

DSP and Comms CV

by Cerys Versey

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SIMULATION OF DIGITAL MODULATION TECHNIQUES



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ACADA5008 [Company address]

Contents

- Contents
- Abstract
- Introduction
- Simulation models
- Results
- Discussion
- Conclusion
- References

Abstract

The following report will discuss the 4 key digital modulation types, ASK, PSK, QPSK and QAM. It will discuss what they do and how to simulate them. It will go on to test and evaluate their noise rejection by using bit error rate calculation [Abstract - results](#) using graphs to help draw conclusions. Whilst establishing key ideas such as QAM's initial linear noise rejection in low SNR and ASK's struggle in high noise environments.

Introduction

Antennas are a key aspect of wireless transmission and form part of the case for the need of modulation schemes. As explained by B.Schweber in "Understanding Antenna Specifications and Operation" [1] antenna frequency and size are linked via wavelength. The higher the frequency the smaller the antenna, and as all digital modulation schemes use higher frequency carriers a smaller antenna can be used reducing not only the size but also in some cases cost.

Another benefit of modulation scheme is spectral efficiency [2]. The main goal of spectral efficiency is to fit as much data as possible into a small portion of the electromagnetic spectrum. A further benefit is there resistance to noise. Noise within RF systems is anything that is not the desired signal [3]. Noise affects different modulation schemes differently with varying severities with more complex modulation schemes generally being more noise resistant.

Modulation schemes have varying levels of sophistication from simple modulation schemes such as ASK and PSK to more complex modulation schemes such as QAM or QPSK.

Amplitude shift modulation consists of mixing a message signal and a carrier typically higher in frequency together. The message signal consists of only 1's and 0's. This results in a mixed signal which contains the message and carrier signal [4].

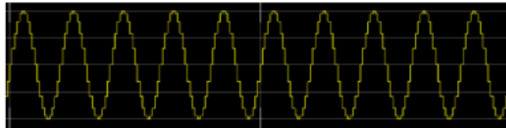


Figure 1 - High Frequency Carrier

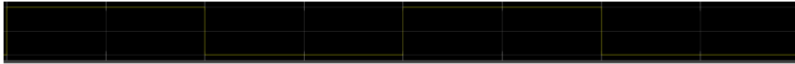


Figure 2 - Lower frequency Message Signal

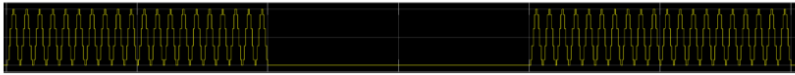


Figure 3 - Mix of Message and Carrier signal

This is then sent down cables or transmitted over the air. To demodulate the signal there are two methods that can be used one is coherent detection and the other is envelope detection. Envelope detection requires the use of a diode, low pass filter and a switch with a threshold condition. Coherent detection requires the use of a copy of the carrier signal, a low pass filter and a switch with a threshold condition [5]. Both types of demodulation allow retrieval of the initial data however coherent detection requires a copy of the initial carrier signal.



Figure 4 - signal output post low pass filter

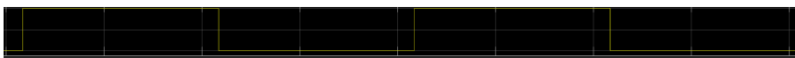


Figure 5 - post switch output

ASK is commonly found in low-frequency RF applications, automated devices in homes and in wireless base stations [6].

PSK or Phase shift keying is very similar to ASK as it only requires the change of one key parameter. A carrier phase is altered as the message amplitude changes [7]. As can be seen below. The two out of phase signals are mixed based of a switch threshold resulting in a phase changing signal which carries the digital signals characteristics. This type of PSK modulation is known as BPSK or binary phase shift keying where the transmission signal is either 0 or 180 degrees out of phase [8].

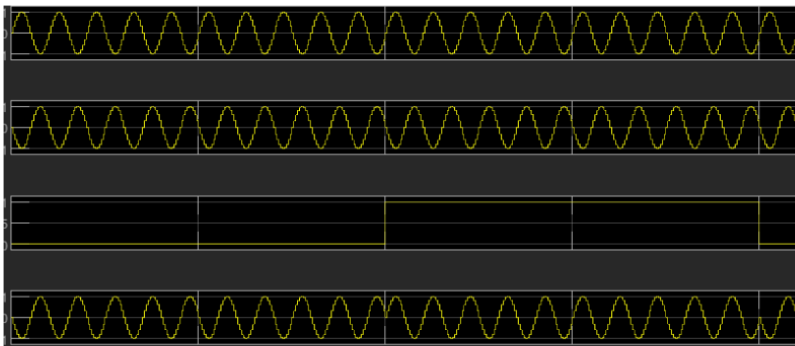


Figure 6 - PSK scope

To demodulate a BPSK signal a similar process is used for that of ASK. A reference signal is mixed with that of the transmission signal, it is then filtered and sent through a switch with a threshold value[9].

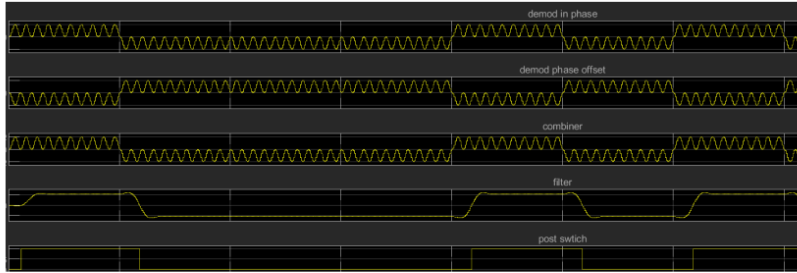


Figure 7 - PSK output

BPSK is commonly used for Bluetooth as well as wireless local networks and telemetry operations [10].

QPSK or Quadrature Phase shift keying takes the same principles as PSK but crucially allows the signal to take twice as many values, therefore requiring twice as many thresholds. This allows QPSK to transmit two bits per symbol allowing the carrier to experience up to 4 phase states. 45, 135, 225 and 315 degrees. This can be done by using I and Q modulation and then summing them together[10.5].

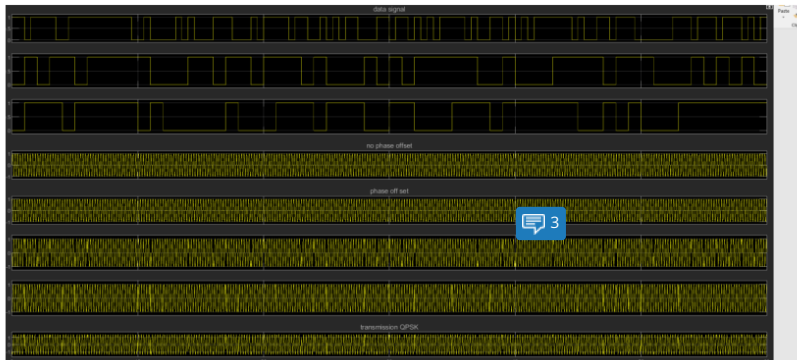


Figure 8- QPSK



Figure 9 - QPSK Output

The above image shows the way multiple phases look within a signal, producing what can look like a jiggered no cohesive signal.

QPSK is more advanced than PSK and so is often used for more advanced uses such as cable modems or used in satellites [11].

QAM

QAM or quadrature amplitude modulation can be considered as a mix of ASK and PSK. It consists of mixing two carrier signals with 2 different amplitudes and then one is then mixed with a carrier with an 90 degree offset and another with no offset this gives 4 total options making it 16 bit QAM.

This can be viewed using a constellation diagram.

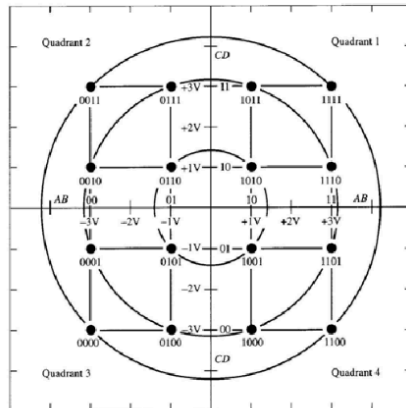


Figure 10 - constellation diagram from AKPAK.COM

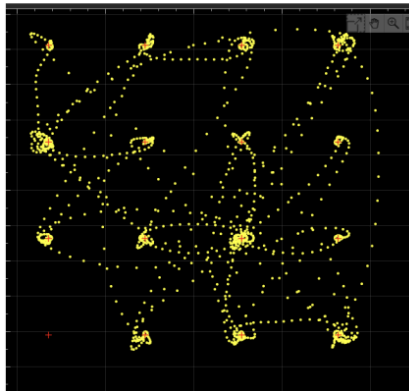


Figure 11 - QAM constellation diagram

Each point on the diagram represents a different, state of each characteristic. The first bit from left to right is I phase, I Amplitude and then Q Phase and finally Q amplitude.

QAM can take more values such as 4,8,16,64 and 256, QAM 256 can be found in 5G technology.

Simulation models

ASK (Amplitude Shift Keying)

To create ASK you initially need a set of data this is done in Simulink using a Bernoulli binary generator and a sine wave to create a message signal. It is then mixed again with a high frequency sine wave. To conduct tests on the modulations noise rejection an AWGN or additive white Gaussian noise block was added. However, it is important to note to prove the model worked with no noise added. As no noise would be added in an ideal environment although not something that would ever be seen practically.

AWGN is a specific style of noise, it has a flat spectral density across the spectrum [12,13]. The term gaussian refers to its shape or more specifically the distribution probability of the samples, which is a normal distribution [14].

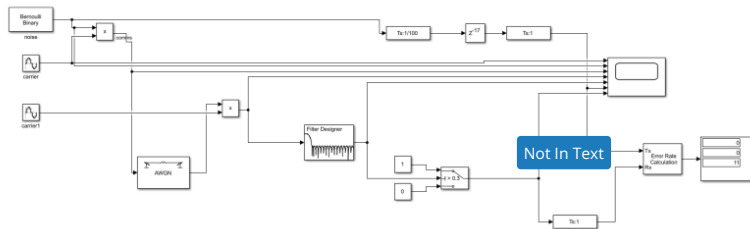


Figure 12 - QAM Modulation simulation

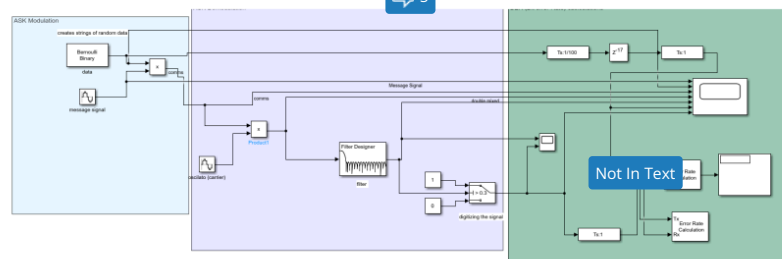


Figure 13 - Colourful QAM Modulation

Blue – data and modulation

Purple – transmitted and demodulation

Green – BER calculation

To demodulate the signal, it is multiplied by a copy of the carrier and passed through a low pass filter and finally a switch for digitising. The filter has been used in all the modulation schemes its parameters can be seen below.

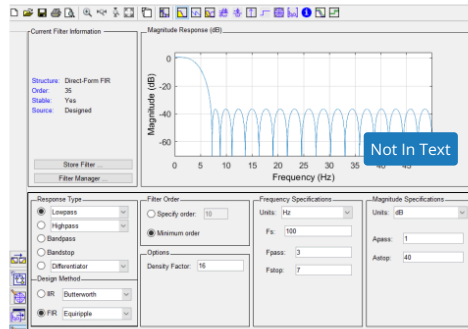


Figure 14 - filter settings

PSK (Phase Shift Keying)

To create PSK Modulation a Bernoulli binary generator is used in conjunction with a threshold switch, when the value is greater than 0 it changes to the other switch condition. Each switch condition is either attached to an in phase or out of phase carrier. This is then sent through a AWGN block. To demodulate the signal it is split into two identical copies. One half is mixed with an in-phase carrier and the other half is mixed with an out of phase carrier. The positive half is then added and the negative half is subtracted which long term adds the signal. As the signal is negative it adds it (- - = +). The negative half isn't required but helps with noise rejection in noisier environments.

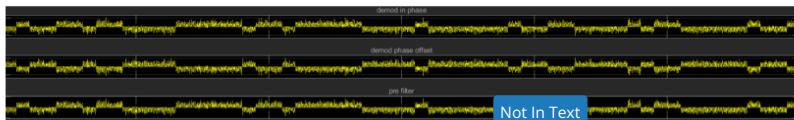


Figure 15 - scope of a section of Demod for PSK

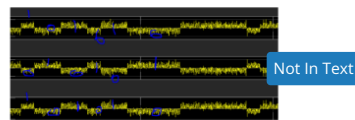


Figure 16- explanation of how PSK Demod works

Another way to understand this process is through the above plot, showing in phase and out of phase elements. As can be seen when the phase plot is high then it will be plotted and when it is zero it won't be.

The signal is then passed through a filter to sharpen it up.



Figure 17- post filter scope

This is then passed through a switch to work as a digitizer.



Figure 18- post switch

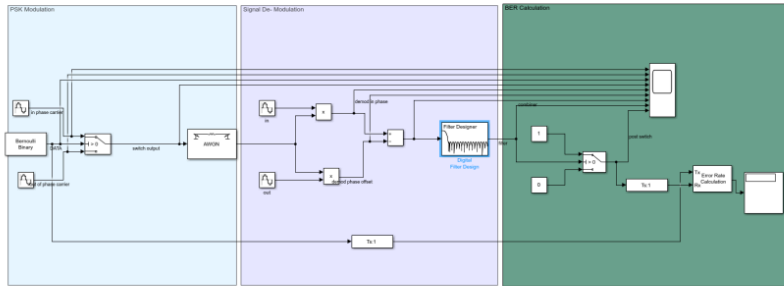


Figure 19 - PSK Simulation model

QPSK

To create a QPSK modulator a **Cap. Error** binary data stream is used to create message data this is then passed through a de serializer this works as a delay for the data [15]. This is then passed into a **demux** 8 which splits the signal down into more parts, one to many. The two parts of the signal are then mixed respectively with an in phase and out of phase character. Another half is then mixed with a negative constant. This is then passed through a threshold switch and mixed together.

To demodulate the signal it is mixed with a in phase and out of phase carrier and filtered, passed through a switch set and a MUX and finally a serializer.

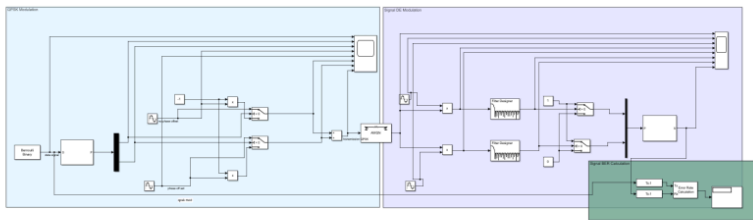


Figure 20 - QPSK Simulation model

QAM

To create a QAM modulator a binary data stream is passed through a De-serializer and then a Demux.

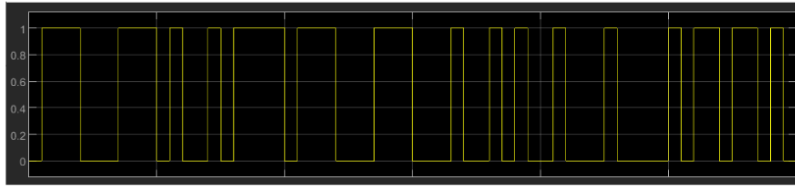


Figure 21 - Bernoulli binary data

This splits the signal into the four characteristic that can be edited, the In- Phase Phase, the in-phase amplitude, the quadrature phase and the quadrature amplitude. The parts are then used for switch conditions. The in-phase and quadrature phase are either outputs a 1 or -1. The in-phase amplitude and quadrature amplitude are then mixed with 3 or 1. This allows for the multiple heights seen in the amplitudes.

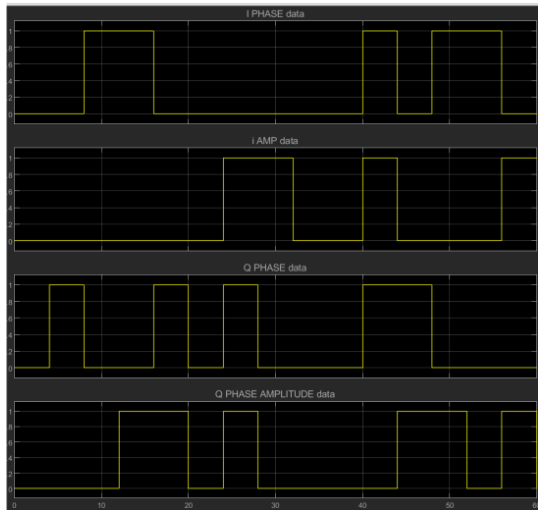


Figure 22 - I and Q post de serializer

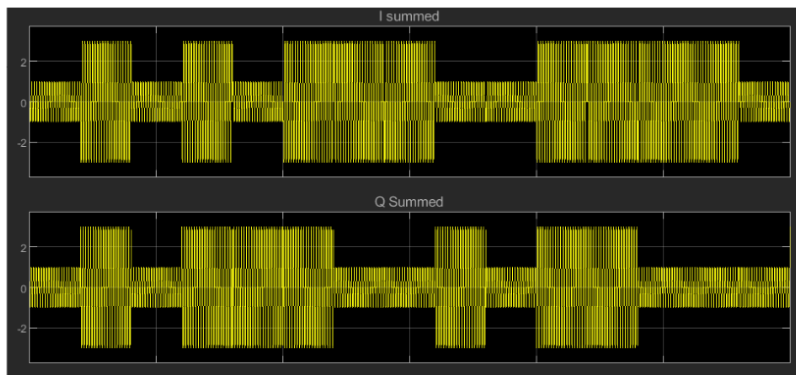


Figure 23 - I and Q Mixed together

To demodulate the signal it is split into two halves half is the mixed with a phase off set carrier and the other half is then mixed with an in phase carrier. This sharpens the signal up and the message signal can start to be seen.

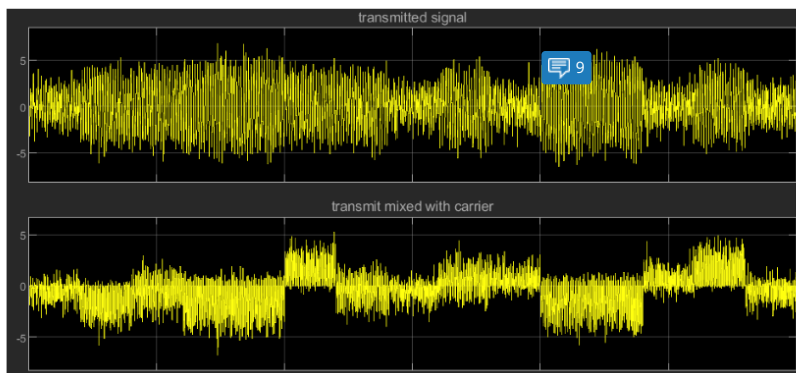


Figure 24 - Transmitted signal with carrier

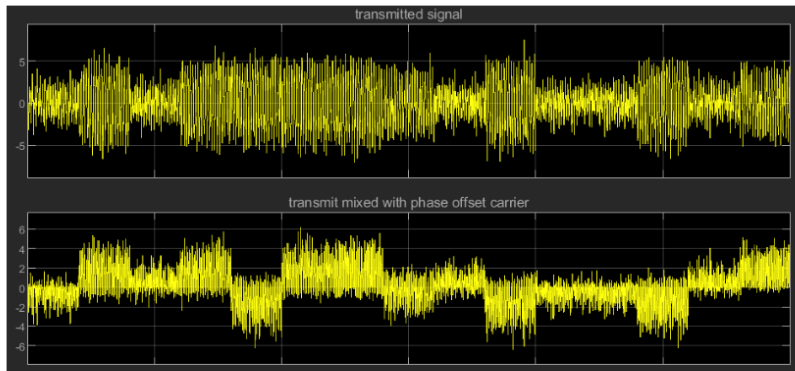


Figure 25 - QAM signal mixed with offset carrier

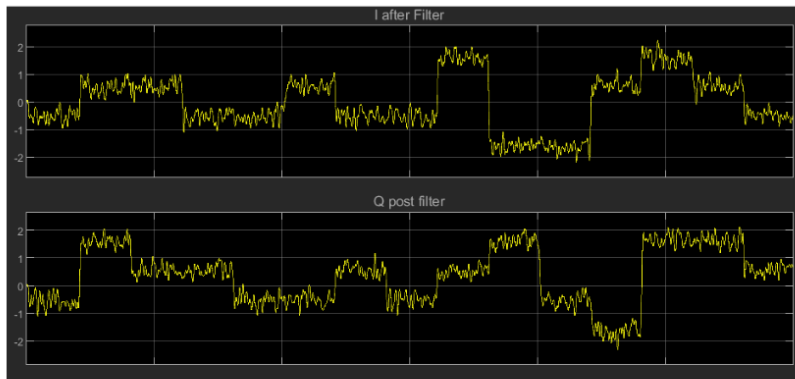


Figure 26 - I and Q post filter

As can be seen from the above figure the filter further sharpens up the signal.

The I and Q signals are then split as previously done . The I and Q streams are put through an abs block to find there absolute value. Depending on the input signal each of the 4 streams outputs a 1 or 0. To recreate the message signal. The 4 elements are then passed through a Mux and a serializer.

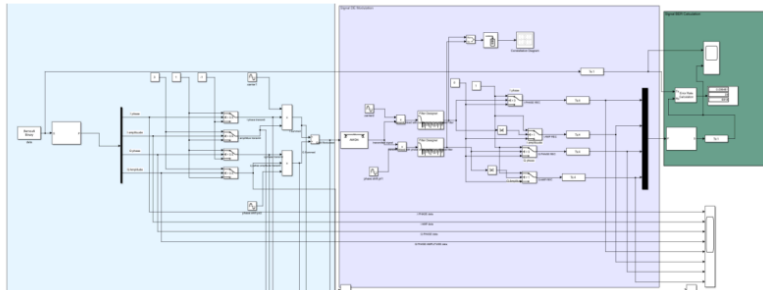


Figure 27 - Full QAM Mod and DeMod

investigation

The goal of the investigation is to find out which modulation technique has the most noise redundancy, this means which one is the least effected by noise. To do this each model was fitted with a AWGN block, in between the modulator and demodulator parts of the design.

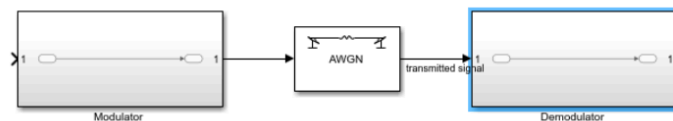


Figure 28 - AWGN Position in the modulation schemes

To work out which was the most resistant to noise BER (bit error rate) was calculated. This is done by comparing the same bit in the sequence before and after transmission. The BER block outputs three values the percentage of data that is wrong as a decimal. The amount of errors and the amount of total data received. It is important to understand what the decimal value means, if it is at 0.5 or above it means that 50% of the data that put through is wrong and as the data is either a 1 or 0 it means it is almost a complete guess and so has failed. Hence why 0.5 has been chosen as the critical fail point. To make sure that comparing BER is fair, each modulation scheme had the same amount of data sent through in each run to keep it a fair test.

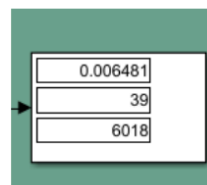


Figure 29 - BER Block

To calculate BER the Tx connection must be made immediately after the Bernoulli binary generator and the RX after the serializer. This is to ensure **Pronouns** comparing the data at its original state and after demodulation. Once this is done you have to check you are comparing the same data bits as certain blocks can add delays. To check if you need to add a delay in add no noise and check the output looks the same then add the Error calculation box and check its output if it is 0 errors there is no delay.

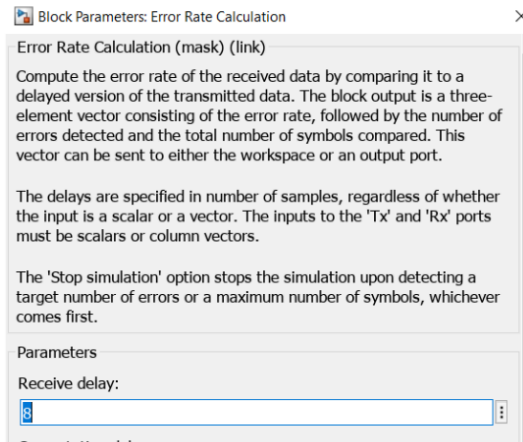


Figure 30 - receive delay

Control variables

Control variables will keep the experiment consistent across all of the modulation schemes.

For this investigation the following are control variables

- Simulation time
- Data rate
- Carrier frequency
- Sample rate
- Data shape (sample per frame)
- Filter design (coefficients)
- Amplitude of the carrier

Independent variable SNR – BER failure.

To make sure it is a complete failure and not just an anomaly a critical failure is when the average of the data for that SNR level is equal to or above 0.5 .

Results

The output from each modulation type was initially plotted to make it clear and easy to read.

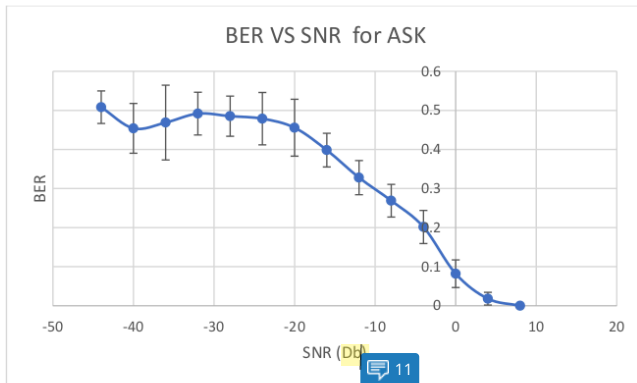


Figure 31 - ASK Graph

The error bars are made by using a standard deviation either side of the data.

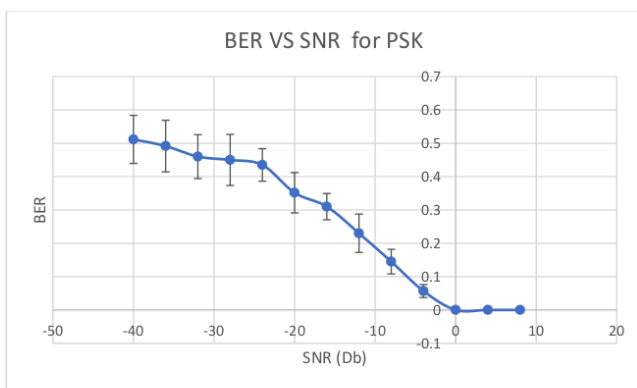


Figure 32 - PSK Graph

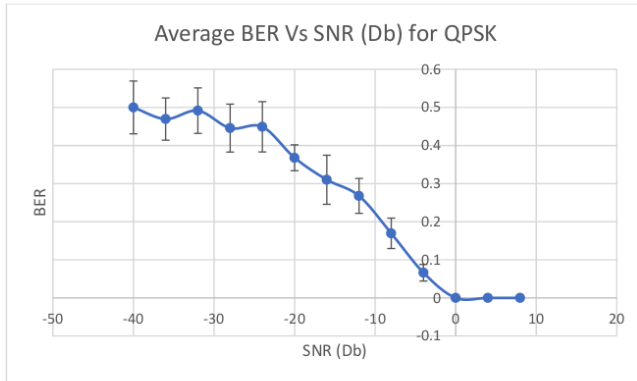


Figure 33 - QPSK Graph

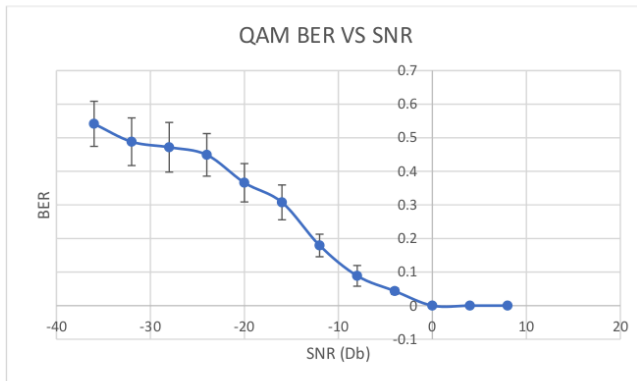


Figure 34 - QAM Graph

Discussion

The results show that all the modulation schemes have a basic level of noise rejection. A set of graphs with and without error bars were made to make the data comparison more accurate.

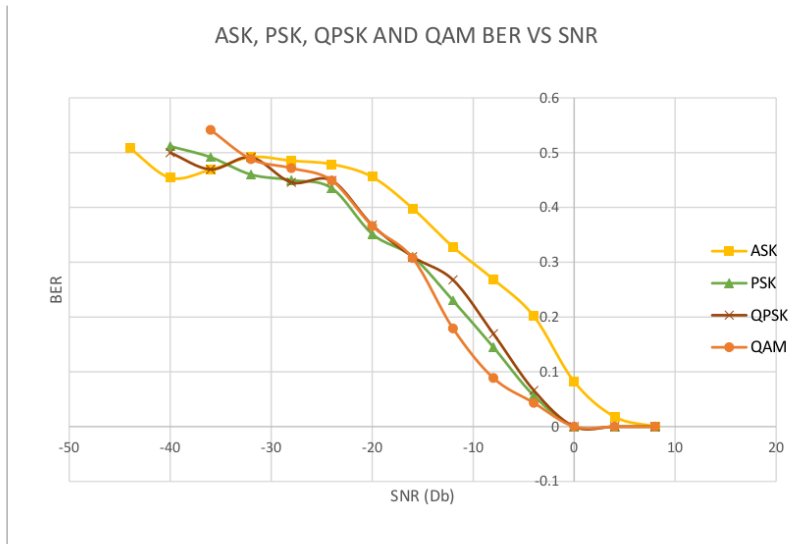


Figure 35 - BER GRAPH VS SNR

As can be seen from the graph ASK has the least noise rejection overall, QAM initially has the least noise rejection but overall across the whole SNR range PSK is the most noise resistant. However, it took ASK the longest to average 0.5. ASK was more reliable overall but has errors much quicker reducing the quality of the signal transmitted.

ASK has the least noise rejection at lower SNR levels with only -4 Db of SNR causing 0.2 BER compared to PSK'S 0.05, QPSK'S 0.066105 or QAM's 0.04.

QAM has the steepest rise in SNR compared to the BER.

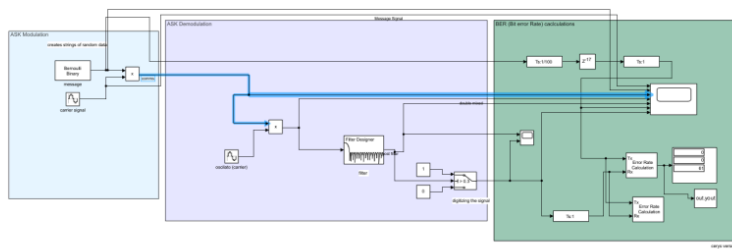
Conclusion

In conclusion in low noise settings QAM is the most resistant however at higher noise ranges PSK, QPSK and QAM are not that dissimilar with QPSK being ever so slightly better. To be able to decisively decide which modulation scheme is most noise resistant. A wide range of SNR is required along with a greater variety of sample times and samples of data to make it a fair test. It is also important to consider the part the filtering takes in the de-modulation and so changing its values could affect the outcomes.

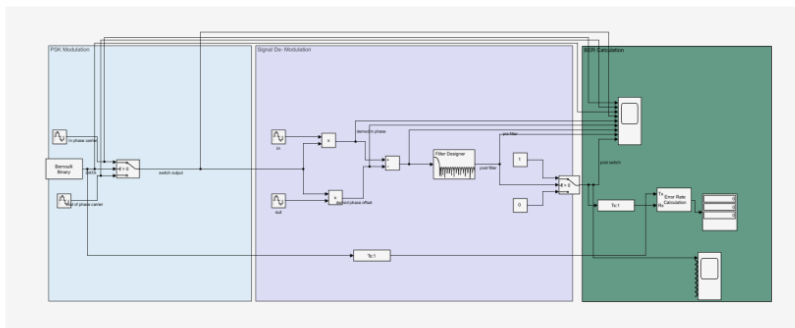
APPENDIX

Modulation schemes with no noise and zero BER

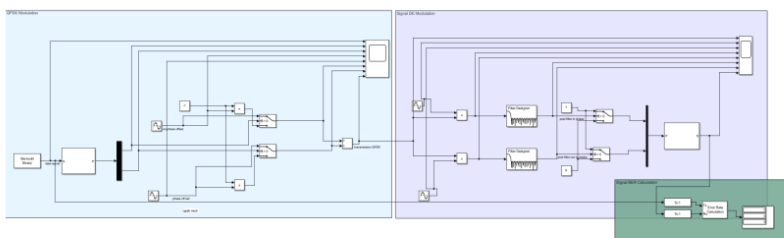
ASK



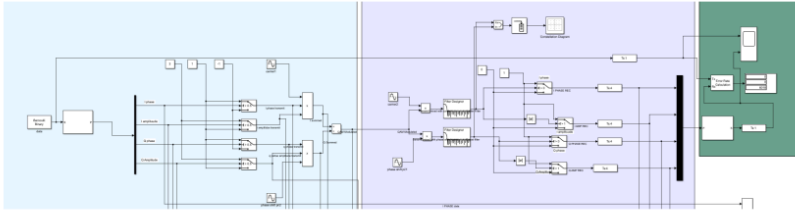
PSK



QPSK



QAM



Refer: 13

- [1] B.Schweber. "Understanding Antenna Specifications and Operation, Part 1." *Digikey*. Accessed: 10/10/2024. [Online]. Available: [Antenna Principles, Part 1 | DigiKey](#) 14
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- [3] "All About Wireless: Noise in RF Systems." *Shure*. Accessed: 10/10/2024. [Online]. Available: [All About Wireless: Noise in RF Systems - Shure USA](#)
- [4] "Practical Guide to Radio-Frequency Analysis and Design." *Digi key*. Accessed: 13/10/2024. [Online]. Available: [Amplitude Modulation in RF: Theory, Time Domain, Frequency Domain | Radio Frequency Modulation | Electronics Textbook \(allaboutcircuits.com\)](#)
- [5] "Amplitude Shift Keying – ASK." *Electronics Coach*. Accessed: 13/10/2024. [Online]. Available: [What is Amplitude Shift Keying \(ASK\)? Theory, advantages, disadvantages and applications of ASK - Electronics Coach](#)
- [6] "Amplitude Shift Keying (ASK) Working and Applications." *EL-PRO-CUS* Accessed: 13/10/2024. [Online]. Available: [Amplitude Shift Keying: Circuit Diagram, Working and Its Applications \(elprocus.com\)](#)
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[9] J.Mark Steber "PSK Demodulation (Part 1)." *The communications edge*. Accessed: 13/10/2024. [Online]. Available: [Cite This Right - Web pages with individual authors \(uwtsd.ac.uk\)](#)

[10] "Phase Shift Keying – PSK." Electronics Coach. Accessed: 13/10/2024. [Online]. Available: [What is Phase Shift Keying \(PSK\)? BPSK modulation, BPSK demodulation, advantages, disadvantages and applications of PSK - Electronics Coach](#)

[11] [Basics of QPSK modulation and display of QPSK signals - Electrical Engineering News and Product](#) Refs missing info (.com)

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[14] "awgn." *Mathworks*. Accessed: 13/11/2024. [Online]. Available: [awgn - Add white Gaussian noise to signal - MATLAB - MathWorks United Kingdom](#)

[15] "Deserializer1D." *Mathworks*. Accessed: 14/11/2024. [Software Help]

16

[10.5] [Understanding Quadrature Phase Shift Keying \(QPSK\) Modulation - Technical Articles](#)

Figure 1 - High Frequency Carrier	1
Figure 2 - Lower frequency Message Signal.....	2
Figure 3- Mix of Message and Carrier signal.....	2
Figure 4 - signal output post low pass filter.....	2
Figure 5 - post switch output	2
Figure 6 - PSK scope	2
Figure 7 - PSK output	3
Figure 8- QPSK.....	3
Figure 9 - QPSK Output	3
Figure 10 - constellation diagram from AKPAK.COM.....	4
Figure 11 - QAM constellation diagram	4
Figure 12 - QAM Modulation simulation	5
Figure 13 - Colourful QAM Modulation	5
Figure 14 - filter settings	6
Figure 15 - scope of a section of Demod for PSK	6
Figure 16- explanation of how PSK Demod works.....	6
Figure 17- post filter scope	6
Figure 18- post switch.....	7
Figure 19 - PSK Simulation model	7
Figure 20 - QPSK Simulation model	7
Figure 21 - Bernoulli binary data.....	8
Figure 22 - I and Q post de serializer	8

Figure 23 - I and Q Mixed together	9
Figure 24 - Transmitted signal with carrier	9
Figure 25 - QAM signal mixed with offset carrier	10
Figure 26 - I and Q post filter	10
Figure 27 - Full QAM Mod and DeMod	11
Figure 28 - AWGN Position in the modulation schemes.....	11
Figure 29 - BER Block.....	11
Figure 30 - receive delay	12
Figure 31 - ASK Graph	13
Figure 32 - PSK Graph.....	13
Figure 33 - QPSK Graph	14
Figure 34 - QAM Graph	14
Figure 35 - BER GRAPH VS SNR	15

DSP and Comms CV

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

71 /100

PAGE 1

PAGE 2

QM

Abstract - results

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

PAGE 3



Comment 1

wave's



Comment 2

shift

PAGE 4



Comment 3

Maybe a bit less data would have made this clearer

PAGE 5

PAGE 6



Comment 4

QAM 4096 is used in the current Wifi - 7 standard. 12 bits per symbol!

QM

Not In Text

You have included a figure without mentioning it in the text. You should refer to the figure in the text, otherwise it is not worth including as the reader will not know what it relates to.



Comment 5

Do you mean ASK?

QM

Not In Text

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PAGE 7

QM

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Comment 6

Which figure do I need to look at?

Direct the reader..

"As can be seen in figure XX, ..."



Comment 7

The filter is there to remove the carrier wave from the message signal.

PAGE 8

QM

Cap. Error

Capitalization



Comment 8

demultiplexer

PAGE 9

PAGE 10



Comment 9

It may have been better to demonstrate this without noise added

PAGE 11

PAGE 12



Comment 10

Check your punctuation. This should be a single sentence with commas separating the list items, not a full stop.

PAGE 13

Pronouns

Do not use pronouns like "you" "we" "they" "I" etc.

PAGE 14



Comment 11

dB not Db

PAGE 15

PAGE 16



Comment 12

You could have done this.

PAGE 17

PAGE 18



Comment 13

Should be before the appendix



Comment 14

You need to include the URL for your sources as hyperlinks cannot be relied upon - especially when printed!

PAGE 19



Comment 15

I'm not sure this is the right link for this reference

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



Comment 16

It is very difficult for me to judge the quality and validity of your reference sources when the URLs are missing.

PAGE 20

GRADING FORM: SMU GENERIC_SMOSEY

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

Please include URLs in your reference lists.

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.

22.5

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, materials, tools and/or techniques.
The context of the application is well considered, with extensive use of relevant examples.
Application and deployment extend beyond established conventions. Innovation and creativity evident throughout

21

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 well, confidently and consistently in a suitable format.
Work is coherent and fluent and is well structured and organised.

6.5

If you discuss an image in the text, tell the reader which image it is. "An example of this can be seen in Figure 5."