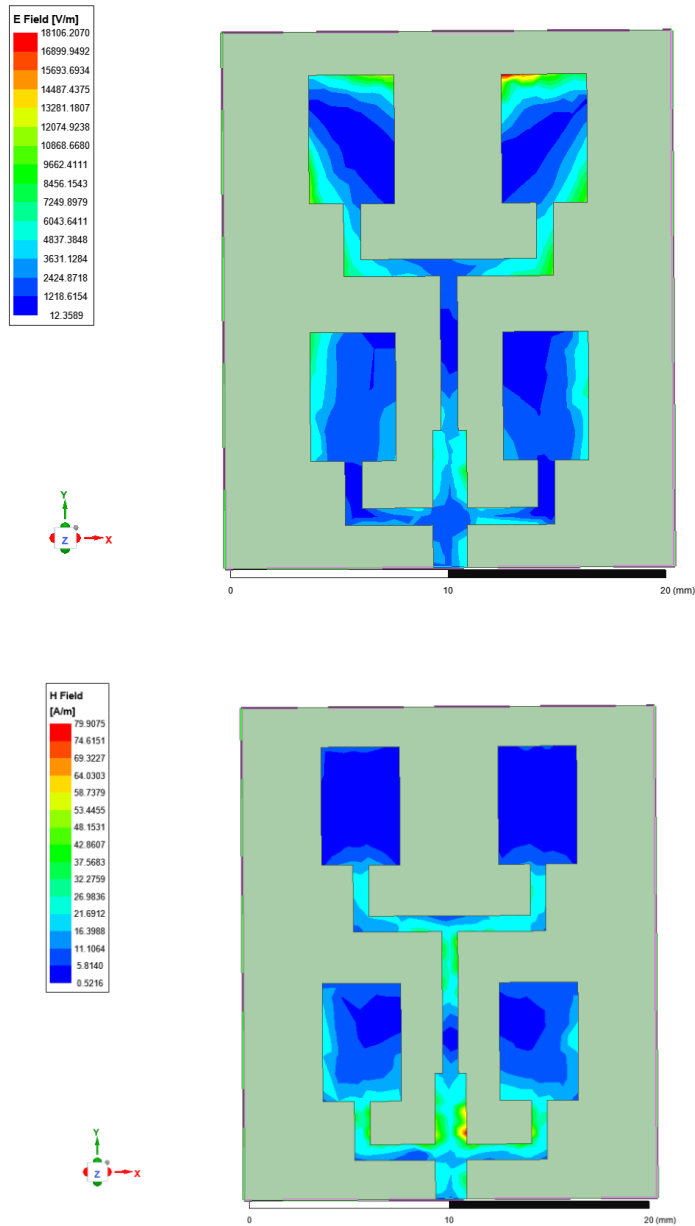


Fig 5.15 and Fig 5.16: Electric Field Flow and Magnetic Field Flow on the patch

The above figures Fig .15 and Fig 5.16 display the electric and magnetic field flow on the patch of the antenna. So, from the above figures it is clearly shown that the flow of both the electric and magnetic field in the patch is very good.

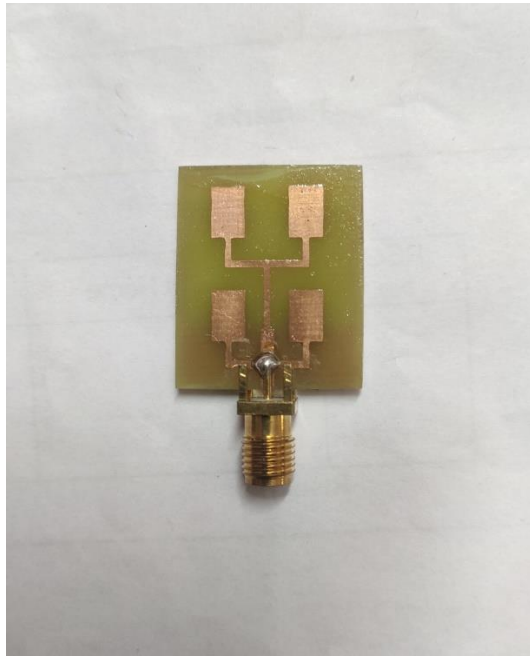


Fig 5.17 and 5.18: Front Side and Back side of the Fabricated Microstrip Patch array Antenna

The above Fig 5.17 and 5.18 shows the picture of the fabricated microstrip patch array antenna. As we can see clearly that the antenna is designed or fabricated perfectly as the design that was shown in the ansys hfss software. The antenna was fabricated and it was in good working condition and satisfies its applications. Now this antenna is ready to be integrated with the processors and to be added in the automobiles to work for the application of V2X communications. A microstrip antenna consists of a metal patch of length usually equal to one-half wavelength. The length is maintained so that the antenna behaves as a resonator. The metal patch is mounted to the ground plane and the dielectric material is filled in between. Due to the presence of a conducting patch, a microstrip antenna is also known as a microstrip patch antenna. Generally, copper material is used to make the patch.

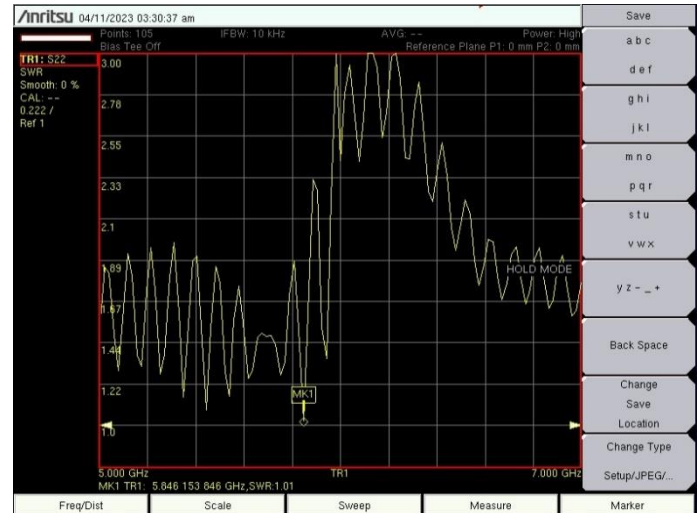
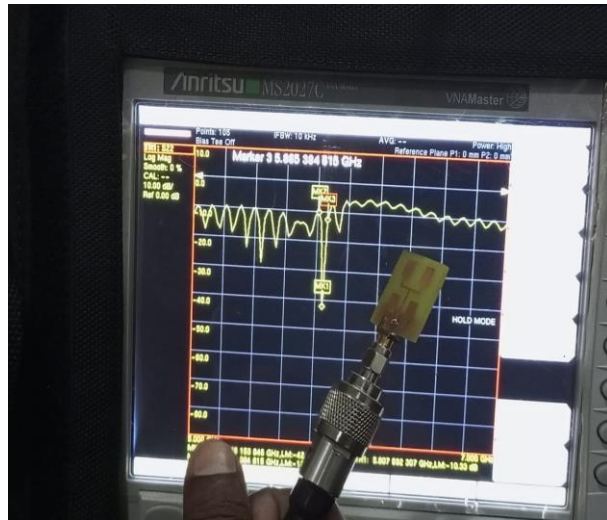


Fig 5.19 and 5.20: Log Mag and SWR plot of the fabricated microstrip antenna

The above Fig 5.19 and 5.20 shows the pictures of testing fabricated microstrip patch array antenna in real time and 5.19 shows the log mag plot of the microstrip patch antenna in real time and 5.20 shows the SWR plot of the fabricated microstrip patch array antenna. When a thin microstrip antenna is excited from a feeding network, waves are generated and reflected in the dielectric material.

When the waves reach the corners or edges of the metal patch, a fraction of the incident energy is radiated outwards. Dielectric material is used between the metal patch and the ground plane. The dielectric constant is very important in determining antenna performance. A thick dielectric material of low dielectric constant is preferred in microstrip patch antennas to give high antenna performance.

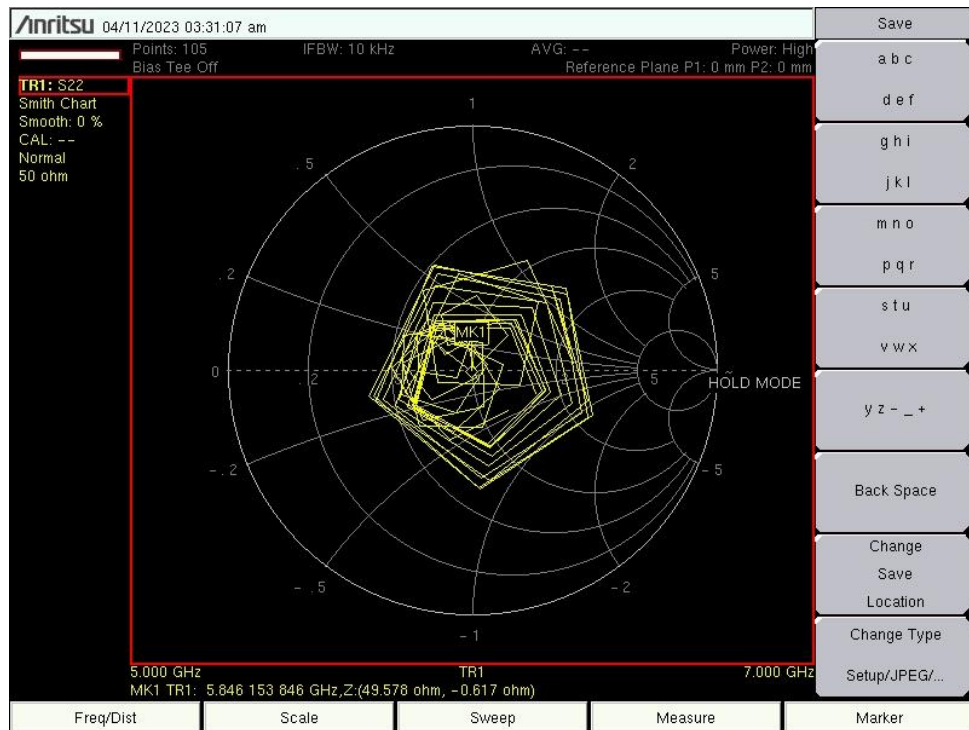


Fig 5.21: Smith chart plot of the fabricated microstrip antenna

The above Fig 5.21 shows the Smith chart plot of the fabricated microstrip patch array antenna. The results received from the testing of the designed microstrip patch array antenna in real time. Hence there is not a much difference in their output plots. The results are closer to the one that got in the simulation. So it is considered that this antenna is working well and it will satisfies its application and conditions.

Table 5.1: Dimensions and positions of the Microstrip Patch array antenna

Model	Type	Material	Position	X	Y	Z	Assign Excitation	Assign Boundary
Substrate	Solids Box1	FR4- epoxy	0,0,0	21	25	1.6	None	None
Ground	Ground	None	0,0,0	21	7	-	None	Perfect E
Ground 1	Ground 1	None	0,25,0	21	-0.8	-	None	Perfect E
Ground 2	Ground 2	None	0,0,0	0.8	25	-	None	Perfect E
Ground 3	Ground 3	None	21,0,0	-0.8	25	-	None	Perfect E
Sub. Ground	Ground 4	None	10.1,25,0	1.6	-0.8	-	None	Perfect E
Patch 1	A1	None	4,5,1.6	4	6	-	None	Perfect E
Patch 2	A2	None	13,5,1.6	4	6	-	None	Perfect E
Patch 3	A3	None	4,17,1.6	4	6	-	None	Perfect E
Patch 4	A4	None	13,17,1.6	4	6	-	None	Perfect E
Feed 1	Rectangle1	None	9.7,0,1.6	1.6	6.4	-	None	Perfect E
Feed 2	Rectangle2	None	5.6,13.6,1.6	0.8	3.4	-	None	Perfect E

Feed 3	Rectangle3	None	14.6,13.6,1.6	0.8	3.4	-	None	Perfect E
Feed 4	Rectangle4	None	6,13.6,1.6	9	0.8	-	None	Perfect E
Feed 5	Rectangle5	None	10.1,6.4,1.6	0.8	8	-	None	Perfect E
Feed 6	Rectangle6	None	6,2,1.6	9	0.8	-	None	Perfect E
Feed 7	Rectangle7	None	5.6,2,1.6	0.8	3	-	None	Perfect E
Feed 8	Rectangle8	None	14.6,2,1.6	0.8	3	-	None	Perfect E
Lumped Port	Port	None	9.7,0,0	1.6	-	1.6	Lumped port	None

The above table 4.1 shows the positioning, Dimension and name of the materials implemented on the antenna. It also shows the excitation and boundary condition of the design. What is the type of material used and its perimeter conditions are explained in the above table. The X, Y and Z size of the materials are explained, and it shows that the material is perfectly matched or not. Using the values mentioned in the above table the Microstrip Patch array antenna is designed accordingly. The port is assigned as lumped port. The port should be fixed in the middle in the XZ axis and thus the designed MSP array antenna is after then fabricated. The Position values are taken from the calculation using the formula. The formula used for obtaining the values are mentioned above.

Table 5.2: Comparison between existing and proposed methodology

Contents	Existing Method	Proposed Method
Frequency	3.3-3.7 GHz	5.85-5.95 GHz Also supports Cellular (LTE or 5G)
Description	In the existing v2x application the working has a wide spectrum of frequency for each application.	In the proposed method it is possible for all v2x applications to work in the specified bandwidth.
Communication Mode	DSRC (Direct Short-Range Communication)	Cellular V2X (C-V2X)
Communication Range	Short range (up to 300 meters)	Short range (up to 300 meters) for DSRC and long range (up to several kilometres) for C-v2x
Data Transfer rate	Up to 27 Mbps	Up to 1 Gbps (for 5G based C-v2x)
Security	Basic security features	Advanced security features, including encryption, authentication, and certificate-based security
Reliability	Basic reliability features	Advanced reliability features, including multi-path propagation and adaptive transmission power control
Interoperability	Limited interoperability	Interoperable with other V2X technologies, including DSRC and C-V2X
Example	Forward Collision Warning(FCW), Blind Spot Warning (BSW), Intersection Movement Assist(IMA), Emergency Electronic Brake Lights (EEBL)	Advanced Driver Assistance Systems(ADAS), Traffic Management, Smart Infrastructure, Autonomous Driving.

The above table 4.2 shows the comparison of existing and proposed methodology. Overall, the latest V2X capabilities offer significant improvements over older V2X technologies, including longer range, higher data transfer rates, and more advanced security and reliability features.

CHAPTER 6

CONCLUSION

The future of mobility opened new dimensions with vehicles communicating with other entities. This method of communication is typically wireless, involving vehicles, infrastructure, pedestrians, and networks, and is referred to as a V2X. For the past several years, DSRC has been the only V2X technology to enable communication between vehicles. After some time, research communities have shown cellular networks may serve the same purpose for the communication link. The research community has also proved that the hybrid approach may enable vehicular safety for more extended range and enhanced reliability use cases. Globally, members from different automotive industries and telecommunications companies have recognized the significant impact of V2X on ITS. Given the widespread concentration of such technology, there is little certainty that it will become ubiquitous within the next decade. As a result, this study evaluates V2X technology to classify the adaptability of communication technology, platforms, deployed products, and deployment challenges.

6.1 FUTURE WORK

Important challenges are highlighted, and we call for future research, for example developing innovative security and privacy means. In particular, we extend the hitherto view from a technology independent perspective on technical challenges in prior research by adding environmental and organizational challenges as well. We thus want to raise red flags, that researchers and practitioners should not solely focus on technological issues, but rather focus on the demanded solutions and needs to further push the acceptance and therefore diffusion of the technology. To counteract current shortcomings a holistic approach of V2X communication as an integral part of the transportation infrastructure is required. Interviewing different stakeholders provides practice with a good overview of major challenges in the V2X ecosystem. We contribute the required context to not only grasp existing interdependencies between several topics and the related challenges but also provide recommendations on how to tackle challenges.

STANDARDS AND CONSTRAINTS

IEEE STANDARDS

IEEE 802.11.a - Wireless Networking - "Wifi"

IEEE 802.11.ay - Quadruples the bandwidth and adds MIMO upto 8 streams

IEEE 802.15 - Wireless Personal Area Network

IEEE 802.16 - Wireless Networking - "WiMAX"

CONSTRAINTS

In this we are having a two-way multi antenna relay or electrical small loop antenna in which it transmits simultaneously wireless information and power transfer with the help of the buffer. The buffer is working under a electromagnetic interference. This interference is having a range of zero to 1. This buffer is having air medium dual channel access. Without this buffer we cannot do this transmission. The main intention is to transfer the information and power wirelessly without loss and the optimization is done accordingly.

REFERENCES

- [1] Adnan Basir Patwary, Ifana Mahbub, “Design and Simulation of UWB Phased Array Antenna For Wireless Power Transfer to Micro Aerial Vehicle (MAV) Through Beam Steering” 2022 IEEE Radio and Wireless Symposium (RWS).
- [2] Bhobe.A. U, Holloway. C. L, Piket-May. M, and Hall. R, “Wide-band slot antennas with CPW feed lines: Hybrid and log-periodic designs,” IEEE Trans. Antennas Propag., vol. 52, no. 10, pp. 2545–2554, Oct. 2004.
- [3] Fallgren, M., Dillinger, M., Alonso-Zarate, J., Boban, M., Abbas, T., Manolakis, K., Mahmoodi, T., Svensson, T., Laya, A., Vilalta, R.: Fifth-Generation Technologies for the Connected Car. IEEE Veh. Technol. Mag. 13, 28–38 (2018).
- [4] Hasan U. Zaman; Touhidul Islam; Kazi Shanjidul Hasan, “Mobile phone to mobile phone wireless power transfer” 2015 International Conference on Advances in Electrical Engineering (ICAEE).
- [5] Huo. Y, Dong .X, and Xu. W, “5G cellular user equipment: From theory to practical hardware design,” IEEE Access, vol. 5, pp. 13992–14010, 2017.
- [6] Hsu Y.-W., Huang T.-C., Lin H.-S., and Lin Y.-C., “Dual-polarized quasi-Yagi-Uda antennas with end-fire radiation for millimeter-wave MIMO terminals,” IEEE Trans. Antennas Propag., vol. 65, pp. 6282- 6289, 2017.
- [7] Kanjanasit. K, Wang .C, “A wideband resonant cavity antenna assembled using a micromachined CPW-fed patch source and a two-layer metamaterial superstrate,” IEEE Trans. Compon. Package. Manuf. Technol., vol. 9, pp. 1142-1150, 2019.
- [8] Li. A, Luk. K.-M, and Li. Y, “A dual linearly polarized end-fire antenna array for the 5G applications,” IEEE Access, vol. 6, pp. 78276–78285, 2018.

- [9] Li. A and Luk. K. M, "A dual-polarized magneto-electric dipole array for 60 GHz applications," in Proc. Cross Strait Quad-Regional Radio Sci. Wireless Technol. Conf. (CSQRWC), Xuzhou, China, Jul. 2018, pp. 1–3.
- [10] Omar. H, Abboud, K., A., Zhuang, W.: Interworking of DSCR and Cellular Network Technologies for V2X Communications. *IEEE Trans. Veh. Technol.* 65, 9457-9470 (2016).
- [11] Park. J, Choi. D, Hong. W, "28 GHz 5G dual-polarized end-fire antenna with electrically small profile," 12th European Conference on Antennas and Propagation (EuCAP 2018), 9-13 April 2018, London, UK.
- [12] Shi. Y, Chen. S, Hu. J and Zhao. L, "LTE-V: A TD-LTE-Based V2X Solution for Future Vehicular Network," in *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 997-1005, Dec. 2016.
- [13] Wang. J, Li. Y, Ge. L, Wang. J, and Luk. K.-M., "A 60 GHz horizontally polarized magnetolectric dipole antenna array with 2-D multibeam endfire radiation," *IEEE Trans. Antennas Propag.*, vol. 65, no. 11, pp. 5837–5845 Nov. 2017.
- [14] Kawasaki, R.; Onishi, H.; Murase, T. Performance evaluation on V2X communication with PC5-based and Uu-based LTE in crash warning application. In Proceedings of the 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE), Nagoya, Japan, 24–27 October 2017.
- [15] Kawser, M., Sajjad, S. S., Fahad, S. Ahmed, S., Rafi, H. A. The perspective of vehicle-to-everything V2X communication towards 5G. *IJCSNS International Journal Computer Science and Network Security*. 2019.
- [16] MacHardy, Z., Khan, A., Obana, K., Iwashina, S.: V2X Access Technologies. *IEEE Commun. Surv. Tutorials* 20, 1858–1877 (2018).

- [17] Mannoni, V., Berg, V., Sesia, S., Perraud, E. A comparison of the V2X communication systems: ITS-G5 and C-V2X. In: IEEE 89th Vehicular Technology Conference VTC 2019: proceedings [online]. IEEE. 2019.
- [18] Naik, G., Choudhury, B., Park, J.-M. IEEE 802.11bd and 5G NR V2X: evolution of radio access technologies for V2X communications. IEEE Access [online]. 2019, 7, p. 70169-70184. eISSN 2169-3536.
- [19] Shi, M.; Lu, C.; Zhang, Y.; Yao, D. DSRC and LTE-V communication performance evaluation and improvement based on typical V2X application at intersection. In Proceedings of the Chinese Automation Congress (CAC), Jinan, China, 20–22 October 2017.
- [20] Zhang, C, Li, F, Ou, J, Xie, P and Sheng, W, "A New Cellular Vehicle-to-Everything Application: Daytime Visibility Detection and Prewarning on Expressways," in *IEEE Intelligent Transportation Systems Magazine*, vol. 15, no. 2, pp. 85-98, March-April 2023.