

DSP Assignment

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Digital Signal Processing and Communications

Simulation of Digital Modulation Techniques

Embedded Electronic Systems

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Abstract

In this report shift keying methods are modelled in Simulink and messages are transmitted in the presence of increasing noise levels. Model approximations of Amplitude Shift Keying, Binary Phase Shift Keying, Quadrature Phase Shift Keying, and Quadrature Amplitude Modulation have been produced to provide a data set from based on the Signal to Noise ratio and the Bit Error Rate.

The Signal to Noise ratio was increased for each model and the Bit Error Rate was recorded to establish which modulation method was most effective in the presence of increased noise levels – the QPSK model performed best under test. The QAM model produced failed to generate valid comparable results.

Introduction

In this report the aim is to compare digital Signal processing methods in the presence of noise; each of the methods detailed in this report consist of digital data and an analog carrier wave.

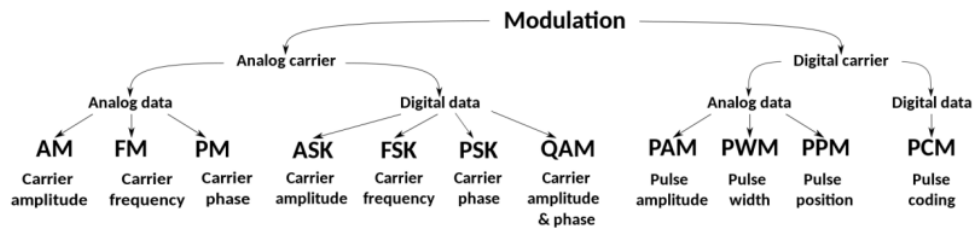


Figure 1 – Modulation Not In Text ^[1]

Amplitude Shift Keying

ASK is a “digital modulation technique in which the amplitude of the carrier wave is altered according to the modulating signal”^[2] in this report the model will be the simplest form of ASK, often referred to as On-Off Keying, utilising a two level amplitude key.

ASK is phase and frequency constant and only the amplitude is varied in accordance with the binary modulating signal. ASK is used for low-speed data transmissions as it is a very simple technique.^[3]

Phase Shift Keying

PSK is much more complex than ASK and more so than Frequency Shift Keying, allowing it to be used for very high-speed data transmission.^[3] PSK is used for “wireless LAN, bio-metric, contactless operations, along with RFID and Bluetooth communications”.^[4]

PSK is a “digital modulation technique in which the phase of the carrier signal is changed by varying the sine and cosine inputs at a particular time.”^[4] It is more efficient and can be simply implemented using a phase-locked loop. The simplest PSK is Binary Phase Shift Keying using two phase states – one in-phase and the other is antiphase from it.^[5]

Quadrature Phase Shift Keying

QPSK is a more advanced PSK technique utilising two carrier waves take four phase reversals such as 0°, 90°, 180°, and 270°. If this technique is further extended, PSK can be done by eight or sixteen values.^[4]

“QPSK is very spectrally efficient since each carrier phase represents two bits of data. The spectral efficiency is 2 bits/Hz, meaning twice the data rate can be achieved in the same bandwidth as BPSK.”^[3] This allows for much faster data rates.

Quadrature Amplitude Modulation

QAM uses multiple phases and amplitudes to transmit more bits per symbol as there are more combinations. 8QAM uses four carrier phases and two amplitude levels to transmit 3 bits per symbol. 16QAM, 64QAM, and 256QAM, all transmit 4, 6, and 8 bits per symbol respectively.

QAM is incredibly efficient, but it is more difficult to demodulate when affected by noise. QAM is used in cable TV, Wi-Fi wireless LAN, satellites, and mobile phone systems.^[3]

Simulation Models

The simulations performed for this report required a message signal to be recovered from a received signal in the presence of additive white gaussian noise. The Bit Error rate was to be calculated for each signal to noise level and this figure was to be compared with other modulation techniques.

Data Parameters:

- Bernoulli Binary Generator – 0.5 probability of a zero, sample time 1, samples per frame
- Carrier – 7Hz frequency, sample time 1/1000
- PSK Carriers 7Hz frequency, I wave and Q wave (pi phase difference)
- QPSK Carriers 7Hz frequency, I wave and Q wave (pi/2 phase difference)

Filter Parameters:

- Sample Frequency – 1000Hz
- Pass Frequency – 6.5Hz
- Stop Frequency – 7.5Hz
- Pass Insertion Loss – 1dB
- Stop Insertion Loss – 60dB

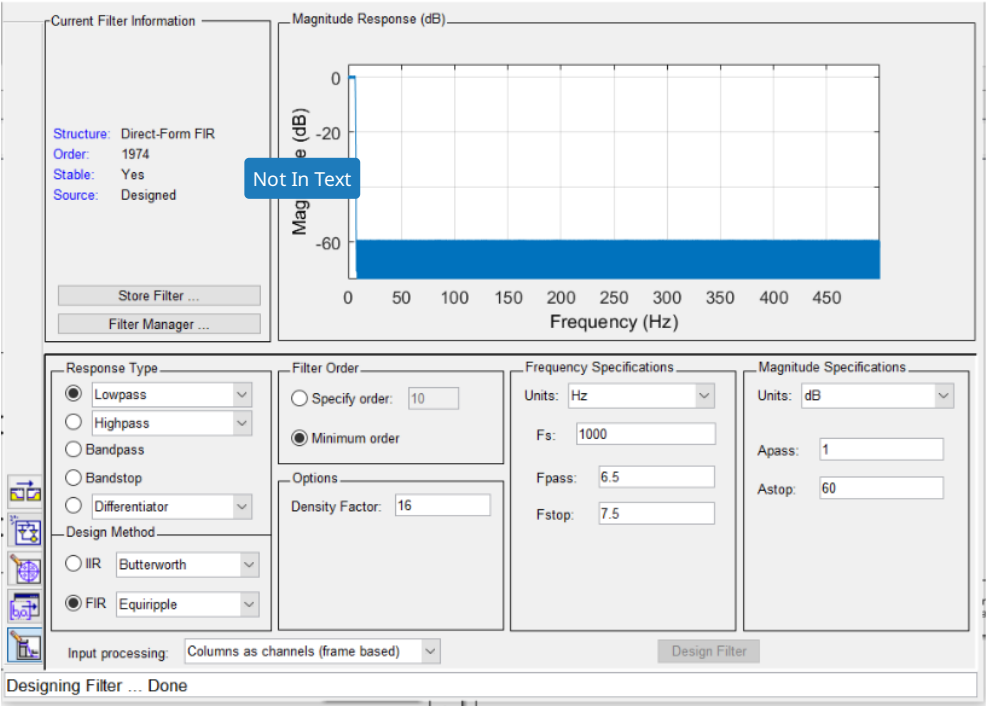


Figure 2 – Digital Filter Design Parameters

Additive White Gaussian Noise

This type of noise is additive in nature, the received signal is equal to the sum of the transmitted signal and noise. This noise is statistically independent of the signal.

White refers to the fact that it has uniform power across the whole frequency band. The Power Density of white noise is constant for all frequencies, and noise power is directly proportional to the equivalent temperature at the receiver (thermal noise).

The probability distribution of the noise samples is Gaussian with a zero mean; using this distribution values close to zero are more probable, while the values further from zero are less probable.^[6]

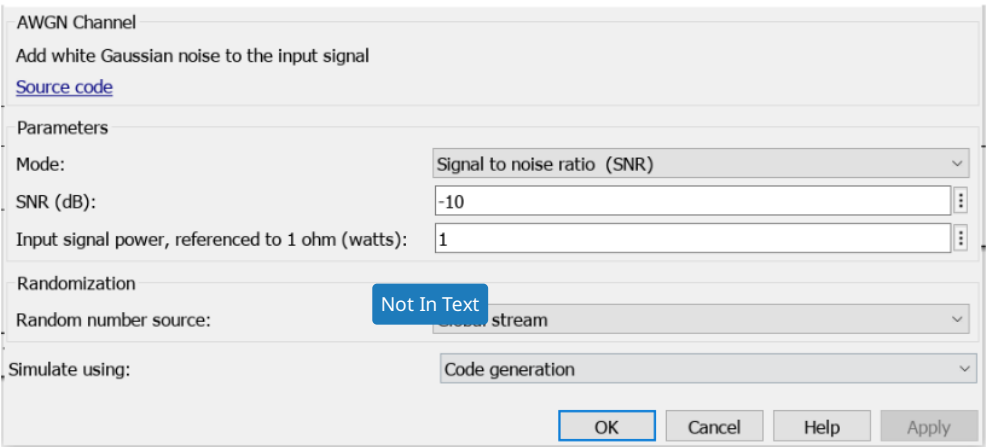


Figure 3 - Additive White Gaussian Noise Channel

ASK

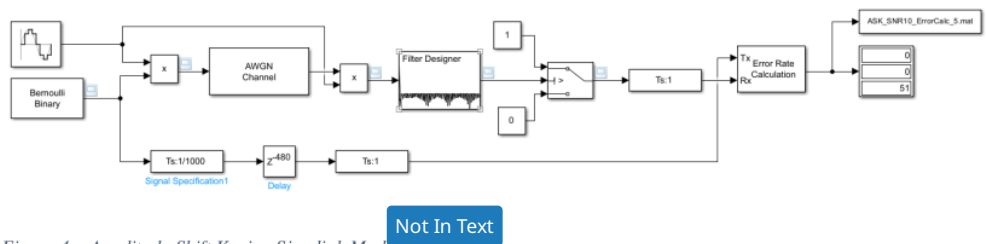


Figure 4 – Amplitude Shift Keying Simulink Model

BPSK

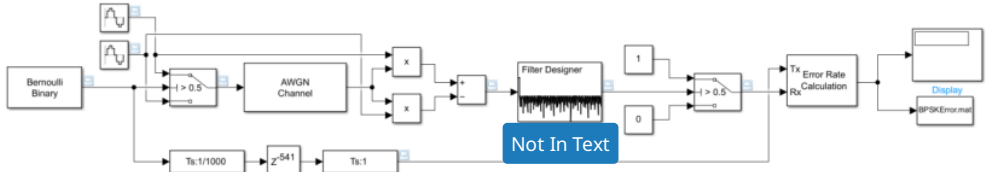


Figure 5 – Binary Phase Shift Keying Simulink Model

QPSK

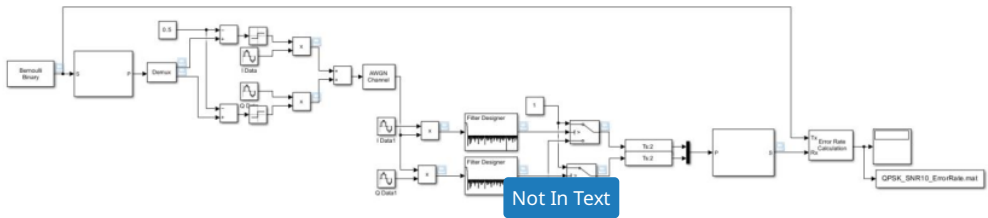


Figure 6 – Quadrature Phase Shift Keying Simulink Model

6

QAM

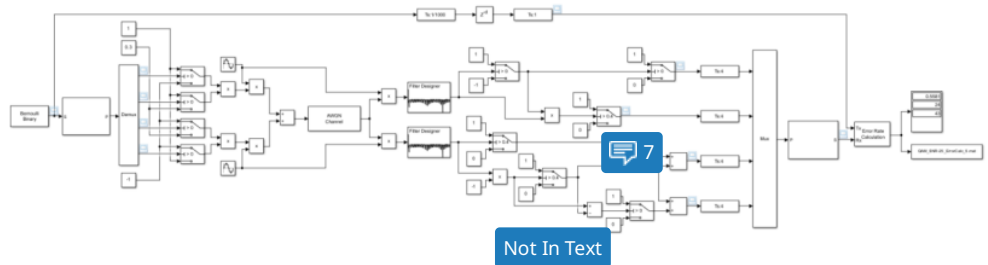


Figure 7 – Quadrature Amplitude Modulation Model

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Results

The following graphs are to display the Bit Error Rate for each Shift Keying method in the presence of Additive White Gaussian Noise.

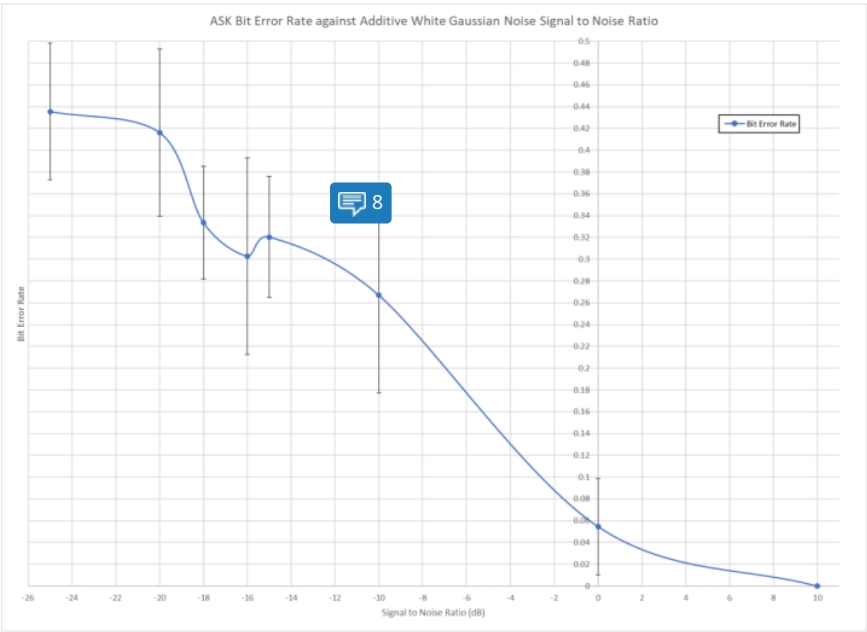


Figure 8 – ASK BER against SNR Graph

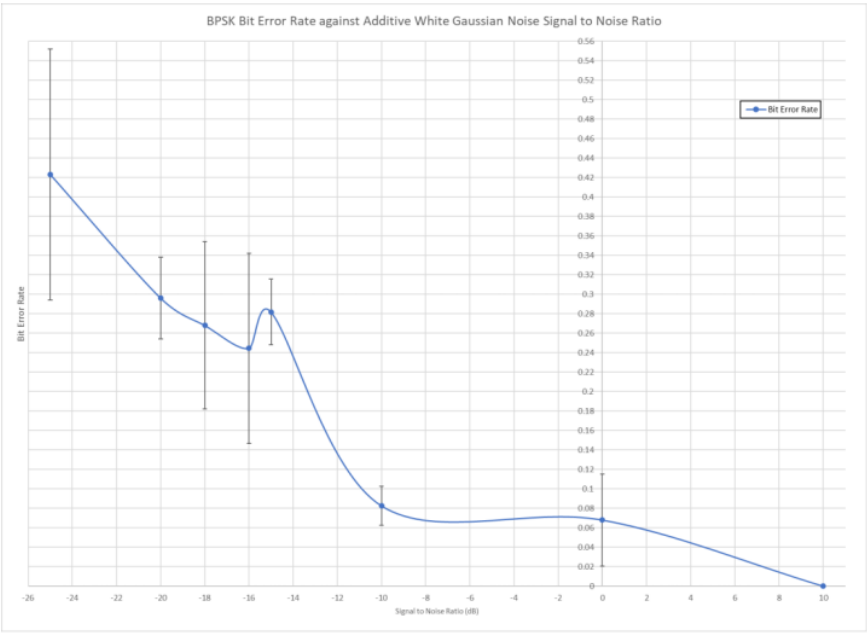


Figure 9 – BPSK BER against SNR Graph

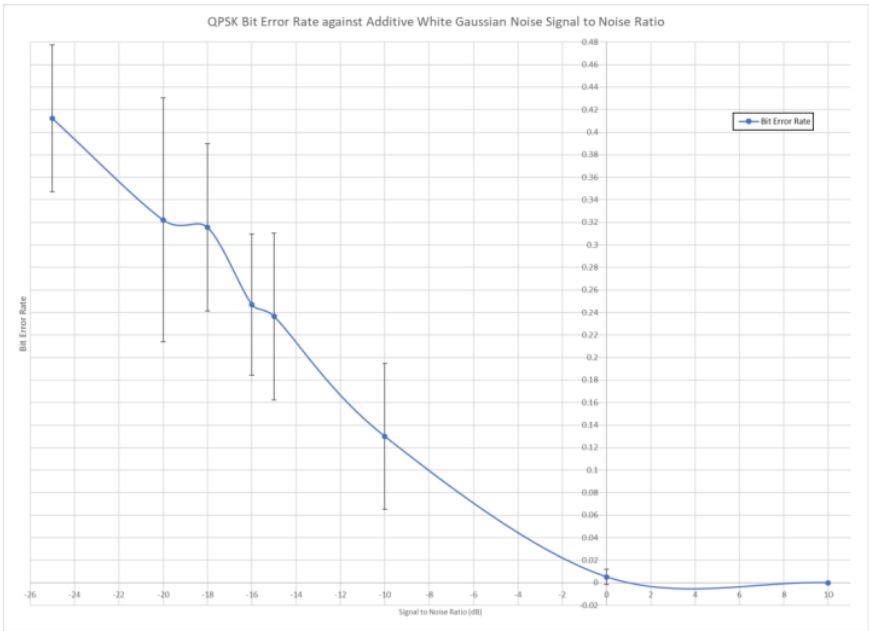


Figure 10 – QPSK BER against SNR Graph

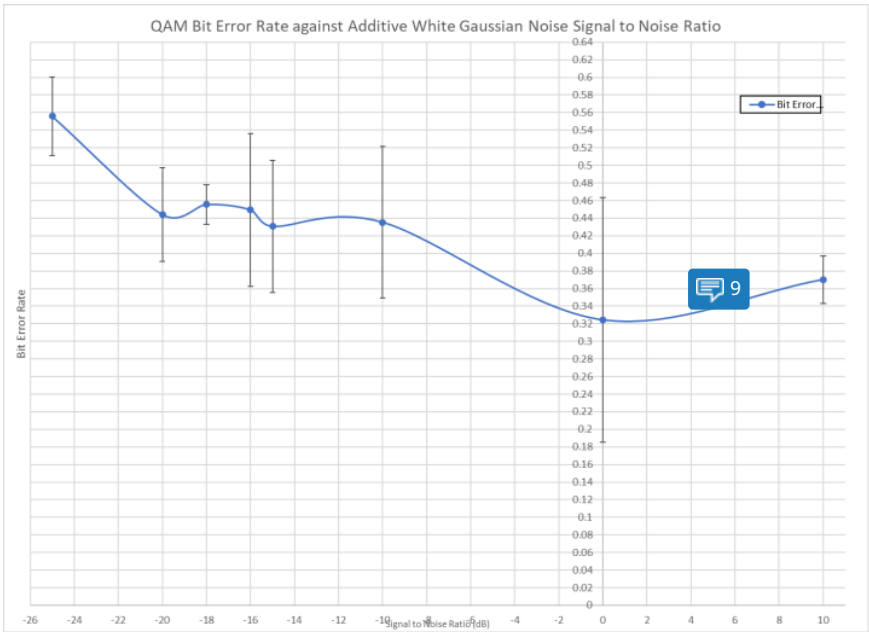


Figure 11 – QAM BER against SNR Graph

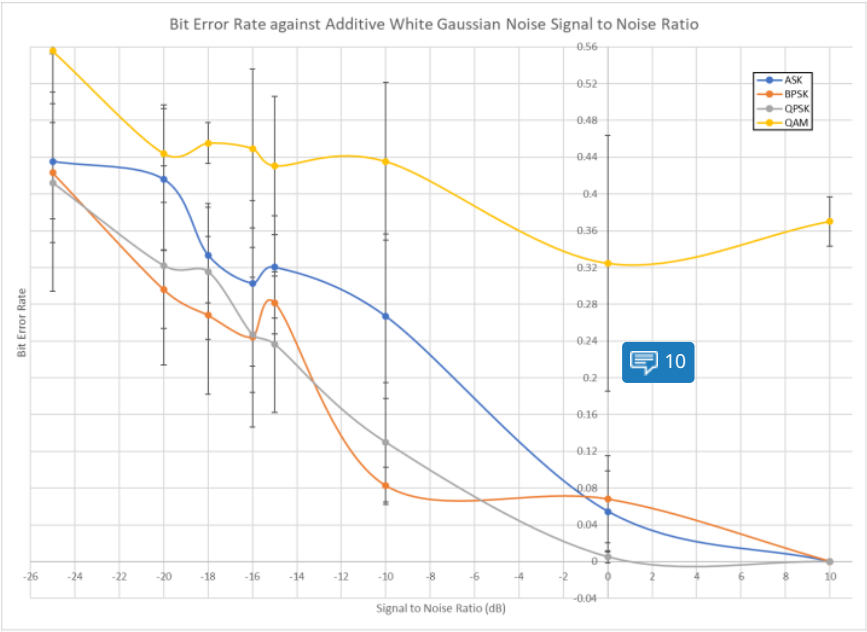


Figure 12 - All BER Trends

Also included are the following graphs which display the Total Symbol Errors for each Shift Keying method in the presence of Additive White Gaussian Noise.

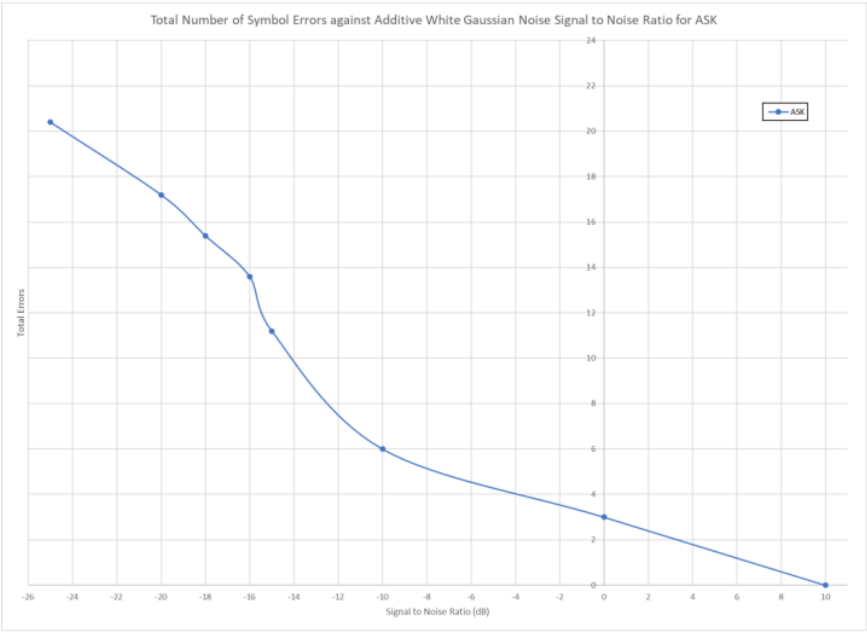


Figure 13 – ASK Symbol Errors against SNR Graph

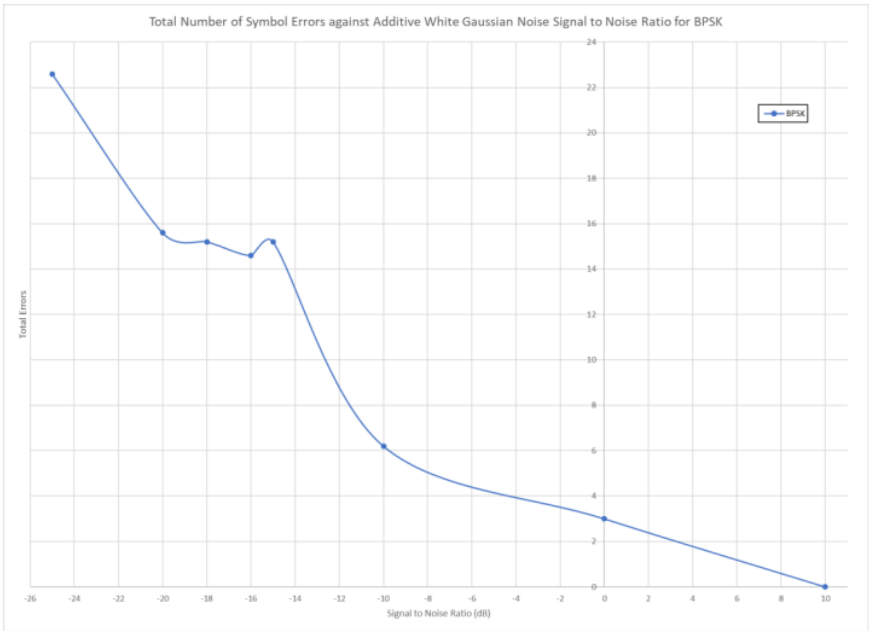


Figure 14 – BPSK Symbol Errors against SNR Graph

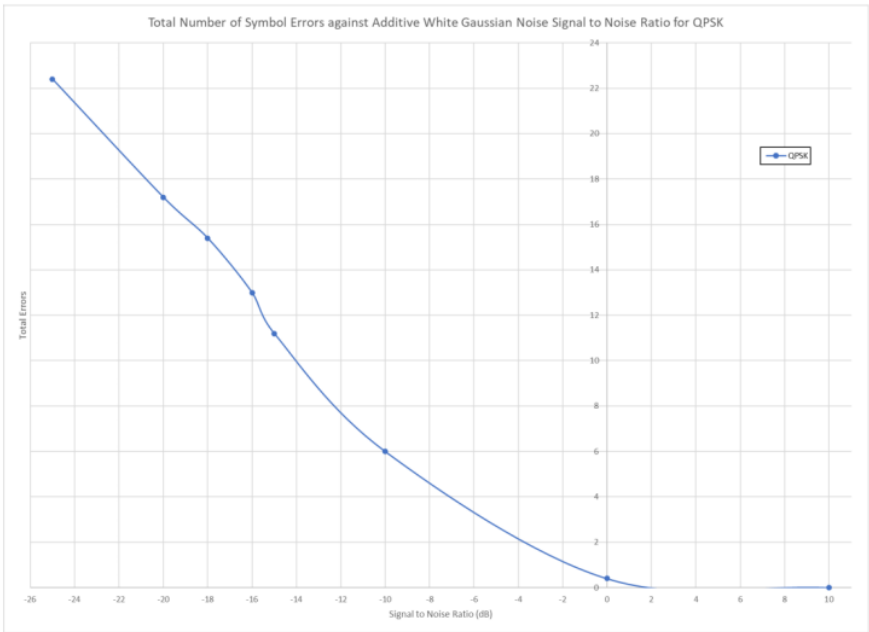


Figure 15 – QPSK Symbol Errors against SNR Graph

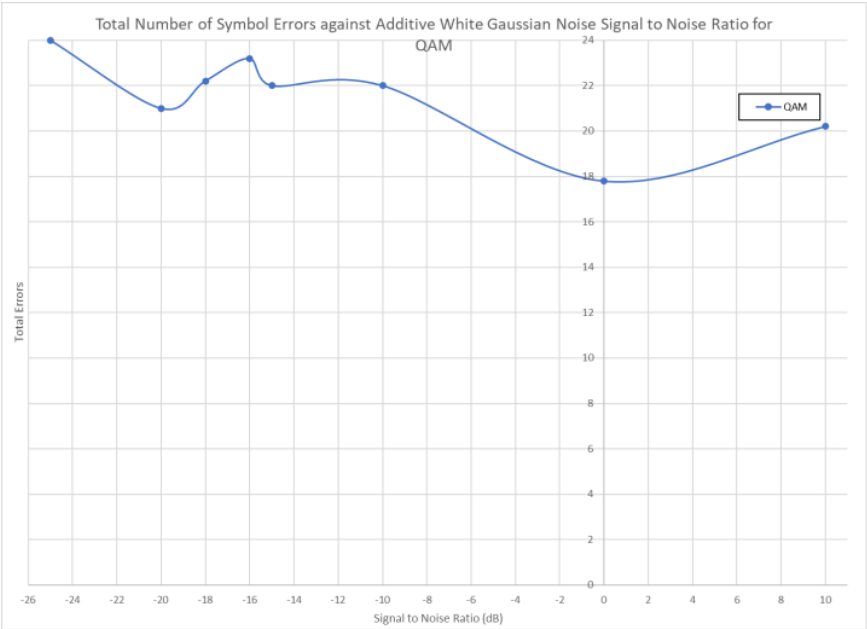


Figure 16 – QAM Symbol Errors against SNR Graph

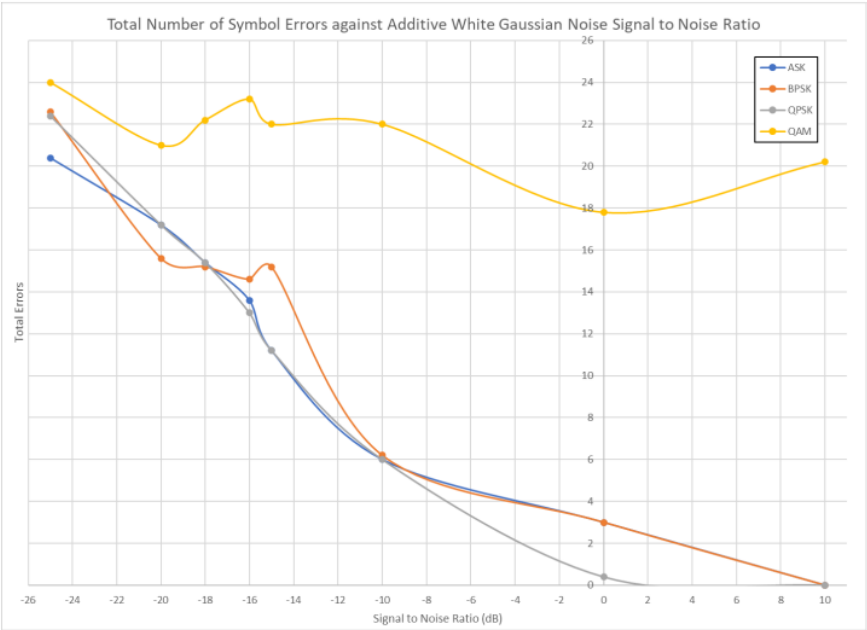


Figure 17 – All Total Symbol Error Trends

Discussion

The Error Rate Calculation block produces three data values against the timestamp of the simulation, the three values are Bit Error Rate, Number of Errors, and the Total Symbols sent (a cumulative value). The BER is a value between 0 and 1 to give a percentage error for each symbol transmitted and the Number of Errors is a cumulative integer total which increases for each error identified.

The simulation was set to run for 50 seconds so that it produces a large number of data points to ensure the data collected is representative. Due to running the simulation for 50 seconds each run produces 51 data points therefore, in order to utilize the data from the Error Calculation Block an average was produced from the 51 data points so that a single data point could be used with the single SNR Value.

The simulation was run 5 times so that an average could be produced for each modulation method. The Signal to Noise ratio values chosen were 10, 0, -10, -15, -16, -18, -20, and -25dB. These values were chosen because the **modulating signal is digital and therefore less susceptible to noise**. In this report a failed transmission is considered to be a BER of 0.5 as the modulating signal is digital, this is because 0.5 BER is effectively the same as guessing the transmitted signal.

Both the ASK and BPSK graphs display a dip in BER at -16dB – from 0.32 to 0.3 and 0.28 to 0.24 respectively – which is not present in the QPSK graph as at the same SNR the results lie at ~0.24. All of the methods started with a BER of 0 at 10dB, at 0dB the BER for each method rises to above 0 – ~0.06 for both ASK and BPSK, and ~0.01 for QPSK – from -10dB SNR the variation in the methods becomes more apparent with ASK rising to almost 0.27 BER, BPSK rising to ~0.08, QPSK rises to ~0.13.

At -25dB ASK has a BER 0.435 compared with BPSK at 0.423 and QPSK at 0.412 which suggests that each modulation method breaks down similarly from this SNR onwards. Between -15dB and -25dB each graph trends differently, however ASK & BPSK both display a sudden dip in BER between -15dB and -16dB.

The QAM graphs that I had produced indicate that the model was not working as the BER was consistently above 0.32 even though the results should have followed a similar pattern to the other Shift Keying Techniques. Despite QAM failing between -20dB and -25dB it still produced the rise and fall in data that is present in the ASK & BPSK graphs.

I have included the total number of symbol errors for each technique to show another metric from the error calculator function in Simulink. As shown in the graphs above the ASK & QPSK techniques have a similar typical progression while BPSK & QAM have very irregular progressions which is likely due to the stochastic nature of the Binary Generator; the zero probability of the binary generator was set to 0.5.

The total symbol error value shows the average error for each technique at each SNR value. Based on the total number of symbols transmitted and the number of errors identified the more effective techniques can be isolated from the less effective more quickly. Once again, the QAM data is not representative of the technique due to errors within the Simulink model.

Conclusion

In this experiment, it has been determined that QPSK is the most effective Shift Keying Modulation technique as it has the lowest Bit Error Rate and generally has the lowest Symbol Error for each SNR. This is due to the method of modulation used to produce QPSK, by having each element represent two bits of data the system is able to use part of the data to check the incoming signal.

The QAM model did not work and therefore failed to produce data that aligned with the other techniques. This method should have been the most effective due to its much more robust modulating method. ASK can be considered to be the worst technique to transmit the symbols due to the trend displayed in figure 8 and the fact that the BER was consistently higher than BPSK & QPSK.

BPSK varied much more than QPSK throughout the simulations the BER sat either side of the QPSK trendline the whole way along the and the total symbol errors were typically higher than the values for QPSK with a much more varied trend than ASK and QPSK.



References

- [1] 'Amplitude-shift keying', *Wikipedia*. Jun. 23, 2023. Accessed: Oct. 13, 2023. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Amplitude-shift_keying&oldid=1161574964
- [2] R. Y, 'What is Amplitude Shift Keying (ASK)? Theory, advantages, disadvantages and applications of ASK', *Electronics Coach*. Accessed: Oct. 13, 2023. [Online]. Available: <https://electronicscoach.com/amplitude-shift-keying.html>
- [3] L. Frenzel, 'Understanding Modern Digital Modulation Techniques', *Electronic Design*. Accessed: Oct. 13, 2023. [Online]. Available: <https://www.electronicdesign.com/technologies/communications/article/21798737/electronic-design-understanding-modern-digital-modulation-techniques>
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- [5] '2.13: Phase Shift Keying Modulation', *Engineering LibreTexts*. Accessed: Oct. 13, 2023. [Online]. Available: [https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_I_-_Radio_Systems_\(Steer\)/02%3A_Modulation/2.13%3A_Phase_Shift_Keying_Modulation](https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_I_-_Radio_Systems_(Steer)/02%3A_Modulation/2.13%3A_Phase_Shift_Keying_Modulation)
- [6] Q. Chaudhari, 'Additive White Gaussian Noise (AWGN)', *Wireless Pi*. Accessed: Oct. 13, 2023. [Online]. Available: <https://wirelesspi.com/additive-white-gaussian-noise-awgn/>

Ref Qual

DSP Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

56/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

modulation techniques



Comment 2

repetition



Comment 3

Good abstract although you should always include a statement of your results

PAGE 4



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.

PAGE 5



Comment 4

This is a very long filter. By setting the pass and stop frequencies further apart you would have made a shorter filter (fewer coefficients, lower order). This would reduce the delay in processing the signal in your demodulators



Comment 5

What about the number of simulation runs you'll do, or the length of the data you're sending?

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.

PAGE 6

QM

Not In Text

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QM

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PAGE 7

QM

Not In Text

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Comment 6

These systems are not explained in your text. You need to explain HOW your systems work.



Comment 7

These switches look wrong. You are only trying to pick out 4 amplitude levels (2x positive and 2x negative) on each channel. I think this is why your system didn't work well.

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.

PAGE 8



Comment 8

What are your error bars set to?

They are there to indicate the confidence you have in the mean value of the data. - Small error bars = high confidence, large error bars = low confidence. You have large error bars indicating low confidence in the data. Doing more simulation runs would have improved this.

PAGE 9



Comment 9

I suspect there is something wrong with your QAM model. I think it is to do with the switching in the demodulator

PAGE 10



Comment 10

Is it worth having the other graphs when this graph shows more than the others? Not only does it show what the other graphs show, it also shows the relative performance of each system by allowing the reader to compare each data set.

PAGE 11

PAGE 12

PAGE 13



Comment 11

This is a bold statement which should be referenced.



Comment 12

Your discussion has not gone far beyond the observational. You should be asking "Why am I getting *these* results?" "Why do the systems perform the way they do?" You need to explain your results, not just describe them

PAGE 14



Comment 13

Good description, but WHY did this happen?

PAGE 15



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.

GRADING FORM: SMU GENERIC_SMOSEY

JACK HEEKS

55.80

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.
You need to be using HIGHER QUALITY sources - look at textbooks, journal articles, course texts etc.

5.7

KNOWLEDGE & UNDERSTANDING

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



Knowledge is accurate with a good understanding of the field of study.
You need to explain HOW your systems work, only then will you be able to explain WHY they don't work well in the presence of noise.

10.8

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.



"Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument.

Please see comments in your text regarding your analysis.

16.2

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A good and appropriate application of standard methods, materials, tools and/or techniques.

Good appreciation of the context of the application, with some use of examples, where relevant.

16.8

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.

Generally a good writing style, a little repetitive in

6.3

places. Good structure.

There is no point in putting a diagram in your report if you don't talk about it.