Faculty of Electrical and Electronic Engineering Technology

DESIGN OF TRANSPARENT MILIMETRE WAVE REFLECTARRAY ANTENNA FOR 5G COMMUNICATION SYSTEM

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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DESIGN OF TRANSPARENT MILIMETRE WAVE REFLECTARRAY ANTENNA FOR 5G COMMUNICATION SYSTEM

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ABSTRACT

The increase rate development of 5G communication systems has introduced the need for efficient and compact antenna solutions capable of supporting high-frequency millimeter wave signals. In order to get used to milimetre band, an antenna design needs to meet all the requirements of 5G. This project proposed a reflectarray antenna that can integrated with other component in flat surfaces without affecting the components performance.This work presents a design approach for a transparent millimeter wave reflectarray antenna specifically tailored for 5G applications.Reflectarray antennas offer the advantages of low profile, lightweight construction, and beam steering capabilities, making them suitable for deployment in various communication scenarios. The proposed design focuses on utilizing a transparent substrate to enable seamless integration into modern urban environments and aesthetically sensitive areas without compromising performance.The design process involves the careful selection of suitable transparent materials with desirable electrical properties, such as low loss and high permittivity. A printed patch array is then placed on the transparent substrate, which acts as a reflective element. By varying the size and spacing of these patches, the phase of the reflected millimeter wave signals can be adjusted to achieve the desired beam steering characteristics.Furthermore, advanced simulation tools are employed to optimize the antenna's performance parameters, including gain, directivity, and beam coverage. The impact of various design parameters, such as patch dimensions, spacing, and substrate thickness, is analyzed to achieve the desired operating frequency bands and beam steering capabilities. The proposed transparent millimeter wave reflectarray antenna offers several advantages, including compatibility with modern building materials, unobtrusive deployment, and enhanced aesthetic integration into urban environments. Moreover, the design demonstrates promising performance characteristics, such as high gain and wide beam coverage, suitable for meeting the demanding requirements of 5G communication systems.

ABSTRAK

Pembangunan pesat sistem komunikasi 5G telah memperkenalkan keperluan untuk penyelesaian antena yang cekap dan kompak yang mampu menyokong isyarat gelombang milimeter frekuensi tinggi. Abstrak ini menyajikan pendekatan reka bentuk bagi antena reflectarray gelombang milimeter transparan yang khas untuk aplikasi 5G.Antena reflectarray menawarkan kelebihan profil rendah, pembinaan ringan, dan keupayaan penstabilan sinar, menjadikannya sesuai untuk penggunaan dalam pelbagai senario komunikasi. Reka bentuk yang dicadangkan memberi fokus kepada penggunaan substrat transparan untuk membolehkan integrasi yang lancar ke dalam persekitaran bandar moden dan kawasan yang sensitif estetik tanpa mengorbankan prestasi.Proses reka bentuk melibatkan pemilihan bahan transparan yang sesuai dengan sifat elektrik yang dikehendaki, seperti kehilangan rendah dan permitiviti tinggi. Array patch cetak kemudiannya diletakkan pada substrat transparan, yang bertindak sebagai elemen pantulan. Dengan mengubah saiz dan jarak patch ini, fasa isyarat gelombang milimeter yang dipantulkan dapat disesuaikan untuk mencapai ciri-ciri penstabilan sinar yang dikehendaki.Selain itu, alat simulasi canggih digunakan untuk mengoptimumkan parameter prestasi antena, termasuk keuntungan, direktiviti, dan liputan sinar. Kesan parameter reka bentuk yang berbeza, seperti dimensi patch, jarak, dan ketebalan substrat, dianalisis untuk mencapai jalur frekuensi operasi yang dikehendaki dan keupayaan penstabilan sinar.Antena reflectarray gelombang milimeter transparan yang dicadangkan menawarkan beberapa kelebihan, termasuk keserasian dengan bahan bangunan moden, penempatan yang tidak ketara, dan integrasi estetik yang lebih baik ke dalam persekitaran bandar. Selain itu, reka bentuk ini menunjukkan ciri-ciri prestasi yang menjanjikan, seperti keuntungan yang tinggi dan liputan sinar yang luas, sesuai untuk memenuhi keperluan yang mencabar sistem komunikasi 5G

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CHAPTER 1

INTRODUCTION

1.1 Background

The design of a transparent millimeter-wave reflectarray antenna for 5G communication involves careful consideration of various factors. These include selecting the appropriate frequency band for 5G, defining performance requirements, choosing transparent materials with suitable transmission characteristics, designing unit cells and phase shifters, optimizing array layout and configuration, conducting simulations, testing, and characterizing the antenna's performance while considering integration with the overall 5G communication system. These processes are to achieve high gain, desired beam characteristics, low sidelobe levels, polarization control, and wide bandwidth. Therefore, the design parameters are fine-tuned through simulations and optimization. Furthermore, testing is crucial to validate the antenna's performance, and integration considerations include beamforming and system-level compatibility. Lastly, a comprehensive research-based approach is necessary to successfully design a transparent millimeter-wave reflectarray antenna for 5G communication system.

1.2 Problem Statement

Designing a transparent millimeter-wave reflectarray antenna for 5G communication presents several challenges and considerations. The problem at hand is to find characteristics of reflectarray antenna that meets the specific performance requirements of 5G applications while leveraging transparent materials for seamless integration into flat surfaces and environments. Key challenges include selecting the optimal frequency band, designing unit cells and phase shifters, optimizing array layout and configuration, and ensuring compatibility with the overall 5G system. Furthermore, the antenna needs to have a wide bandwidth, low sidelobe levels, high gain, and the necessary beam characteristics. For effective phase shifting, cutting-edge technology like varactor diodes or liquid crystals must be researched. The successful design and implementation of a transparent millimeter-wave reflectarray antenna for 5G communication system depends on simulations, testing, and integration considerations.

1.3 Project Objective

The main aim of this project is to design transparent milimetre wave reflectarray antenna that meets the requirements for 5g Communication with relevant characteristics. Specifically, the objectives are as follows:

a) To design a transparent millimeter-wave reflectarray antenna using CST MWS.

b) To optimize antenna performance for 5G requirements

c) To ensure compatibility and integration with 5G systems

1.4 Effect of Transparent Millimeter Wave Reflectarray antenna towards Societal Issue and Environment.

These antennas help to enhance connectivity, close the digital divide, and foster social inclusion by enabling high-speed wireless communication. They make it easier for people to access information, chances for education and employment, healthcare, and smooth data transfer. Additionally, the design's transparency feature guarantees that the antennas may be incorporated into urban environments without drastically changing their aesthetic appeal. By doing this, visual pollution is reduced, and cities' structural integrity is maintained. Additionally, these antennas' effective usage of millimeter-wave frequencies lowers electromagnetic interference, creating a cleaner electromagnetic environment and safer living conditions for both people and wildlife. Transparent millimetre reflectarray antennas for 5G communication systems are designed in a way that, all things considered, represents the values of development, sustainability, and peaceful cohabitation with the environment.

1.5 Scope of Project

The scope of this project are as follows:

a) The design and optimization of a transparent millimeter-wave reflectarray antenna for 5G communication. This encompasses the selection of an appropriate frequency band, design of unit cells and phase shifters, optimization of array layout and configuration, and simulation-based performance optimization.

b) The selection of suitable transparent materials for millimeter-wave transmission and their integration into the antenna design.

c) The integration of the transparent reflectarray antenna into 5G communication systems.

d) Conducting relevant research on transparent millimeter-wave reflectarray antennas, 5G communication requirements, and emerging technologies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's modern society, the fifth generation (5G) communication system has revolutionized wireless connectivity with its ultra-fast speeds, low latency, and massive device connectivity. At the core of this technological advancement are advanced antenna systems, including the innovative transparent reflect array antenna. Antennas serve as the interface between the physical world and the electromagnetic spectrum, enabling the seamless exchange of information. Transparent reflect array antennas, consisting of antenna elements arranged on a flat surface with a reflective, transparent material, offer a promising solution for 5G networks. These antennas redirect and focus electromagnetic waves, enabling beamforming and precise signal targeting. The transparency of these antennas allows for integration into various surfaces, integrating into the environment while providing excellent wireless connectivity. As 5G continues to evolve, the development and adoption of advanced antenna technologies such as transparent reflect array antennas will be instrumental in unlocking the full potential of this transformative communication system.

2.2 Millimeter wave in 5G Communication System

Millimeter-wave frequency is significant in 5G communication systems because it permits faster data rates and less latency than conventional wireless communication technologies, millimeter-wave frequency is important in 5G communication networks [1]. Compared to lesser frequency bands, millimeter-wave frequencies which span from 30 GHz to 300 GHz, offer a substantially broader bandwidth. Higher data rates made possible by this greater bandwidth are necessary for applications like virtual reality, augmented reality, and streaming ultra-high-definition video. The coverage and dependability of wireless communications might be impacted by the attenuation and blocking of millimeter-wave signals by objects like trees and buildings [1]. As a result, thorough system design and optimization are necessary for millimeter-wave technologies to provide consistent performance in various settings. Figure 2.2.1 shows a D2D 5G cellular network architecture with mmWave [1].

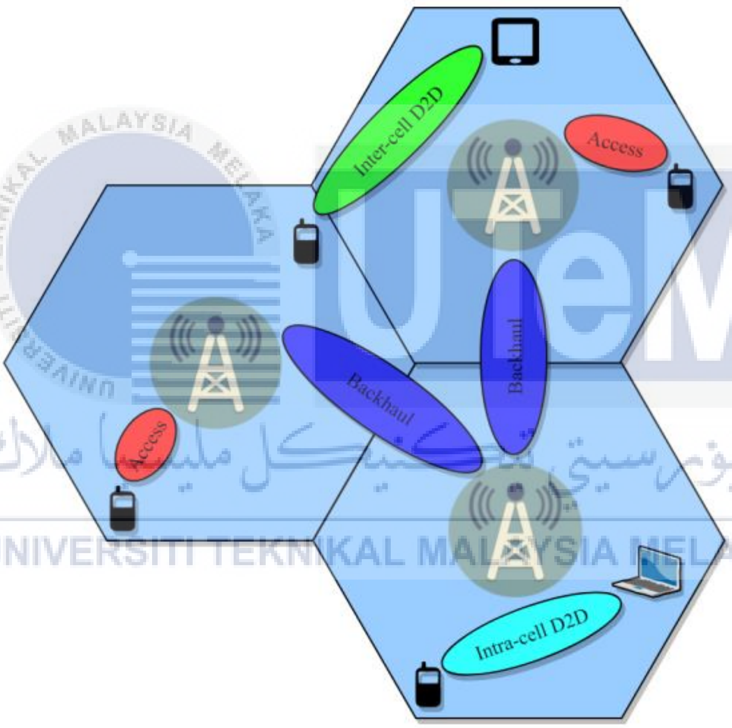


Figure 2.2.1 : Network architecture of mmWave 5G cellular network while D2D. Adapted from [1]

Next, the substantial free-space path loss of the emitted waves at mm-wave frequencies has been efficiently addressed by beamforming techniques in 5G wireless networks which direct the energy emitted in the desired directions. The whole design of a 5G mm Wave BS, comprising the active antenna units (AAUs), baseband units (BBUs), and core network

(CN), is shown in Figure 2.2.2. An antenna array, down/up converters, analogue-to-digital converters, digital-to-analogue converters, beam management units, and AAU baseband signal processing units are all components of the beamforming AAU. Each antenna element needs to be given the right amplitude and phase to achieve the desired beamforming functions.

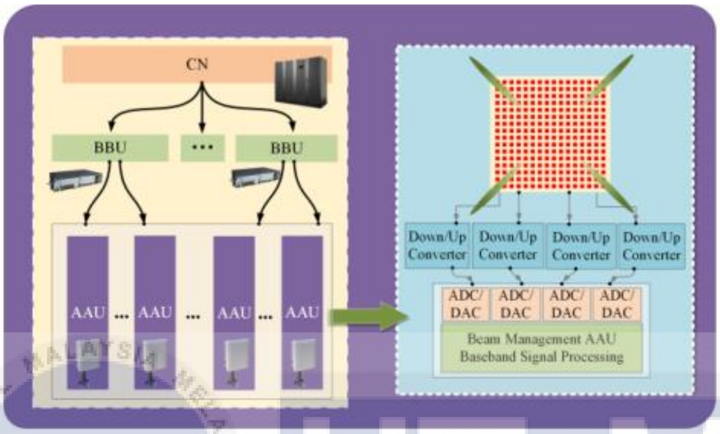


Figure 2.2.2 : System architecture. Adapted from [2].

Besides, the three primary 5G application scenarios outlined by the International Telecommunication Union (ITU) are Massive Machine Type Communications (mMTC), Ultra-Reliable Low Latency Communications (uRLLC), and Enhance Mobile Broadband (eMBB). These scenarios can be modified to fit several of the smart grid's usual functions. The uRLLC scenario is primarily adapted to high-reliability demand services like intelligent distributed distribution automation and power load demand side response. The eMBB scenario is primarily adapted to the wide connection demand services like distributed energy regulation and advanced metering [2]. Table 2.2.3 shows the four main technical scenarios and the key challenges.

Table 2.2.3: The Main 5G scenarios and Key Performances Challenges. Adapted from [2]

Scenes	The key challenge
Continous wide area coverage	100 Mbps user experience rate
Hot spot large capacity	User experience rate: 1 Gbps
	Peak rate: Dozens of Gbps
	Flow density: Dozens of Tbps/km^2
Low power consumption and large connections	Connection density: 10^6/km^2
	Ultra low power consumption and ultra-low cost
Low latency and high reliability	Empty port delay: 1 ms
	End-to-end latency: ms order of magnitude
	Reliability: Close to 100%

In addition, the existing communication capacity is anticipated to be greatly increased by the fifth-generation mobile network (5G), which is anticipated to utilize a considerable portion of the mm-wave frequency bands. A benefit of millimeter-wave communication is the high data speeds and bandwidth accessibility. It also presents difficulties, such as those related to propagation characteristics. One of the antennas that was mentioned is The UWB Slot-Loaded Printed Antennas applied concurrently in millimeter wave and microwave frequencies. The antennas work in the frequency ranges of (5.5-9.5 GHz for microwave band and (55-95 GHz for mm-wave band), covering a fractional bandwidth of around 40% in both microwave and millimeter wave applications. Figure below shows the 5G spectrum for both microwave and millimeter wave bandwidths [3]

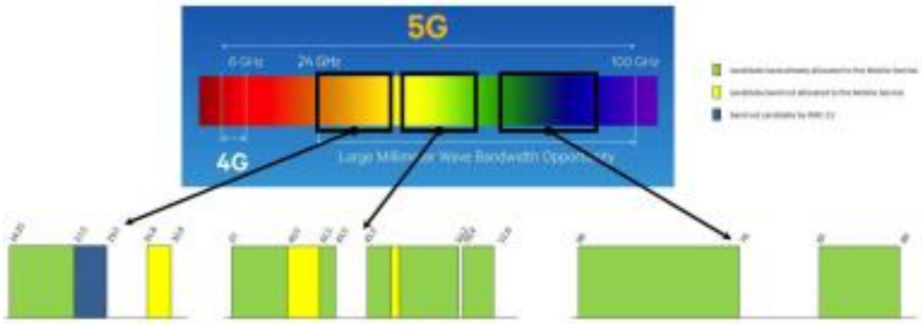


Figure 2.2.4: 5G Spectrum in Microwave and mm-wave bandwidths – ITU Standardization in July 2019. Adapted from [3].

Moreover, the key benefit of mmWave frequency bands over sub-6 GHz bands in 5G systems is the boost in capacity provided by the significantly greater accessible bandwidths. Higher throughput and the ability to serve more customers could result from this increase in capacity [4]. However, there are drawbacks to using mmWave frequency bands as well that including higher penetration losses indoors or through walls, significant channel variation caused by objects in the path between the transmitter and receiver, and signal degradation brought on by meteorological factors. It occurs when building 5G systems that utilize mm Wave frequency bands, these difficulties may result in extra attenuations and shadowing effects that must be taken into consideration [4].

2.3 Transparent Antenna

A novel transparent substrate integrated waveguide (SIW) cavity-based slot antenna operating in the millimeterwave band has been introduced for usage in fifth-generation wireless communication applications. The proposed antenna, which differs from conventional opaque SIW antennas, is made of transparent conductive mesh with excellent conductivity qualities acting as the radiating element and ground, as well as transparent polyethylene terephthalate material utilised as the substrate. The SIW cavity can be effectively produced for the TE103 mode by deleting a few metallic vias. The radiating element has several slots etched on it, which causes multiple hybrid resonances. As a result, the proposed antenna operates in the 24.31–27.81 GHz band with a peak gain of 7.8 dBi at 26.5 GHz. The suggested antenna has good optical transparency and both the cross-polarization ratio and front-to-back ratio are greater than 20 dB inside the working band, according to simulation and measurement data that are presented together with the fabrication of the planned antenna's prototype [5]. Figure 2.3.1 shows the proposed antenna configuration.

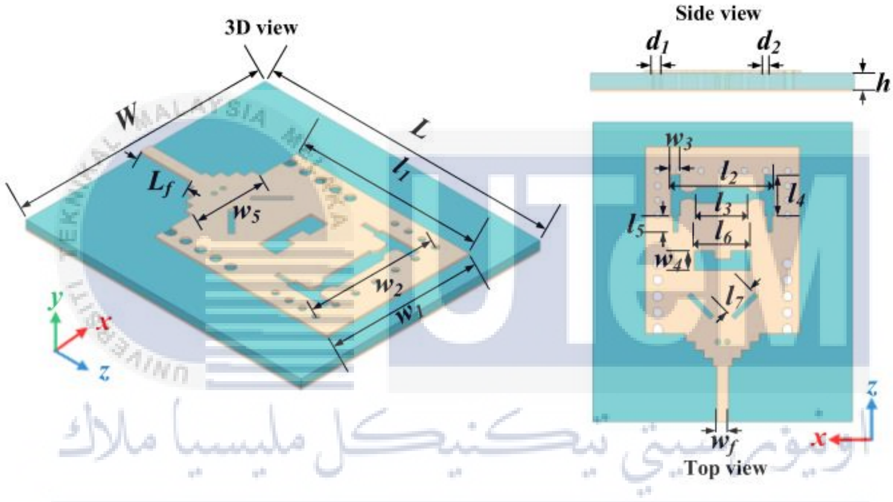


Figure 2.3.1 : Proposed antenna configuration. Adapted from[5]

On the basis of absorbing metasurface, a transparent and small radar cross section (RCS) antenna is presented. The substrate of the antenna is made of transparent glass, and the transparent absorbing structures with high square resistance are arranged around the transparent radiation patch. The ground and radiation patch of the antenna are made of indium tin oxide (ITO) conductive film with low square resistance. According to the simulation results, the suggested antenna operates at 8.88GHz. From 8GHz to 12GHz, it exhibits a considerable RCS decrease when compared to the original antenna. 10dB is the bare minimum reduction. Additionally, the antenna exhibits a consistent RCS reduction effect in the incident angle range of -20° to 20° [6]. Figure 2.3.2 shows related antenna.

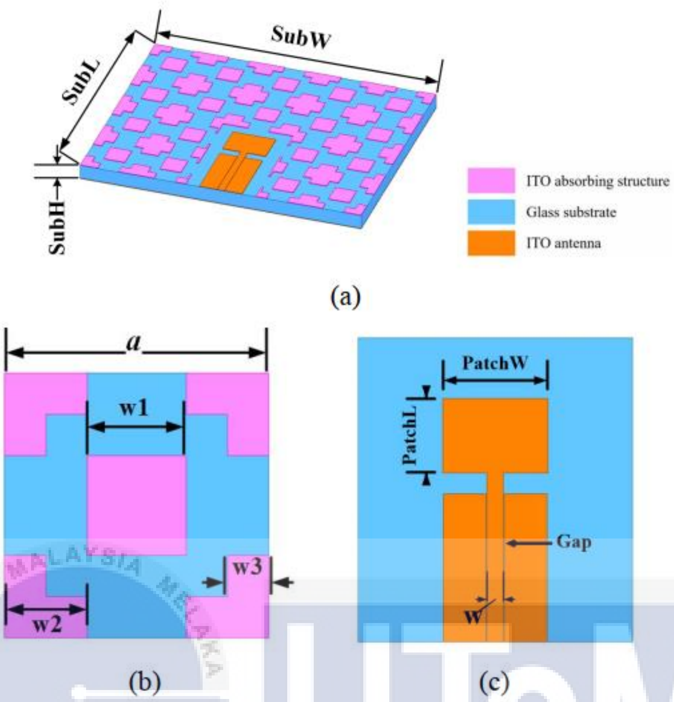


Figure 2.3.2 : a) Configuration of the proposed antenna. (b) The top view of the absorbing metasurface unit cell. (c) Top view of transparent CPW feed microstrip antenna [6]

Then, other research proposes an optically transparent metasurface-based patch antenna for mmWave 5G mobile applications. The proposed architecture consists of three layers, with the microstrip patch serving as the principal radiator in the bottom layer, which is housed inside the 5G device. The remaining layers are integrated into the device's display and are optically transparent in nature. In this method, the design's overall physical dimensions can be minimised. A broad operational bandwidth for the patch antenna can be produced by placing the optically transparent metasurface atop it. The goal of the proposed mmWave 5G antenna's design is to minimise overall size without sacrificing antenna properties. The 5G NR257 frequency spectrum is covered by the proposed design, which is wideband and has a fractional bandwidth of roughly 15%. At 28 GHz, an ideal peak gain of more than 8 dBi is also noted [7]. Figure 2.3.3 shows the views of the proposed antenna.

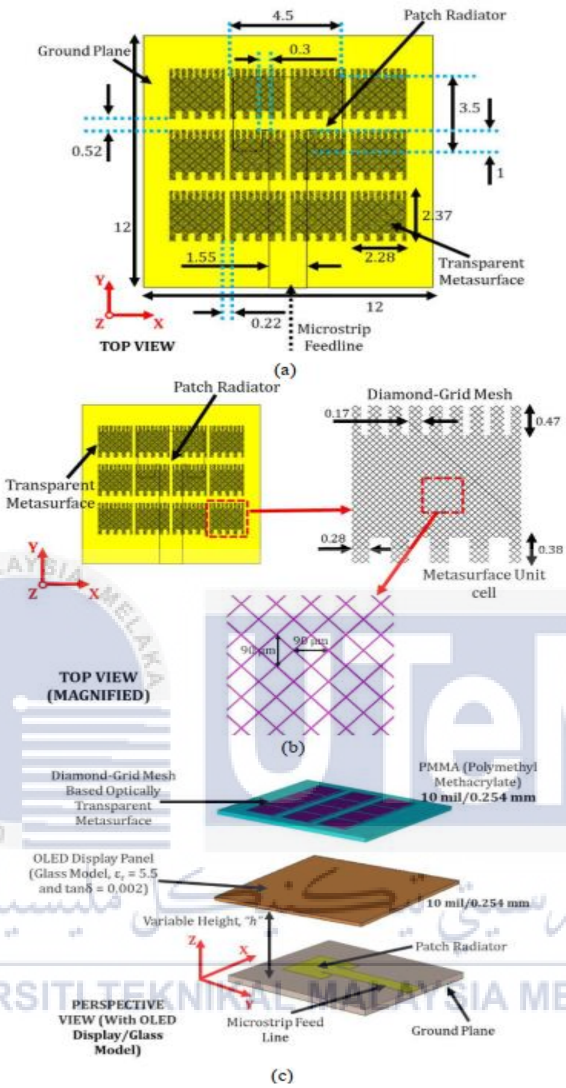


Figure 2.3.3 :Schematics of the proposed mmWave 5G antenna. (a) top view, (b) magnified view of diamond grid mesh-based metasurface and (c) perspective view [7]

In other hand , an ultrawideband (UWB) halved coplanar Vivaldi antenna (HCVA) with metal mesh film (MMF) is proposed in one work. The ground plane is used in place of a radiation fin to create the halved type antenna, which is based on the equivalence principle. The advantages of the proposed HCVA include UWB impedance matching, a small aperture size, good directivity, and a straightforward feed arrangement. The antenna is completely transparent thanks to the use of MMF, which has a high optical transmittance above 72% and a low sheet resistance of 0.35 /sq in the radiating fin and ground plane. A transparent example of HCVA is created and measured. The majority of the reflection coefficient is below -10 dB from 0.78 to 20 GHz, according to the findings of the simulations and measurements .Furthermore, the tiny size of 0.320.470.052L3, where L is the wavelength at the lowest operational frequency, results in a peak realised gain of 10.4 dBi [8].

2.4 Reflectarray antenna

One of the research that related to reflecarray antenna was proposed which used a unique ultra-wideband reflectarray antenna for multifunctional devices employing coupled dipoles. An elliptical dipole and a slot line printed on a single substrate make up the reflectarray element. To obtain the ultra-wide bandwidths for both the impedance and the radiation pattern bandwidths concurrently, adjacent elements are coupled. The suggested reflectarray antenna provides ultra-wide bandwidth with significantly lower feeding complexity and manufacturing cost by combining the benefits of traditional reflectarray antennas and connected array antennas. A 354-element reflectarray antenna is created as a proof of concept. Over a bandwidth of 100%, or from 10 to 30 GHz, the described reflectarray antenna maintains undistorted beams and good antenna gain [9].

For Ku-band transmit-receive frequencies and dual polarisation operation in broadcast satellite applications, a reflectarray antenna with increased performance is proposed. Two orthogonal sets of four coplanar parallel dipoles, each set combining lateral and broadside coupling, are printed on two surfaces of the reflectarray element. A 40-cm prototype has been created, produced, and put through testing. In order to produce a collimated beam with dual polarisation in the transmit and receive bands, the lengths of the linked dipoles in the reflectarray cells have been optimised. The outstanding performance of the antenna in terms of bandwidth (27%), minimal losses, and low levels of cross polarisation are confirmed by the measured radiation patterns. For the purpose of demonstrating the potential of the suggested antenna for Ku-band spaceborne antennas, some early simulations at 11.95 GHz for a 1.2-m antenna with South American coverage are shown [10]. Figure 2.4.1 shows the drawing of reflectarray antenna.

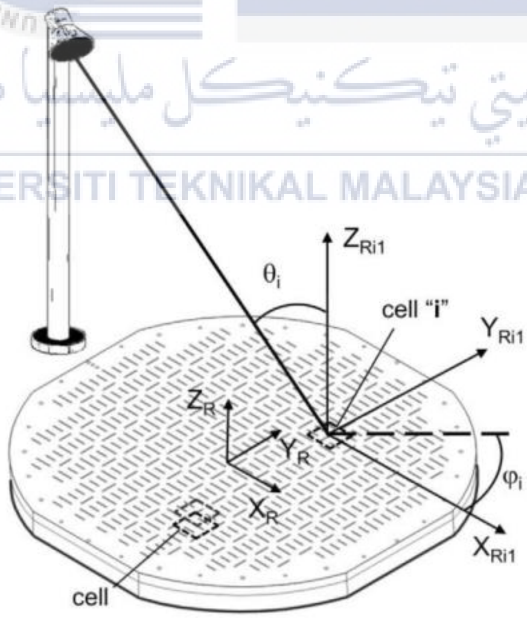


Figure 2.4.1: Drawing of reflectarray antenna. Adapted from [10]

Next, other research presents a reflectarray antenna design for fifth generation (5G) applications employing hexagonal shape unit cells. It has been suggested that unit cells having a 0°–360° reflection phase range be designed in a hexagonal configuration. In addition, the reflectarray is built with a single layer topology for simplicity, compactness, and low-cost manufacture. The obtained results demonstrate a respectable level of gain (27 dBi) at the operational frequency of the 5G band at 28 GHz [11]. Figure 2.4.2 is the layout of proposed unit cell.

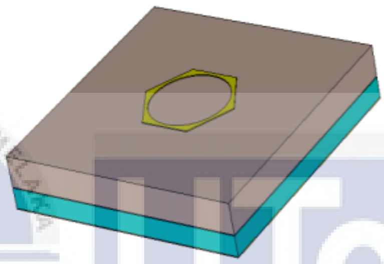


Figure 2.4.2: Layout of Proposed Unit cell

Furthermore, there is one research proposes a dual-polarized wideband reflectarray antenna for 5G communication that uses tightly linked elements. Ellipsoid dipoles that are tightly linked are utilised as array components, and a feed antenna is a log periodic dipole. The unit cell element is designed to minimise phase error using the equivalent distance delay principle. The egg-crate-shaped dual-polarized reflectarray antenna is set up in this way. Design and analysis are done for a 21*21 reflectarray. According to simulation results, the antenna can operate without main beam distortion between 1.7GHz and 5GHz. In both polarisations, the antenna's gain ranges from 10.5 dBi to 21.4 dBi [12].

In addition, a new wireless communication system known as 5G technology enables large bandwidths and a high data transfer rate. The reflectarray antenna is one kind of antenna that can meet these requirements. Reflectarray antennas are intended to increase gain by modifying the phase of electromagnetic waves across their array members. The objective of this project is to create a reflectarray that operates at 28 GHz and has 196 ring-loaded components in a 14 14 array. A Koch patch model with the zeroth iteration was employed in simulation and manufacturing as a feed antenna, yielding a gain of 6.59 dBi [13].

2.4.1 Beam Steering

The proposed work presents a reconfigurable reflectarray (RA) at the millimetre wave band consisting of an electronically biassed liquid crystal (LC) two-finger element.. In order to realize reflection phase along directions x and y and adjust the equivalent relative permittivity of the liquid crystal, an orthogonal bias network is proposed and built. By doing this, beam steering at both the E-plane and the H-plane may be accomplished. A typical horn antenna is used as the feed for the 10-by-10-element LC RA, and the radiation pattern is developed using array synthesis and complete wave simulation. It is discovered that beam scan is possible at both the E-plane and the H-plane. In contrast to earlier studies on LC RA, this work presents a straightforward method for achieving beam scan for LC RA at both the E-plane and the H-plane [14].

Another study builds and analyses a beam steering reflectarray antenna for use at 26 GHz based on the array's mechanical rotation. Measurements of the scattering parameter and unit cells based on circular ring elements have been done in order to produce a progressive phase distribution. The measurements of the unit cell revealed a maximum reflection loss of 4 dB, given a total phase range of nearly 360°. By tilting the reflectarray at various angles, the symmetry of the array and the resonant elements has been proved to be exploited to steer the main beam. A beam steering range of more than 60 has been demonstrated by altering the tilt angle from C30 to 30.. The 2020 element array's maximum gain, which was supposed to be 26.47 dB at zero and drop to 19.8 dB at 61.9 in the elevation plane. The reflectarray antenna, on the other hand, showed a maximum bandwidth of 13.1% and a minimum side lobe level of 25.9 dB [15].

2.4.2 Beam Shaping

In order to create shaped beam reflectarrays efficiently and produce correct results, this research introduces the use of machine learning algorithms. The method is based on using Support Vector Machines (SVMs) to characterize the reflection coefficient matrix, which offers an effective method for determining the scattering parameters related to the dimensions of the unit cell. In this method, a reflectarray layout is created throughout the design phase using SVMs rather than a Full-Wave analysis technique based on Local Periodicity (FW-LP). The SVMs' precision is evaluated, and the effect of discretizing the angle of incidence is investigated. Regarding the FW-LP and other sources in the literature using artificial neural networks, a sizable acceleration is finally attained [16].

Previously, whilst building a reflectarray antenna that emits a shaped beam, just the center frequency was optimized. In this study, in addition to applying the traditional design method, researchers constructed a curved beam reflectarray antenna by optimizing the center frequency as well as various frequencies [17].

Moreover, according to the earlier study the centre frequency was the only thing that was optimized while building a reflectarray antenna that emits a shaped beam. In this investigation, a shaped beam reflectarray antenna was created by applying the normal design approach and optimizing the center frequency and multiple frequencies [18].

2.5 Patch Antenna Dimensions

Antennas are parts of metal structures that are used to send messages over radio waves. Antennas come in different shapes now, based on what they are used for and how strong the signal is. The bowl-shaped structure of antennas used for space and large-scale communications helps to focus the signals on a single place. [19]Some antennas are made to move both horizontally and vertically so that they can send signals in both ways. Microstrip patch antennas are very small and are a type of printed antenna. Microstrip patch antennas are used a lot in medical devices and cell phone communications. In recent years, the performance of microstrip patch antennas has been getting better, and the goal of this review is to figure out how that happened. In the same way, this work looks at the pros and cons of the new methods that have been made to improve the performance of microstrip patch antennas.

2.5.2 Patch

In a microstrip antenna, electromagnetic waves are sent into the air by using a patch. It is put on top of the base sheet and has a certain shape. Copper or gold are examples of materials that can be used to make a patch.

In order to increase the frequency band, a slotted microstrip antenna's emitting patch's length and width are adjusted and slotted during modelling.. Here are the numbers that are used to make this antenna:

$$W = \frac{C}{2f}\sqrt{\frac{2}{(\in r+1)}}$$

Where W = width of patch, c = light speed, f = resonance frequency.

$$L = L_{eff} - 2 \Delta \mathrm{L}$$

Where L = patch length, L_{eff} = effective length, Δ L = extension of length.

$$L_{eff} = \frac{c}{2f0}\sqrt{\frac{2}{\varepsilon \mathrm{eff}}}$$

Where ε_{eff} = effective dielectric constant of substrate.

2.5.3 Dielectric Substrate

Substrate is a base that is used to make a microstrip patch antenna and to hold it up. It also has dielectric material in it, which could affect how well the antenna, circuit, and broadcast line work. So, the right material must be chosen in order to meet the electrical and mechanical requirements. Substrate is also used to improve electrical and mechanical safety, reduce antenna size, and improve antenna's ability to radiate. Figure 2.5.3.1 showing an example of dielectric substate.

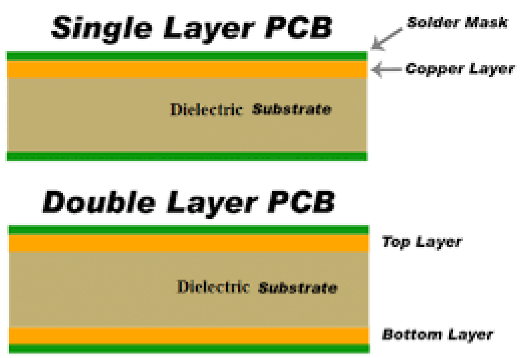


Figure 2.5.3.1: Example of dielectric substate

2.5.4 Ground Plane

The ground plane is a surface that lets electricity flow through it and is linked to the electrical ground. For the antenna, it works as a surface that radio waves can bounce off. Typically, an antenna's horizontal, flat conducting surface reflects radio waves. Therefore, the radiation properties, such as gain, depended on how the ground plane was made and how big it was.

2.6 Computer Simulation Technology (CST) for antenna design

Active electronically scanned arrays are used more and more as high-end antennas for things like RADAR, monitoring, and communication because they are flexible and have many benefits.

Both on the ground and in the air, technology has changed a lot in the last few years. The electromagnetic design of these devices is hard, and numerical modeling has become an important part of the design process but the plan puts a lot of pressure on a simulation tool. This paper talks about new array design features in CST STUDIO SUITE. These features make it much easier and more powerful to build phased arrays and related planar devices like polarizers or frequency selective surfaces (FSSs), both at the cell level and for the whole array.[20]

This paper shows a full design flow for a Ku band uplink satellite communications array that works in the 14-14.5 GHz frequency band and can be used in the air. One of the most important new features will be shown in the first design of the low profile antenna elements, the ability to improve the unit cell geometry at the same time for operation at multiple frequencies and multiple scan angles. In order to put an antenna on the roof of an airplane, an aerodynamic radome must be designed. This radome must be thought of as part of the transmitting structure at both the unit cell and the full array levels. A hybrid field coupling method is also used to find out what happens when the array is put in different places on the airplane.

The Complete Technology approach in CST STUDIO SUITE helps people use a number of numerical methods together to do a full analysis. For example, a FEM simulation is used to optimize the antenna at the unit cell level, a time domain approach is used to analyze the whole array, and an asymptotic shooting bouncing ray (SBR) simulation is used to predict how well the array will work when it is installed. The unit cell design concept can also be used to make sure that planar periodic structures, like polarizers and FSSs, work well for a wide range of incident angles. This is an important thing to think about when an FSS is meant to fit into a bent structure like a redone.

Antenna makers are interested in microstrip slotted patch antennas because they are light and don't take up much space. However, they also have some problems, such as low gain, narrow bandwidth, and higher VSWR (Voltage Standing Wave Ratio). Some of these problems can be lessened by the way antennas are made. [21]This study comes up with a new way to improve the bandwidth, efficiency, and VSWR of a microstrip patch antenna by putting a slotted patch next to the radiating patch. In this study, there is also the idea of using a microstrip slotted patch antenna for 5G transmission. The frame is made to work at 29.416 GHz. Using the CST studio suite (Computer Simulation Technology) software, a simulation is made of the suggested design. The VSWR is 1.0115, the return loss is -44.78 dB, and the frequency is 900 MHz. The results show that the proposed design has properties that are good for Ka-band uses. Figure 2.6.1 showing 3D view of proposed microstrip slotted patch antenna in CST.

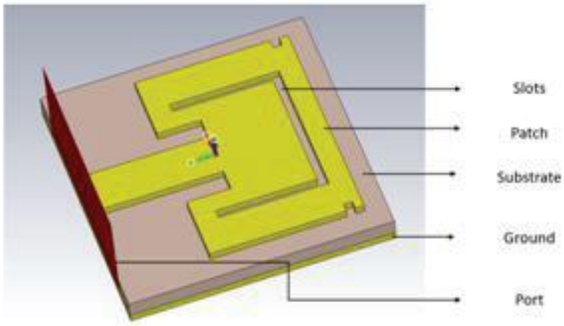


Figure 2.6.1: 3D view of proposed microstrip slotted patch antenna in CST

Table 2.6.2 Project's Comparison

No.	Project title	Idea	Method
1.	Development of Beam Steerable Reflectarray with Liquid Crystal for Both E-Plane and H-Plane.	Proposed a reconfigurable reflectarray (RA) at the millimeter wave band with a two-finger element made of electrically biassed liquid crystal (LC).	Adjust the equivalent relative permittivity of the liquid crystal, an orthogonal bias network and built.
2.	Millimeter Wave Beam Steering Reflectarray Antenna Based on Mechanical Rotation of Array	Construct beam steering reflectarray antenna based on the mechanical rotation of the array and analysed for use at 26 GHz	Built unit cells based on circular ring elements and made scattering parameter measurements for producing a progressive phase distribution.
3.	Efficient Shaped-Beam Reflectarray Design Using Machine Learning Techniques.	create shaped beam reflectarrays efficiently and produce correct results	using Support Vector Machines (SVMs) to characterise the reflection coefficient matrix, which offers an effective method for determining the scattering parameters related to the dimensions of the unit cell

4.	Shaped-Beam Reflectarray Antenna Optimized at Multiple Frequency	Optimize the centre frequency of reflectarray antenna that emit a shaped beam.	Constructed a curved beam reflectarray antenna by optimising the centre frequency as well as various frequencies
5.	Design of Optimized Multiple-Frequency-Shaped Beam Reflectarray Antenna	Optimize other than centre frequency while building reflectarray antennas that using beam shaping.	applying the normal design approach and optimising the centre frequency and multiple frequencies

CHAPTER 3

METHODOLOGY

3.1 Introduction

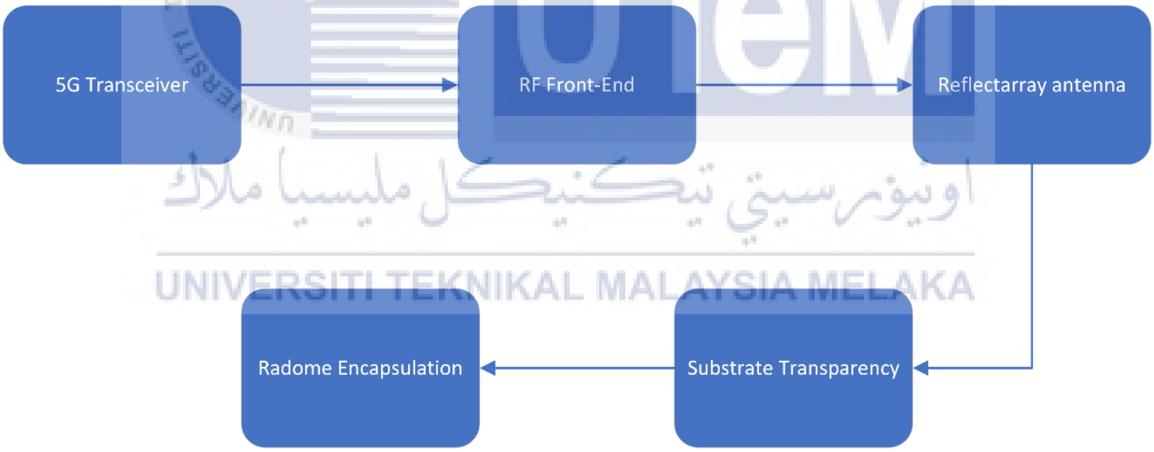
The study method tells how the design is made and why. The study goals may not be accomplished right without this part. Some parts of how research is designed are talked about in this chapter. Research is the process of figuring out what parts and things a project needs to be successful. It's best to start a study as soon as possible to avoid problems down the road. Reflectarray antennas have emerged as a promising solution for mm Wave communication systems. It offers several advantages over traditional antenna designs, including lightweight, low-profile construction, and beam-steering capabilities. Moreover, the integration of transparent materials into reflectarray antennas presents a unique opportunity for seamless integration into modern urban environments, where aesthetics and visual considerations are crucial.

3.2 Project Design

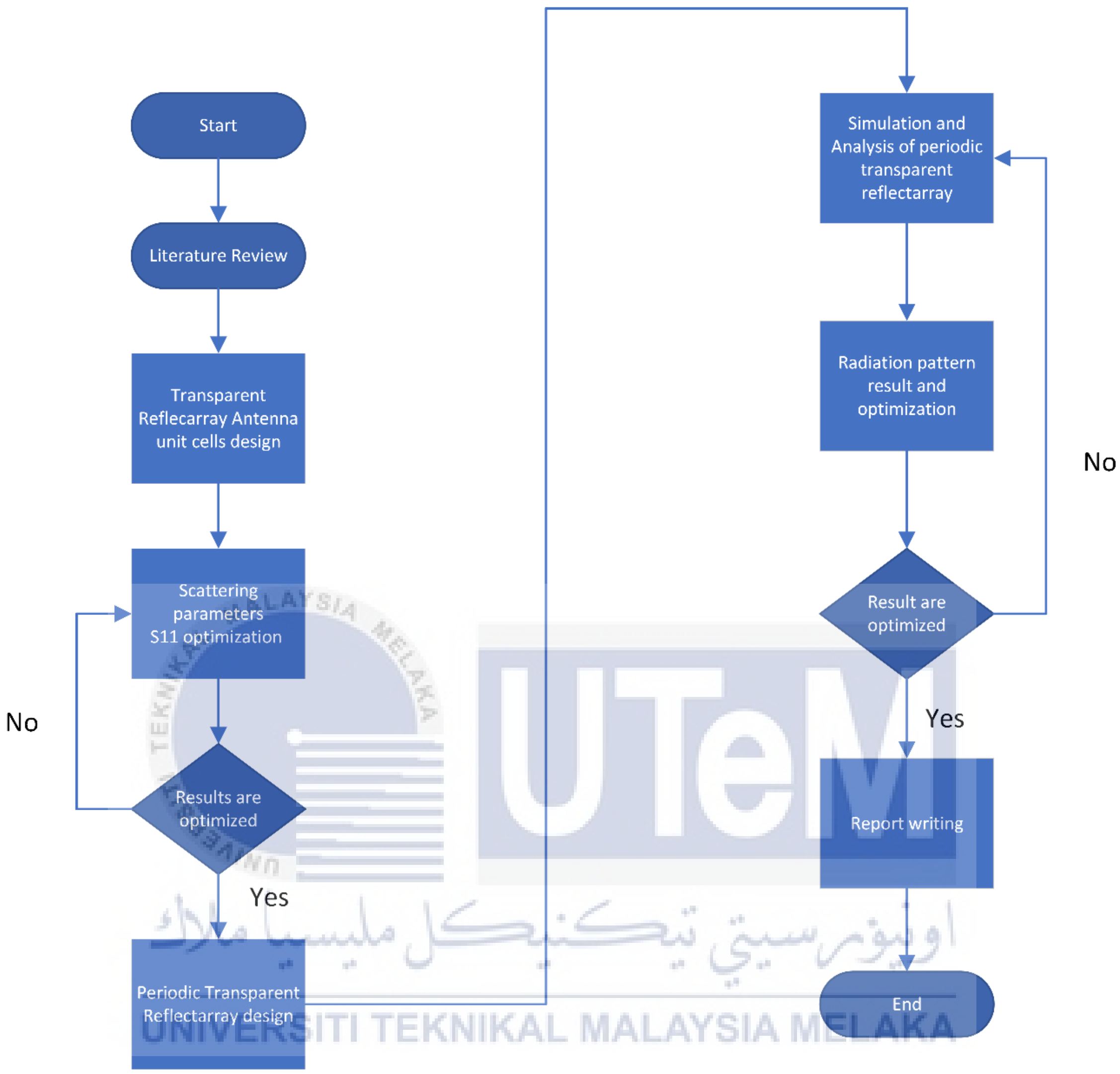
Components plan for making a transparent refelectarray antenna that can integrate with other component while applied to the 5G communication system involves a few key steps. A requirements analysis is done to find out what the antenna design needs to do and what its limits are. The features of the chosen antenna design are also found out. After installing and setting up the CST program, a detailed 3D model of the antenna is made. In CST, simulation settings are set up, and electromagnetic simulations are run to look at how well the antenna works. Then comes an iterative optimization process where the design factors of the antenna are changed to make it achieve millimeter wave band.

An actual prototype of the antenna is made, and then it is tested in the real world to find out how well it works. The antenna design that was made is judged on how well it works and whether it can be used for 5G communication system while maintaining the performance of other components. During the whole project, the antenna selection, modelling details, simulation setup, optimization steps and experimental results are all carefully recorded and reported. In the end project report, the reasoning behind the design, the results of simulations, the results of optimization, and the experimental validation are all summed up.

3.2.1 Block Diagram



3.2.2 Flow chart



3.2.3 Software

Computer Simulation Technology or CST, is a powerful software suite that is widely used in the area of electromagnetic simulation. It has different modules for different uses, such as CST Studio Suite for general electromagnetic modelling, CST Microwave Studio for high-frequency and microwave analysis, and CST PCB Studio for designing printed circuit boards. CST uses numerical methods like the finite-difference time-domain (FDTD) or the finite element method (FEM) to solve Maxwell's equations and model how electromagnetic fields behave. It has an easy-to-use interface that lets users build and change geometries, set up simulation parameters, define material properties, and see simulation results. It has advanced features for antenna design, optimisation, and performance analysis, such as radiation pattern analysis, input impedance calculation, and electromagnetic compatibility (EMC) evaluations.

CST has been used in many fields, such as telecommunications, aerospace, automobiles, electronics, medical products, and more. It helps with the creation and optimisation of antennas, microwave circuits, radar systems, wireless communication systems, electromagnetic shielding, and more. . Figure 3.2.3.1 shows a logo of Computer Simulation Technology (CST) and figure 3.2.3.2 shows the interface of CST Studio Suite 2021 software.

Figure 3.2.3.1: Logo of Computer Simulation Technology (CST)

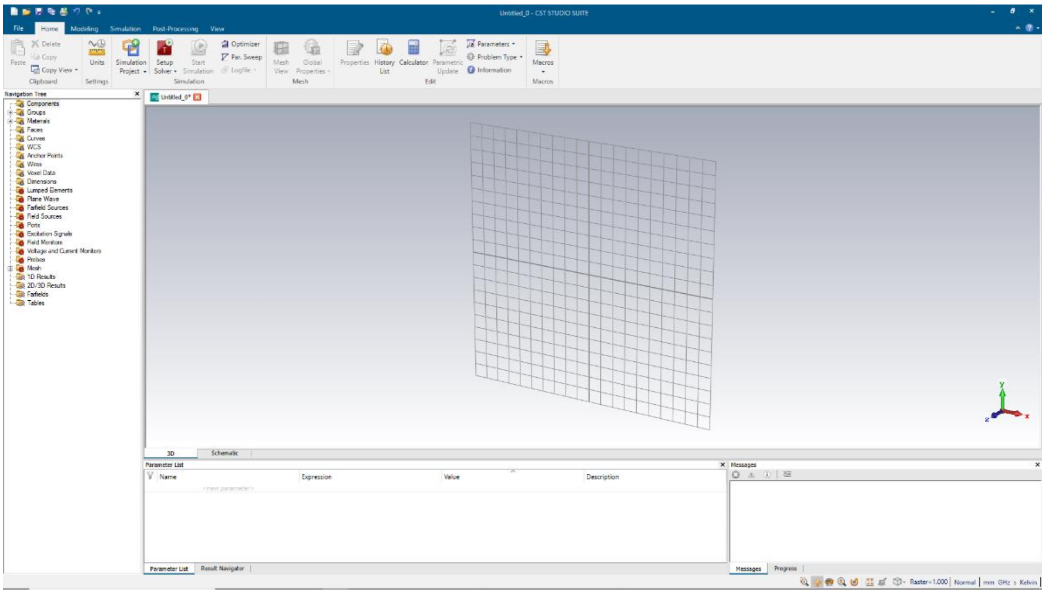


Figure 3.2.3.2: Interface of CST Studio Suite 2021 software

3.3 Designing Patch, Substrate and Ground

This section talks about how to design unit cell that consists of patch, substrate, and ground. Before designing, the parameter list of the patch needs to be calculated based on the substrate material because each substrate has different permittivity. In this project there are three set of materials that been used in order to find the comparison. Therefore, the equation helps find the parameters. The frequency chosen is 28 GHz as it in the range of millimeter wave band.

$$W = \frac{c}{2f}\sqrt{\frac{2}{(\epsilon r+1)}}$$

Figure 3.3.1: The equation to determine width

$$L = L_{eff} - 2 \Delta \mathrm{L}$$

Figure 3.3.2 : The equation to determine length

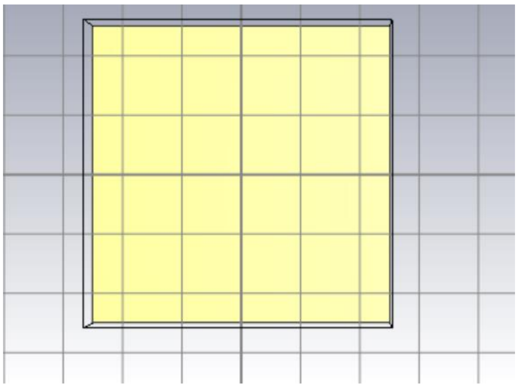


Figure 3.3.3 : The design of ground unit cells.

From the equation, the ground has been designed with the width = 5.36 mm, Ls = 5.36 mm and the height of the ground is 0.035mm. The figure above shows an example of a ground which is are the same for each material in this project. This is because it has same size with the substrate. The type of material that has been used in the example is copper (annealed).

Figure 3.3.4: The design of substrate unit cells

From the equation, the substrate has been designed with width = 5.36 mm, Length = 5.36 mm and the height of substrate is 1.6 mm. As mentioned before, the size of the substrate is the same with ground. The figure above shows an example of substrate consist of the material FR-4(lossy)

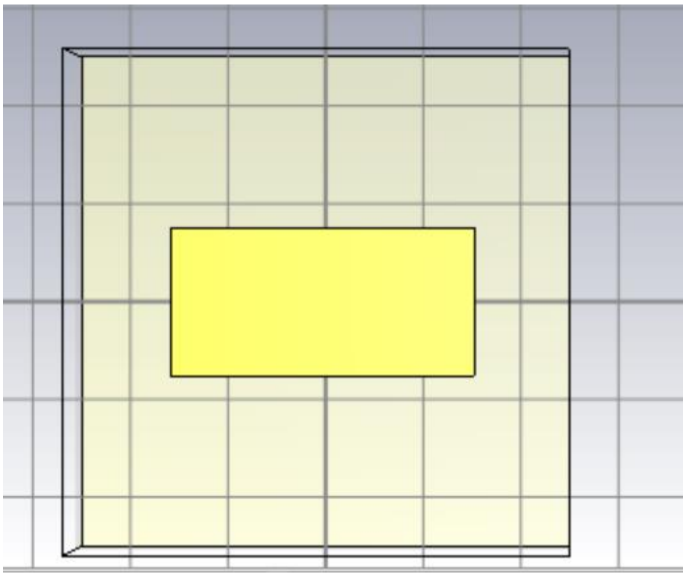


Figure 3.3.5 : The design of patch unit cells

From the equation, the patch has been designed with width = 3.07mm, Length = 1.5 mm and the height of patch is 0.035 mm. The type of materials is copper(annealed) as it is lossy metal.

3.4 Limitation of proposed methodology

This section disscuss the limitation of methodology as it only to design unit cells of reflectarray antenna. The periodic structure will be continue in PSM2. It also not include the transparent materials that has not been determined yet. Also, the optimization of the result is not fully been achieved as it wil be include in the next part which is at the PSM 2.

3.5 Summary

This chapter presents the proposed methodology in order to design a reflectarray antenna that can be integrated with other componennts that have flat surfaces. The primary focus of the proposed methodology is in accomplishing a 5G requirements as the fifth generation band has been used a lot in these modern society.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and analysis on the design of a unit cells reflectarray antenna. This include the parameter that has been calculated to design the patch, ground and substrate of the unit cells reflectarray antenna. Next, the phase dimension is shown as the result from the calculation. Also, the estimation of the frequency is about 28 GHz as it is in the milimetre wave band. All the results were optimized to get the best result.

4.2 Results and Analysis

4.2.1 Dimensions of unit cells

This section shows the dimensions of each unit cell that is made by different set of materials. Every substrate material has a different permittivity, so calculations need to be made according to the permittivity. The set of materials were patch and substrate respectively which are copper and FR-4, copper and rogers, PEC and glass. It will display different parameter lists and size of the unit cells. Figure below will show the unit cells in CST software following by the parameter list of each dimensions.

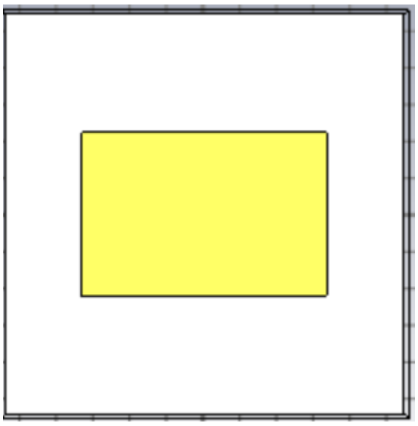


Figure 4.2.1.1 Dimension of FR-4

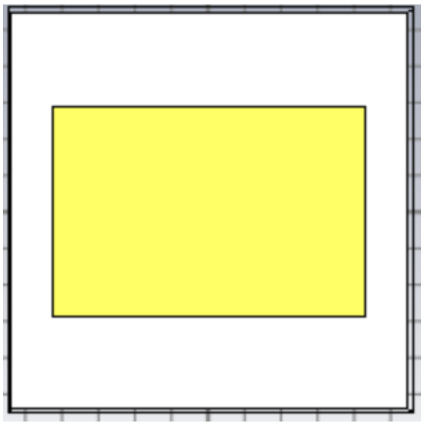


Figure 4.2.1.2 Dimensions of Rogers

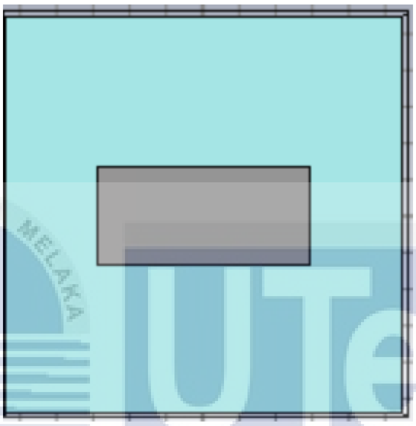


Figure 4.2.1.3 Dimension of glass

Parameter list	**Type of materials**		
	Copper and FR-4	**Copper and Rogers**	**PEC and Glass**
Width Substrate	5.36 mm	5.36 mm	5.36 mm
Length Substrate	5.36 mm	5.36 mm	5.36 mm
Height Substrate	1.6 mm	1.6 mm	1.6 mm
Width Patch	3.29 mm	4.24 mm	2.86 mm
Length Patch	1.69 mm	2.43 mm	1.37 mm
Height Patch	0.035 mm	0.035 mm	0.035 mm

4.2.2 Scattering parameters for unit cells

The figure below shows the return loss was -14.14 dB at 30 GHz. The material that was used in building this unit cell was FR-4 for the substrate and copper for the patch and ground. It shows the return loss was lower than needed for reflectarray antenna. It also differs a bit from the desired frequency. It was supposed to display at 28 GHz. The result has been optimized and it was the closest to 28 GHz. It was considered acceptable as it is still in the 5G millimeter wave band.

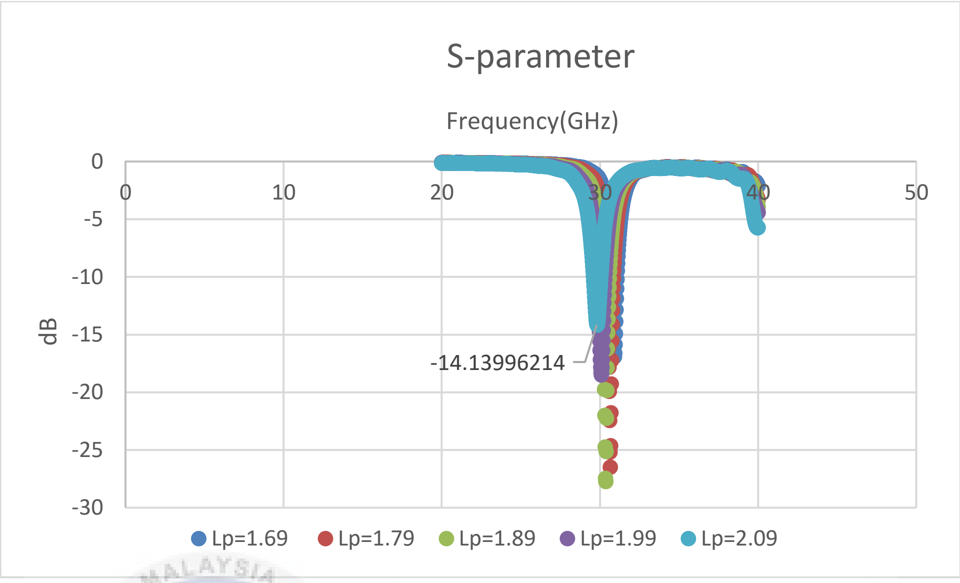


Figure 4.2.1.4 : The S-parameters for FR-4 substrate

Next, the second material was used which is rogers3035. Then, the material used for the patch and ground is the same as FR-4 which is copper The figure below shows the return loss was -0.07 dB achieved at 28GHz. The result was obtained after the optimization by using the parameter sweep. It shows good result as it gains return loss near to zero for the effectiveness of reflectarray antenna. However, the material used has low transparency which is opposite to the purpose of this project.

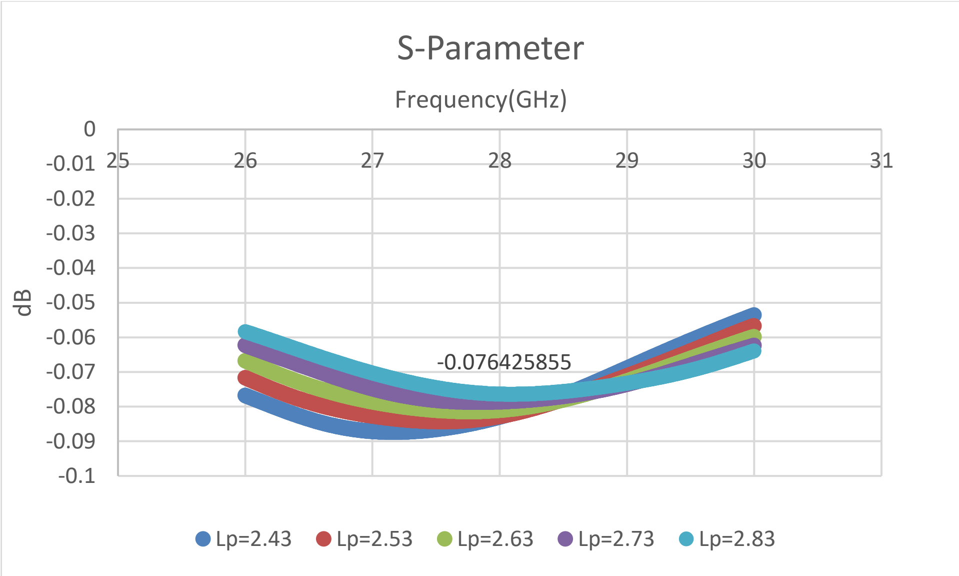


Figure 4.2.1.5 : S-Parameters for Rogers3035

Figure 4.2.1.6 shows the graph of S-Parameters of PEC with lead glass. The graph shows the return loss is -0.14dB at the frequency of 29.5 GHz. The return loss is achieved wit length patch of 1.37 mm. The result was captured in the range of 26GHz to 30GHz.

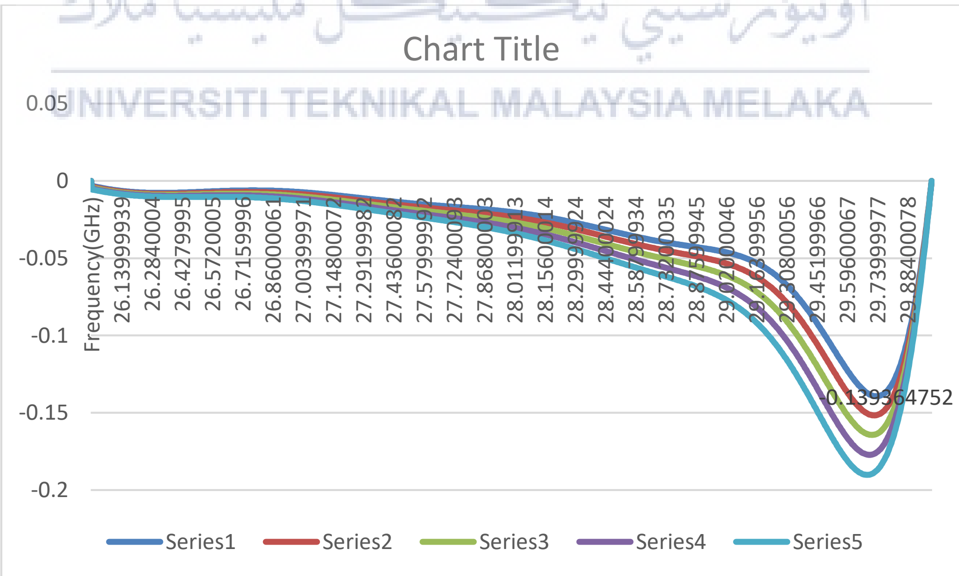


Figure 4.2.1.6: S-parameter for PEC

4.2.3 Full Array structure

After design the unit cells, the material that has been chosen was Perfect electric conductivity (PEC) to built up the full array antenna. This antenna consists of 81 elements which is 9 x9. The antenna receive signal by the feed horn antenna to reflect it back. This antenna have width substrate = 10.71 mm with the ground. This antenna will focus on multiple beam to one centre. The pyramid horn antenna located at the centre of full array antenna. Figure below shows the antenna position.

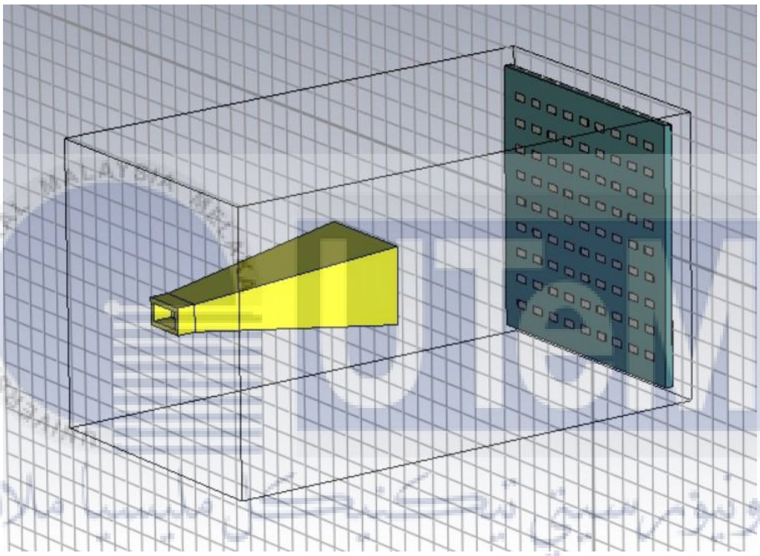


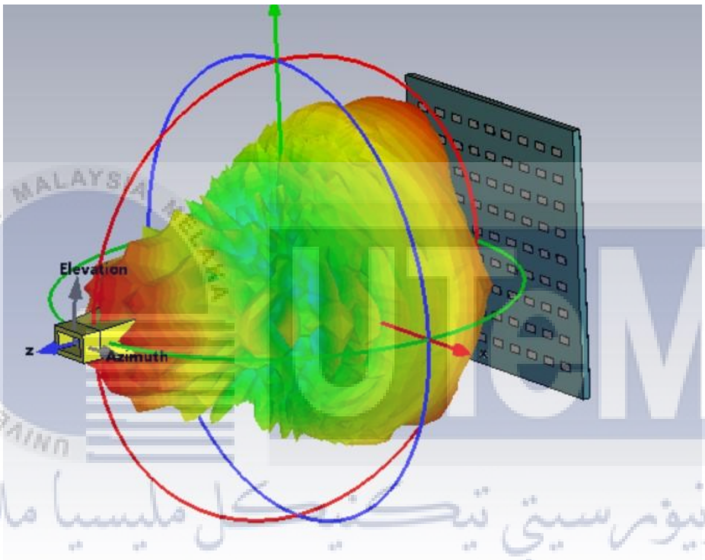
Figure 4.2.3.1 Full array antenna

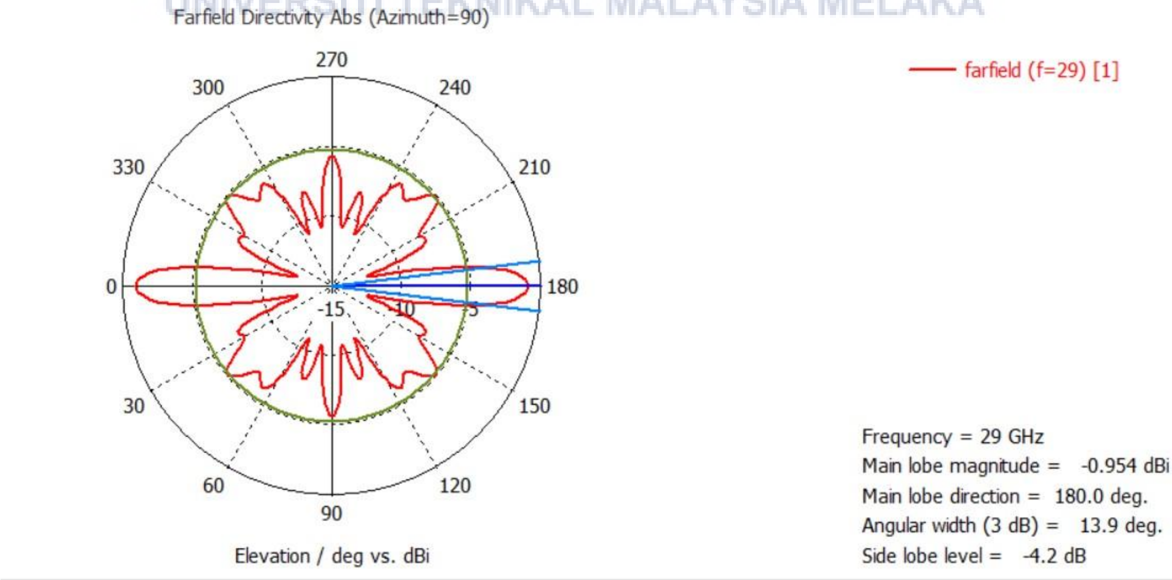
4.2.4 Full array antenna analysis

This section will introduce the analysis of the full array antenna after being optimized and obtain the final results. It also shows the radiaton pattern in 3D, radiaton pattern in polar 1D, max gain over frequency and the radiation efficiency of the antenna.

4.2.4.1 Radiation pattern in 3D and 1D

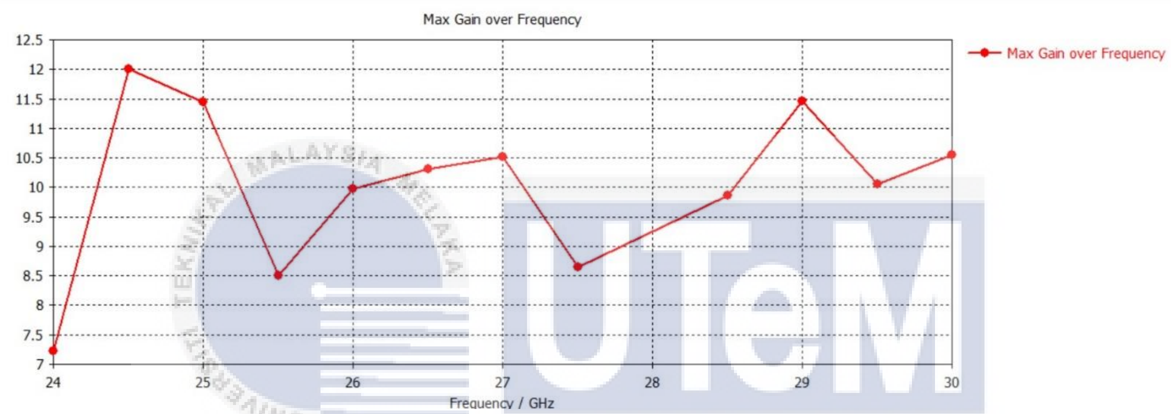
The figure below shows the radiation pattern in 3D with the full array structure. It seems like the radiation was not fully radiates in one way also call as directional. The expected result should be low sidelobe levels. In this radiation, the side lobe level was bigger which is -4.2 dB. The antenna also radiates in omnidirectional pattern causing more loss. The main lobe magnitude has only -0.954 dB.





4.2.4.2 Max gain over frequency

The figure below shows the max gain over frequency. From the graph, it seems that the max gain obtain at 24.5 GHz was higher than the selected frequency 29GHz. However, the max gain was only 12 compare to the expected which is higher than 15. This occur because of material properties that must be optimized more.



4.3 Summary

This chapter presented case studies to demonstrate the preliminary result. The result achieved is at early design of an reflectarray antenna which consist of unit cells. The result must optimized again to get the exact characteristics of 5G application.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this thesis, a technique for creating transparent reflectarray antennas for 5G communication systems is presented. The suggested approach is efficient and reliable for getting good results, however it needs to be refined in the software because the computation might change. The suggested analytical method of designing patch dimensions using CST in order to obtain the outcome and analyse it has been produced. The method that is being described uses reasonable amounts and types of scattering parameters as well as s11 parameters, involves less complex mathematical operations, and is able to generate findings that are rapid, credible, representative, and roughly accurate. Additionally, unit cells have been used in the work done to create periodic structures.

5.2 Future Works

For future improvements, accuracy of the frequency estimation results could be enhanced as follows:

i) Adjust the width of the patch reflectarray antenna unit cells.

ii) The length of patch must be increased.

iii) Choose suitable materials of substrate to get the right permittivity.

iv) Re-calculate the parameter to get the suitable scattering parameters.

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