Implementation and Analysis of Quadrature Amplitude Shift Keying Modulation Using SDR Devices for Wireless Communication Systems

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Abstract --This research aims to implement and analyze the performance of Quadrature Amplitude Shift Keying (QASK) modulation in wireless communication systems using Software Defined Radio (SDR) devices. This research uses ADALM-PLUTO as the transmitter and RTL-SDR as the receiver, with signal processing performed through GNU Radio software. The main focus of this research is to evaluate the implementation of 4-QASK modulation in wireless data transmission at several different frequencies (300 MHz, 500 MHz, 1 GHz, and 1.5 GHz) and different distances (1 meter to 5 meters), as well as to measure transmission quality using the Packet loss and Received Signal Strength Indicator (RSSI) parameters. The test results show that this system is capable of transmitting data with good quality, with RSSI values ranging from 51.41 dBm to -62.59 dBm, indicating good to very good signal quality. This test also showed that the further the distance between the transmitter and receiver, the lower the signal reception quality, especially at higher frequencies, indicating a significant influence of distance and frequency on the received signal strength. Based on the results obtained, it can be concluded that QASK modulation using SDR, particularly 4-QASK, is effective in wireless communication with good performance at short to medium distances.

Keywords—*SDR, QASK, ADALM-PLUTO, RTL-SDR, RSSI*

1. Introduction

Modern communication technology continues to develop rapidly to meet the increasing demand for data transfer, creating a need for efficient, high-performance telecommunication systems capable of handling large information flows with minimal error rates [1]. Current developments in telecommunications systems utilize various modulation technologies, such as Quadrature Amplitude Shift Keying (QASK), PSK, and FSK in both wired and wireless transmission [2].

QASK modulation has high spectral efficiency and the ability to transmit data at high speeds while minimizing data loss [3]. In implementing this system, Software Defined Radio (SDR) devices are used to provide high flexibility in testing and experimentation with various modulation techniques [4]

ADALM-PLUTO and RTL-SDR are SDR devices that provide an easy-to-use platform for developing and testing communication techniques. ADALM-PLUTO allows users to implement various modulation techniques and transmit data in real time (Dixe et al., 2024), while RTL-SDR is an economical receiver that can be used to receive and analyze these signals. This research implements QASK modulation, using ADALM-PLUTO as a transceiver and RTL-SDR as a receiver, and utilizes GNU RADIO to demodulate the received signals [5].

This research is expected to provide significant information and results in the implementation of QASK modulation and demodulation using SDR devices. It also provides a strong basis for supporting the selection of QASK technology as a research subject. This study is also expected to bridge the gap between theoretical research and practical implementation in SDR-based wireless communications.

2. Literature Review

Several studies on the implementation and analysis of Quadrature Amplitude Shift Keying (QASK) modulation using Software Defined Radio (SDR) devices have been conducted in recent years. A study by (Anisah et al., 2018) discussed the topic “Implementation of Wireless Communication

Systems Using Orthogonal Frequency Division Multiplexing (OFDM) Techniques Based on Software Defined Radio (SDR)". In this study, various modulation schemes such as 4-QASK and 16 QASK were tested to assess system performance. The results of the study show that the use of 16-QASK modulation in the OFDM system can significantly increase throughput compared to 4- QASK and BPSK. In addition, the results of the constellation diagram analysis show that the system has a low error rate, proving that SDR is capable of providing reliable and efficient data transmission in wireless communications (Anisah et al., 2018).

Another study was conducted by (Hapsari & Ismail, 2021) entitled "Analysis of Software Defined Radio (SDR) Performance Using Quadrature Amplitude Shift Keying (QASK) Technique". In this study, they used the Wireless Open-Access Research Platform (WARP) to implement QASK modulation and measure its performance. The results of the study showed that SDR was able to implement QASK modulation efficiently, providing good signal quality and producing a low Bit Error Rate (BER). In addition, this study also confirmed that SDR platforms such as WARP can be used effectively for the development and testing of QASK modulation-based wireless communication systems (Hapsari & Ismail, 2021).

Research by (Pambudiyatno et al., 2020a). Entitled "QASK (Quadrature Amplitude Shift Keying) Communication Design Using GNU Radio," this study focuses on the design of Quadrature Amplitude Shift Keying (QASK) communication using GNU Radio software. GNU Radio is open source software that provides signal processing techniques to be implemented in software-based radio. In this study, the authors explain the basics of QASK communication design, including the functions of each block in the transmitter and receiver, as well as the settings for each block to produce optimal QASK simulation. The results of the study show that the QASK communication design using GNU Radio works well. This study makes a significant contribution to the development of QASK modulation learning media, which can be used to support related courses in educational institutions.

Overall, the above studies show that the application of QASK modulation using SDR devices can improve the performance of wireless communication systems in various aspects, such as throughput, spectrum efficiency, and bit error rate. In addition, the use of SDR allows for more flexible and efficient testing and development of communication systems.

3. System Design

This stage involves designing a system that allocates hardware and software requirements by forming the overall system architecture. At this stage, hardware and software designs are realized as a series of interconnected designs and programs.

3.1 Modulation System Device Architecture

Figure 1 shows the architecture of a QASK- based wireless communication system using Software-Defined Radio (SDR) devices. On the transmitter side, a computer equipped with software such as GNU RADIO performs the QASK modulation process, producing a digital signal that is ready for transmission. This signal is then sent to the SDR device, which converts the digital signal into an RF (radio frequency) signal to be transmitted through the air. The RF signal is received by the SDR device on the receiver side, such as RTL-SDR, which converts the RF signal back into a digital signal. The computer on the receiver side performs QASK demodulation using software, restoring the original signal that was transmitted. This system demonstrates how SDR is used to implement QASK-based wireless communication, with hardware and software playing important roles in each stage of the process.

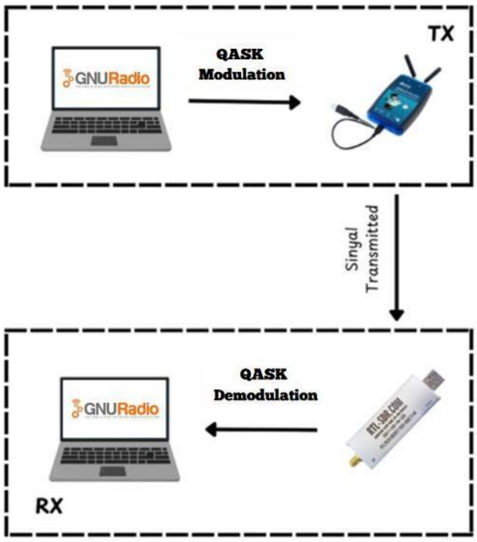


Figure 1. Architecture of the QASK-based wireless communication system.

3.2 System Design

Figure 2 shows a flowchart of the transmitter (TX) side of the communication system. The process begins with User Input Data, which is the stage where the user enters the initial data, such as text, numbers, or other digital information to be sent. The data that has been entered then enters the System Encode Data stage, which is the process of encoding data by the system. The purpose of this stage is to make the data more compatible with the transmission system used. After that, the data will be processed at the Data Modulated stage, which is the modulation process using the Quadrature Amplitude Shift Keying (QASK) method. At this stage, digital data is converted into analog signals. The final stage is Signal Transmitted & Show Constellation, where the modulated signal is transmitted through a transmitter device, such as a Software-Defined Radio (SDR) device. This signal is then transmitted into the air and is ready to be received by a receiver. At this stage, the signal constellation can also be displayed as a visualization of the modulation results.

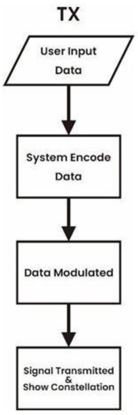


Figure 2. Transmitter System Flowchart.

Figure 3 illustrates the process on the receiver side (RX) in a GNU Radio-based communication system with QASK (Quadrature Amplitude Shift Keying) modulation scheme. The first stage is RTL-SDR Receive Signal, where the RTL-SDR device receives the RF signal transmitted by the transmitter. The received signal is still a modulated signal. Next, the signal is forwarded to the Data Demodulated stage, where the demodulation process is performed to convert the signal back to its original digital data form. At this stage, the system removes the effects of modulation. If error correction coding is used on the transmitter side, the data will also be corrected for greater accuracy. The final stage is Decode Signal, which converts the demodulated signal into understandable data. The results of this process are then displayed in the Show Result stage, allowing users to visualize and analyze the reception results and evaluate the performance of the communication system.

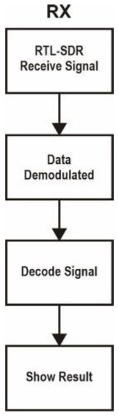
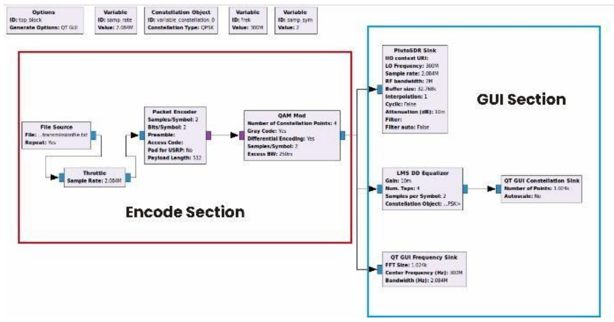


Figure 3. Receiver System Flowchart.

Figure 4 shows the signal processing flowchart for a transmission system using GNU Radio with Quadrature Amplitude Shift Keying (QASK) modulation. This system consists of two main parts, namely the 50 Encode Section and the GUI Section. In the Encode Section, data is prepared for transmission using ADALM Pluto, while the GUI Section displays all parameters in GNU Radio. The process begins with the File Source, which is responsible for reading bit data from a file containing the information to be transmitted. This bit data is then forwarded to the Throttle block, which regulates the sample rate to maintain system stability. Next, the data that has been adjusted to the sample rate is forwarded to the Packet Encoder, which encodes the data into packets that are ready for modulation.

The encoded data is processed in the QASK Mod block, where QASK modulation is applied to convert bit data into analog signals that can be transmitted. In this block, Constellation Points can be set as desired. In addition, this block shows that the system uses several types of QASK modulation. Then, this modulated signal is forwarded to the LMS DD Equalizer block, which is used to balance the received signal and compensate for interference that occurs during transmission. This block adjusts the gain and number of taps to maximize the quality of the received signal. It is then visualized in the QT GUI Constellation Sink block, which allows users to monitor the quality of the transmitted signal.

The modulated signal is transmitted through the ADALM Pluto device using the PlutoSDR Sink block, which connects the system to the SDR device for wireless signal transmission. With the Lo Frequency set to the specified conditions (300MHz, 500MHz, 1000MHz, 1500MHz) and sample rate, the signal is transmitted through the wireless channel. This diagram illustrates the overall process flow from data reading to QASK signal transmission through the SDR device. In addition, the QT GUI Frequency Sink is also used to visualize the frequency spectrum of the transmitted signal, providing an overview of the signal characteristics in the frequency domain.



Options
ID: top_block
Generate Options: QT GUI

Variable
ID: samp_rate
Value: 2.084M

Constellation Object
ID: variable_constellation_0
Constellation Type: QPSK

Variable
ID: frek
Value: 300M

Variable
ID: samp_sym
Value: 2

File Source
File: ...transmisionfile.txt
Repeat: Yes

Throttle
Sample Rate: 2.084M

Packet Encoder
Samples/Symbol: 2
Bits/Symbol: 2
Preamble:
Access Code:
Pad for USRP: No
Payload Length: 512

QAM Mod
Number of Constellation Points: 4
Gray Code: Yes
Differential Encoding: Yes
Samples/Symbol: 2
Excess BW: 250m

PlutoSDR Sink
IIO context URI:
LO Frequency: 300M
Sample rate: 2.084M
RF bandwidth: 2M
Buffer size: 32.768k
Interpolation: 1
Cyclic: False
Attenuation (dB): 10m
Filter:
Filter auto: False

LMS DD Equalizer
Gain: 10m
Num. Taps: 4
Samples per Symbol: 2
Constellation Object: ...PSK>

QT GUI Constellation Sink
Number of Points: 1.024k
Autoscale: No

QT GUI Frequency Sink
FFT Size: 1.024k
Center Frequency (Hz): 300M
Bandwidth (Hz): 2.084M

Figure 4. Block Diagram of QASK Modulation Transmitter

Figure 5 shows the signal processing flowchart on the receiver side in a QASK communication system using an RTL-SDR device. The process begins with the RTL-SDR Source block, which functions to receive signals that have been transmitted via a wireless channel. This received signal has a sample rate of 2.084 Msps and a frequency of 1 GHz, which is adjusted to the transmission channel. The Gain parameter is controlled manually, with an RF Gain setting of 35 dB, to ensure optimal signal reception quality.

The received signal is then forwarded to the QASK Demod block (QASK Demodulation), which is responsible for converting the received analog signal back into digital data. In this stage,
4 Constellation Points and Differential Encoding are used to overcome errors that may occur during transmission. After the signal is successfully demodulated, the Packet Decoder block is used to decode the received data packets. Here, the Threshold setting is used to determine the threshold at which a packet is considered valid. The decoder checks the data to ensure that there are no errors in signal reception.

For visualization, the decoded signal can be viewed in the WX GUI Waterfall Sink block, which displays a waterfall plot graph to monitor channel quality. This graph provides a visual representation of the strength and stability of the received signal. With Dynamic Range 100 and FFT Size 512 settings, users can see the frequency distribution and characteristics of the channel being used.

Finally, the successfully decoded data is saved in a file using the File Sink block, which writes the data to the received file.txt file. This process ensures that the received data can be further processed or analyzed as needed.

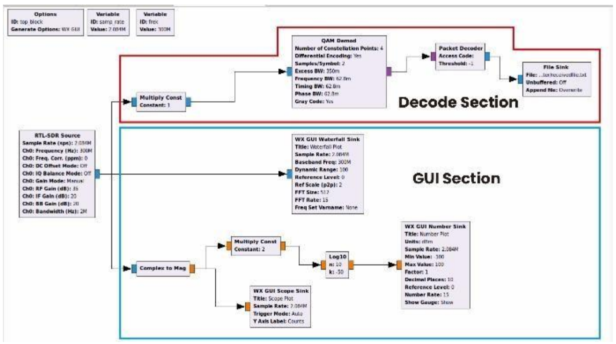


Figure 5. Block Diagram of QASK Modulation Receiver

4. RESULTS AND DISCUSSION

4.1 ADALM PLUTO Testing

This test aims to measure the ability of ADALM-PLUTO to transmit data packets through an antenna. The test was conducted at several frequencies, namely 300 MHz, 500 MHz, 1000 MHz, and 1500 MHz. Each frequency was tested using QASK modulation. The ADALM PLUTO test results are shown in Table 4.1

Table 4.1 ADALM PLUTO Testing

No	Frequency	Data Sent	Status
			4 QASK
1	300 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
2	500 Mhz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
3	1000 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
4	1500 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful

The results obtained show that data transmission was successful across all frequencies without any obstacles. This success indicates that the ADALM-PLUTO device is capable of stable and consistent data transmission across the various frequency spectrums tested. The QASK modulation used in this test proved to be effective in encoding digital information through a combination of variations in the amplitude and phase of the carrier signal. This also shows that system configurations such as gain, bandwidth, and sample rate have been well adjusted to produce optimal transmission performance.

Overall, the results of this test prove that ADALM-PLUTO is reliable as a digital data transmission medium in Software Defined Radio (SDR)-based communication systems, and is suitable for use in learning, research, and development in the field of telecommunications engineering.

4.2 RTL SDR Testing

This test aims to measure the ability of the RTL SDR to receive and decode signals received from the antenna at various frequencies. The signals obtained are then displayed using GNU Radio software, which is an open-source platform for signal processing. Several frequencies are used for testing, including 300 MHz, 500 MHz, 1000 MHz, and 1500 MHz.

This frequency range is selected to evaluate the SDR's ability to capture signals in different settings because the propagation characteristics of radio signals can change based on frequency.

Table 4.2 RTL SDR Testing

No	Frequency	Data Sent	Status
			4 QASK
1	300 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
2	500 Mhz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
3	1000 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful
4	1500 MHz	Ini Pesan Dari Politeknik Negeri Semarang.	Successful

4.3 RSSI Value Testing

This test is the final test of the research that has been conducted, which tests the wireless communication system using QASK modulation, ADALM PLUTO as the transmitter, and SDR RTL as the receiver. This test was conducted to determine whether the wireless communication system that had been created was able to modulate and transmit data through the ADALM Pluto device to SDR RTL so that the data could be visualized in GNU Radio. The testing for this final project was conducted directly in an open area, specifically in a large yard without any physical obstacles such as walls, trees, or tall buildings. The location was chosen so that signal transmission would not be disrupted by external obstacles. In other words, the testing environment was deliberately designed to minimize interference that could disrupt the test results. This was done so that any decline in signal quality during the testing process would be purely due to technical factors such as the distance between devices or the capabilities of the equipment used, rather than external influences. In this situation, distance is the only primary variable affecting the strength or weakness of the received signal. Each data collection process is conducted for approximately three minutes for each frequency and distance tested, with the goal of obtaining sufficient data for analysis and representing actual conditions. The following table shows the overall test results.

Table 4.3 RSSI Value Testing

Distance (Meters)	Frequency			
	300 MHz	500 MHz	1 GHz	1,5 GHz
1	-51.41 dBm	-53.38 dBm	-54.5 dBm	-57.48 dBm
2	-55.29 dBm	-57.29 dBm	-57.52 dBm	-57.63 dBm
3	-56.43 dBm	-58.22 dBm	-59.33 dBm	-59.76 dBm
4	-59.39 dBm	-59.93 dBm	-61.11 dBm	-59.94 dBm
5	-62.21 dBm	-62.74 dBm	-62.2 dBm	-62.59 dBm

Based on the results of testing signal strength at several frequencies, namely 300 MHz, 500 MHz, 1 GHz, and 1.5 GHz, RSSI values ranging from -51.41 dBm to -62.59 dBm were obtained. All of these values are within the range of ≥ -70 dBm, which is categorized as an excellent signal. This means that the signal quality received at all frequencies tested is good. There are no RSSI values that fall into the fair, poor, or no signal categories. In telecommunications, RSSI measurement is very important because it can be used to analyze connection quality, data transmission efficiency, and the best location for installing network devices. Therefore, knowing the RSSI value and its classification can help in troubleshooting and network optimization. The RSSI value itself is a measure used to indicate how strong the signal received by the receiving device is from the signal source, such as a transmitter or access point. The higher the RSSI value (closer to zero or smaller in negative terms), the better the signal received.

4.4 Testing of 300 MHz Frequency Data

Testing at a frequency of 300 MHz shows that system performance is highly dependent on transmission distance. At close range, 1 to 2 meters, the system works very well. The amount of data received is high with a low and stable error rate of around 2.5%. This indicates efficient and reliable communication at this range.

However, performance declines dramatically starting at a distance of 3 meters, where the amount of data received drops and the error rate rises to 3.89%. This decline continues at a distance of 4 meters, indicating that the signal begins to weaken significantly. Finally, at a distance of 5 meters, the system fails completely and no data is received at all.

Table 4.4 Testing of 300 Mhz Frequency Data

DISTANCE (METERS)	**DATA RECEIVED**	**PERFECT DATA**	**ERROR (%)**
1	67562	65897	2.46
2	39609	38636	2.5
3	3008	2891	3.89
4	601	577	3.99
5	0	0	0

4.5 Testing of 500 MHz Frequency Data

Testing at a frequency of 500 MHz shows that the system works effectively at short distances, but its performance declines dramatically with increasing distance. At a distance of 1 to 2 meters, the system is able to maintain good communication with a low and stable error rate (around 2.4%), although the amount of data received decreases at a distance of 2 meters.

A significant decline in performance occurs starting at a distance of 3 meters, where the amount of data received drops and the error rate begins to increase to 2.99%, continuing to worsen at a distance of 4 meters. At a distance of 5 meters, communication fails completely with no data successfully received.

Table 4.5 Testing of 500 Mhz Frequency Data

DISTANCE (METERS)	DATA RECEIVED	PERFECT DATA	ERROR (%)
1	51503	50264	2.41
2	12379	12078	2.43
3	1370	1329	2.99
4	354	342	3.39
5	0	0	0

4.6 Testing of 1000 MHz Frequency Data

Testing at a frequency of 1000 MHz (1 GHz) shows that the system performs very well at very close distances, but performance declines as distance increases. At distances of 1 to 2 meters, the system functions efficiently with a high amount of data received and a relatively low error rate (ranging from 2.77% to 3.02%).

Performance began to decline significantly at a distance of 3 meters, marked by a drastic decrease in the amount of data received and an increase in the error rate to 3.39%. This decline continued at a distance of 4 meters. At a distance of 5 meters, the system failed completely and was unable to receive any data at all.

Table 4.6 Testing of 1000 Mhz Frequency Data

DISTANCE (METERS)	DATA RECEIVED	PERFECT DATA	ERROR (%)
1	35090	34119	2.77
2	30714	29785	3.02
3	1208	1170	3.39
4	513	494	3.7
5	0	0	0

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4.7 Testing of 1500 MHz Frequency Data

Testing at a frequency of 1500 MHz (1.5 GHz) showed very limited communication range and a significant decrease in performance as distance increased. At a distance of 1 meter, the system worked well and accurately (error rate of 2.23%). However, performance declined sharply at a distance of 2 meters, where the amount of data received dropped dramatically, although the error rate was still under control (2.5%).

The performance decline becomes even more severe at a distance of 3 meters, with very little data and an error rate that jumps to 4.31%. At 4 meters, communication becomes very unreliable with an error rate reaching 8.14%. The system experiences total failure at a distance of 5 meters and is unable to receive any data at all.

Table 4.7 Testing of 1500 Mhz Frequency Data

DISTANCE (METERS)	DATA RECEIVED	PERFECT DATA	ERROR (%)
1	5284	5166	2.23
2	600	585	2.5
3	348	333	4.31
4	86	79	8.14
5	0	0	0

4.8 Distance Comparison With SNR

Signal Noise Ratio (SNR) has several variables to determine its value, namely Signal Power (Ps) and Noise Power (Pn), which can be calculated using the SNR formula in equation (7). In this test, there are limitations to testing signal power and noise power, but the total signal strength in the data transmission process is tested through RSSI value testing. It is not possible to accurately calculate the SNR value because testing is required to measure the Signal Power and Noise Power. However, there are ways to determine the SNR value using the data in the device datasheet and also using the RSSI data obtained. For example, the ADALM-PLUTO SDR device states that the transmitted signal power has a value of 7dBm, with a noise figure

<3.5 dB. The RSSI value shows the total signal strength received, where RSSI includes signal power, noise power, and interference power from other sources in the test environment. Because the values in RSSI cannot be separated, it is not possible to calculate the SNR value accurately.

From the device specification data and RSSI test data, the SNR value can be estimated using the Thermal Noise Power (Pthermal) formula with the formula

$$Pthermal = k.T.B \qquad (9)$$

Description:

k (Boltzmann Konstant) = $1{,}38 \, x \, 10^{-23}$ J/K
T (Standard Temperature) = 290˚ K
B (Bandwidth) = 2 MHz atau $2 \, x \, 10^{6}$ Hz
$Pthermal = k.T.B$

$Pthermal = (1{,}38 \, x \, 10^{-23}) \, x \, 290 \, ^{\circ} \, x \, (2 \, x \, 10^{6}) = 8{,}004 \, x \, 10^{-15}$ W

$Pthermal$ (dbm) $\approx -111 \, dBm$

$Pnoise$ (dBm) = $Pthermal$ (dbm) + Noise figure

$Pnoise$ (dBm) = $-111 \, dBm + 3{,}5 \, dB = -107{,}5 \, dBm$

SNR (db) ≈ RSSI (dBm) − $Pnoise$ (dBm)

Using the thermal noise power formula, an estimate of the SNR value at each tested distance can be obtained. Using the test sample data at a frequency of 300 MHz, Table 4.8 shows the estimated SNR value at each distance.

Table 4.8 SNR calculation based on RSSI values from 300 MHz Frequency Testing

Distance (Meters)	RSSI Value (dBm)	SNR Calcultion (dB)
1	-51.41	56.09
2	-55.29	52.21
3	-56.43	51.07
4	-59.39	48.11
5	-62.21	45.29

5. Conclusion

Based on the results of the design, testing, and analysis of the QASK Modulation technique using ADALM-PLUTO SDR device several conclusions can be drawn as follows:

a. The wireless communication system with 4-QASK modulation worked well at frequencies of 300 MHz, 500 MHz, 1000 MHz, and 1500 MHz, especially at close range without physical obstacles.
b. The 4-QASK modulation system tested effectively at close range, but began to experience a decline in performance at distances greater than 2 meters. Testing showed that at a distance of 5 meters, the system failed to receive data on most of the frequencies tested.
c. The RSSI value is in the range of -51 dBm to -62 dBm, which indicates that the signal is received in good condition.
d. Testing shows that ADALM-Pluto is capable of transmitting stable signals across a wide range of frequencies (300 MHz to 1500 MHz).
e. RTL-SDR is capable of receiving signals transmitted by ADALM-Pluto well, although there is a decrease in quality at longer distances. At close range, RTL-SDR can decode signals accurately, indicating optimal performance in wireless signal processing under more ideal conditions.

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