CHAPTER 1: PROBLEM INTRODUCTION

1. Introduction

This section discusses the introduction to the problem underlying the research, specifically related to the need for an antenna with high gain and wide bandwidth. Some of the problems will be described in the background. In this section, the proposed solution is given and some of the theoretical and conceptual frameworks used in dealing with the problem are shown. The problem statement is clarified in several points followed by hypotheses and assumptions. Finally, the problem is limited in scope and limitation.

1.1 Background

With the widespread use of technologies such as the fifth generation (5G) and the demand for greater bandwidth continues to increase [1-4]. This growth in data traffic is further exacerbated by the high consumption of 4K/8K quality video streaming services, online gaming, and real-time applications such as video conferencing. However, amidst the demand for data usage, many regions still face limited network infrastructure that is unable to support the surge in demand. Many Internet Service Providers (ISPs) face constraints in increasing network capacity due to limited resources and budgets. In addition, challenges such as limited frequency spectrum, the high cost of upgrading infrastructure, and uneven internet access in remote areas further complicate the situation. While urbanization has brought network infrastructure to major cities, remote areas still experience low or no bandwidth. In this case, an antenna capable of adjusting the frequency is needed [5][6]. One type of antenna that can be used is the microstrip antenna, which has been researched to resonate in various applications as well as support more than one frequency.

Nowadays, technology is expected to have antennas with high gain and large bandwidth to facilitate human activities [7]. High gain allows humans to reach and enjoy data services at a great distance from the transmission source. Bandwidth is important to determine how fast information such as text, images, or videos can be loaded on a device. Bandwidth measures how much time it takes to transport data from one point to another. Larger bandwidth can increase internet speed, while small bandwidth means getting slow internet. The need for speed and bandwidth is a problem and challenge for data users.

In general, regulations regarding all operating frequency usage are set by the ITU. For the development of gain and bandwidth to be carried out properly, the operating frequency set by the ITU is explained in [8]-[9]. For example, 5G technology is set to use two spectrums, namely the sub-6 GHz spectrum and the millimeter wave spectrum [10].

Sub-6 GHz uses 410-7125 MHz which is known as Frequency Range 1 (FR1). Millimeter wave uses Frequency Range 2 (FR2) in the range of 24.25-71.00 GHz [11]. This can be seen in Figure 1.1.

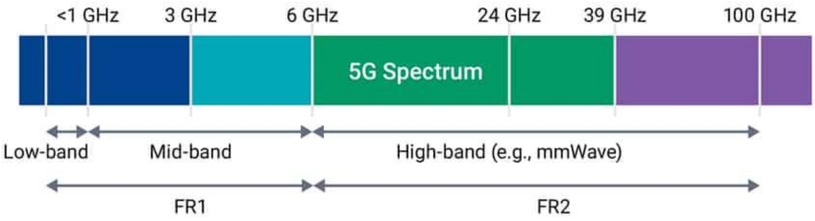
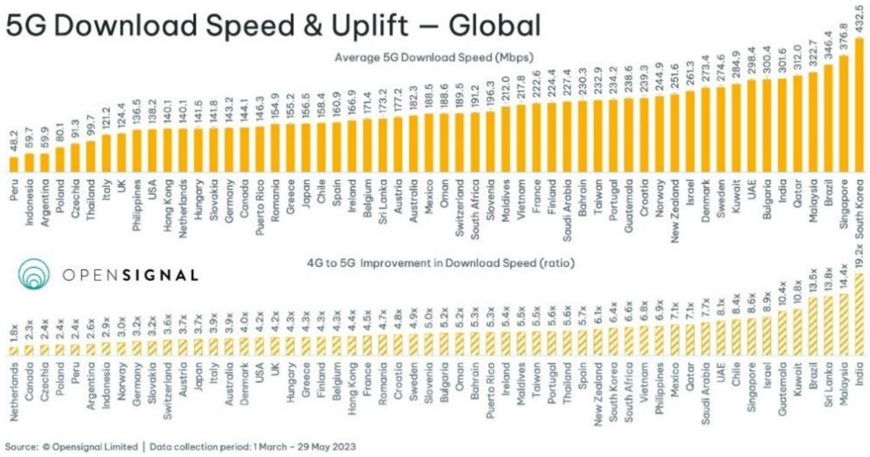


Figure 1. 1. 5G spectrum band.

Source: (https://moniem-tech.com/questions/what-is-the-difference-between-5g-fr1-and-fr2-spectrum-bands/)

(Accessed 24/1/2025)

The 5G standard specifies the use of wide radio channels. Whereas 4G LTE is limited to a maximum radio channel size of 20 MHz, the 5G standard specifies the use of radio channels of up to 100 MHz in frequency bands below 7 GHz and up to 400 MHz in mmWave radio channels at 24 GHz and higher. Beyond these wide channels, 5G can incorporate radio channels with a total bandwidth of 800 MHz [12]. In 5G technology, the need for wide bandwidth or high internet speeds continues to increase as data collected and reported in [13]. This can be seen in Figure 1.2.



Source: © Opensignal Limited | Data collection period: 1 March – 29 May 2023

Figure 1. 2. Global 5G experience by 2023.

Source: (https://www.opensignal.com/2023/06/30/benchmarking-the-global-5g-experience-june-2023)

(Accessed 24/1/2025)

Based on the report [13] as shown, the country that has the fastest internet is Korea with a speed of 432.50 Mbps. Based on regulations from Kominfo [14], currently the 5G networks prepared in Indonesia are Low Band in the 700 MHz frequency band, Middle Band in the 3.5 GHz and 2.6 GHz frequency bands, and High Band in the 26 GHz and 28 GHz frequency bands.It is also mentioned in the 5G spectrum roadmap [15] that for the 3.5 GHz band, the challenge that Indonesia must face is to be able to provide at least 300 MHz of the 3.5 GHz range, namely 3.3 - 3.7 GHz, which will be available by 2023.Based on an article from one of the operators in Indonesia [16], in theory 5G signals can provide download speeds of up to 400Mbps for Orbit and up to 750Mbps for mobile.However, the average download experience can reach speeds of up to 100Mbps - 250Mbps, depending on the signal quality, the capabilities of the 5G devices used, and the density of 5G subscribers in the location [17].

In recent years, several studies have been conducted on gain and bandwidth enhancement. In [18-19], the antenna uses a metamaterial/metasurface to increase gain and bandwidth. There are other studies on improvements made to gain and bandwidth but using mm-wave frequencies such as in [20-21]. In [20], a prototype with size (0.72λ × 0.72λ × 0.04λ) was fabricated and tested at 2.4 GHz. The proposed metasurface consists of 4×4 circular rings and produces a Near Zero Refractive Index

(NZRI) surface with a wide band and successfully increases the antenna gain by 4.30 dB and bandwidth by 11.50% (i.e. 45 to 320 MHz).

In [21], a new type of metasurface antenna working at 28 GHz mm-wave as a two-layer superstrate was proposed with a substrate radius R = 20 mm and a square patch measuring 21.60 mm × 21.60 mm. Experiments show that the large impedance bandwidth increases from 2.60 GHz to 3.60 GHz, while the gain of the patch antenna increases from 6.59 dB to 12.90 dB.

For 5G mobile applications to provide high gain, it is recommended that the frequency used is in the mid band and in this case is 3.5 GHz [22]. In order for the antenna to be realized in a place that contains many data users indoors, the basic antenna to be used in the design is a microstrip antenna. In the design, microstrip antennas are suitable candidates because of their compact and low profile. In this research, an antenna design using metasurface is proposed to increase gain and bandwidth. One of the commonly used metasurface enhancement methods is using split ring resonators. In this case, the split ring resonator needs to be studied further to understand how to obtain a wide bandwidth at a frequency of 3.5 GHz. Therefore, this research will design a 5G metasurface antenna using a split ring operating at a frequency of 3.5 GHz, in order to have high gain and wide bandwidth.

1.2 Theoretical Framework

This research is based on the Resonant Circuit Theory by Devendra K. Misra [23], which states that the resonant frequency can be determined by considering the inductance and capacitance of the resonant circuit. In this case, the resonant frequency of the split ring resonator (SRR) is determined by the capacitance at the ring gap acting as a capacitor and the inductance generated by the ring arms acting as inductors.

In addition, this research also refers to the theory of SRR-based metamaterials by B. Lahiri [24] who showed that by modifying the SRR geometry such as the size, shape, and spacing between elements, the resonant characteristics can be changed. With proper tuning of such indicators, this SRR-based metamaterial can be designed to operate over a wide frequency range. SRR produces a resonant magnetic response when exposed to an external magnetic field. This resonance occurs at a frequency determined by the geometry of the ring, making it useful for creating materials with negative permeability. However, the challenge that this research focuses on is finding a way to increase the bandwidth capability of the antenna by using SRR. While in general if the permeability is negative, the antenna tends to be limited to a certain frequency range.

With proper design and arrangement of elements, a wide bandwidth can be achieved. Based on the theory, to increase the inductance, the ring arm of the SRR is set longer so that it is rectangular or can be called Rectangular Split Ring Resonator (RSRR). According to Lahiri, the magnetic response of SRR (*LC* resonance) is caused by the circulation of electric current when the electric field of the incident wave is normally parallel to its gap.

1.3 Conceptual Framework

The conceptual framework in this study explains the relationship between metasurface antenna design and antenna performance. RSRR metasurface antenna design can be designed through several indicators such as microstrip spacing with RSRR metasurface layer, RSRR cutting gap, spacing between RSRR elements on x-axis and y-axis. Meanwhile, antenna performance can be observed through gain, bandwidth, return loss and radiation pattern. In designing the RSRR metasurface antenna, the framework can be seen in Figure 1.3.

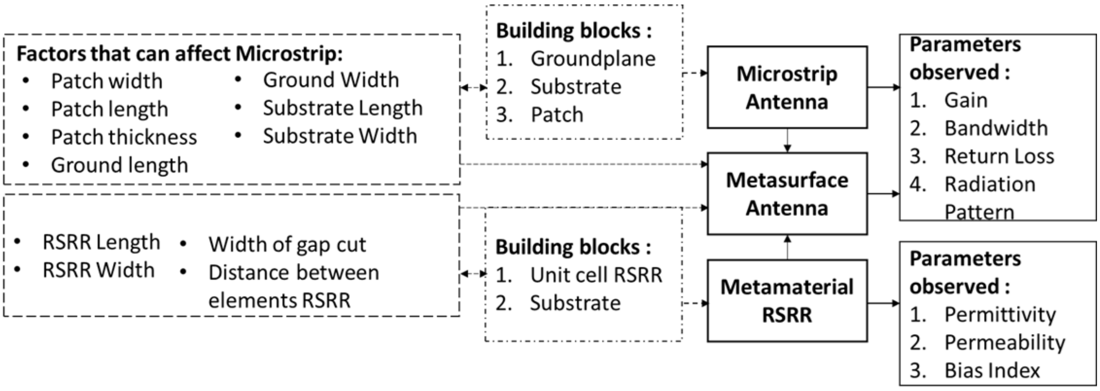


Figure 1. 3. Conceptual framework of metasurface antenna design.

From the conceptual framework of the metasurface antenna design, the relationship between the variables is very clear. The parts to be observed are in the rightmost box. For microstrip antennas and metasurface antennas, what will be observed are gain, bandwidth, return loss and radiation pattern. The parts to be investigated are the microstrip antenna, RSRR metamaterial and metasurface antenna in the thickly outlined boxes. Parts that are constituent components in the study are marked with dot-striped boxes. While the part that affects the microstrip antenna and RSRR metamaterial is in the leftmost box or box with a dotted line. The existence of this conceptual framework is a map or guide that helps researchers determine the direction of research, define relevant variables, and explain the relationship between concepts to be analyzed.

1.4 Problem Statement

Based on the description of the research background, the author can identify the following problems:

1. Many regions still face limited network infrastructure that is unable to support the surge in bandwidth demand.
2. Many Internet Service Providers (ISPs) face constraints in increasing network capacity due to limited resources and budgets.
3. Amidst the high cost of upgrading infrastructure, uneven internet access in remote areas, limited frequency spectrum further complicates the situation.

1.5 Hypothesis

Based on the theoretical framework, conceptual framework and some empirical evidence mentioned earlier, the hypotheses in this study can be proposed, namely as follows:

Ha1 : RSRR are capable of significantly expanding bandwidth to support communication and bandwidth demand.

Ha2 : RSRR antennas that are compact, efficient, energy efficient, and can improve signal transmission performance without the need for large antenna size or expensive materials will minimize the budget in increasing network capacity

Ha3 : The RSRR antenna is able to increase the need of bandiwidth amidst spectrum limitations, so that it can work in many areas and its costs are affordable

Ho1 : RSRR are not capable of significantly expanding the bandwidth to support communication.

Ho2 : RSRR antennas that are compact, efficient, energy efficient, and can improve signal transmission performance without the need for large antenna size or expensive materials will not minimize the budget in increasing network capacity.

Ho3 : The RSRR antenna unable to increase the need of bandiwidth amidst spectrum limitations, so that it can work in many areas and its costs are affordable.

1.6 Assumptions

In this antenna the indicators on the specifications are working frequency, return loss, gain, bandwidth, radiation pattern, and polarization. Based on research and literature in [18-24], the specifications of the metasurface antenna to be designed can be assumed in Table 1.1.

Table 1. 1. RSRR metasurface antenna specifications.

Parameters	**Value**
Operation Frequency	3,5 GHz
Return Loss	< -10 dB
Gain	≥ 5 dB
Bandwidth	≥ 100 MHz
Radiation Pattern	Unidireksional

From the literature study conducted, the antenna to be designed has specifications that are in accordance with the needs of wideband in this current technology. In addition, because the basic antenna as a peradiation in this design uses a microstrip antenna, the microstrip antenna also has specifications. In this study, the microstrip antenna specifications are assumed to be as in Table 1.2.

Table 1. 2. Microstrip antenna specifications.

Parameters	**Value**
Operation Frequency	3,5 GHz
Return Loss	< -10 dB
Gain	≥ 2.50 dB
Bandwidth	> 100 MHz

In its design, the dimensions of the patch, substrate, substrate type and joining technique need to be determined because they will affect the value of the antenna parameters. Therefore, calculations on the micostrip antenna need to be done to determine the value of the antenna dimensional parameters.

1.7 Scope and Limitation

This research was conducted to analyze and design a wideband antenna using a metasurface RSRR. The scope of this research includes:

- Object Research : RSRR Metasurface Antenna Prototype.
- Research Location : Laboratorium antena dan ruang Anechoic.
- Time Period : October 2023 - February 2024.
- Research Variable : RSRR metasurface antenna design as the independent variable and antenna performance as the dependent variable.

This research only focuses on designing, fabricating RSRR metasurface antennas, and testing the performance of wideband antennas. This research does not include the realization of antenna devices due to limited time and resources.

1.8 Research Objectives

In accordance with the issues raised in the research, the importance of this research aims as follows:

1. Designing and developing an antenna based on RSRR technology that can significantly expand bandwidth to support communication.
2. Create a compact, efficient, and energy-efficient RSRR antenna design that improves signal transmission performance without the need for large antenna size or expensive materials.
3. Using RSRR to optimize the use of the limited frequency spectrum, so that the antenna can work at various frequencies with high performance and minimal interference.