



Simulation of Digital Modulation Techniques

ACDA 5008

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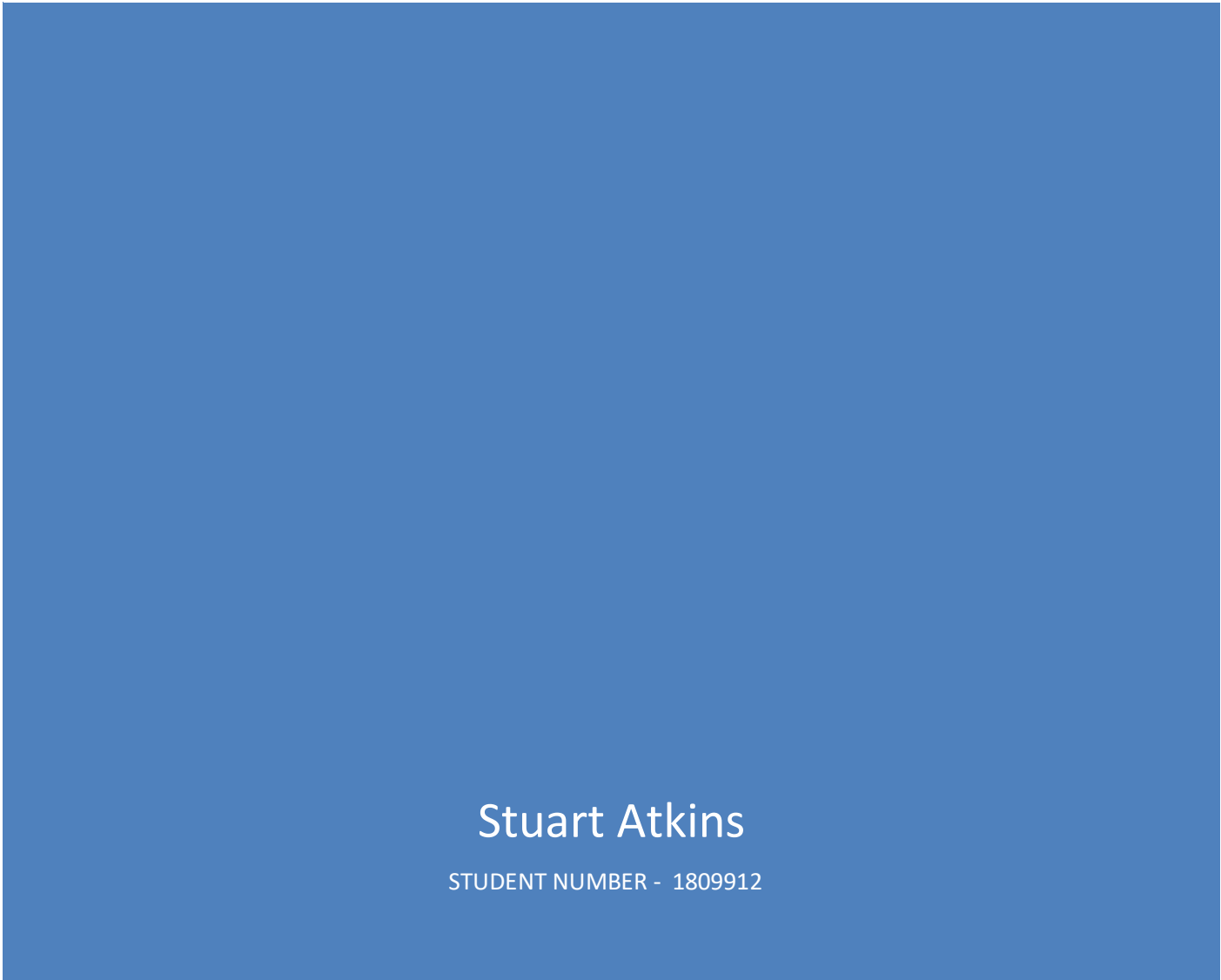


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1. Simulation of Digital Modulation Techniques

2. Abstract

The purpose of the experiment was to simulate different digital modulation methods and to compare the calculated Bit Error Rate (BER) at different levels of signal-to-noise ratio (SNR). The results show that for all of the modulation techniques simulated, as the SNR is increased the BER decreases. It can be concluded from this experiment that the Bit Error Rate of a digital modulation method is determined by Signal to Noise Ratio. Higher order modulation techniques (such as Quadrature Amplitude Modulation) are commonly used as they have a higher data rate but are more susceptible to errors when encountering noise and therefore require a strong signal to counteract this.

3. Introduction

3.1 Objective

The aim of this assignment was to critically compare the performances of variants of Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK) in the presence of additive white Gaussian noise (AWGN).

3.2 Digital modulation

There are three basic types of modulation methods used for the transmission of a digital signal. These methods are based on three different parameters of a signal; the amplitude, the frequency and the phase. The names of these basic digital modulation methods are: Amplitude shift keying (ASK), Frequency shift keying (FSK) and Phase shift keying (PSK) [1].

An example showing the waveforms for the basic binary digital modulations can be seen in Figure 1.

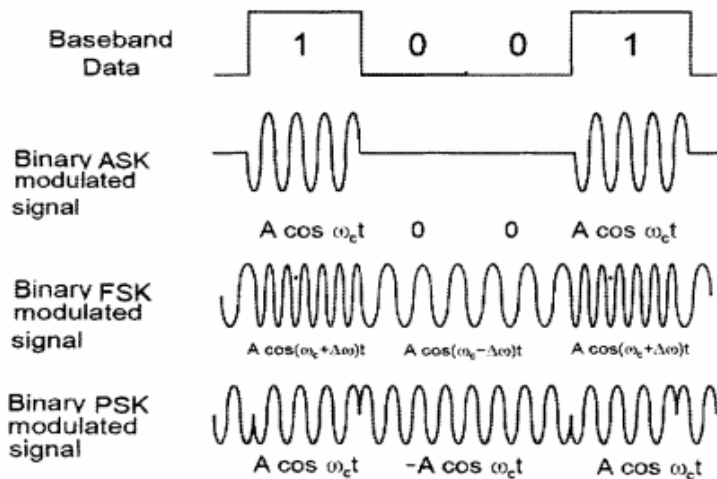


Figure 1 – Waveforms of basic modulation methods

[2]

3.2.1 Amplitude shift keying (ASK)

Amplitude shift keying (ASK) is the simplest form of digital modulation. In ASK the carrier wave amplitude is changed between two discrete levels in relation to the input binary data. One of the binary values is represented by the presence of the carrier wave at a constant amplitude and the other binary value is represented when there is no carrier wave. The ASK signal mathematically is shown as [1];

$$s(t) = \begin{cases} A \cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases}$$

[3]

3.2.2 Frequency shift keying (FSK)

In frequency shift keying the frequency of the carrier signal is shifted between two values where each of these frequency values represents either a '1' or a '0'. The amplitude of the carrier signal does not change. The basic form of FSK is known as BFSK where only two frequencies are used [1].

The FSK signal mathematically is;

$$s(t) = \begin{cases} A \cos(2\pi f_1 t) & \text{binary 1} \\ A \cos(2\pi f_2 t) & \text{binary 0} \end{cases}$$

(Where f_1 and f_2 are typically offset from the carrier frequency f_c by an equal but opposite amount)

[3]

3.2.3 Phase Shift keying (PSK)

Phase modulation includes techniques such as BPSK (Binary Phase Shift Keying) and QPSK (Quadrature Phase Shift Keying) etc. In these techniques the phase of the carrier wave is changed to represent the data. The BPSK modulation method is the simplest form of the phase shift keying modulation, which utilises two phases separated by a shift of 180° . This type of phase shifting is also known as 2-PSK. [4]

The PSK signal mathematically is;

$$y = \cos(2\pi f_c t); \text{ for a binary '0'}$$
$$y = \cos(2\pi f_c t + \pi); \text{ for a binary '1'}$$

[3]

3.2.4 Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying is a higher order PSK that transmits two bits per symbol at the same time by having four different signalling alternatives or states i.e. it allows for up to two bits of information to be communicated during each modulation interval. Each of the phase shifts correspond to bits of 00, 01, 10, 11. This equates to twice the amount of information being transmitted over the same bandwidth. [5]

A constellation diagram is a good way to represent high order signals. A constellation diagram for QPSK can be seen in *Figure 1*. The x-axis and y-axis act as the thresholds to determine in which state a point lies and therefore what value it has. If the constellation point crosses the threshold due to noise, then the modulation output will be wrong resulting in an error in the signal. The calculation of the Bit error rate (BER) is based on the probability than any of the points within the constellation are forced across one of these thresholds and when this occurs, bits are received in error. [6]

3.2.5 Quadrature Amplitude Modulation (QAM)

QAM is similar to PSK, however, the amplitude can also vary with phase. This means two different signals can be transmitted on the same carrier frequency. QAM can be seen in various forms depending on the number of bits of information that are communicated per symbol, for example, 8QAM, 16QAM, 64QAM etc. Higher order QAM produces more points within the constellation, and therefore are able to transmit more bits per symbol. This enables data to be transmitted over a much smaller bandwidth, which means higher data rates can be achieved but at the cost of the noise margin. A constellation diagram for 16QAM can be seen in *Figure 2*. In higher order modulation methods, the closer together the states in the constellation get, the less noise that can be tolerated before a state could be mistaken for one of the states nearby, which can lead to potential errors. [6]

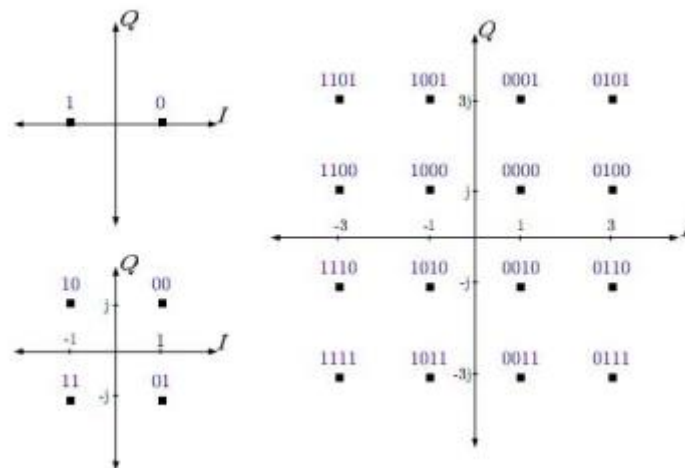


Figure 2 – Constellation Diagram of BPSK, QPSK and 16QAM

[7]

3.2.6 Signal to Noise Ratio (SNR)

A signal's signal-to-noise ratio (SNR) can be described by how well the received signal can be interpreted. SNR relates directly to the expected number of bits we will receive in error, also known as the bit error rate (BER). A high SNR means that the waveform contains a greater signal power than it does noise power, and vice versa, a low SNR indicates that the waveform's signal power is greater than the waveform's noise power, but not by much. A negative SNR value means that the power of the noise is greater than the signal power.

For a digital signal, the SNR, along with other factors such as the modulation method and symbol rate give us an idea of what to expect in terms of BER of the received signal.

In order for a signal to be 'problem-free' the digital signal requires at least $1\text{E-}5$ BER, and in most applications a BER of $1\text{E-}6$ is expected. The SNR required for a particular BER depends on the signal's modulation.

In *Figure 3* it can be seen what effects can be caused by BER on the signal quality and the required SNR to produce a BER of $1\text{E-}6$ for the different modulation methods.

[8]

Bit Error Rate (BER)	Signal Quality
$>10\text{E-}2$	The signal is not processable, but some signal characteristics are discernable.
$10\text{E-}3$	A listener can identify the sex and language of a speaker. Complete signal parameters can be measured.
$10\text{E-}4$	The static, pops, and crackles in voice are fatiguing for a listener.
$10\text{E-}5$	The occasional pops in voice are acceptable.
$10\text{E-}6$	There are perfect voice and data.

Modulation Type	Required SNR (dB) to Produce $1\text{E-}6$ BER
BPSK	10.8
QPSK	13.7
8PSK	18.9
16QAM	20.4
32QAM	23.5
64QAM	26.6

Figure 3 – Table showing BER expected signal quality and Required SNR to produce $1\text{E-}6$ BER

[8]

3.2.7 MATLAB Theoretical Results

The graph in *Figure 4* was created in the MATLAB Simulink BER tool to calculate the theoretical BER vs SNR for both BPSK and QPSK. The green line indicates BPSK and the red line indicates QPSK. This supports the data shown in *Figure 3*.

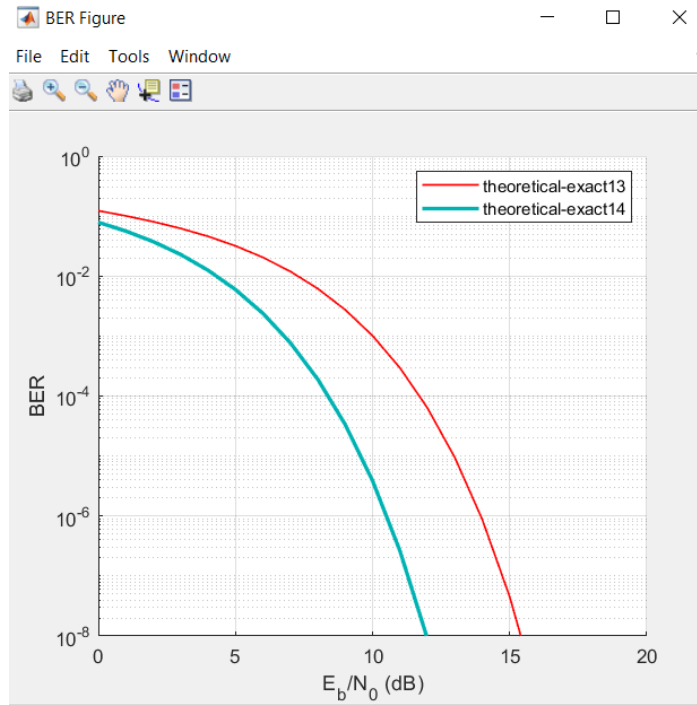


Figure 4 – Graph showing theoretical BER vs SNR for BPSK and QPSK

4. Simulation Modelling & Method

To simulate the ASK and PSK methods a Bernoulli Binary Generator was used to generate random binary numbers using a Bernoulli distribution. The AWGN Channel block enabled white Gaussian noise to be added to the input signal. The Digital Filter Design block implements a digital Finite Impulse Response (FIR) and was set up to be stable with an acceptable delay. The Error Rate Calculator computes bit error rate or symbol error rate and compares input data with output data. A scope was used to look at the signal at different points within the modulation process. [9]

4.1 Amplitude Shift Keying Model

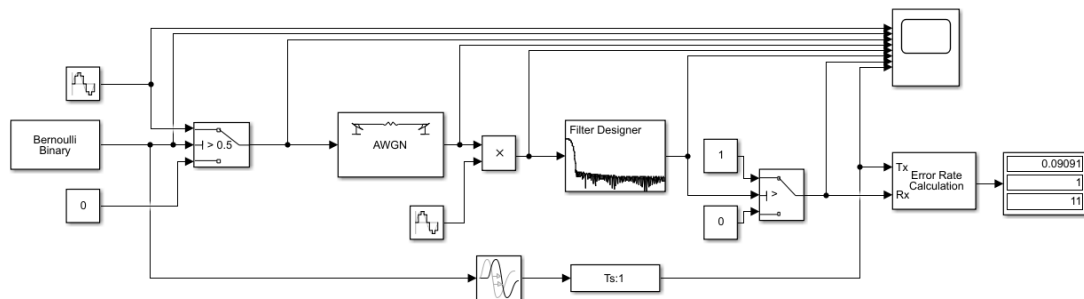


Figure 5 – ASK model in Simulink

4.2 Phase Shift Keying Model

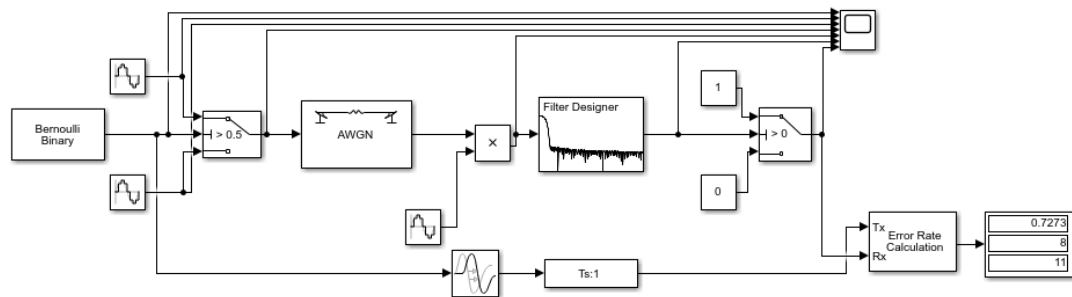


Figure 6 – PSK model in Simulink

4.3 Quadrature Phase Shift Keying and QAM Model

For the higher order modulation methods, the models below were created in Simulink. They utilise built in function blocks that modulate using the method specified. For these models the data input is produced using a Random Integer Generator and then modulated using the specified method. Noise is modified within the AWGN channel block and then the data is demodulated. The Error Rate Calculator is set up to compare the input data to the data that has been demodulated.

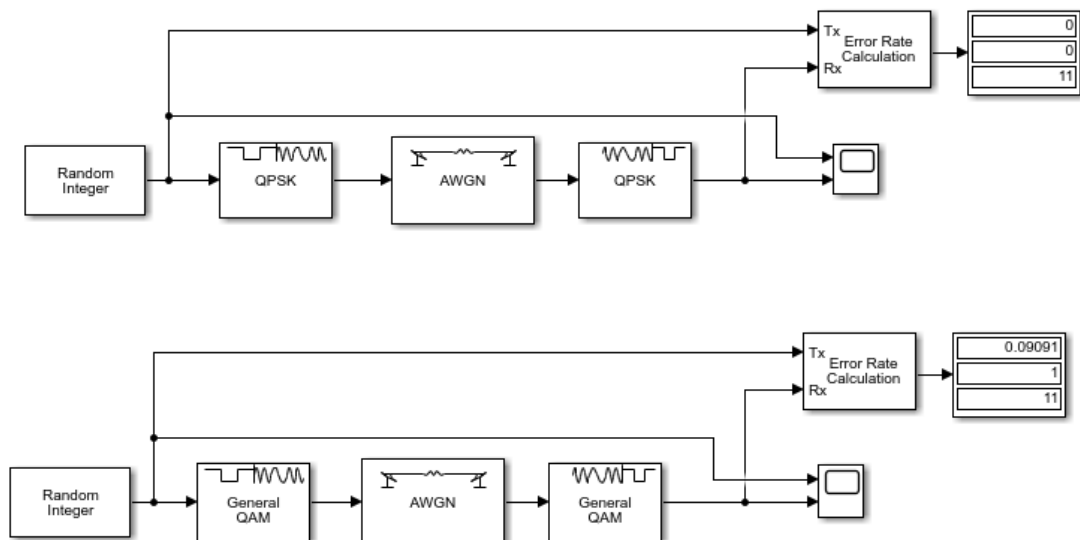


Figure 7 – QPSK and QAM model in Simulink

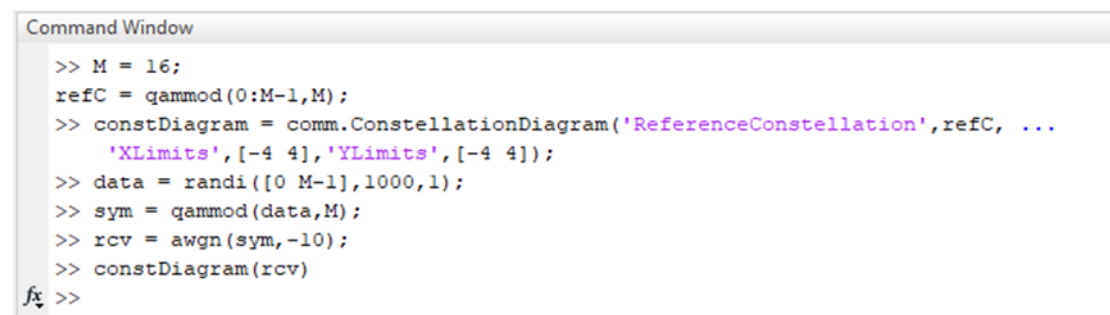
4.4 Simulation Method

For each of the four methods of digital modulation being tested, the following method/experiment was conducted;

1. A Simulink model of the modulation method was created.
2. A Signal to Noise Ratio (SNR) of 0 dB was selected in the AWGN channel, and the model was then simulated.
3. The simulation was repeated twelve times and the average error rate calculated was recorded.
4. The SNR was increased/decreased and the experiment repeated for a range of SNR values.
5. This was repeated for the different modulation methods.

For QPSK modulation the number of samples per frame was increased to 1000 and a constellation diagram box was introduced to show the constellation plot of the signal output from the AWGN channel. Different SNRs were selected to see how the constellation plots were affected by noise.

For QAM modulation the following code (*Figure 8*) was entered into MATLAB;



```
Command Window
>> M = 16;
refC = qammod(0:M-1,M);
>> constDiagram = comm.ConstellationDiagram('ReferenceConstellation',refC, ...
'XLimits', [-4 4], 'YLimits', [-4 4]);
>> data = randi([0 M-1],1000,1);
>> sym = qammod(data,M);
>> rcv = awgn(sym,-10);
>> constDiagram(rcv)
fx >>
```

Figure 8 – MATLAB code to view 16QAM constellation diagram

[10]

Different SNRs were selected to see how the constellation plots were affected by noise.

5. Results

ASK	
SNR (dB)	BER
-300	0.4697
-200	0.41665
-100	0.371193
-50	0.409076
-25	0.439392
-10	0.265128
-5	0.151503
-1	0.037879
0	0.068183
0.1	0.060607
0.15	0.037879
0.2	0
0.25	0
0.5	0
1	0
5	0

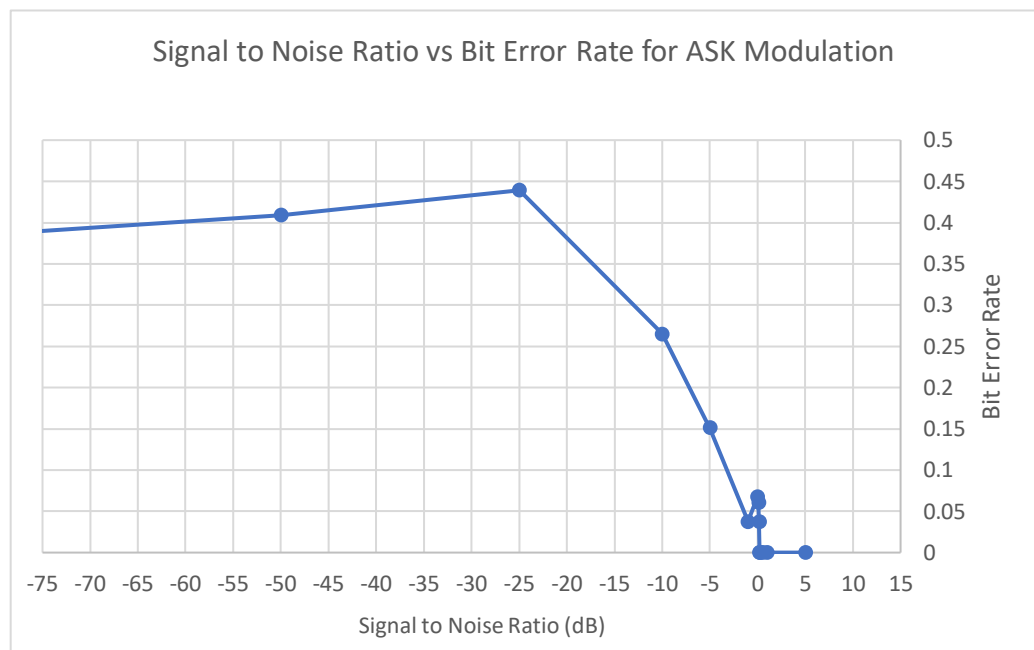


Figure 9 – Table of results for ASK Modulation and Graph plotting SNR vs BER

The results of the simulated ASK method (Figure 9) show that this method of modulation requires a positive signal to noise ratio for the data to be transmitted with no errors. In my experiment, for values of SNR greater than 0.2 dB the simulation computed no errors when comparing the input signal to the received signal. The results show that when noise is high compared to the signal, the bit error rate can be up to 50%.

BPSK	
SNR (dB)	BER
-300	0.431808
-200	0.401501
-100	0.424225
-50	0.393926
-25	0.363608
-10	0.189378
-9	0.151503
-8	0.060607
-7	0.068183
-6	0.030303
-5.9	0.053031
-5.85	0
-5.8	0
-5.75	0
-5.5	0
-5	0
-1	0
0	0

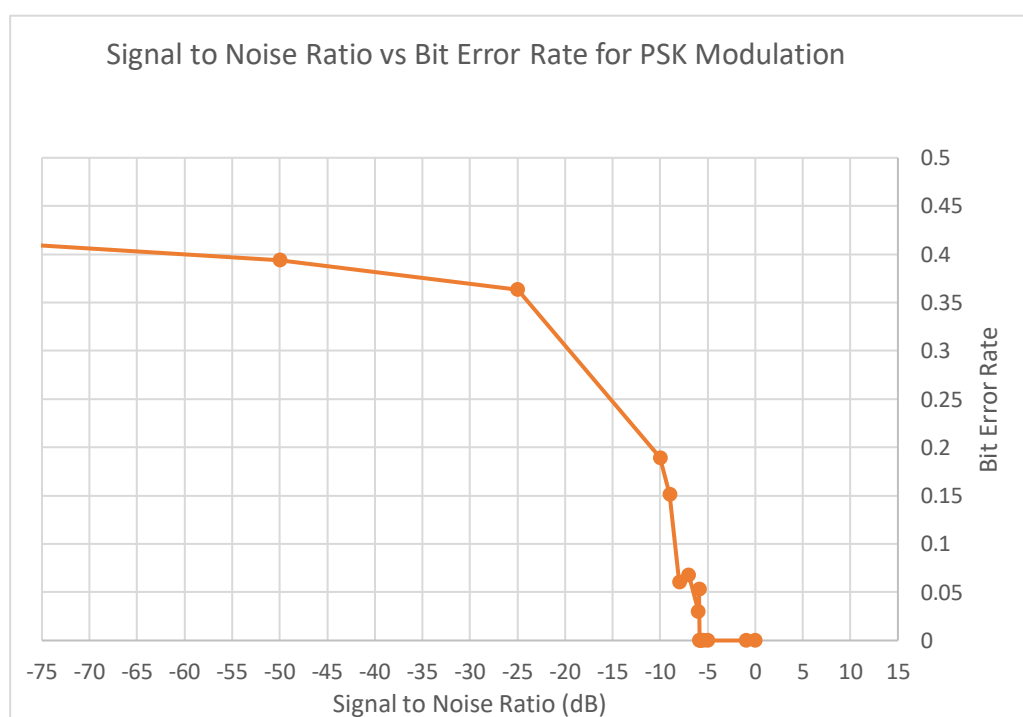


Figure 10 – Table of results for BPSK Modulation and Graph plotting SNR vs BER

In this experiment for BPSK modulation (Figure 10), the point at which no errors occurred was between -5.85 and -5.9 dB. The results show that when noise is high compared to the signal, the bit error rate can be up to 50%.

QPSK	
SNR (dB)	BER
-300	0.719708
-200	0.810625
-100	0.7273
-50	0.651542
-25	0.7576
-10	0.560625
-5	0.348459
0	0.280275
5	0.090905
6	0.060607
6.5	0.045455
6.75	0
7	0
7.5	0
10	0
15	0

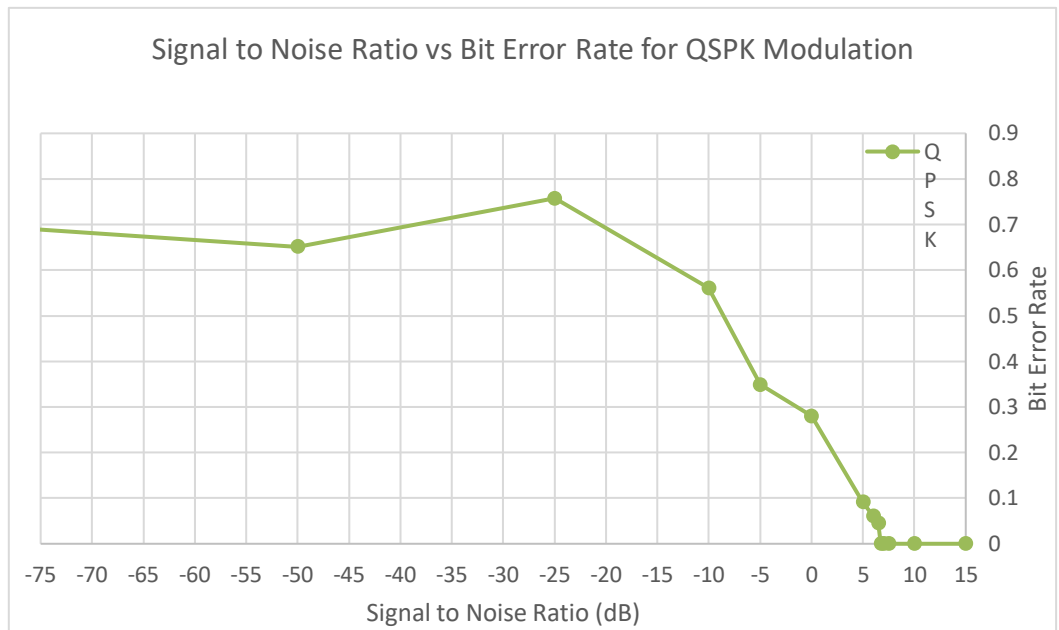


Figure 11 – Table of results for QPSK Modulation and Graph plotting SNR vs BER

The results of the simulated QPSK method (Figure 11) show that with this method of modulation the signal strength must be higher than the noise level in order for there not to be any errors in the system. In this experiment, the point at which no errors occurred was between 6.5-6.75 dB. The results show that when noise is very high compared to the signal, the bit error rate can be up to 82%.

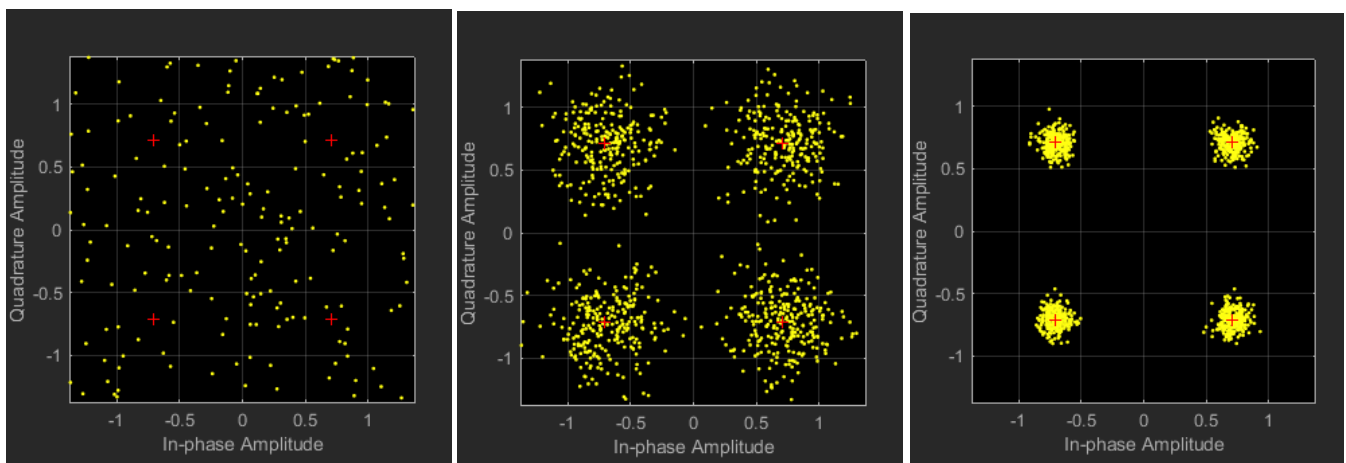


Figure 12 – Constellation diagrams for QPSK at different levels of SNR. -10dB, 10dB, 20dB (left to right)

QAM	
SNR (dB)	BER
-300	1
-200	0.9091
-100	0.9091
-50	0.8182
-25	0.7273
-10	0.8182
-5	0.8182
0	0.4545
5	0.1818
7.5	0.1818
8	0.09091
10	0
10.5	0
11	0
15	0

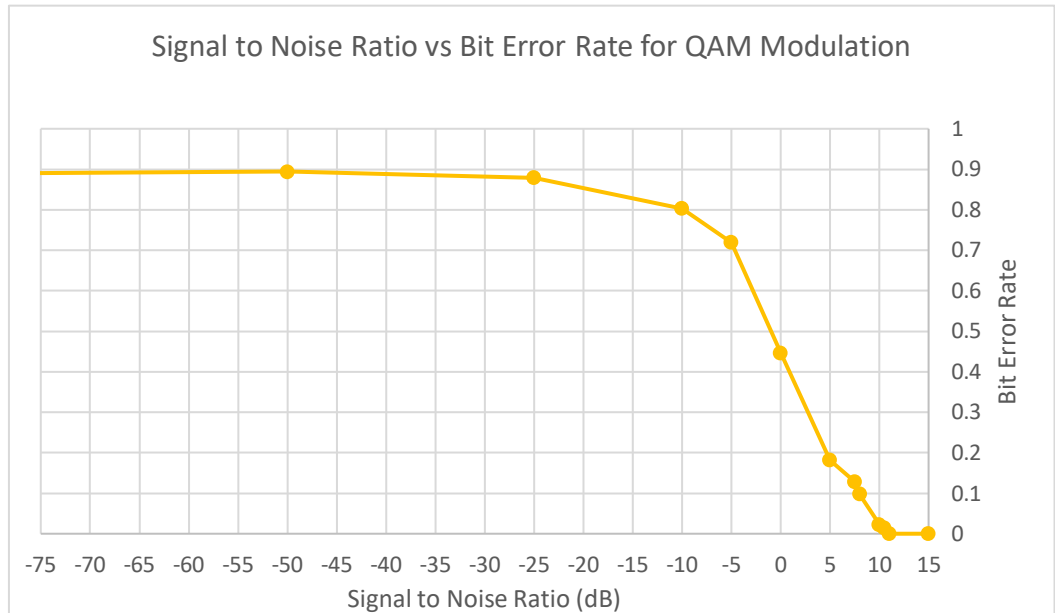


Figure 13 – Table of results for QAM Modulation and Graph plotting SNR vs BER

The results of the simulated QAM modulation (Figure 13) show that with this method the signal strength must be higher than the noise level in order for there not to be any errors in the system. In this experiment, the point at which no errors occurred was between a SNR 8-10 dB. The results show that when noise is very high compared to the signal, the bit error rate can be up to 100%.

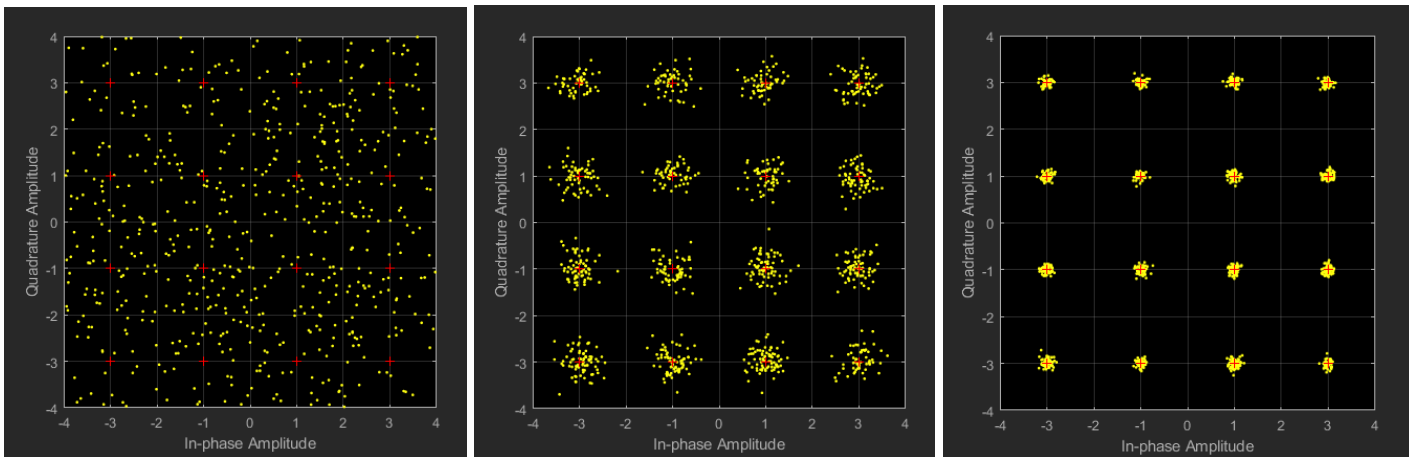


Figure 14 – Constellation diagrams for 16QAM at different levels of SNR. -10dB, 10dB, 20dB (left to right)

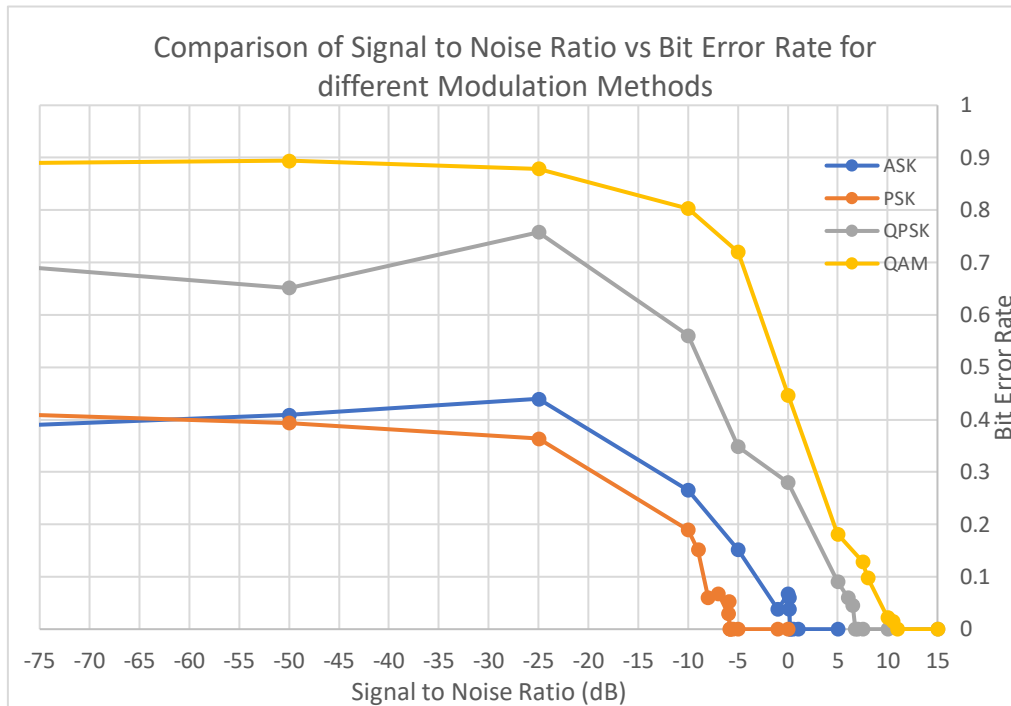


Figure 15 – Graph showing comparison of SNR vs BER for different Modulation Techniques

Figures 15 & 16 shows the comparison of the simulated results. It can be seen that the error rate for both QPSK and QAM is much higher for low signal to noise ratio values compared to the ASK and PSK methods. This also shows the difference in error rate for a given value of SNR.

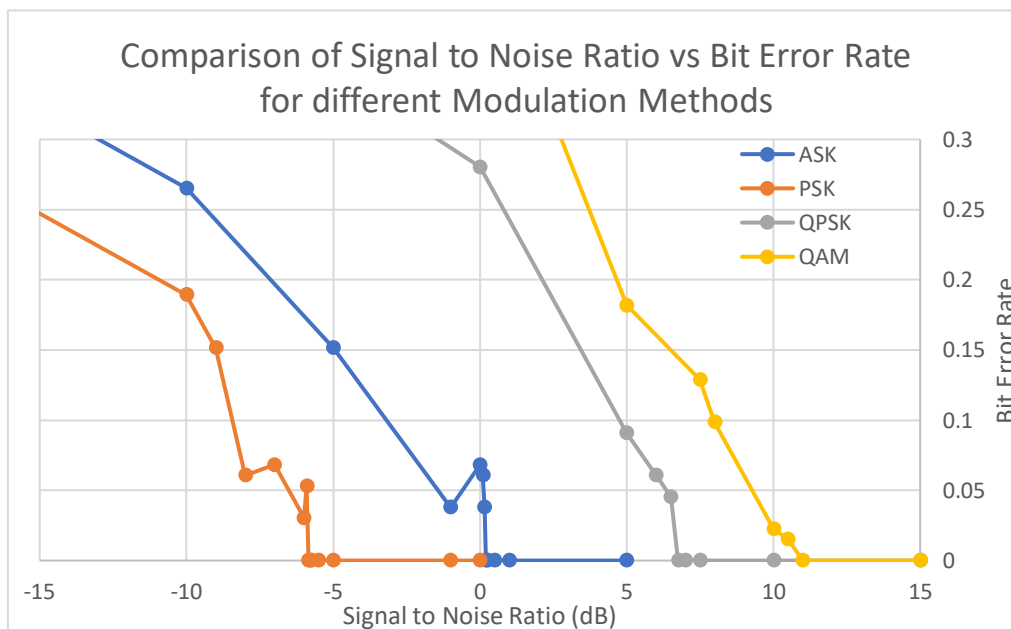


Figure 16 – Graph showing comparison of SNR vs BER for different Modulation Techniques

6. Discussion/Analysis of results

The results from the experiment show that the higher the data rate of a modulation technique i.e. the amount of data in relation to its bandwidth, the more susceptible to noise it is. For QPSK and QAM, this can be seen in the results by the requirement of a much higher signal strength in comparison to the noise for the simulation to find no bit errors.

The results of the simulated constellation diagrams for QPSK and QAM show that as the order of PSK increases, the signal is degraded since the constellation is more susceptible to noise (this is why there are more errors simulated for QAM than QPSK). QPSK has four signalling states, whereas 16QAM has 16 signalling states. The more states a constellation diagram has, the smaller the distance between the points on the constellation diagram, which therefore leads to a higher possibility of data errors being introduced. We can see that this is the case in this experiment as the simulated QAM error rates are higher than the other methods of modulation for a given level of SNR.

Research showed that in real world communication applications the required SNR to achieve a BER of $1\text{E-}6$ is 10.8 for BPSK, 13.7 for QPSK and 20.4 for 16QAM. The simulations follow the same pattern, in that for a given BER, the SNR for QAM is higher than QPSK and QPSK is higher than BPSK. However, the point at which no failures occurred in the simulations is much lower than these figures. This could be partly due to the limited sample size tested in this experiment, and that if the simulations were run for a longer time i.e. transmitting more data, there would be more chance of errors occurring. Where these simulations generated no errors, it could be because not enough bits were in the transmitted signal.

As the input data for each simulation was different each time, an average of the BER was taken. In this experiment an average of 12 calculations was made. If this experiment was conducted again with more simulations to take an average from, the average BER would be more accurate. In addition to this, if larger amounts of data (thousands or millions of bits, for example) were simulated over a longer time, the likelihood of an error occurring would increase. Finding the point at which no errors occurred would then be much more accurate and closer to the theoretical BER in relation to SNR.

7. Conclusion

It can be concluded from this experiment that the Bit Error Rate of a digital modulation method is determined by Signal to Noise Ratio. Higher order modulation techniques are commonly used as they have a higher data rate but are more susceptible to errors when encountering noise. Therefore, a higher SNR is required to combat this.

8. References

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9. Annex A

Excel spreadsheet showing full results tables for each modulation method.

ASK														
SNR	BER													Average
-300	0.4545	0.5455	0.4545	0.3636	0.5455	0.5455	0.2727	0.5455	0.5455	0.3636	0.3636	0.6364	0.4697	
-200	0.1818	0.2727	0.3636	0.3636	0.6364	0.3636	0.4545	0.4545	0.3636	0.5455	0.5455	0.4545	0.41665	
-100	0.3636	0.3636	0.4545	0.2727	0.3636	0.5455	0.1818	0.4545	0.3636	0.6364	0.3636	0.09091	0.371193	
-50	0.09091	0.4545	0.5455	0.4545	0.4545	0.7273	0.2727	0.3636	0.2727	0.3636	0.3636	0.5455	0.409076	
-25	0.3636	0.4545	0.3636	0.5455	0.6364	0.5455	0.4545	0.2727	0.2727	0.5455	0.5455	0.2727	0.439392	
-10	0.4545	0.09091	0.2727	0.4545	0.3636	0.09091	0.09091	0.2727	0.4545	0.1818	0.2727	0.1818	0.265128	
-5	0.09091	0.1818	0.09091	0.09091	0.1818	0.1818	0.1818	0.1818	0.1818	0	0.2727	0.1818	0.151503	
-1	0.09091	0	0.09091	0	0.09091	0	0.09091	0	0	0	0.09091	0	0.037879	
0	0.09091	0.09091	0.09091	0.09091	0.09091	0	0	0.09091	0.09091	0	0.09091	0.09091	0.068183	
0.1	0	0.09091	0.09091	0.09091	0.09091	0.09091	0	0.09091	0	0.09091	0.09091	0	0.060607	
0.15	0	0	0.09091	0	0.09091	0	0	0.09091	0	0.09091	0	0.09091	0.037879	
0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0	0	0	
PSK														
SNR	BER													Average
-300	0.2727	0.4545	0.3636	0.5455	0.6364	0.4545	0.1818	0.5455	0.1818	0.4545	0.3636	0.7273	0.431808	
-200	0.3636	0.3636	0.2727	0.5455	0.3636	0.2727	0.09091	0.4545	0.4545	0.5455	0.8182	0.2727	0.401501	
-100	0.3636	0.3636	0.6364	0.3636	0.4545	0.4545	0.3636	0.5455	0.5455	0.4545	0.1818	0.3636	0.424225	
-50	0.4545	0.2727	0.3636	0.5455	0.1818	0.4545	0.3636	0.6364	0.3636	0.09091	0.4545	0.5455	0.393926	
-25	0.3636	0.2727	0.6364	0.2727	0.2727	0.2727	0.2727	0.2727	0.4545	0.4545	0.3636	0.4545	0.363608	
-10	0.3636	0.2727	0.1818	0.1818	0	0.3636	0.2727	0.09091	0.1818	0.09091	0.09091	0.1818	0.189378	
-9	0.1818	0.09091	0.1818	0.1818	0.09091	0	0.09091	0.1818	0.1818	0.2727	0.1818	0.1818	0.151503	
-8	0.09091	0	0.09091	0	0.09091	0.09091	0.09091	0	0.09091	0.09091	0	0.09091	0.060607	
-7	0.09091	0.09091	0.09091	0.09091	0	0	0.09091	0	0.09091	0.09091	0.09091	0.09091	0.068183	
-6	0.09091	0	0	0	0	0	0.09091	0	0.09091	0	0	0	0.030303	
-5.9	0	0.09091	0	0	0	0.09091	0.09091	0	0.09091	0.09091	0.09091	0.09091	0.053031	
-5.85	0	0	0	0	0	0	0	0	0	0	0	0	0	
-5.8	0	0	0	0	0	0	0	0	0	0	0	0	0	
-5.75	0	0	0	0	0	0	0	0	0	0	0	0	0	
-5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	
-5	0	0	0	0	0	0	0	0	0	0	0	0	0	
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QPSK														
SNR	BER													Average
-300	0.7273	1	0.7273	0.4545	0.5455	0.9091	0.8182	0.7273	0.9091	0.3636	0.6364	0.8182	0.719708	
-200	0.8182	0.6364	0.8182	0.9091	0.7273	0.7273	0.7273	0.9091	0.9091	0.9091	0.8182	0.8182	0.810625	
-100	0.5455	0.6364	0.8182	0.6364	0.7273	0.7273	0.6364	0.7273	0.8182	0.8182	0.7273	0.9091	0.7273	
-50	0.5455	0.9091	0.7273	0.5455	0.8182	0.5455	0.5455	0.7273	0.6364	0.7273	0.6364	0.4545	0.651542	
-25	0.7273	0.9091	0.6364	0.9091	0.6364	0.8182	0.7273	0.6364	0.7273	0.5455	1	0.8182	0.7576	
-10	0.6364	0.7273	0.5455	0.4545	0.4545	0.5455	0.2727	0.5455	0.5455	0.5455	0.6364	0.8182	0.560625	
-5	0.5455	0.3636	0.1818	0.3636	0.3636	0.2727	0.4545	0.3636	0.4545	0.3636	0.3636	0.09091	0.348459	
0	0.2727	0.3636	0.2727	0.2727	0.3636	0.1818	0.3636	0.3636	0.2727	0.1818	0.2727	0.1818	0.280275	
5	0.09091	0	0.1818	0	0.09091	0.09091	0.09091	0.1818	0	0.09091	0.09091	0.1818	0.090905	
6	0.09091	0	0.09091	0	0.09091	0.09091	0.09091	0.09091	0	0.09091	0.09091	0	0.060607	
6.5	0	0.09091	0	0.09091	0.09091	0	0.09091	0.09091	0	0	0	0.09091	0.045455	
6.75	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	0	0	0	0	0	0	0	0	0	0	0	0	

QAM													
SNR	BER												Average
-300	1	0.9091	0.9091	0.9091	0.8182	1	0.9091	0.8182	1	1	1	0.9091	0.931825
-200	0.9091	0.8182	0.9091	0.8182	0.7273	1	1	0.9091	0.9091	0.6364	0.8182	1	0.871225
-100	0.9091	0.8182	0.8182	1	0.9091	0.9091	0.8182	0.9091	0.9091	0.9091	0.9091	0.8182	0.886375
-50	0.8182	0.9091	0.9091	0.9091	0.9091	0.9091	1	1	0.8182	0.6364	1	0.9091	0.893395
-25	0.7273	0.9091	0.8182	1	1	0.7273	1	0.7273	0.9091	1	1	0.7273	0.8788
-10	0.8182	0.8182	0.7273	0.8182	0.7273	0.7273	0.9091	0.7273	0.8182	0.9091	0.8182	0.8181	0.803042
-5	0.8182	0.6364	0.8182	0.7273	0.7273	0.6364	0.8182	0.6364	0.7273	0.6364	0.8182	0.6364	0.719725
0	0.4545	0.5455	0.4545	0.5455	0.4545	0.3636	0.4545	0.4545	0.3636	0.5455	0.2727	0.4545	0.44695
5	0.1818	0.2727	0.2727	0.1818	0.2727	0	0.09091	0.09091	0.1818	0.2727	0.09091	0.2727	0.181803
7.5	0.1818	0.09091	0.09091	0.09091	0.1818	0.1818	0.09091	0.1818	0.1818	0	0.1818	0.09091	0.128779
8	0.09091	0.2727	0.1818	0	0	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.098482
10	0	0	0	0.09091	0.09091	0	0	0	0	0	0.09091	0	0.022728
10.5	0	0	0	0	0	0	0.09091	0	0	0.09091	0	0	0.015152
11	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0