# PERFORMANCE ANALYSIS OF TRIANGULAR LATTICE PLANAR ARRAY FOR MIMO SYSTEM

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# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

### PERFORMANCE ANALYSIS OF TRIANGULAR LATTICE PLANNAR ARRAY FOR MIMO SYSTEM

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours Faculty of Electronic and Computer Engineering Universiti Teknikal Malaysia Melaka

2023

# DECLARATION

I declare that this report entitled "PERFORMANCE ANALYSIS OF TRIANGULAR LATTICE PLANNAR ARRAY FOR MIMO SYSTEM" is the result of my own work except for quotes as cited in the references.

Date : 13/1/2023

## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with



# DEDICATION

To my family, supervisor and friends



### ABSTRACT

Massive MIMO has been recognized as one of the most promising technologies to fulfil 5G network needs because it provides directive beams with extremely high antenna gains. To obtain better data rates or reliable links, antenna arrays with large number of elements have been used to provide high multiplexing gain with high directivity. However, increasing number of elements could lead to grating lobes or high lateral lobes inside the visible region as well as resulting in large surface size. Most of the designed array solutions for massive MIMO rely on square or rectangular array structures with a uniform lattice. Thus, this project aims to propose an irregular elements array by exploiting triangular lattice to overcome aforementioned drawbacks. Triangular lattice planar arrays will be modelled in multi-elements array arrangements in MATLAB to analyse the performance in terms of directivities, half power beam width (HPBW), gain and side lobes. Then, the results will be validated with CST (Computer simulation technology) simulation and comparison will be made with regular rectangular lattice. The purpose of this project is to assess the benefit of adopting a triangular lattice to improve overall performance of massive MIMO and will provide significant advantages with respect to the regular lattices.

### ABSTRAK

MIMO telah diiktiraf sebagai teknologi yang memenuhi keperluan rangkaian 5G kerana ia menyediakan pancaran arahan dengan keuntungan antena yang sangat tinggi. Untuk mendapatkan kadar data yang lebih baik atau pautan yang boleh dipercayai, tatasusunan antena dengan bilangan elemen yang besar telah digunakan untuk memberikan keuntungan pemultipleksan yang tinggi dengan kearaharah yang tinggi. Walau bagaimanapun, peningkatan bilangan elemen boleh menyebabkan lobus parut atau lobus sisi tinggi di dalam kawasan yang boleh dilihat serta mengakibatkan saiz permukaan yang besar. Kebanyakan penyelesaian tatasusunan yang direka untuk MIMO bergantung pada struktur tatasusunan segi empat sama dengan kekisi seragam. Oleh itu, projek ini bertujuan untuk mencadangkan tatasusunan unsur yang tidak teratur dengan mengeksploitasi kekisi segi tiga untuk mengatasi kelemahan yang dinyatakan di atas. Tatasusunan satah kekisi segitiga akan dimodelkan dalam susunan tatasusunan berbilang elemen dalam MATLAB untuk menganalisis prestasi dari segi arahan, lebar pancaran separuh kuasa (HPBW), keuntungan dan lobus sisi. Kemudian, simulasi CST (Computer simulation technology) akan dibandingan dengan kekisi segi empat Tujuan projek ini adalah

untuk membandingkan kekisi segi tiga untuk meningkatkan prestasi keseluruhan MIMO dan akan memberikan kelebihan yang ketara berkenaan dengan kekisi biasa.



### ACKNOWLEDGEMENTS

Thank you to god had help and gave me this opportunity to complete this Final Year Project with ease and successfully,

Firstly, I would like to express my deepest gratitude to those who contributed and provided help to me throughout the semesters to complete this thesis. A special appreciation I give to my supervisor Dr Mawarni Binti Mohamed Yunus, for giving endless suggestions and encouragement to help me to contribute my project, especially in thesis writing.

Also, deepest thanks to my parents, family and friends that had contributed to giving endless support in terms of financial and mental support.

Last but not least, many thanks go to the coordinator of this course which is Dr Mas Haslinda Binti, who have invested their full effort in guiding all fourth-year student in completing this project. Finally, special appreciation to my panel's Dr PM Azmi and Dr Mas Haslinda especially during the presentation that has improved our presentation skills thanks to their comment and advices.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| MIMO    | :   | Multiple Input Multiple Output               |
|---------|-----|--|
| HPBW    | :   | half-power beam width                        |
| MUMIMO  | :   | Multiple User Multiple Input Multiple Output |
| SIR     | MAL | Signal-to-Interference Ratio                 |
| CST     | :   | Computer Simulation Technology               |
| BS      | :   | Base Station                                 |
| LTE     | :   | Long Term Evolution                          |
| HSPA    | i ( | High Speed Packet Access                     |
| HSDPA   | : . | High-Speed Digital Packet Access             |
| AF UNIV | /EF | Array Factor IKAL MALAYSIA MELAKA            |
| EM      | :   | Electromagnetic                              |
| L       | :   | Length                                       |
| W       | :   | Width  |
| h       | :   | height of the dielectric substrate           |
| Er      | :   | dielectric constant                          |
| f       | :   | Frequency                                    |
| VNA     | :   | Vector Network Analyzer                      |
| dB      | :   | Decibel                                      |

### **CHAPTER 1**

### **INTRODUCTION**



#### 1.1 Background of Project

Large scale antenna arrays have been researched for a variety of purposes, but the current focus is on massive MIMO with a myriad of tiny and active antennas. Technology of Massive MIMO was selected as one of the most promising technologies. Technologies to meet the requirements of the 5G network given their highly focused beams and strong antenna gain [1]. The analysis of the performance of planar arrays having an irregular periodic lattice is conducted and applied to massive multiple-input and multiple-output (5G) MIMO systems. Improving massive MIMO 5G performance in terms of directivity, gains, and half-power beam width (HPBW) by using a triangular lattice [2].

The project will investigate using the array factor theory. The spacing between element gives on the properties of large antenna arrays (planar arrays). The number of elements, element spacing, amplitude, and phase of the applied signal to each element depends on array factor. All of the elements are identical which array factor is influenced by antenna type. The antenna array is aligned along either x and y-axis or z-axis. A uniform array is defined by uniform spaces containing identical elements of equal magnitude and linearly increasing phase from element to element. [2]. The array factor (AF) for the planar array is expressed by

$$AF = \sum_{n=1}^{N} I_{n1} \left[ \sum_{m=1}^{M} I_{m1} e^{j(m-1)(kd_x \sin\theta\cos\phi + \beta_y)} \right] e^{j(n-1)(kd_y \sin\theta\cos\phi + \beta_y)}$$
(1)

Where

N: number of elements along y-axis M: number of elements along x-axis In1 and Im1: excitation coefficient of each element along y-axis and x-axis d: spacing between elements  $\beta$ : progressive phase shift between elements k: propagation constants=  $2\pi/\lambda$ 



Figure 1.1 Massive MIMO

MIMO technology sends and receives data on two polarities of the radio wave at simultaneously. This dual-polarized technology doubles the network's capacity as

against a single-polarized system. This is known as 2X2 MIMO. By combining multiple antennas to send and receive data, more complex MIMO systems may be constructed. 4X4 and 8X8 MIMO is to boost the wireless nodes' processing capacity. Each node must be able to differentiate between the data transmitted by one antenna and those transmitted by another antenna. Typically, Massive MIMO is 16x16 or 64x64, denoting the number of available antennas. As a result, instead of sharing an antenna with a large group of people, it will only be shared by a few. Nokia claims that a 64x64 setup might result in an 8x increase in uplink speeds and a 5x increase in download rates.

A triangular lattice makes it possible to achieve a greater array gain and average sidelobe level reduction, in addition to increased robustness of antenna element impedance change during beam steering by utilizing reduced Mutual Coupling levels. Additionally, a higher minimum spacing between triangle grid components ensures a higher angular resolution, which, in a huge MIMO scenario, gives improved interference resistance and, hence, improved Spectral Efficiency. [3].

Construction of antenna arrays by changing a single antenna element in the x- and y-axes, the radiation pattern distortion and mutual coupling caused by neighboring elements were not taken into account. The irregular antenna arrays are more effective in terms of mutual coupling and channel correlation valuated and compared with the regular arrays and it is determined that when the number of antennas exceeds a specific threshold, the irregular arrays may better than regular arrays. [4].

An important drawback of the MU-MIMO idea is that the number of digital channels limits the number of simultaneous users. Increasing the number of digital channels of array antenna in transmitter base station is complex due to the fact that the design complication increases as the carrier frequency increases, but the connection period decreases. However, by irregularly arranging the components in accordance with array spatial power distribution will provide the advantages in term of power consumption in which antennas could be built in a way that decrease the power variation throughout the array. This is done to reduce the level of grating lobes by irregularly arranging elements. Shifting from a dense to a sparse irregular antenna array improves the overall system performance, even when a minimal number of antenna elements are employed and the irregularity is produced randomly [5].

#### **1.2 Problem Statement**

The large scale of antenna array known as Massive MIMO. In massive MIMO technology, is a crucial component in 5G wireless communication network structure. Base stations is a large number of array antennas work continuously to direct signals to smaller regions of space. [1]. The architecture of the array location, the distance of elements, the radiation pattern features, the inter component separation, and mutual interaction between array components give the eventual performance of any huge MIMO system [2]. Prior works had shown that increasing the number of elements and inter-element spacing will improve direction beams but at the same time led to the increasing in grating lobes or increase lateral lobes. This problem can be even more severe in the case of multi-user communication in terms of Signal-to-Interference Ratio (SIR) [3]. Therefore, this project proposes to study the effect of irregular elements arrangement by exploiting triangular lattice array as opposed to the regular rectangular lattice array in MIMO system. Triangular lattice arrangement is chosen as it allows additional spatial diversity between array elements as well as enables avoiding the premature development of grating lobes [6].

#### 1.3 Objectives

- i. To model the triangular lattices of planar arrays using MATLAB
- ii. To validate the efficacy of performance of the triangular lattice with CST simulations
- iii. To fabricate and measure the design of triangular lattice

#### **1.4 Scope of Project**

- i. Planar array is set to operate at 3-6 GHz
- ii. Array elements will be designed up to 256 elements (16 x 16)

iii. Parameters will be examined in the variations of directivities, half power beam width (HPBW), gain and side lobes.

iv. Design and simulate using MATLAB and CST software.

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There are five (5) chapters in this project that must be completed in order to complete the writing thesis, and the outline must be completed as follows:

The first chapter (1) has an introduction section that gets the project history, the issue description, and therefore the objectives of this project as well as the scope of this project.

As in the second chapter (2), it consists of a review of the literature on the projects discussed, as well as the real title of the project that was completed by previous researchers and is recognized as the current title of the project.

The third chapter (3) incorporates the technique or methodology section, which covers the project flow, design and simulation, measurement, field test as well as how the antenna will be operated.

The next chapter is four (4), which includes the results and discussions that have upheld the project's goals. The results of the proposed antenna in terms of directivities, half power beam width (HPBW), gain and side lobes.

The last chapter, chapter (5), will provide an explanation of the findings and suggestions for future study in order to enhance antenna performance.

![](_page_23_Picture_3.jpeg)

## **CHAPTER 2**

### LITERATURE REVIEW

![](_page_24_Picture_2.jpeg)

# 2.1 Multiple Input Multiple Output

MIMO stands for Multiple Input and Multiple Output which is produced by using multiple antennas at both the transmitter and receiver called spatial diversity. Spatial diversity was frequently restricted to systems that alternated between two antennas. Multiple antennas at the transmitter are known as transmitter diversity, and multiple antennas at the receiver are known as receiver diversity. One benefit of this technology is that it allows us to boost capacity and efficiency while also reducing error rates. In MIMO, communication occurs in spatial diversity and spatial multiplexing are two formats. Spatial diversity refers to the fact that the same data is delivered across several pathways before being received and processed by multiple antennas. Besides, the alternative method is spatial multiplexing, in which data is split into smaller pieces and each piece is transmitted on a different line. Spatial multiplexing can increase link dependability while also increasing speed. Basically, a MIMO system is made up of a transmitter and receiver antenna as well as a fading channel through which data is transmitted. The number of transmitter antennas, M and number of receivers, N. An antenna matrix for transmitters and receivers with t rows in the transition matrix and r rows in the receiver matrix. [8]

![](_page_25_Figure_1.jpeg)

![](_page_25_Figure_2.jpeg)

Figure 2.1 MIMO System

#### 2.2 Massive Multiple Input Multiple Output

Massive MIMO is the attractive technology for 5G and the future of wireless networking. Massive MIMO is an improvement of current MIMO systems used in wireless networks that combines hundreds or even thousands of arrays at the base station and provides many of customers at the same time [19]. Massive MIMO's usage of additional antennas will aid in concentrating energy into a smaller region of space, hence improving spectral efficiency and throughput.

![](_page_26_Figure_2.jpeg)

Figure 2.2 Massive MIMO

MU-MIMO takes use of multi-user diversity in the geographical domain by allocating a time-frequency resource to many users, which produces significant gains, especially when the channels are spatially correlated [20]. MU-MIMO Antennas at the base station serve multiple users at the same time. Since MU-MIMO systems are less sensitive to the propagation environment, scattering is usually necessary.

![](_page_27_Picture_0.jpeg)

Figure 2.3 Multi-User Multiple Input Multiple Output

### 2.2.1 Frequency for 5G MIMO

The next generation of wireless and mobile communication technologies is 5G that is capable to provide ultra-fast speeds, low latency, and good reliability. The band that employed in the 5G are C-Band is between 3300-4200 and 4400-5000 MHz, in which transmit information from devices to base station (BS) to the data's endpoint. 5G frequency range 1 is between 450 MHz and 6 GHz is sharing networks with LTE's frequencies due to 5G is not rapidly and completely replacing LTE. [7].

#### 2.2.2 MIMO suitable for 3G and 4G?

By increasing the capabilities of 3G and 4G systems, MIMO systems can increase transmission rate for mobile high-speed data applications. Experience with antennas is useful which HSPA (High Speed Packet Access) and LTE (Long Term Evolution) wireless system upgrades. Mostly 3G systems configured to operate in the 2 GHz frequency spectrum. Thus, 4G is the next step of cellular innovation after 3G and provides the right basis and bandwidth for more effective wireless multicast services.

Operators must add cell sites to improve capacity. By increasing the number of cell sites, network capacity and throughput per user are roughly doubled while also significantly improving peak user and aggregate throughput [10]. With MIMO research reaching an advanced stage and recent measurement campaign results showing the advantage of MIMO channels, the International Telecommunications Union and the 3GPPs have recently started to standardize MIMO solutions for 3G wireless technologies and beyond. Several techniques that are complementary to MIMO in terms of enhancing throughput, performance, and spectrum efficiency are attracting attention, particularly as improvements to current 3G mobile systems, such as high-speed digital packet access (HSDPA) [11].

#### 2.2.3 Why using MIMO

Multi-Input MIMO technology has been developed and is now widely used in current wireless networks. The system data rate and throughput are considerably improved when both the transmitter and receiver require multiple antennas. The increasing demand for bandwidth has generated various challenges for the fourthgeneration wireless communication infrastructure due to offered with high data rates transmission. The current infrastructure for wireless communication is incapable of delivering a higher data rate with low latency, this infrastructure must be upgraded. Therefore, fifth generation has been released, which has the potential to meet the demand for increased data rates and the necessary low latency level compared the previous generation. The high gain can be very useful for efficiently delivering a stronger signal to the user rather than congested lower frequencies of the spectrum. When compared to single port antennas, the multiple input multiple output (MIMO) arrangement is highly useful in providing a strong channel capacity and data rate, which is one of the primary issues in 5G transmission. Multi-Input Multi-Output (MIMO) technology or system is a required for modern communication systems in order to increase channel capacity. Theoretically, the space between array elements and the size of the antenna decreased as the number of antenna array elements increased. The MIMO antenna remained stable in the face of side channel interferences and fading. So that MIMO enables a higher data rate throughout the antenna by allowing data to travel in multiple routes during spatial multiplexing [9].

#### 2.3 Planar Array

Antenna arrays are considered one of the most unique techniques by massive MIMO and 5G networks for improving performance in multipath environments. The characteristics and configurations of the antenna arrays used in massive MIMO technology have a crucial impact on its performance. The array configurations must be compact and generate high gain while including antenna performance such as radiation pattern, efficiency, and mutual coupling. Due to array aperture constraints, planar arrays are preferred model and more suited for massive MIMO than linear arrays. An antenna array is an electrical and geometric arrangement of single radiating antenna elements. The design of antenna arrays includes first selecting a single antenna element, then array shape, and then determining the element excitations required to achieve a specific metric. The overall field of the array is equal to the field of a single element at a certain reference point multiplied by the array factor (AF). In order to make planar array configuration, the placement of a large number of antenna elements within a certain size yields great directivity and gain. The whole antenna's size array also involved the distance between them and the number of elements [2].

#### 2.3.1 Array Factor

The number of elements, element spacing, signal amplitude and phase applied to each element affect the array factor. The antenna array can be oriented along the zaxis or along the x and y-axes. A uniform array is made up of identical elements that are equally spaced and have a linearly rising phase from one element to the next. Figure 1 shows the configuration of a planar array with N and M elements.

![](_page_30_Figure_2.jpeg)

It is possible to construct the N-element linear array to radiate either in a broadside array that radiates perpendicular to the array orientation along the z-axis or in an end fire array that radiates parallel to the array orientation along the y-axis [12].

#### 2.4 Technique

The investigation planar arrays with regular lattices are analyzed and applied to massive multiple-input multiple-output (5G) MIMO systems, particularly in the sub-6 GHz region. A triangular lattice is one of the techniques that allows to achieve of a superior array gain and average sidelobe level reduction, as well as greater robustness of the antenna elements' impedance variation during beam steering by exploiting lower Mutual Coupling levels. Moreover, the triangular lattice demonstrates a good degree of adaptability in serving customers located in differently shaped sector cells. Furthermore, the greater minimum distance between components in a triangular grid ensures the improved angular resolution, which a massive MIMO system, results in enhanced interference robustness and greater Spectral Efficiency. [6]

#### 2.5 Method Used in Feeding Technique

There are various techniques and measurement procedures that have been introduced for antenna feeding technique [15]. The factor of effective power transmission between the radiation structure, feeding structure, and their impedance matching influences the feeding technique [16]. There are four types of feeding methods which is microstrip line feed, coaxial feed, gap coupled feed, and couple feed [17]. As indicate in research paper, coaxial probe feeding is a famous technique for feeding Microstrip patch antennas in order to get higher performance of antenna with low reflected power. With coaxial feeding scheme, the antenna input impedance and cable impedance can be matched by placing the feed at any desired location on the patch. The primary goal of using probe feeding is to increase gain, provide narrow bandwidth, and match impedance.

#### 2.6 Literature Review Conclusion

In designing 5G antenna, there are many techniques that should be considered in order to improve the antenna performance in term of directivities, half power beam width (HPBW), gain and side lobes. Planar array is the technique to improve antenna directivity. Using this method, a single antenna element is placed along a rectangular grid. Planar arrays with strong directivity can be achieved by placing more antenna elements within a specific size. A triangular lattice provides for the achievement of a superior array gain and average sidelobe level reduction, as well as increased robustness of the antenna elements' impedance change during beam steering by the use of lower Mutual Coupling levels. Additionally, a triangular grid's larger minimum distance between elements ensures a improve angular resolution, which, in a huge MIMO scenario, results in improved interference robustness and, thus, higher Spectral Efficiency.

![](_page_32_Picture_1.jpeg)

## **CHAPTER 3**

## **METHODOLOGY**

![](_page_33_Picture_2.jpeg)

In this chapter describe the process on how this project functions and what are the principles used to make this project successful. Every process or step, which had done to complete the project, will discussed. Methodology is the number of strategies by which researchers experience to finish their work of explaining, detailing, defining and predicting phenomena. The following segment will give an overview of the work method followed by a detailed explanation. This project necessitates the theoretical idea and experimental method throughout the antenna development procedure.

#### **3.2 Project Flowchart**

To satisfy the objectives of the project, a flow chart is refined to illustrate the methodology for the study as shown in figure 3.1. The flow chart is important as it depicts more in detail how this study will be done to in each step and routes. It goes precisely into details of what will be done, by what method it will be done and what action is should have been taken to fulfil the objectives of the study.

![](_page_34_Picture_2.jpeg)

![](_page_35_Figure_0.jpeg)

Figure 3.1 Project Flowchart
#### 3.3 Software

#### 3.3.1 Matlab Software



### Figure 3.2 MATLAB

MATLAB is a platform designed for engineers and scientists to assess and build new solutions and systems. MATLAB's core is the MATLAB language and a matrixbased language that enables the most natural representation of computer mathematics.

The basic data element of the interactive system MATLAB is a dimensionless array. This enables the solving of numerous technical computer problems, particularly those using matrix and vector formulations, in a fraction of the time required to build a programmed in a scalar noninteractive language such as C or Fortran.

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The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art software for matrix computation.

MATLAB improved through time with feedback from several users. It is the standard tool for basic and advanced courses in mathematics, engineering, and science in academic contexts. MATLAB is the standard in industry which highly productive research, implementation, and evaluation.

Toolboxes in MATLAB's set of application are specific solutions. Toolboxes are important to the all MATLAB users since they allow you to understand and use specialist technologies. Toolboxes are full sets of MATLAB software (M-files) that enhance the MATLAB environment in order to solve specific classes of problems. Toolboxes are provided in the following fields: signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

### 3.3.2 CST Software



CST Studio Suite is a high-performance 3D electromagnetic (EM) analysis software suite for the design, analysis, and optimization of electromagnetic (EM) components and systems.

CST Studio Suite contains electromagnetic field solutions for real application the EM spectrum inside a single user interface. The solvers may be connected to generate hybrid simulations, offering engineers the ability to evaluate multicomponent systems as a whole in a simple and effective manner. Co-design with other SIMULIA products

enables the integration of EM simulation into the design flow and drives the design process from the early stages.

The performance and efficiency of antennas and filters, electromagnetic compatibility and interference (EMC/EMI), the exposure of the human body to EM fields, electro-mechanical effects in motors and generators, and thermal effects in high-power devices are common topics of EM analysis.

CST Studio Suite is used by global leaders in technology and engineering. It provides significant product-to-market benefits, allowing for faster development cycles and lower costs. Simulation makes virtual prototyping possible. Device performance can be optimized, potential compliance concerns can be recognized and handled early in the design phase, the number of required physical prototypes may be decreased, and the risk of test failures and recalls can be minimized.

#### 3.4 Parameter

### 3.4.1 Directivity

Directivity of an antenna is defined as the ratio of the radiation density intensity along a path given by the antenna to the average radiation intensity along the path. In static conditions, antenna directivity may be utilized to concentrate the beam in the desired direction. For dynamic systems where the transceiver is not stationary, the antenna should emit in all directions equally and is known as an omni-directional antenna.

#### 3.4.2 Gain

Antenna gain is the ratio of intensity in a given direction to the radiation that would be produced if the power received by the antenna were transmitted isotopically. The intensity of radiation corresponding to the isotopically radiated power is equal to the accepted power (input) of the antenna divided by  $4\pi$ .

The gain function can be defined as:

$$G = 4\pi x \frac{U(\theta, \phi)}{P_{in}}$$
(3)



The relation between directivity and gain can be given as:

$$G = nD \tag{4}$$

#### **3.4.3** Half Power Beam Width (HPBW)

Half-power beam width (HPBW) is the angle between two vectors starting at the origin of the pattern and going through the locations of the major lobe where the intensity of the radiation is half of its maximum value.



Figure 3.4 Half Power Points on the major lobe and HPBW

# 3.4.4 Side Lobes

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Sidelobes are the lobes in the local maximums of an antenna's or other radiation source's far field radiation pattern.



Figure 3.5 Directional antenna radiation pattern

A major lobe is the maximum radiation direction containing radiation lobe. A minor lobe are lobes other than a major lobe. A side lobe is a radiation lobe that is directed in a direction other than the original lobe. A side lobe occupies the hemisphere in the direction of the main beam and is close to the main lobe. A back lobe is a radiation lobe which axis forms an angle of about 180° with respect to the antenna's beam. Normally, minor lobes produce radiation in undesirable directions and should be minimized. Typically, side lobes are the largest minor lobes.

#### 3.5 Calculation

## **3.5.1** Determination of the actual length (L) of the patch

The total length of the patch, L, is calculated by subtracting the effective length from two times the length extension of the patch. It is represented mathematically as;

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# **3.5.2** Determination of the width (W) of the patch

The width of the patch is calculated using the formula give as;

$$W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon r + 1}{2}}} \tag{6}$$

## **3.5.3** Determination of the length extension (L)

Extension is the additional length at the end of the patch because of the fringing field along its width. It is calculated using the formula given as:

$$\Delta L = 0.412H \left[ \frac{(\varepsilon_r + 0.3) \left( \frac{H}{W} + 0.264 \right)}{(\varepsilon_r - 0.258) \left( \frac{H}{W} + 0.8 \right)} \right]$$
(7)

## 3.5.4 Determination of the effective dielectric constant (*ceff*)



#### **3.5.5** Determination of the effective length of the patch (L<sub>eff</sub>)

The effective length of the patch is given by the formula:

$$L_{eff=\frac{c}{2F_o\sqrt{F\varepsilon_{eff}}}}\tag{10}$$

## **3.5.6** Determination of the ground plane dimensions

The length and width of the ground plane are determined. The length and width of the ground plane are six times the patch's thickness or height larger than the length and width of the patch. They are calculated using the formula given as.

$$L_g = L + 6H \tag{11}$$

$$W_{g} = W + 6H \tag{12}$$

## **3.6 Modelling in MATLAB**

The process of modelling in MATLAB is initial process in order to simulate the performance of the antenna. The spacing between elements was calculated to model the design. The process of modelling the triangular lattice in MATLAB is shown in Figure 3.6.

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UNIVERS Figure 3.6 Modelling MATLAB Flowchart



Figure 3.7 MATLAB Coding for Modelling the spacing between elements

The formula that obtained from the coding is:  

$$INIVERSITI TEKNIKA \int \frac{MA(\frac{4}{2})^2}{V_{dist}} = \sqrt{4^2 - \left(\frac{4}{2}\right)^2}$$
(13)

= 3.46





# 3.7 Designing Antenna in CST

There is some important specification to consider before designing a triangular lattice planar array, such as length (L), width (W), height of the dielectric substrate (h) of the patch, dielectric constant of the substrate ( $\epsilon$ r), and operating frequency. The proposed antenna is designed using RT/duroid 5880 substrate material with dielectric constant ( $\epsilon$ r) of 2.2 and thickness of 1.57 mm. Table 3.1 lists the specifications of the triangular lattice planar array. The base layer of the antenna is a fully ground plane of copper with a thickness of 0.035mm. The patch is fed by a 50 $\Omega$  input impedance microstrip line.

| Parameter              | Symbol           | Value   |
|------------------------|------------------|---------|
| Frequency              | f                | 3.5Ghz  |
| Dielectric             | Er               | 2.2     |
| Thickness of Copper    | t                | 0.035mm |
| Thickness of Substrate | Substrate height | 1.57mm  |

**Table 3.1 Parameter Setup for Antenna Design** 

Before designing and simulating an operating frequency of 3.5 GHz, the theory of the topic was studied for triangular lattice planar array antenna. The CST software allows the user to create an antenna model, run simulations, and generate results. CST software was used for this project due to the precision demonstrated during the initial test and because its wide-ranging use generates massive amounts of online documentation.

The radiating patch elements are determined using appropriate equations, which are still dependent on the patch form, which can be circular, rectangular, or triangular. The basic starting design in this study is a rectangular shape patch. The following are the formulae for determining rectangular patch dimensions: The patch's width can be calculated using the formula:

$$W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon r + 1}{2}}} \tag{6}$$

Where:

$$c = speed of \ light (3 \times 10^8)$$

*f* = *middle frequency* 

 $\epsilon r = material \ relative \ constant$ 





Next to calculate the width of substrate, the formula below is used:

$$\lambda = \frac{c}{f} \tag{14}$$

Where:

$$c = speed of light (3 \times 10^8)$$

*f* = *middle frequency* 

$$=\frac{3x10^8}{(3.5G)}$$

$$= 0.0857mm$$

For the actual length of a patch antenna, it is calculated using this formula:



*f* = *middle frequency* 

 $\varepsilon reff =$  effective dielectric constant

 $\Delta L = the \ length \ extension$ 

$$L = \frac{3X10^8}{2(3.5G)\sqrt{2.2}} - 2\Delta L$$

= 28.05979*mm* 



Figure 3.9 Design Antenna in CST

# 3.8 Fabrication Process



**Figure 3.10 Fabrication Process Flowchart** 

## 3.8.1 Cutting Process

This process is to ensure that the board and the simulated board are same size. So that, after etching we no need to cut because the risks of cutting after etching is high.



Figure 3.12 Design to be print

# 3.8.3 UV Exposure Process

Pass the copper plate with the pattern facing down three to five times through a laminator until the board is heated.



## 3.8.4 Developing Process

Unexposed areas are developed away, exposing bare metal that is shielded by the hardened photoresist. The hardened resist shields the part for the etching process.



This etching method is done manually; this is because the board is big and cannot fit the machine for etching process. Etching solution, ferric chloride is used during this UNVERSITI TEKNIKAL MALAYSIA MELAKA process. This solution is to remove the unwanted metal from the board.



Figure 3.15 Etching Manually

#### **3.8.6** Solder Process

Soldering process is to attach the SMA port to the board. This SMA port is to connect the board with Vector Network Analyzer (VNA) during measuring the reflection coefficient.



The antenna measurement is to fulfil the objective of the specification of the antenna. Antenna measurement is the important task before the antenna is being placed on field. Normally, antenna is tested by using method of Vector Network Analyzer (VNA) and Anechoic Chambers. The measured parameter is then compared with the simulation to prove the performance of the antenna. If the antenna's performance does not match the simulation, the process of identifying the problem and troubleshooting must be done.



Figure 3.17 Gain Results



# **CHAPTER 4**

# **RESULTS AND DISCUSSION**



# 4.1 Radiation Pattern Analysis Sub-Array

The derivation from Array factor formula, MATLAB code has been written to plot the NXN (N= 4, 8, 16) 2D array factor plots, starting with a 4x4 (16 element) planar array as a sub-array and proceeding to a large planar array of up to 16x 16 elements (256 elements). The plots are depicted in Figure 4.1,4.2 and 4.3.



Figure 4.2 Polar Plots of an Antenna Pattern 8x8



Figure 4.3 Polar Plots of an Antenna Pattern 16x16

### 4.2 Analysis in MATLAB

Based on the characteristics of the array factor shown in Figure 4.1, 4.2 and 4.3, the directivity, gain, half-power beams widths, no of sidelobes and sidelobe levels are calculated to determine the modularity of sub-array. The performance of modular planar arrays is observed to derive the impact of placing planar antenna arrays in modular form 4x4, 8x8 and 16x16. The directivity, half-power beam widths, number of sidelobes appearing and as well as the sidelobe level variations are presented in Figure 4.4, 4.5 and 4.6.



Figure 4.5 MATLAB Design 8x8



 Table 4.1 Comparison the parameter for Triangular Lattice model with

 Rectangular Lattice Planar Array [1]

| Array    | Directivi | Gain (dB) |       | HPBW      |         | No of |           | Sidelobe level |        |       |
|----------|-----------|-----------|-------|-----------|---------|-------|-----------|----------------|--------|-------|
| Elements | IIV LI CO |           |       | Grille IV | 1 Chart |       | sidelobes |                | (dB)   |       |
|          | Rect.     | Tri.      | Rect. | Tri.      | Rect.   | Tri.  | Rect.     | Tri.           | Rect.  | Tri.  |
| 4x4      | 13.48     | 8.61      | 12.67 | 7.00      | 26.47   | 55.00 | 2         | 2              | -11.3  | -36.2 |
| 8x8      | 19.71     | 14.00     | 18.53 | 16.23     | 12.87   | 14.87 | 6         | 6              | -12.8  | -29.7 |
| 16x16    | 25.88     | 26.20     | 24.33 | 21.88     | 6.39    | 6.31  | 14        | 10             | -13.15 | -29.4 |

There are some similarities in their directivities, half-power beam widths, and sidelobes. To begin with directivity, it increases by 6dB when the array size is expanded by a factor of 4, which is 4x4, 8x8 and 16x16. For instance, a 4x4 planar array has a directivity of 8.61 dB, while an 8x8 array has a directivity of 14.00 dB and

16x16 array has directivity of 26.20 dB. By comparing 4x4 and 8x8, the directivity result between rectangular and triangular, shown that the triangular lattice planar array was resulted less directive. When comparing 16x16 between rectangular and triangular, clearly seen that the triangular lattice is better than rectangular lattice planar array. As a result, it is possible to conclude that the directivity is directive and gain as the array expands along the modular form.

Furthermore, the value of half power beam width decreases when the value of array size is increasing. This will show the half power beam width decrease indirectly disclosed as the directivity and array increasing. When the array size increases, the 3dB half power beam width decreases where drops by 41dB. For example, the 3dB half power beam width for 4x4, 8x8 and 16x16 planar array is 55.00°, 14.87° and 6.31° respectively. Overall, results in rectangular and triangular are compatible, except for small lattices of 4x4 elements array as significant comparison between rectangular and triangular can be seen which reflects from lower directivity of triangular lattices.

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#### 4.3 Analysis in CST

MATLAB software was used to investigate the radiation properties of triangular planar arrays in order to determine the outputs of constructing arrays by repeating a compact triangle sub-array in 4x4, 8x8, and 16x16 configurations. As a result, in order to prove those results, the CST application software is used to simulate planar and patch antennas. This section will focus on the practical antenna effects of coupling between two components. As a result, the MATLAB and CST results will be compared in order to evaluate the ability of the generated model to evaluate radiation performance of array such as directivities, half power beam width (HPBW), gain and side lobes.

# 4.3.1 4x4 Triangular Lattice Array Antenna

The design is implemented by arranging two patch 1x4 array antenna with 29.59mm separate distance. When creating 4x4 array antenna thickness of substrate as 1.57mm and having dielectric constant 2.2 and dielectric loss tangent tan  $\delta$ = 0.025, and the dimension of the substrate and ground are also altered to fit the whole antenna design. Figure 4.7 illustrates the design of 4x4 array patch antenna in CST simulation.





Figure 4.7Array Antenna 4x4 Arrangement

Figure 4.8 S11 Parameter for 4x4 Array Antenna

The results for S11 parameters of H-field and E-field return loss, gain, and radiation pattern were collected after simulating the above design. Return loss is a critical measurement during an antenna test. It relates to the impedance and maximum power transfer theory. It is also a measure of an antenna's efficiency in transferring energy from the source to the antenna. For antenna array 4x4 antennas, S-calculations were completed successfully.

Figures 4.8 show a strong linear graph view of S11 characteristics, which dropped at 4.03 GHz with a corresponding return loss of -30.15 dB. With a return loss of less than -10 dB, this meets one of the research goals.



Figure 4.9 3D Radiation Pattern of 4x4 Array Antenna



Figure 4.10 Polar view of antenna *phi* = 90°

# 4.3.2 8x8 Triangular Lattice Array Antenna

The 8x8 antenna design in this section is to ensure that the result is better compared to 4x4 array antenna. This 8x8 array antenna is redesign the different form and shape. Figure 4.10 shows the real 8x8 array antenna design performed.



Figure 4.11 Array Antenna 8x8 arrangement



Figure 4.12 S11 Parameter for 8x8 Array Antenna

The graph in figure 4.12 shows the S11 waveform, which represents the return loss for 8 X 8 array antenna configurations. The results of the return loss provided are less than -10dB, which is -34.73 dB at 4.036 GHz. This indicates the low return loss of the antenna at 4.036 GHz. The antenna thus transmits a good amount of the signal.



Figure 4.13 3D Radiation Pattern of 8x8 Array Antenna



Figure 4.14 Polar View of Antenna at *phi* = 90°

# 4.3.3 16x16 Triangular Lattice Array Antenna

In this section, 16x16 array antenna have been design. This design is transformed from 8x8 design to get better results. Figure 4.13 shows the design of 16x16 array antenna.



Figure 4.16 S11 Parameter for 16x16 Array Antenna

The graph in figure 4.16 shows the S11 waveform, which represents the return loss for 16 X 16 array antenna configurations. The results of the return loss provided are less than -10dB, which is -34.67 dB at 4.03 GHz. This indicates the low return loss of the antenna at 3.5 GHz. As a result, the antenna transmits a significant portion of the signal.



Figure 4.18 Polar View of Antenna at *phi* = 90°

#### 4.3.4 Analysis on Various Design of Antenna

The purpose of this analysis is to determine the best research design. All antenna designs were separated and compared to analysis the directivities, half power beam width (HPBW), gain and side lobes. Table 4 shows chapter presents the findings for comparing various antenna designs.

| Array    | Directivity (dB) |      | Gain (dB) |       | HPBW (°) |      | No of sidelobes |     | Sidelobe level (dB) |       |
|----------|------------------|------|-----------|-------|----------|------|-----------------|-----|---------------------|-------|
| Elements | MATLAB           | CST  | MATLAB    | CST   | MATLAB   | CST  | MATLAB          | CST | MATLAB              | CST   |
| 4x4      | 8.61             | 19.1 | 7.00      | 17.9  | 55.00    | 16.2 | 2               | 2   | -36.2               | -14.8 |
| 8x8      | 14.00            | 24.1 | 16.23     | 23.99 | 14.87    | 8.5  | 6               | 6   | -29.7               | -15.1 |
| 16x16    | 26.20            | 30.1 | 21.88     | 30.08 | 6.31     | 3.3  | 10              | 8   | -29.4               | -11.9 |

Table 4.2 Comparison the parameter for Triangular Lattice model inMATLAB and CST Simulation

The overall antenna performance with different number of array elements were simulated on CST are shown in Table 4. For the first parameter is about antenna's directivity, Directivity is a measurement of how concentrated a radiation pattern is coming from an antenna in a specific direction. As a result, the directivity of 4x4 array element, 8x8 array element and 16 x16 array element are 19.1 dB, 24.1 dB, 30.1dB respectively. The directivity gets higher when the array element is higher. The higher the directivity, the more concentrated or focused is the beam radiated by an antenna and the beam will travel further. The beam area and the directivity of an antenna are inversely proportional. When the directivity is increased, the beam area will be reduced, meaning the smaller the radiating area of the transmitting antenna, more directed is the emitted energy.

The second parameter evaluated antenna's gain. An antenna gain is the intensity ratio in each direction to radiation generated if the power received by the antenna was isotopically transferred. Gain is also related to the antenna's directivity because the gain is a combination between directivity and electrical efficiency. The result of gain shows, the higher number of array elements was produced the higher number of gains. For example, the antenna with 16X16 array element produced the higher gain, 30.08 dB compared from the previous designed antenna which are 4x4 array element and 8x8 array element.

Next, the antenna's HPBW was exanimated. The HPBW is inversely proportional to the antenna gain. According to the result, the HPBW of the antenna with 4x4 array elements, 8x8 array element and 16x16 array element were decreased from 16.2°, 7.1° and 3.3°. The decreased number of HPBW has caused the angular to become narrower. At the same time, the gain will increase, and the coverage area will be smaller.

Sidelobes are typically associated with unwanted radiation in undesirable directions. As we can see from table 4, the higher number of array elements has produced a large amount of sidelobes, which is a minimum of 2 sidelobe on a 4x4 array element up to a maximum of 8 sidelobe on a 16x16 antenna array. It can conclude that the higher number of array elements, the higher number of sidelobe that radiates more consumes energy and may generate interference problems.

When comparing the sidelobes level in CST and m, the sidelobes level in MATLAB achieve higher than CST. The sidelobe level of 4x4 elements in MATLAB is -36.2 dB while CST software increase to -14.8 dB. The sidelobes element for 8x8 and 16x16 is -29.7 and -29.4 dB in MATLAB while in CST Software is -15.1 and -
11.9 db. It can conclude that, when the number of array elements increase, the number of sidelobe level will decrease. Overall by increasing the number of elements, it reduces the grating lobes and high lateral lobes as well as resulting in large surface size. Therefore, by reducing the side lobes level, the signal-to-interference ratio (SIR) will increase. This will provide the greatest modulation rate, highest throughput, and the fastest and most dependable service to end users.



#### 4.4 Fabrication and Measurement



**Figure 4.20 Far-Field Measurement** 

The purpose of this analysis is to determine the best design for this research project. All of the designed antennas are separated and compared in terms of performance, such as directivities, half power beam width (HPBW), gain and side lobes. Figure 4.19 depicts the antenna measurement using Far-Field Measurement Systems at the Microwave Laboratory, Faculty of Electronics and Computer Engineering, University of Technical Malaysia, Malacca.



Figure 4.21 S11 Results using Vector Network Analyzer

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The initial parameter discussion focused on the difference in gain between simulation and measurement for each antenna, as illustrated in Figure 4.21. The simulated result of a Triangular Lattice Planar Array antenna with 16 elements shows a return loss of -12.76 dB at 3.5GHz, while the observed return loss is -15.81 dB.

The return loss in Figure 4.22 shows the analysis of S11 that insert u-slot on each patch can enhance antenna performance. This parameter measures the reflected power from the input. There should not be reflected power, and the transmitter will provide maximum power. When the return loss is below -10 dB, the device or receiver receives at least 90% of the input power and less than 10% of the reflected power.



Figure 4.23 Analysis of Radiation Pattern (H-Field) Simulation

The polar view of the radiation pattern at phi =  $0^{\circ}$  (H-Field) are shown in Figure 4.23 respectively. As a result, the gain of the main lobe of a triangular lattice planar array antenna at phi =  $0^{\circ}$  (YZ) plane is 13.34 dB at 0 degrees in theta direction. Then, the side lobe is -5.5 dB. The half power beam width (HPBW) of the antenna at phi =  $0^{\circ}$  are 83.2°.



Figure 4.24 Analysis of Radiation Pattern (E-Field) and (H-Field) Measurement

The second parameter measured the antenna radiation pattern as displayed in Figure 4.24. Radiation patterns for all antenna types were measured at phi=0 degree (H-Field) and phi=90 degrees (E-Field). Consequently, it is clear that the radiation pattern remains its dimensions and shape, which are substantially identical to the one that was simulated. Therefore, the difference between measured and simulated antenna radiation is low. Additionally, parameters such as the main lobe and minor lobe are in the simulated configuration. From the radiation pattern illustrated, it can be seen that by increasing array antenna, the HPBW angle becomes smaller and the antenna becomes more directive.

## **CHAPTER 5**

# **CONCLUSION AND FUTURE WORKS**



Large-scale antenna arrays have been focused on evaluating the possibility of a simple and efficient strategy for utilizing sub-arrays in the creation of large uniform arrays. It has been observed that three proposed antenna designs, 4x4, 8x8 and 16x16 which resonate at 4.03 GHz with operating bandwidth of 3-6 GHz and return loss are -30.15dB, -31.24dB and -34.67dB. The directivity corresponding to the resonant frequency are observed at 19.1dBi, 24.1dBi, 30.1dBi. The proposed antenna design has high gain, which is 17.90 dB, 23.99 dB and 30.08 dB. Can conclude that when the value of inter-element spacing increases, the number of side lobes increases and the width of the main lobe narrows. Moreover, when the number of antenna elements increase, the directivity of planar array increase and the half power beam width will decrease. Lastly, the simulated antenna design has been practically fabricated and

tested using anechoic chamber and Vector Network Analyzer (VNA) and it has been inferred that the theoretical results closely match with the simulated ones.

The overall findings of the project objective achieved. The knowledge from this study will give a positive impact on telecommunication technology as well as the 11<sup>th</sup> sustainable Development Goal which is sustainable Development Goal which is sustainable cities and communities. Furthermore, this antenna provides enhancements to Communications Service Providers' (CSPs) operations through lower operational costs due to more efficient networks.

#### 5.2 **Future Works**

Additional work may be done to improve the side lobes level. The performance of antenna parameters can also be determined by using different types of dielectric materials. It is also required to modify the antenna's structural design in order to compare the results. More research should be done to improve the antenna sidelobes level. Lastly, when the material and the size of the patch change, may improve the antenna's efficiency.

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