Chapter I Introduction

I.1 Rationale

The evolution of 5G technology demands innovative antenna designs to meet the best performance with higher capacity, more bandwidth, more efficiency in spectral, minimize interference and multipath fading, and gain improvement.

5G services have several issues to deal with, such as interference, multipath fading [2], [3], [4], [5], [6] and capacity, which leads to receiving power at the antenna side. In 5G base stations, one of the issues faced is linear polarization [7] and cross polarization [2], [8] which can affect the receiving power. Therefore, if the polarization is linear, it can cause reflection, misalignment, change the rotation and movement of objects which leads to signal emission and its receiving power.

This project research explore and focuses on the design of circular patch antenna that use several combination of methods, such as material changing [9], [10], [11], [12], CSRR [9], [10], [11], [12], [13], ring [14], DGS [15], [16] diversity [17], miniaturization [13], [15], [17], [18], PRDL [19], CMA [20], open ring artificial dielectric [21], circular array [22], [23], circular shaped [24], circular polarization [25] and given strategically slits, optimized for MIMO Antenna applications for base station with 3.5 GHz frequency bands operating. Utilizing some material can improve the performance of antenna [9], [10], [12], [14].

In addition, the development of technology allows users, both mobile and fixed networks, to connect with each other with very little delay. This is because there is no lag-free system. For example, ultra-reliable low latency (URLL) for 5G requires sub-1ms latency or delay for self-driving cars, surgical robots, etc. As the successor of 4G, the fifth-generation communication technology, or 5G, is expected to be able to meet the demand for high capacity and data transmission speed. can reduce delays [9], [10], [12], [14] .

The antenna features are designed by circular patch with square CSRRs [9], [10], [12], [14], which help for miniaturizing antenna size and improving performance, such more bandwidth and gain characteristics. Slits are incorporated to enhance isolation and directivity, crucial for Massive MIMO configurations. The innovative composite material, combining polymethyl methacrylate substrate and carbon nanotube conductive material with copper [9], [10], [12], [14], provides a flexible and high-performance substrate.

In previous research conducted discussing the design and simulation of antennas [14] use CSRR Loaded 2-element that work at LTE Band have the return loss below -10 dB, gain above 5 dBi. Next, antenna with metamaterials and conductive material for sub-6 GHz [11] that have the return loss of -29.75 dB, gain above of 5 dBi and bandwidth of 500 MHz for circular patch.

Other research entitled it is felt that there is still a need for development in testing antenna types or in other work methodologies. The research of antenna design with graphene-based [9] have gain of 49 dBi with THz band frequency. Next, the heterogenous substrate material [12] have reached peak gain of 3.6 dBi with bandwidth of 1.8 GHz. The research of antenna design with hexakaidecagon [26] have (ECC) below 0.02 and high antenna efficiency of about 82–93.2%.

Tables I.1 Comparative Study of Different Antenna Design

Reference	Gain (dBi)	Bandwidth (MHz)	S_{11} (dB)	Frequency (GHz)	Methods
[9]	5.027	7 THz	< -10	2.5 to 11 THz	CSRR, Advanced Material
[11]	5.62 6.42	200 (square) 500 (circular)	Not defined	5.6 (square) 5.8 (circular)	Advanced Material
[12]	3.6	1.84 GHz	-30.52	1.84	Circular CSRR, Advanced Material
[13]	6.48	327	-35	5.8	DGS
[14]	5.8	3 GHz	Not defined	2.8	CSRR
[15]	24.22	840	-45.81	28	Ring slotted between patch and feed
[16]	11.5	3.5 GHz	<-45	3 to 6.5	DGS
[17]	8.60	2.11 GHz	-18.51	5.8	Diversity, Slotted Circulary
[18]	3.94	200	-25	2.4	Square CSRR
[19]	10±0.5	800	-12	6.4 to 7.2	PRDL
[20]	3	2.53 GHz	<-10	5.18 to 7.71	CMA
[21]	6.391	196	-26.46	3.5	Open Ring Artificial Dielectric

[22]	3.661	112.5	-21.87	2.4	Circular Array
[23]	5.78	9.2 GHz	-23.8	2.6 to 11.8	Modified circular patch
[24]	N/A	200	<-10	5	Modified circular patch
[25]	Not defined	Not defined	<-6	3.3 – 6	Hexakaidecagon model, give slits

Therefore, we need the antenna design to minimize the 5G problems, such as multipath fading and polarization. So, we need a technique to mitigate the multipath fading and different polarization problems. The antenna should be implemented at indoor condition for small cell base station (indoor base station/ small cell) [27], [28].

In this thesis, the authors propose a massive MIMO antenna design with a working frequency of 3.5 GHz which uses channel n78 with a bandwidth range of 3300 MHz to 3800 MHz, provided and licensed by the Ministry of Communication and Digital, Republic of Indonesia, for 5G cellular technology using circular polarization. Circular polarization can be established on a circular patch antenna. This research is designed to build a MIMO antenna using circular patches. The main aim is to obtain circular polarization from the MIMO antenna. This antenna will be examined to minimize the polarization problems.

The antenna is created by a circular-shaped directional printed on an FR-4 substrate. The antenna is designed to have parameter performance as follows: The minimum gain of the base station antenna for the frequency of 3.5 GHz with channel n78 is 2.41 to 2.48 dBi, the VSWR is smaller than 2, with a return loss below -10 dB. Next, the antenna has an envelope cross-correlation (ECC) value below 0.5 and diversity gain (DG) above 9.975 dB. This antenna exhibits a minimum mutual coupling of above -15 dB, as the isolation is greater than 15 dB. Consequently, the radiation pattern is obtained to be sectored or directional with circular polarization. Nevertheless, the antenna will be simple and easy to build but give more advantages than others. Because it uses the proposed circular patch model antenna design with several modifications, operates at 3.5 GHz and utilizes an FR-4 dielectric substrate for improving 5G base stations, especially used in indoor small cells. The novel and streamlined design and material selection help to enhance antenna technology, such as improving the received antenna signal and received power, obtaining the Gain Diversity, and addressing the increasing demands of modern wireless communication systems.

I.2 Research Objectives and Problem Identification

The current antenna design challenge is to achieve diversity for better radiation performance and minimize the multipath fading.

The objectives of this research include:

1. Design circular patch MIMO antenna for 5G mobile communication applications at working frequencies of 3.5 GHz with minimum bandwidth of 50 MHz using the CST Microwave Studio 2019 simulator following the given technical specifications.
2. Fabricate, measure and analyze the performance of the antenna that has been designed and simulated according to its technical specifications for miniaturization (mini-dimensional modeling).
3. The results of this design are expected to obtain the gain diversity with reliability improvement.
4. Obtain the realization of an antenna that is suitable for use in 5G mobile communication technology.
5. The results of this design, Massive MIMO Antenna can be used to transmit and receive the signal at 5G Indoor Base Stations.

I.3 Statement of the Problem

This research aims to design and optimize circular patch MIMO antennas operating at the 3.5 GHz frequency band, which use channel n78 that provided and licensed by Ministry of Communication and Digital, Republic of Indonesia, specifically tailored for 5G base station applications. The main target of this design is to optimize the received antenna signal using circular polarization [21] from the antenna design. The study will address key issues such as minimizing interferences, maximizing antenna efficiency, minimizing mutual coupling between MIMO elements, and enhancing radiation patterns to ensure reliable and high-quality communication in diverse and challenging environments.

I.4 Scope of Work

The scope of the work in this final project are:

1. Research and Requirement Analysis
   - Frequency Specification: Specify the frequency of operation or range of frequencies for which the antenna will be used, depending on the intended applications.
   - Performance Metric: Establish the primary performance metrics that include gain, bandwidth, and efficiency.
   - Dimension Constraints: Establish the physical size limitations within which the antenna must fit.
   - Environmental: Temperature, humidity, and exposure to external elements.
2. Antenna Design
   - Circular Geometry: Selecting a specific shape or structure for the antenna to optimize performance for its application.
   - Feeding Technique: Defining the method of delivering power to the antenna (e.g., microstrip, coaxial).
   - MIMO Configuration: Incorporating multiple-input, multiple-output (MIMO) techniques for improved signal performance.
   - Simulation Tools: Using software like CST, HFSS, or COMSOL for simulating and optimizing antenna performance.
   - Key Parameters: Identifying critical parameters, such as impedance matching, polarization, and radiation pattern.
3. Prototyping and Fabrication
   - Material Selection: This is the stage at which one needs to decide on appropriate materials considering performance, cost, and environmental factors.
   - Fabrication Process: Creating a physical prototype through PCB etching, 3D printing, or other forms of manufacturing.
4. Testing and Validation Performance: This could be verified by measuring return loss, radiation pattern, and gain. The design should comply with industry standards and regulatory requirements.

5. Optimization and Iteration

- Fine Tuning: Refining design parameters by testing the results to further improve performance.
- Re-evaluation: Rechecking the design to ensure that the improvements made have aligned with the initial requirements and goals.

6. Documentation and Finalization

- Documentation: Creating detailed documentation of design reports, test results, and technical specifications.
- Deployment Guideline: Guidelines on how the antenna system shall be integrated and deployed into its final application.

I.5 Parameter and Specification

The parameters and specifications of this final project based on the scope of work are:

1. This antenna is a microstrip antenna with a circular patch.
2. The antenna fabrication uses selected materials that are easily found on the market.
3. Technical specifications of microstrip antenna with circular patch:
   a. Substrate Material : Epoxy Fiberglass FR-4
   b. Relative Permittivity : 4.6
   c. Substrate Coating Material : Copper
   d. Coating Thickness (d) : 1.6 mm
   e. Channel Characteristic Impedance: 50 ohms
   f. Width Total : 190 mm
   g. Length Total : 190 mm
   h. Thickness Total : 1.67 mm
   i. Gap/ slits for patch : 0.254 mm
4. Targeting the parametric measurement of microstrip antenna with circular patch:
   a. Operating frequency : 3.3 to 3.8 GHz
   b. Gain : $\geq$ 0 dBi
   c. Return Loss (S_{ii}) : $\leq$ -10 dB or > 0.316

d. ECC : < 0.5

e. DG : > 9.9 dB

f. Mutual Coupling (S_{ij}) : > -20 dB or < 0.1

g. VSWR : ≤ 2

h. Channel Width : ≥ 50 MHz

i. Radiation Pattern : Unidirectional

j. Polarization : Circular

5. The research is limited to the simulation or realization process (product) and measurement of its performance as a test system, while the results shown are only two types of antennas for measuring.
6. Using the CST Microwave Studio 2019 simulator.

I.6 Research Methodology

The preparation of this final project uses experimental methodology with the following steps:

1. Literature Study

   Collect, study, and understand the theories needed from reference books, journals, articles, and other related sources.
2. Simulation and Design

   Antenna design is based on the theory that has been studied. Using the help of the CST Microwave Studio 2019 simulator to know the performance of the designed model, the work process and the output generated in the simulation. This is also a computational calculation technique to model the case.

   If this is not in accordance with the parameters given, it is necessary to modify and optimize some parts as needed (operation adjustment).
3. Prototype / Platform Creation

   The prototype/platform (antenna) manufacturing process is carried out by other experienced parties.
4. Analysis

   Comparing and analyzing simulated data with performance measurements. Observe whether there are any deviations or not. If so, why does it happen and what solutions are provided to solve the problem as described in the previous point.

I.7 Definition of Term

This research is described by writing systematically as follows:

Chapter I **Introduction**

This chapter contains background, problem formulation, problem limitation, discussion objectives, research methodology, and writing systematics.

Chapter II **Literature and Theory Study**

This chapter discusses a general explanation of 5G technology, antennas in general and circular patch MIMO antennas.

Chapter III **Research Methodology**

This chapter discusses the design and simulation process of the quadrilateral microstrip active antenna using the CST Microwave Studio 2019 simulator.

Chapter IV **Data Collection Process and Analysis**

This chapter contains data collection from simulation and measurement result in the data processing that has been given, also explaining analysis process of the measurement results of the antenna made through the simulation process.

Chapter V **Conclusion and Suggestion**

This chapter contains the final conclusions regarding the simulation and analysis results obtained in the research as well as suggestions and expectations for further development.

I.8 Thesis Timeline

This research is scheduled as timeline follow:

Time	**Information**
September to December 2024	Literature Review and State of the Art Paper Review and Determine the Model Design for Antenna

December 2024 to February 2025	Research Methodology Determine the antenna design by mathematics and simulate in CST
March to June 2025	Simulation and Validation Simulate the single circular patch antenna, modify it for MIMO antenna and give some modification to optimize.
June to July 2025	Printing and Measure the Antenna Validating final antenna simulation to implementate by printing the antenna, measure and analysis.
July to August 2025	Documentation and Finalization Deployment guideline and create the final validation by writing them on paper and book