

Harry Woollands DSP & Communications Assignment

by Harry Woollands

Submission date: 21-Nov-2024 02:09PM (UTC+0000)

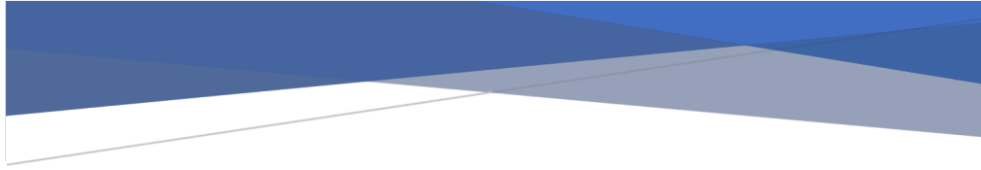
Submission ID: 243332784

File name:

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(1.03M)

Word count: 2649

Character count: 14393



SIMULATION OF DIGITAL MODULATION TECHNIQUES

Digital Signal Processing and Communications

2172 Words

Abstract

This report explains, compares and contrasts the performance of four types of modulation schemes, Amplitude Shift Keying, Phase Shift Keying, Quadrature Phase Shift Keying, and Quadrature Amplitude Modulation, by measuring their Bit Error Rates under increasing levels of noise. The results of the study reveal that Amplitude Shift Keying is the most noise resistant modulation scheme, however it is determined that this is not wholly accurate. Potential explanations are provided for why this could be the case.

Harry Woollands

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Introduction

In communication systems, modulating and demodulating signals is an essential part of wirelessly transmitting and receiving signals across large distance ranges where wired connections are impossible. By modulating signals, the signals become more noise resistant, which is imperative for the received signal quality to be as high as possible.

Modulation can be defined as the process of encoding information by adding a carrier wave to a message signal [1]. This carrier wave can adjust the properties of the message wave, such as amplitude and phase. When the modulated wave arrives at its destination, the message signal is extracted from the carrier wave. Modulation has also become more important over time, with the number of messages needing to be transmitted and received always increasing, the RF spectrum could become overcrowded. By adjusting the frequency that the modulated wave transmits at, the region in which the signal transmits at changes, which can reduce overcrowding.

This report will compare and contrast four different types of modulation schemes – Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM). These modulation schemes will be compared by measuring each scheme's Bit Error Rate (BER) at different levels of Signal to Noise Ratios, in addition to adding different levels of Additive White Gaussian Noise (AWGN). To do this, models for each of the modulation schemes will be designed using *Simulink*, a block diagram simulation tool within *MATLAB*. The results from the simulations will be visually represented through the use of scatter graphs, and an evaluation of these results will follow.

Simulation Models

There are many different types of modulation schemes, however for the purposes of this report, only two types will be focused on. These are Amplitude Shift keying (ASK), and Phase Shift Keying (PSK). Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) will also feature, however they are more complicated forms of PSK and ASK, and not different types of modulation schemes.

This section of the report will define these four versions of modulation schemes, as well as explain how they work, and provide examples of where each of them are used. Finally, the simulation designs developed in *Simulink* will be shown. The designs were created using the basic setup provided in the assignment brief, and is shown below in Figure 1.

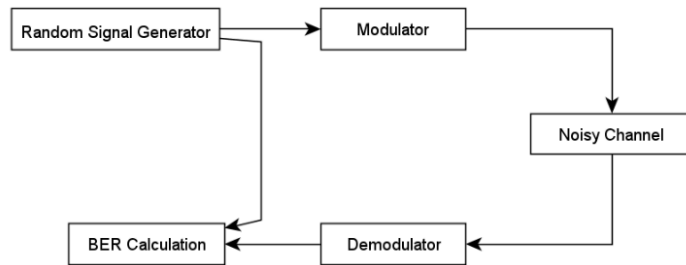


Figure 1. Basic setup provided.

Amplitude Shift keying (ASK)

ASK is a form of modulation where the amplitude of a carrier signal sine wave alters a binary stream of data [2]. A common use of ASK modulation is transmitting audio [3]. The binary stream of data only has two amplitudes, 1 and 0, where 1 is high and 0 is low. When the binary data is modulated using the sine wave, the high regions are given the carrier wave output, and the low regions remain at 0. Figure 2 below shows an example of ASK modulation using *Simulink*.

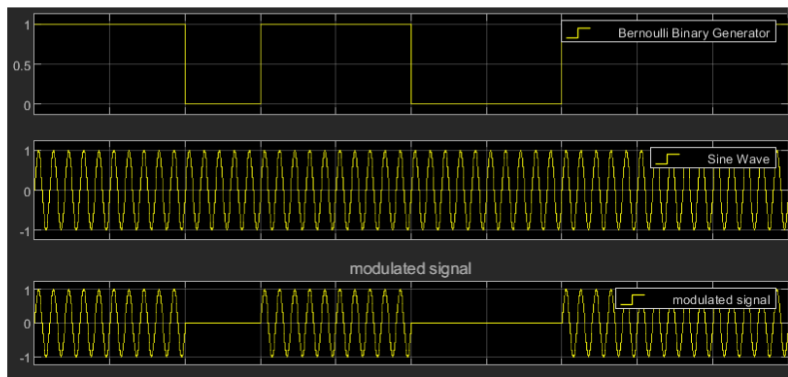


Figure 2. ASK Modulated Signal.

Using the basic setup provided an ASK modulation design was created in *Simulink*. This can be seen below in Figure 3. The setup shows the binary data stream being combined with a carrier sine wave to create the modulated signal, then being put through a filter and demodulated back into the original message signal.

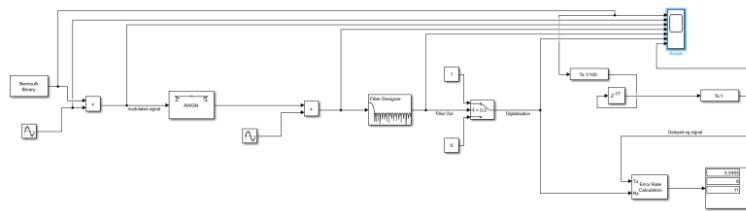


Figure 3. ASK Simulink Design.

Phase Shift Keying (PSK)

PSK is a form of modulation where the phase of a pair carrier signal sine wave alters a binary stream of data [4]. A common use of PSK modulation is Bluetooth. The two sine waves used are π radians (180 degrees) out of phase with one another. When the binary data is modulated using the sine wave, the high regions are given the in-phase sine wave's output, and the low regions are given the out of phase sine wave's output. This results in some bumps in the modulated signal where the binary stream has changed from high to low. This can be visually seen below in Figure 4, an example of PSK modulation using *Simulink*.

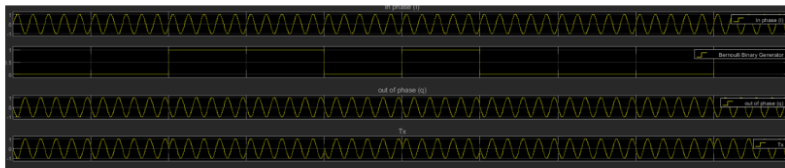


Figure 4. PSK Modulated Signal.

Using the basic setup provided an PSK modulation design was created in *Simulink*. This can be seen below in Figure 5. The binary data stream is combined with the two out of phase sine waves to create the modulated wave. The modulated wave is then multiplied by the same two out of phase sine waves, demodulating the signal, and finally digitalised back into the original message signal.

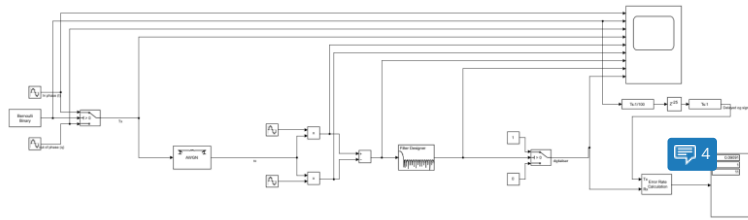


Figure 5. PSK Simulink Design.

Quadrature Phase Shift Keying (QPSK)

QPSK is a form of PSK where two bits are modulated at the same time [5]. These bits can have their phase shifted in four possible ways, 0, 90, 180 and 270 degrees out of phase. This is achieved by using a serial to parallel converter, as well as the pair of out of phase sine waves that were used in PSK. For this simulation the phase difference between the in-phase wave and out of phase wave is 90 degrees. Just as in PSK, when the binary data shifts from high to low and vice versa, the modulated signal switches between the in-phase and out of phase wave. This can be seen below in Figure 6.

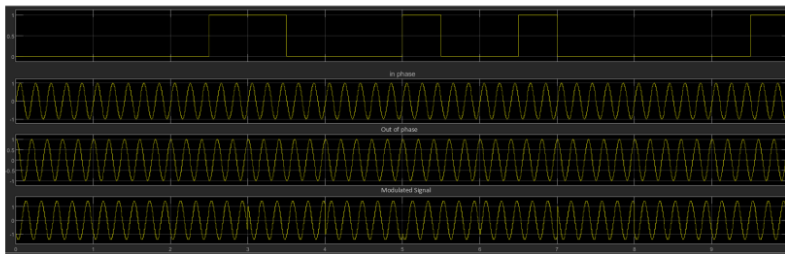


Figure 6. QPSK Modulated Signal.

Figure 7 below shows the QPSK Simulink design created. To modulate the signal, the data stream is separated into two streams using a serial to parallel converter and DEMUX. These two streams are the in phase (I) component, and the Quadrature (Q) component. The streams are then individually modulated, before being added together to be put through an AWGN block. The streams are then separated again to be individually demodulated, before again going through a DEMUX and serial to parallel converter back into the original message signal.

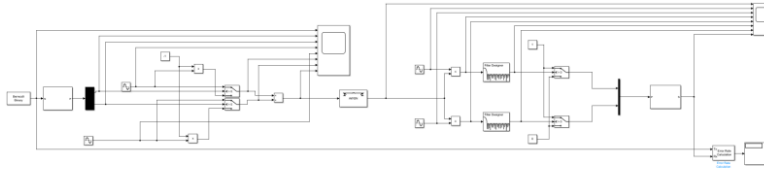


Figure 7. QPSK Simulink Design.

Quadrature Amplitude Modulation (QAM)

QAM modulation is a form of modulation where both the amplitude and phase of a binary stream of data are modulated, resulting in a higher data rate [6]. Figure 8 below shows the QAM *Simulink* design created. As with QPSK, the binary data is separated into its in phase and Quadrature components to be modulated, and are then further split down into each component's amplitude and phase. The data streams are compared to three levels, 3, 1 and -1, which shows that this simulation is 16-bit. The phase and amplitude components are then combined for modulation with the out of phase carrier waves, before being combined again to be put through the. The data stream is then once again split into I and Q for demodulation, and finally going through a DEMUX and serial to parallel converter back into the original message signal.

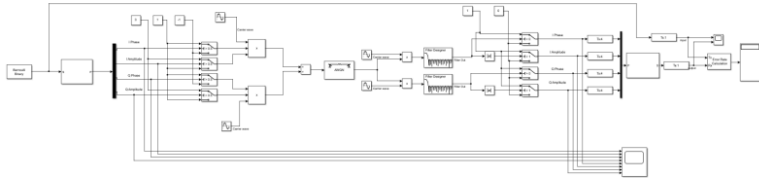


Figure 8. QAM Simulink Design.

Results

This section of the report will show the results for the Bit Error Rate (BER) calculated, and display the graphs to visualise those results.

Before calculating the BER, it was important to add some control variables to the simulations, to increase the validity of the results. Control variables can be defined as factors that remain unchanged and remain constant throughout studies [7]. In this study, one of the most important control variables is the Digital Filter Design. Each of the four modulation schemes include a digital filter design, as it is used to demodulate the signal, extracting the message signal from the carrier

The filter used is a lowpass filter, and its parameters are shown below in Figure 9.

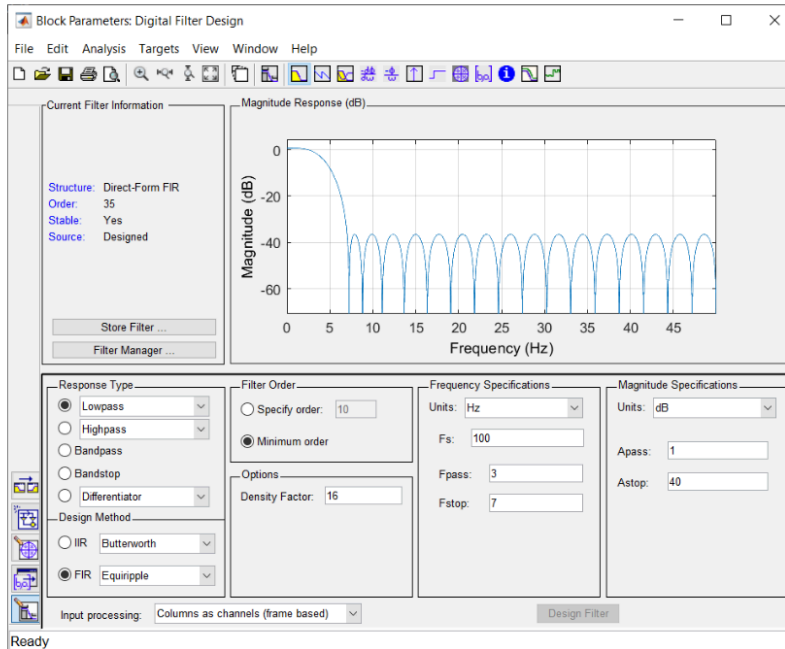


Figure 9. Digital Filter Design.

To measure the Bit Error Rate, an error rate calculator and display are connected to each of the modulation designs. This is shown below in Figure 10. This error rate calculator compares the digitalised demodulated signal and the original message signal. The display connected to it displays three values. The top value is the BER value, the second value shows the number of bits that have an error, and the third value shows the number of bits received. One important thing to make sure of before starting any simulations was to check that the BER value was zero when there was no AWGN added to the system. If this was not the case, then any calculated results would be invalid.

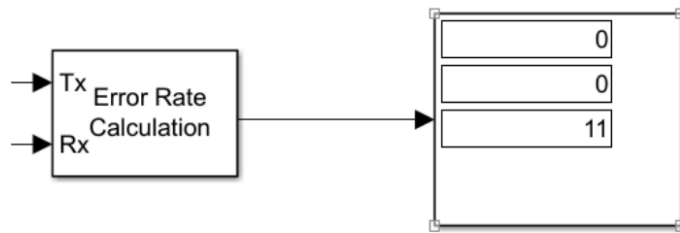


Figure 10. BER Calculator and Display.

To ensure validity in the results, 10 simulations were performed at each noise level. This allowed for another data to calculate a [create table](#) average and reduce the influence of any anomalous values. The first noise value measured was [14](#) and the noise value was increased in 5db increments until system failure occurred. This happens when the BER is 0.5 or above, where more than half of the bits have an error. Finally, as well as taking an average, the standard deviation for each noise level was also calculated. Standard deviation is a measure of how varied the data points are in relation to the average of the data [8]. In this experiment, the standard deviation will be represented as error bars on the graphs.

ASK

Table 1 below shows the results of the ASK simulation. The table shows that system failure occurred at -55db.

ASK	SNR (db)	BER										Average Bit error rate	Standard deviation
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10		
	5	0	0	0	0	0	0	0	0	0	0	0	0
	0	0.09091	0.09091	0	0	0	0.09091	0.09091	0.09091	0	0.09091	0.054546	0.046945722
	-5	0.1818	0.1818	0	0.1818	0	0	0.2727	0.1818	0.1818	0.09091	0.127261	0.097714151
	-10	0.1818	0.3636	0.2727	0.09091	0.2727	0.2727	0.3636	0.1818	0.2727	0.1818	0.245431	0.086233321
	-15	0.2727	0.4545	0.4545	0.3636	0.3636	0.4545	0.1818	0.4545	0.5455	0.3636	0.39088	0.105415008
	-20	0.3636	0.3636	0.4545	0.4545	0.2727	0.4545	0.3636	0.4545	0.5455	0.4545	0.46361	0.108862476
	-25	0.4545	0.4545	0.1818	0.6364	0.5455	0.3636	0.6364	0.4545	0.4545	0.3636	0.47273	0.135542991
	-30	0.4545	0.5455	0.1818	0.4545	0.5455	0.3636	0.6364	0.2727	0.5455	0.2727	0.46361	0.148790106
	-35	0.5455	0.3636	0.4545	0.4545	0.4545	0.4545	0.4545	0.4545	0.3636	0.5455	0.46361	0.060633339
	-40	0.2727	0.6364	0.4545	0.4545	0.5455	0.4545	0.1818	0.5455	0.5455	0.6364	0.47273	0.147238062
	-45	0.3636	0.4545	0.2727	0.3636	0.2727	0.5455	0.6364	0.3636	0.5455	0.4545	0.42726	0.121618869
	-50	0.5455	0.3636	0.5455	0.4545	0.3636	0.4545	0.4545	0.5455	0.5455	0.5455	0.48182	0.07488272
	-55	0.5455	0.4545	0.6364	0.5455	0.8182	0.4545	0.5455	0.5455	0.6364	0.3636	0.55456	0.124596988

Table 1. ASK Results.

Figure 11 below shows a scatter graph of average Bit Error Rate vs Signal to Noise ratio for ASK Modulation. It visually shows how the BER increases as the noise is increased. The error bars on the graph also visible for each noise level, representing the standard deviations.

Scatter Graph showing average Bit Error Rate against Signal-to-Noise Ratio for ASK Modulation

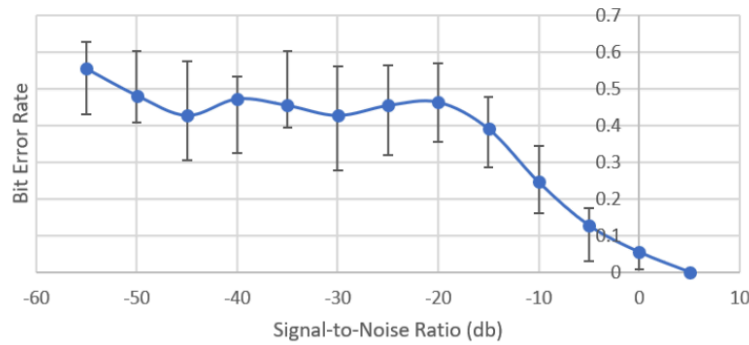


Figure 11. ASK Scatter Graph.

PSK

Table 2 below shows the results of the PSK simulation. The table shows that system failure occurred at -30db.

PSK	SNR (db)	BER										Average Bit error rate	Standard deviation
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10		
	5	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	1.46285E-17
	0	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	0.09091	1.46285E-17
	-5	0.09091	0.1818	0.1818	0.1818	0.09091	0.1818	0.09091	0.1818	0.09091	0.1818	0.1	0.046935394
	-10	0.2727	0.1818	0.1818	0.3636	0.2727	0.1818	0.3636	0.3636	0.2727	0.2727		0.074219539
	-15	0.2727	0.2727	0.3636	0.4545	0.1818	0.2727	0.2727	0.3636	0.3636	0.09091		0.103195928
	-20	0.09091	0.4545	0.5455	0.7273	0.5455	0.3636	0.4545	0.2727	0.3636	0.3636		0.172504826
	-25	0.4545	0.6364	0.2727	0.4545	0.5455	0.4545	0.5455	0.4545	0.2727	0.3636		0.116996707
	-30	0.6364	0.3636	0.5455	0.4545	0.4545	0.5455	0.7273	0.6364	0.3636	0.7273		0.135550443

Table 2. PSK Results.

Figure 12 below shows a scatter graph of average Bit Error Rate vs Signal to Noise ratio for PSK Modulation, including the standard deviation error bars for each noise level.

Scatter Graph showing average Bit Error Rate against Signal-to-Noise Ratio for PSK Modulation

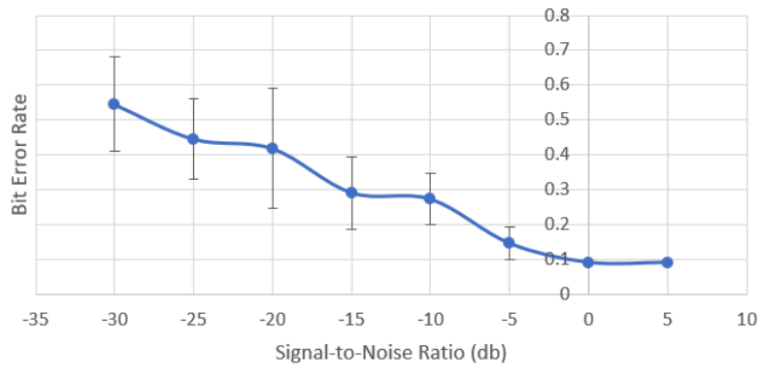


Figure 12. PSK Scatter Graph.

QPSK

Table 3 below shows the results of the QPSK simulation. The table shows that system failure occurred at -45db.

QPSK	SNR (db)	BER										Average Bit error rate	Standard deviation
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10		
	5	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
	-5	0	0.05882	0.05882	0	0.05882	0.1176	0	0.1176	0.05882	0.1765	0.064698	0.058492761
	-10	0.2353	0.1176	0.2353	0.3529	0.1765	0.3529	0.2941	0.1176	0.1176	0.3529	0.2353	0.09998001
	-15	0.1176	0.2941	0.4118	0.2941	0.2941	0.4118	0.3529	0.3529	0.2941	0.2941	0.1176	0.083438923
	-20	0.3529	0.4706	0.5294	0.2353	0.4118	0.4118	0.4706	0.6471	0.4118	0.4706	0.1176	0.108295844
	-25	0.4118	0.4118	0.2941	0.1765	0.5294	0.5294	0.4706	0.7059	0.4706	0.4706	0.44707	0.141933592
	-30	0.2941	0.2941	0.4706	0.3529	0.4706	0.4706	0.4118	0.5882	0.4706	0.3529	0.41764	0.093838315
	-35	0.2941	0.3529	0.4706	0.4118	0.2941	0.5882	0.7059	0.4706	0.2941	0.3529	0.42352	0.138102762
	-40	0.5882	0.4118	0.3529	0.5294	0.7647	0.4118	0.5294	0.3529	0.4706	0.5294	0.49411	0.124628849
	-45	0.5294	0.4706	0.4118	0.5882	0.4118	0.4118	0.6471	0.4118	0.5882	0.5882	0.50589	0.092781038

Table 3. QPSK Results.

Figure 13 below shows a scatter graph of average Bit Error Rate vs Signal to Noise ratio for QPSK Modulation, including the standard deviation error bars for each noise level.

Scatter Graph showing average Bit Error Rate
against Signal-to-Noise Ratio for QPSK
Modulation

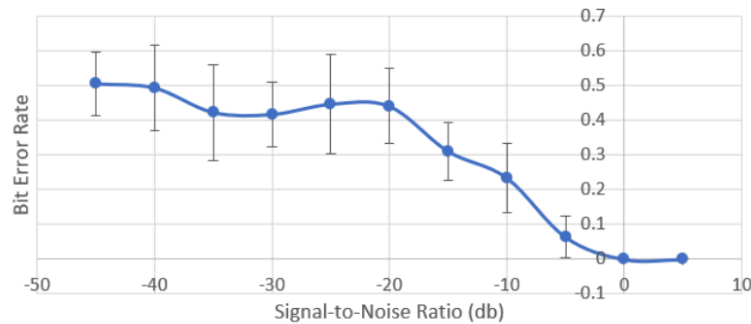


Figure 13. QPSK Scatter Graph.

QAM

Table 4 below shows the results of the QAM simulation. The table shows that system failure occurred at -30db.

QAM	SNR (db)	BER										Average Bit error rate	Standard deviation
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10		
	5	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
	-5	0.0566	0.07547	0.03774	0.07547	0.01887	0.03774	0.03774	0.01887	0.0566	0.0566	0.04717	0.020377301
	-10	0.1321	0.1132	0.1132	0.1509	0.1321	0.1321	0.1509	0.1132	0.1132	0.1132	0.1132	0.15524779
	-15	0.2453	0.3208	0.3208	0.3019	0.3208	0.283	0.283	0.2642	0.3208	0.2642	0.28483984	0.064029005
	-20	0.283	0.3962	0.3962	0.4151	0.4151	0.283	0.4906	0.3774	0.4151	0.3396	0.45282	0.074421469
	-25	0.4151	0.5094	0.4717	0.4151	0.5094	0.3396	0.5472	0.5283	0.3396	0.4528	0.51133	0.047440912
	-30	0.5472	0.566	0.4717	0.4906	0.5472	0.4151	0.5472	0.5283	0.4717	0.5283		

Table 4. QAM Results.

Figure 14 below shows a scatter graph of average Bit Error Rate vs Signal to Noise ratio for QAM Modulation, including the standard deviation error bars for each noise level.

Scatter Graph showing average Bit Error Rate
against Signal-to-Noise Ratio for QAM
Modulation

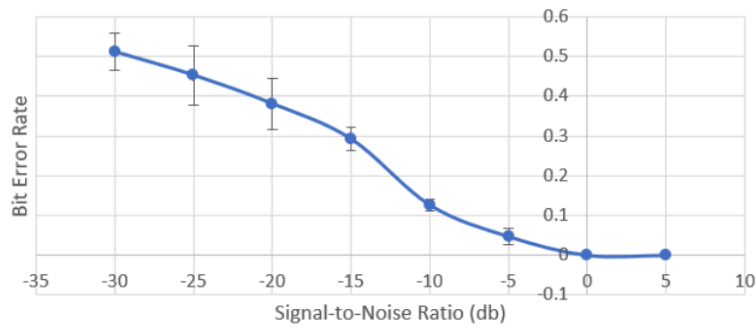


Figure 14. QAM Scatter Graph.

Finally, Figure 15 below shows a combined scatter graph for all of the modulation schemes. This graph is useful to be able to compare where system failure occurs for each modulation scheme.

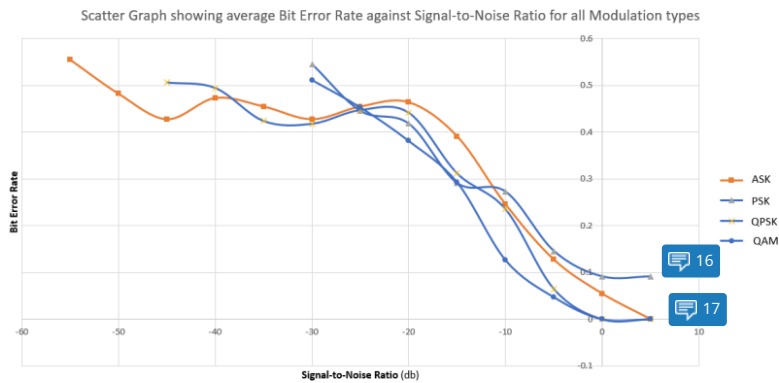


Figure 15. All Modulations Scatter Graph.

Discussion

The results of this reports experiments show that ASK modulation reaches system failure at the highest noise value, followed by QPSK modulation, and finally both PSK and QAM modulation. There are a number of surprises in these results.

The results imply that ASK modulation is the most noise resistant, and more resistant than PSK. However, this should not be the case as ASK modulation is highly sensitive to noise due to noise mostly affecting amplitude of signals, and the modulation scheme changing amplitude [9]. This is in contrast to the effect of noise on phase, which is significantly less. As there is no amplitude change for PSK, the noise should affect the modulation schemes less, and have a higher noise system failure value.

Another surprise from the data is that QPSK is also implied to have significantly better noise resistance ¹⁸ SK. However, their system failure noise should be very similar, due to the way they both modulate signals is changing the signals phase [10]. Therefore, their system failure value should be very close or identical.

Of the four modulation schemes, QAM having the lowest noise resistance is the only expected result. As it combines amplitude and phase modulation, it should be less noise resistant than PSK and QPSK due to the negatives that come with ASK. In addition, due to 16-bit QAM having more points on its constellation diagram, it is even more susceptible to noise. The higher order QAM that is used, the less noise resistant it is [11].

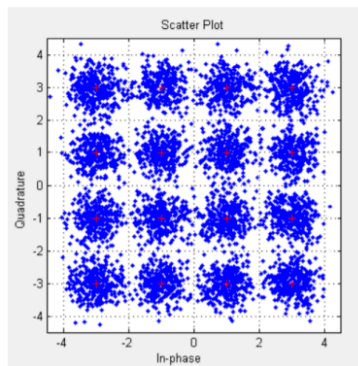


Figure 16. QAM Constellation Diagram [12].

To further investigate the findings of this report, there are several development avenues that could be taken. The first one is to increase the number of simulations for each modulation scheme ¹⁹ this can be done in two ways – the first being increasing the number of BER measurements taken for each noise level. This would increase the reliability of the average BER's and the reliability of the standard deviations, as well as mitigating the influence of any anomalous measurements. The second avenue that could be taken is increasing the number of SNR values measured. In this report the noise was increased in 5db intervals, and reducing the interval number could lead to a more accurate noise value where system failure occurs. Finally, continuing to increase the noise until two noise values in succession reach system failure could help reduce anomalous results and increase the reliability of the data.

Conclusion

In conclusion, this report has investigated the noise resistance by measuring the Bit Error Rate of ASK, PSK, QPSK and QAM modulation schemes in *Simulink*. In this experiment, it has been determined that ASK is the most noise resistant modulation scheme, however research has shown that this is inaccurate, suggesting that some of the data recorded could be anomalous. Despite this, the report has demonstrated an understanding of each of the modulation schemes, showcasing their unique uses, designs and noise resistance. This report has also highlighted the importance of selecting the correct modulation scheme for transmitting and receiving data, depending on the amount of data being transmitted, and how noisy the environment that the data is being transmitted is.

References

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Harry Woollands DSP & Communications Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

69/100

PAGE 1

QM

Abstract - results

Good abstract, although you should include a statement of your results.

Additional Comment

You should quantify your results here. How much better was it than the others?

PAGE 2

PAGE 3

PAGE 4



Comment 1

Other way around. The message signal controls the properties of the carrier wave, such as its amplitude, phase or frequency.

PAGE 5



Comment 2

advanced may have been a better word here

PAGE 6



Comment 3

The filter is not separate from the demodulator - it is part of it.

QM

Citation Needed

Cite Source:

Please use the link below to find links to information regarding specific citation styles:

<https://www.plagiarism.org/article/citation-styles>

Additional Comment

Whenever you make a bold statement like this, it needs to be backed up with a reference.

PAGE 7



Comment 4

Why do you have a 25 sample delay in this when you had a 17 sample delay in your ASK model?
I think this is why your BER values are a little high for this model.



Comment 5

45, 135, 225, 315 degrees, not 0 90 180 270.

This is because when two sinewaves with 0 and 90 degrees phase are added, the resultant is a sinewave with a phase of 45 degrees



Comment 6

What is this for?

You need to describe why each of the blocks is there, and what they do.



Comment 7

Do you mean "the transmission channel", rather than "Additive White Gaussian Noise"?



Comment 8

parallel to serial

PAGE 8



Comment 9

No, the data streams are used to select two of the three constants to modulate each the I and Q channels.



Comment 10

How does it show this?



Comment 11

transmission channel

PAGE 9



Comment 12

These should be discussed when you present the models, not in the results section.



Comment 13

Good

PAGE 10



Comment 14

dB not db



recreate table

You should recreate tables in Word rather than copy and paste them from excel. Recreating them will give a more professional looking result.

PAGE 11



Comment 15

It looks as though you're getting a single bit error without any noise. This should not be happening. I suspect there is an issue with the BER calculator setup in your design.



recreate table

You should recreate tables in Word rather than copy and paste them from excel. Recreating them will give a more professional looking result.

PAGE 12



recreate table

You should recreate tables in Word rather than copy and paste them from excel. Recreating them will give a more professional looking result.

PAGE 13



recreate table

You should recreate tables in Word rather than copy and paste them from excel. Recreating them will give a more professional looking result.

PAGE 14



Comment 16

Different colour lines for each data series would have improved this.



Comment 17

Your PSK error rate seems a little high. Did this model work correctly without the AWGN channel added?

PAGE 15



Comment 18

I suspect your PSK model is not configured correctly



Comment 19

There was nothing stopping you doing this. This would have improved the quality of your data

PAGE 16

PAGE 17



Ref Qual

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.



Refs missing info

Some of your references are missing information. To understand what information should be included, see the university IEEE referencing handbook on the library website.

https://uwtsd.ac.uk/media/uwtsd-website/content-assets/documents/library-and-learning-resources/infoskills/IEEE-eng_v.1.2.pdf

Additional Comment

No access date

QM

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GRADING FORM: SMU GENERIC_SMOSEY

HARRY WOOLLANDS

68.60

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



"Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied."

6.8

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

15

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.

21

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, materials, tools and/or techniques.

18

Very good consideration of the context of the application, with perceptive use of examples, where relevant.
Evidence of some innovation and creativity.

Ensuring all your models were functioning correctly first would have given you more marks here.

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



"Can communicate professionally and, confidently in a suitable format.

Can work professionally within a team, showing leadership skills as appropriate, managing conflict and meeting obligations.

Work is coherent, very fluent and is presented professionally.

"

7.8