

ACDA5008 Report
Simulation of Digital Modulation Techniques

Leon Scammell

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Abstract

The goal of this study was to produce four different variants of modems on a circuit design software called Simulink on Matlab, then test and compare their resistance to noise. Noise causing the output signal to not match the input to the modem, meaning the transmission device has not functioned as required. To do this, noise was added to a simulated transmission channel with the signal to noise ratio being gradually reduced until the bit error rate reaches 0.5. 0.5 is considered here to be failure of the device. The SNR that caused the device to reach failure was noted and the devices were compared to analyse their resistance to noise. The results are shown in the graph below (figure 1)

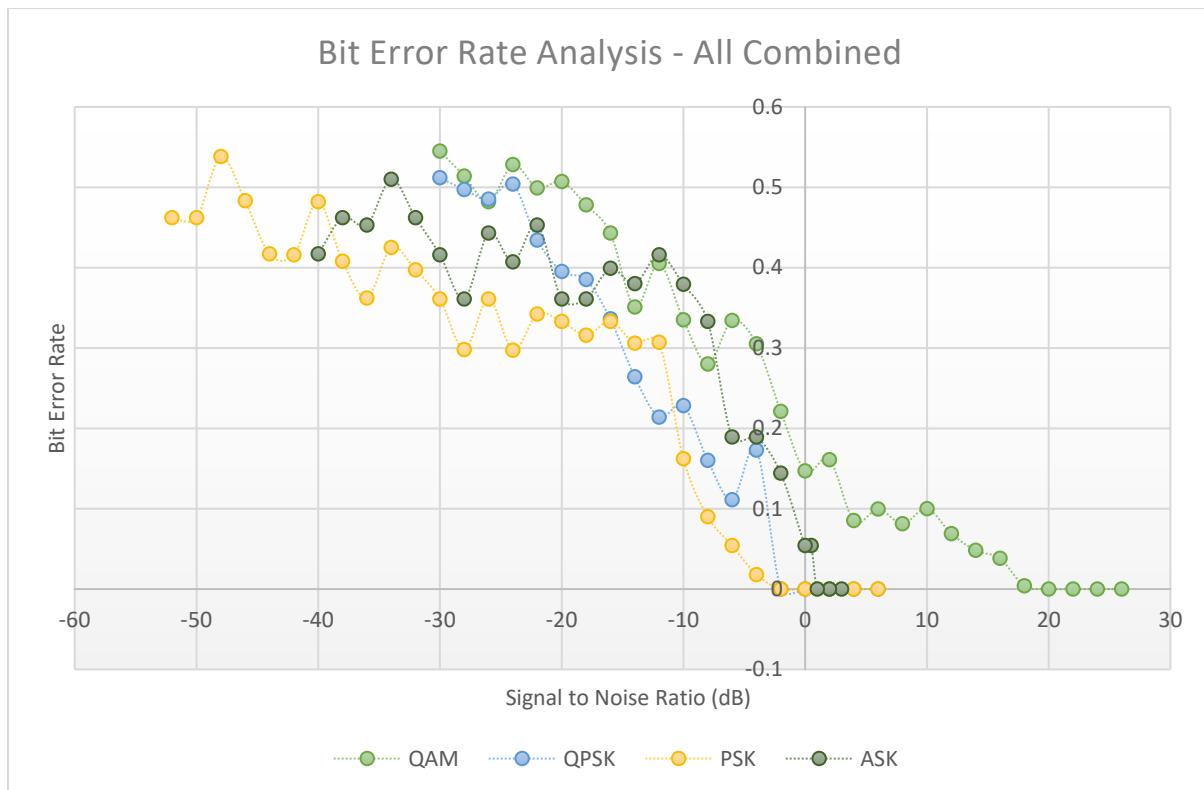


Figure 1 Bit Error Rate Analysis - All Combined

The QAM was most effected by noise, with QPSK being second, then ASK, and finally PSK being the most resistant to noise. IT can be seen that the greater the bandwidth that can be transmitted, the more susceptible it is to transmission noise.

Introduction

Communication systems can be summarised with three main phases, transmitter, transmission channel, and receiver. For a digital signal to be transmitted, it must be converted

[1]

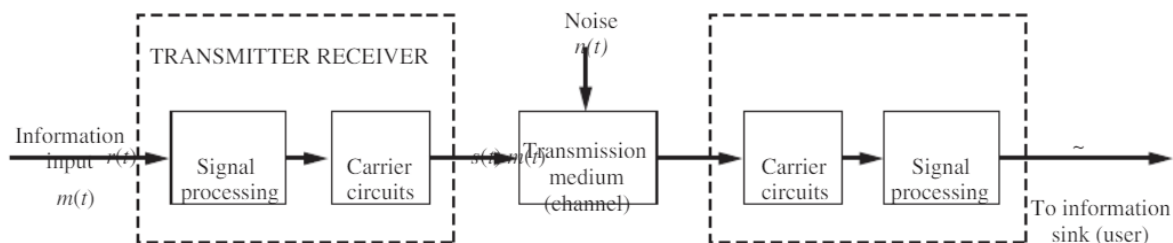


Figure 2 Modem Design

The digital output signal must replicate the digital input signal for the device to function as required, the ratio of errors to good signals is called the bit error rate. The bit error rates when the circuits are exposed to decreasing signal to noise ratios (meaning increasing noise when compared to the signal) are to be analysed in this report to determine the performance of each modem device. The higher the error rate is compared to the accurate data, the more sensitive a modem is to noise on the transmission media. Therefore the more inaccurate the output signal will be when compared to the input signal. Four types of communication systems will be tested, including the following:

- ASK - amplitude shift keying
- PSK - phase shift keying
- QPSK – quadrature phase shift keying
- QAM - quadrature amplitude modulation

It is expected that the ASK will have a worse bit error rate than the PSK due to the distance between each potential signal when seen on a constellation graph. QPSK should then be slightly worse than PSK as there are more signals being transmitted which if the noise is severe enough, can interfere with each other. Then finally QAM which has the most signals being transmitted, and is expected to fail at the highest SNR. This is because the available bandwidth of the system is being increased, which allows signals to be miss interpreted as being another signal due to the noise affecting the amplitude or phase angle.

Method

Design

So the modems being produced were designed and tested on the software called Simulink, which is a part of Matlab.

The four circuits that are being analysed and their bit error rates evaluated are the following:

- ASK - amplitude shift keying
- PSK - phase shift keying
- QPSK - quadrature shift keying
- QAM - quadrature amplitude modulation

ASK Design Procedure

Amplitude shift keying modulation or ASK for short works by altering the amplitude of a carrier wave depending on the digital input signal being sent. When the digital signal is 1 or on, the amplitude increases to the value of the carrier wave, and then when the signal is 0 or off, the amplitude is reduced substantially so that this digital signal can be transmitted via a transmission line. This carrier wave must then later be attenuated with the use of filtering to square the signal back into its original binary digital signal form with 1 and 0. [2] This occurring in the order – digital input, modulation, transmission, demodulation, digital output.

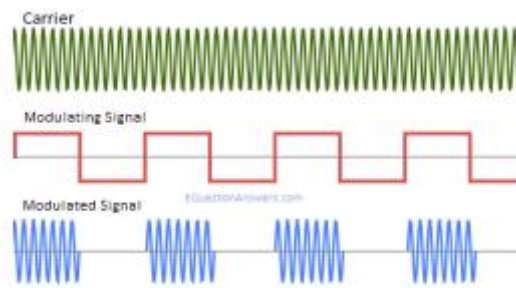


Figure 3 [2] ASK Signal

Modulation Phase

The carrier frequency was added with a sine wave generator, set to 5Hz ($2\pi \cdot 5$) and sample time of 0.02. The random digital input was produced via a bernoulli binary generator.

Added a product block to combine the carrier wave and digital signal.

A switch added with a threshold of 0.5.

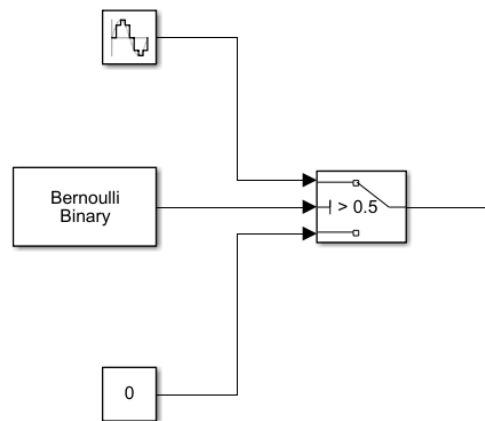


Figure 4 Modulation Phase

Communications Channel

The transmission channel is being replicated with the use of an additive white gaussian noise block (AWGN) (figure 5). The mode of the AWGN channel is set to signal to noise ratio.

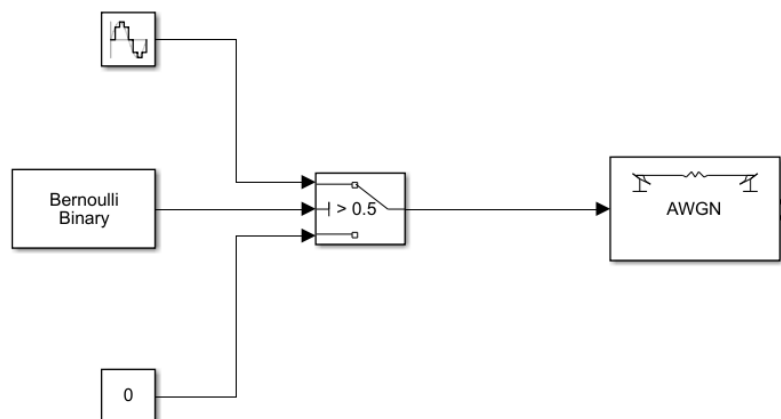


Figure 5 Communication Channel

Demodulation Phase

The demodulation phase consists of another identical sine wave generator, and a product block, which is shown in figure 6.

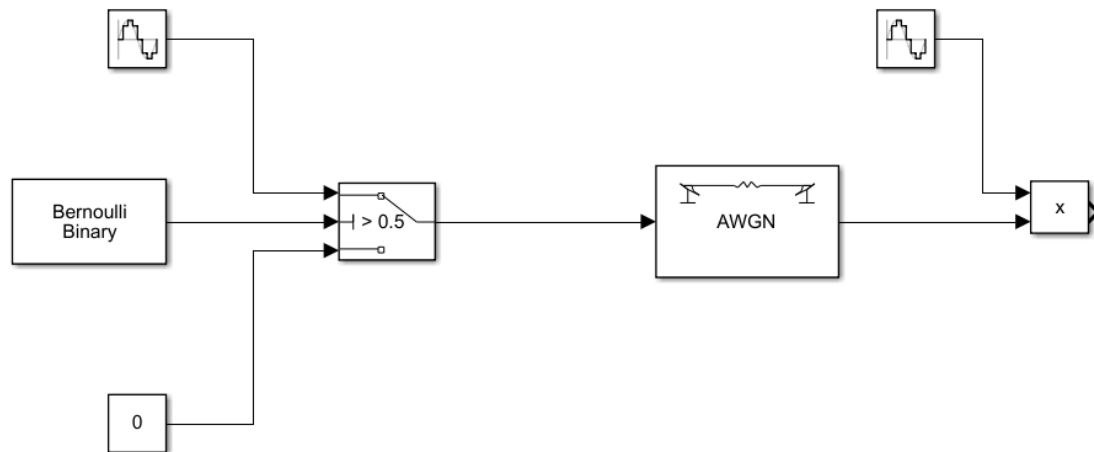


Figure 6 Demodulation Phase

Filtering

A digital filter design block set as a low pass filter was implemented. Sample rate was set as 50Hz. Pass frequency was set at 1Hz and stop frequency set at 2.5Hz.

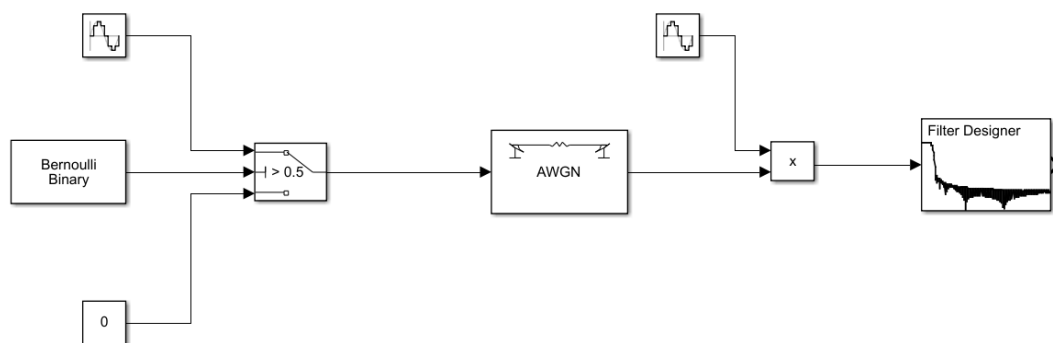


Figure 7 Filtering

A 21 order filter was chosen as this seemed to have a good tradeoff between attenuation and minimum delay.

To change the signal back into a digital signal, a switch was used. Then two constants, being 1 and 0 to replicate on and off signals. Output now mostly resembles the input signal with some shift present.

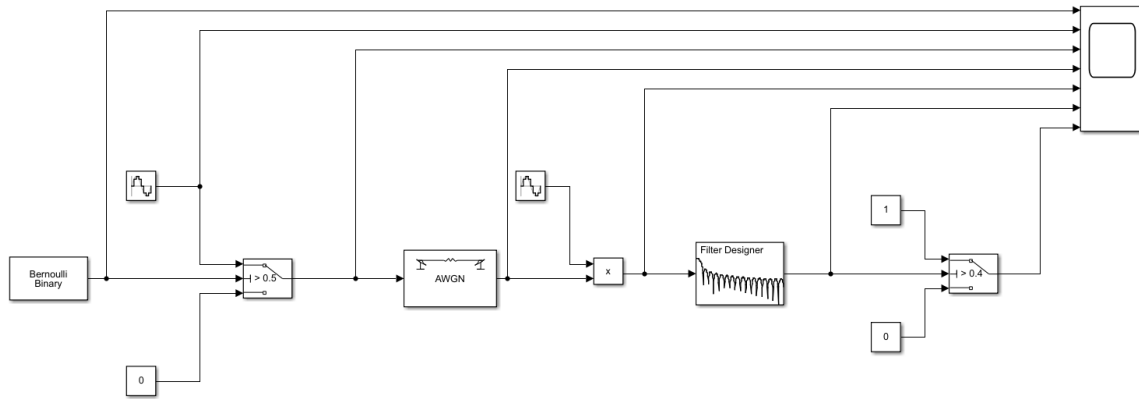


Figure 8 Filter and Switch

Bit Error Rate Calculating

An error rate calculation block and a display screen were implemented (figure 9), using transmitted and received signals.

0dB is equal noise to signal amplitude. Anything below 0.5 is a failure of the system as there is a 50/50 chance of guessing it correctly, which is not good enough for reliable data transmission.

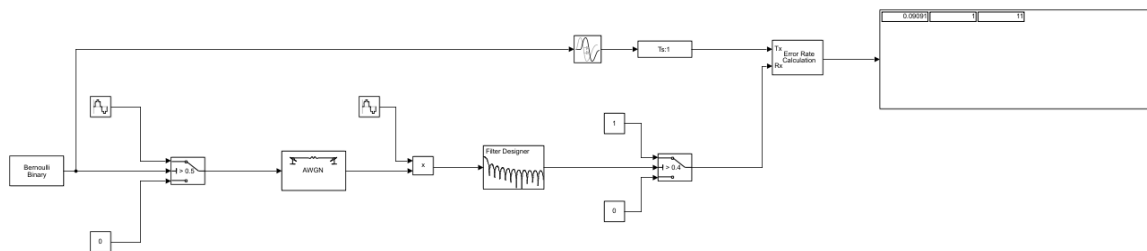


Figure 9 Bit Error Rate Calculating

PSK Design Procedure

For the PSK, all that was changed was the constant 0 block before the modulation phase. This was changed to a sine wave block with a 90° phase shift to the other. So it differentiates between 1 and 0 by the different carrier signal phase (shown in figure 11).

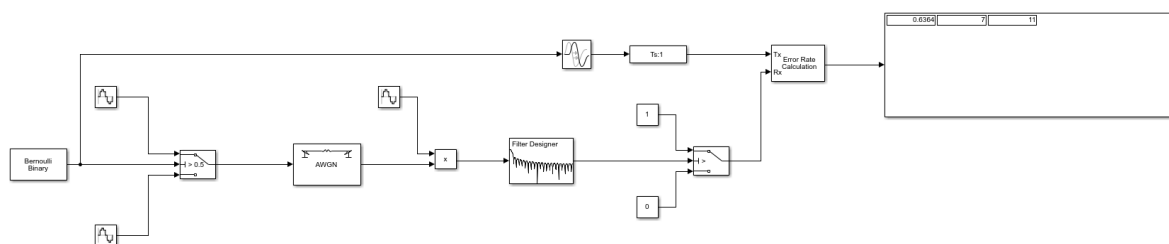


Figure 10 PSK Full Design

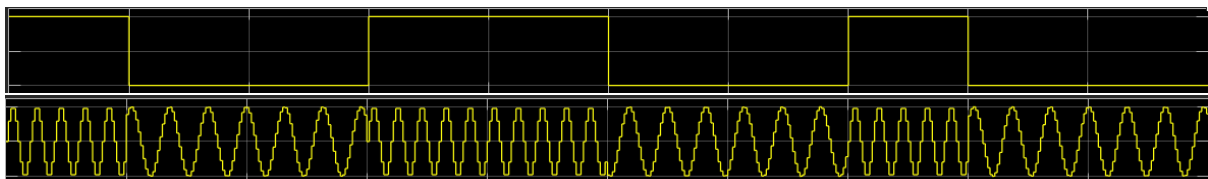


Figure 11 PSK Modulation

QPSK Design Procedure

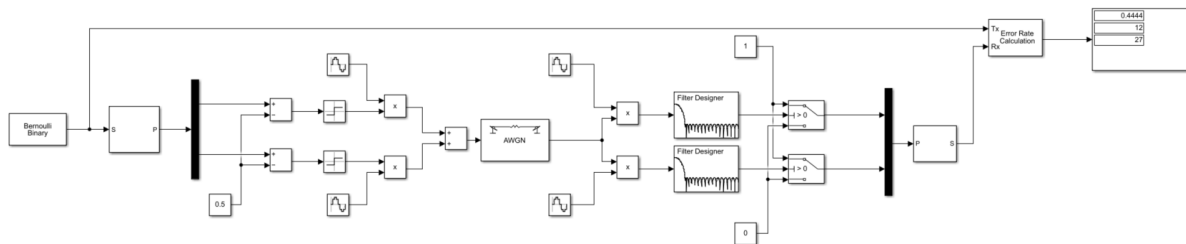


Figure 12 Full QPSK Design

Modulation Phase

Deserializer first used with input vector of 1 and output 2, and a demux to separate them. Two subtractors to half the signals (from 0 - 1, to -0.5 - 0.5).

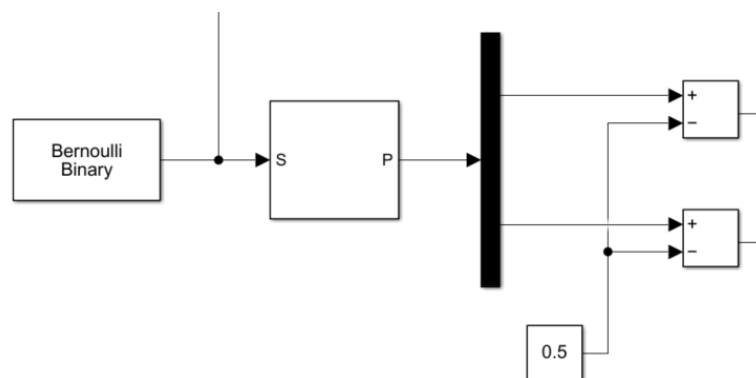


Figure 13 Modulation Phase

Signs added to change the signal to 1 and -1.

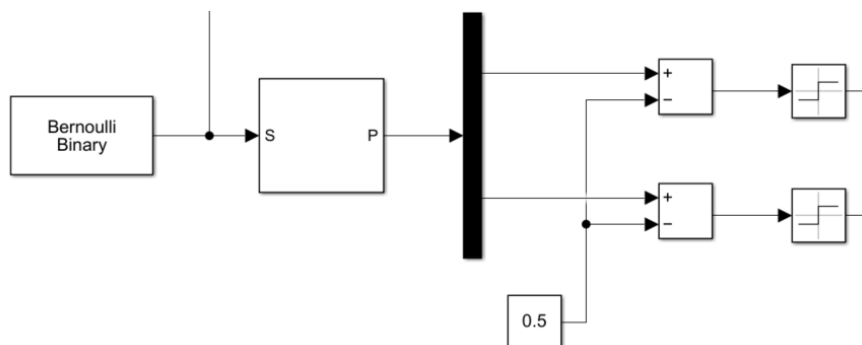


Figure 14 Modulation Phase 2

Two sine blocks set to 5 Hz ($2\pi \cdot 5$), sample time 1/100, and the other being 90° out of phase ($\pi/2$), being the quadrature channel.

Product blocks added to multiply the carrier frequencies by the signals, then an add block to add the two sine waves together.

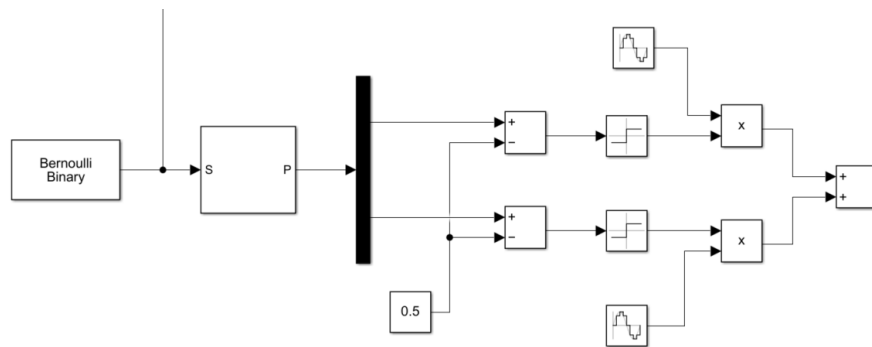


Figure 15 Modulation Phase 3

Communications Channel

Added a white gaussian noise block to simulate a noisy transmission line.

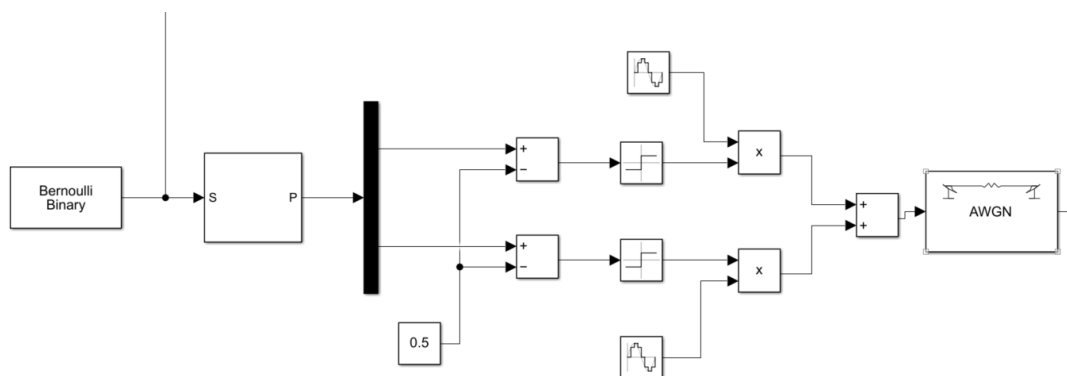


Figure 16 Communications Channel

Demodulation Phase

Added two identical sine blocks and product blocks for the carrier wave to be multiplied by the transmitted signal. Sines setting being the same as the modulating phase.

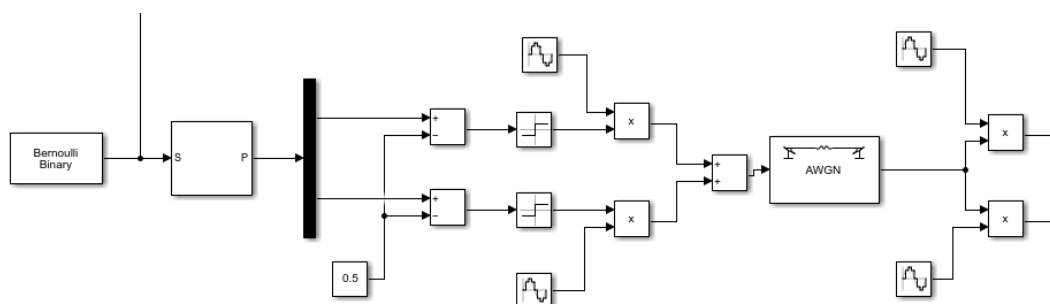


Figure 17 Demodulation Phase

Filtering

Then two low pass filters set with a sample rate that matches the signal.

Specs:

- 33 Order
- 100Fs
- F-pass 0.5
- F-stop 8

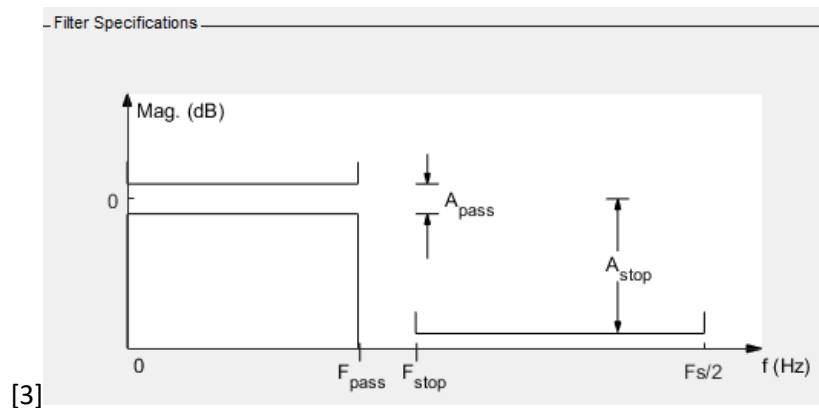


Figure 18 Filter Specifications Used

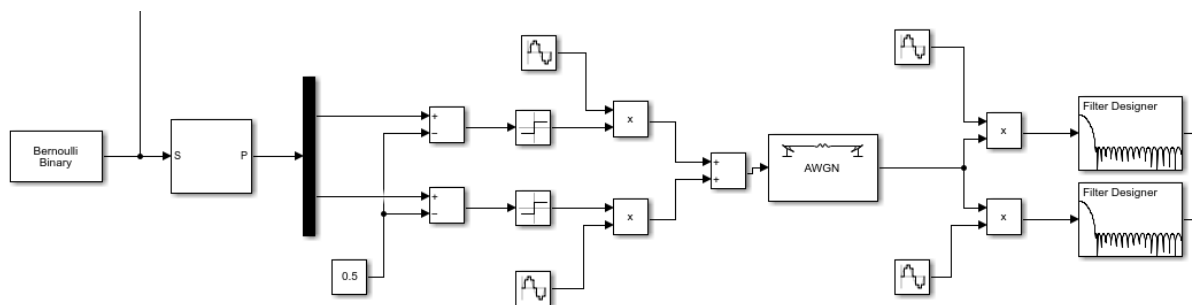


Figure 19 Filters Implemented

Bit Error Rate Calculation

For obtaining the BER of this circuit, an error rate calculation block was added to monitor the similarity of the input signal from the bernoulli binary generator, and the output of the serializer. This is shown in figure 20.

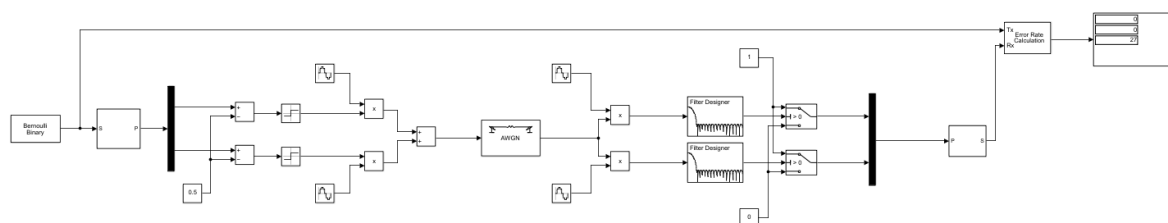


Figure 20 Bit Error Rate Calculating

QAM Design Procedure

QAM combines QPSK with amplitude shifting to allow for greater communication bandwidth. There are two signal paths which are called in-phase and quadrature (I and Q).

Modulation Phase

The QPSK was modified with two additional switches to control the amplitude modulation, as shown in figure 21. So there are the two original signal paths (I and Q) which are 180° out of phase of each other and also four amplitude levels produced by the additional switches.

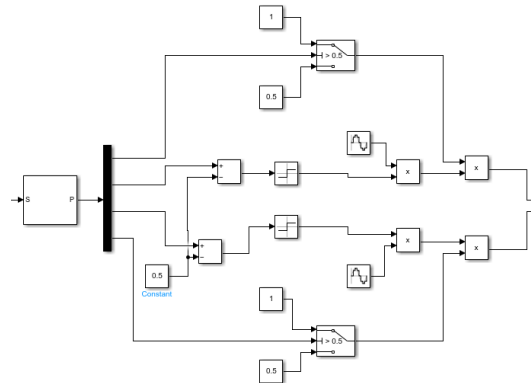


Figure 21 Modulation Phase

Communications Channel

Added a AWGN block to add noise to the signal.

Demodulation Phase

Added two switches to allow the four amplitude levels (1 or 0.5 at 0° phase, as well as -0.5 and -1 at 180°) to be converted to a digital signal that will match the input signal. This means there are 16 potential states representing 4 bits for transmission, being 0000 to 1111.

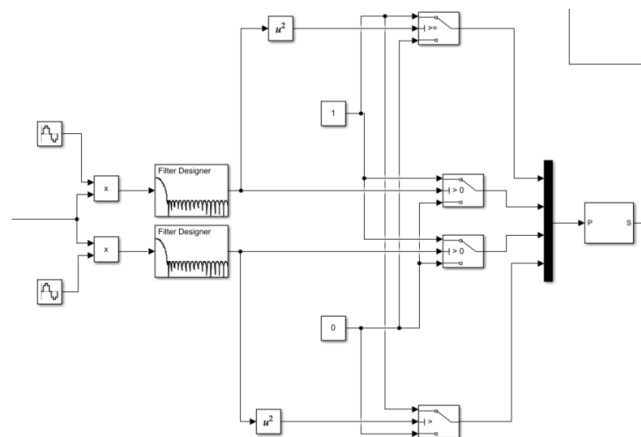


Figure 22 Demodulation Phase

Bit Error Rate Calculation

error rate calculation block was added to monitor the similarity of the input signal from the bernoulli binary generator, and the output of the serializer.

Simulation Results

ASK (Amplitude Shift Keying) Simulations

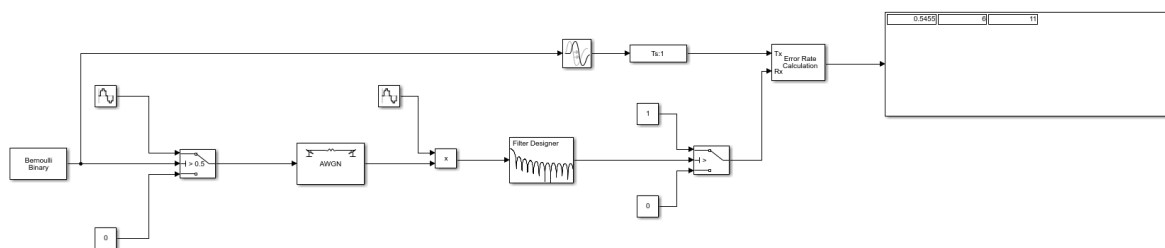


Figure 23 ASK Simulation

Figure 23 shows the ASK modem being used for testing to determine at which point they reach system failure, or where the bit error rate climbs above 0.5. The SNR being generated by the AWGN channel was reduced by 2dB a time until an average BER of 0.5 was reached. 10 Samples being taken at each SNR, and then the average of these 10 samples being taken. This process was repeated for each variation of modem being analysed.

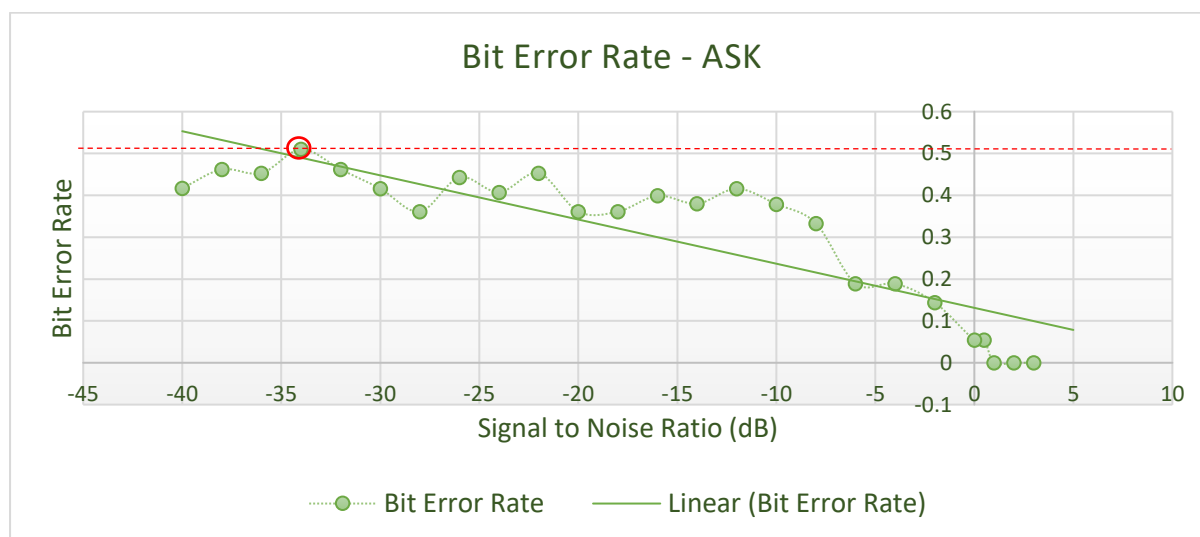


Figure 24 Simulation Results

This ASK modem reached failure at -34dB SNR as the BER climbed to 0.51, 0.01 above 0.5.

PSK (Phase Shift Keying) Simulations

Figure 25 shows the PSK modem being used for testing to determine at which point they reach system failure, or where the bit error rate climbs above 0.5. The testing process is the same here as for the ASK.

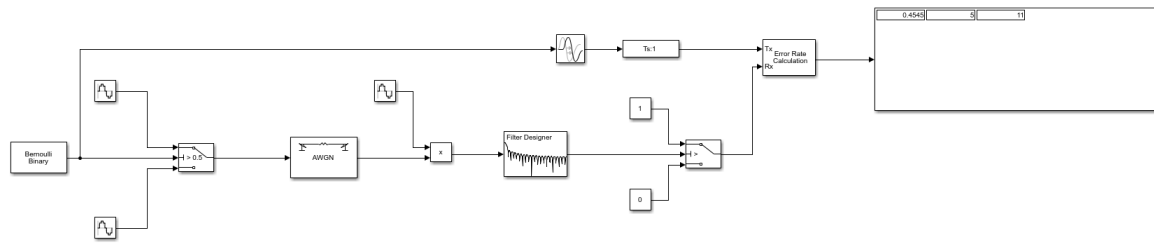


Figure 25 PSK Simulation

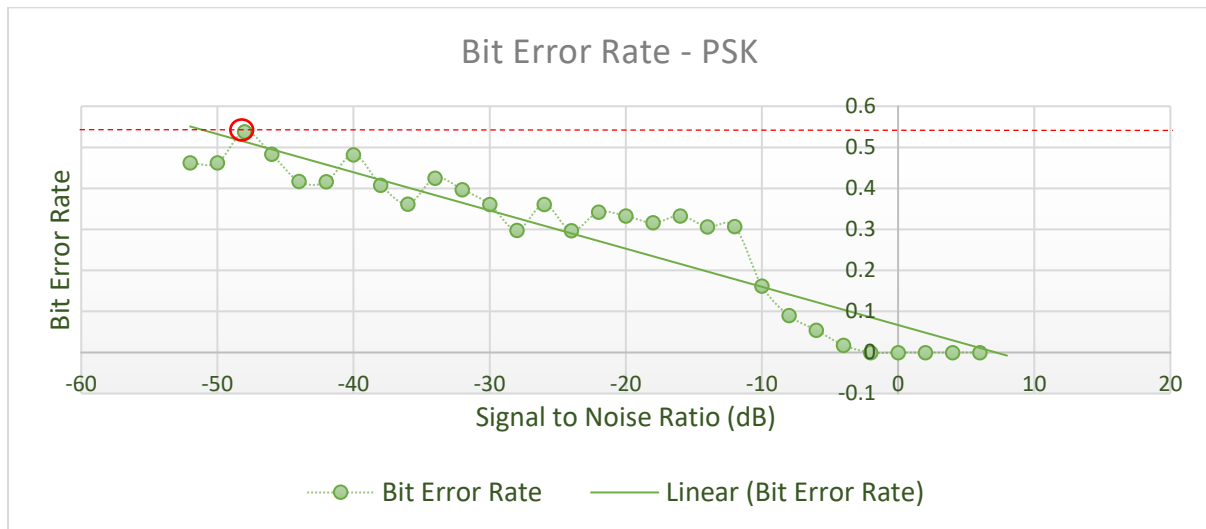


Figure 26 Simulation Results

This PSK modem reached failure (0.5 BER) at -48dB SNR, where the average BER was 0.583.

QPSK (Quadrature Phase Shift Keying) Simulations

Figure 27 shows the QPSK modem being used for testing to determine at which point they reach system failure, or where the bit error rate climbs above 0.5. The testing process is the same here as for the ASK.

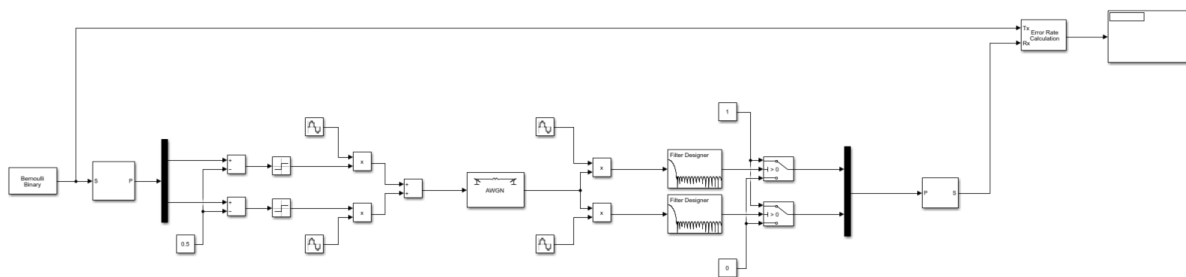


Figure 27 QPSK Simulation

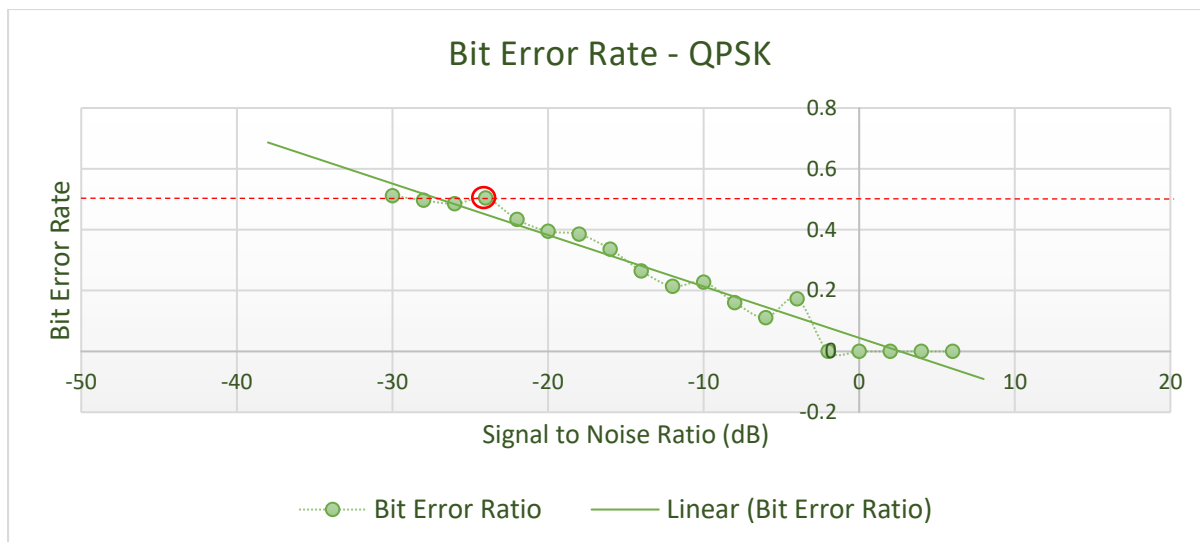


Figure 28 Simulation Results

This QPSK modem reached failure (0.5 BER) at -24dB SNR, where the average BER climbed to 0.504.

QAM (Quadrature Amplitude Modulation) Simulations

Figure 29 shows the QAM design that was used to test the BER of this variation of communication technology. The AWGN was adjusted down from an SNR of 26dB, to -30dB.

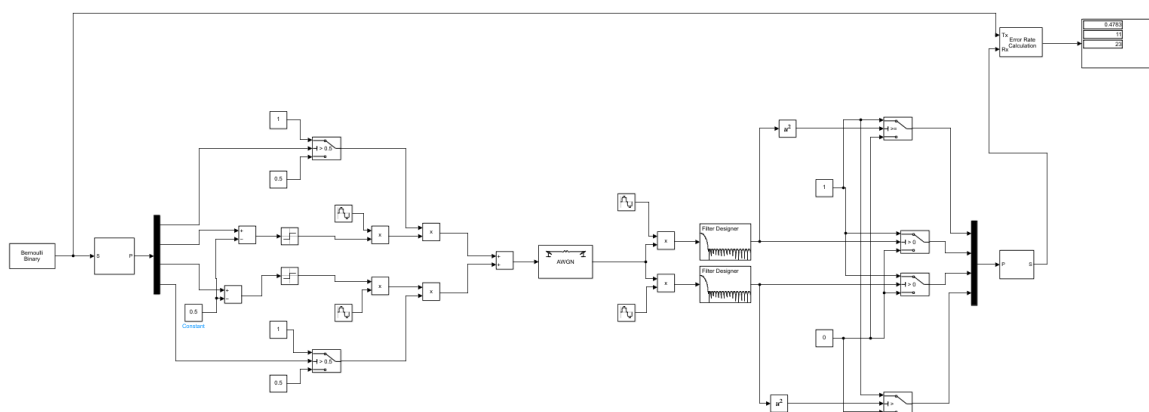


Figure 29 QAM Simulation

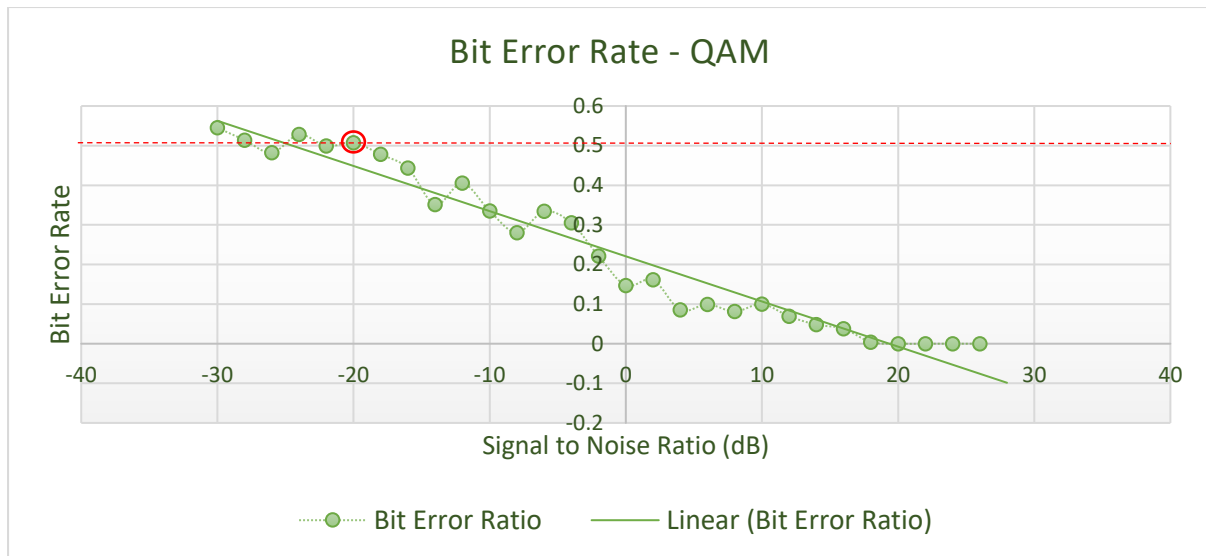


Figure 30 Simulation Results

This QAM modem reached failure at -20dB SNR as the average bit error rate climbed to 0.507, 0.007 above 0.5.

Discussion

The four circuits performed exactly as expected, with the PSK resisting noise interference better than the ASK. The QPSK then being worse than the ASK and PSK. With QAM suffering from noise the worst by reaching 0.5 BER at the highest SNR (higher SNR meaning less noise).

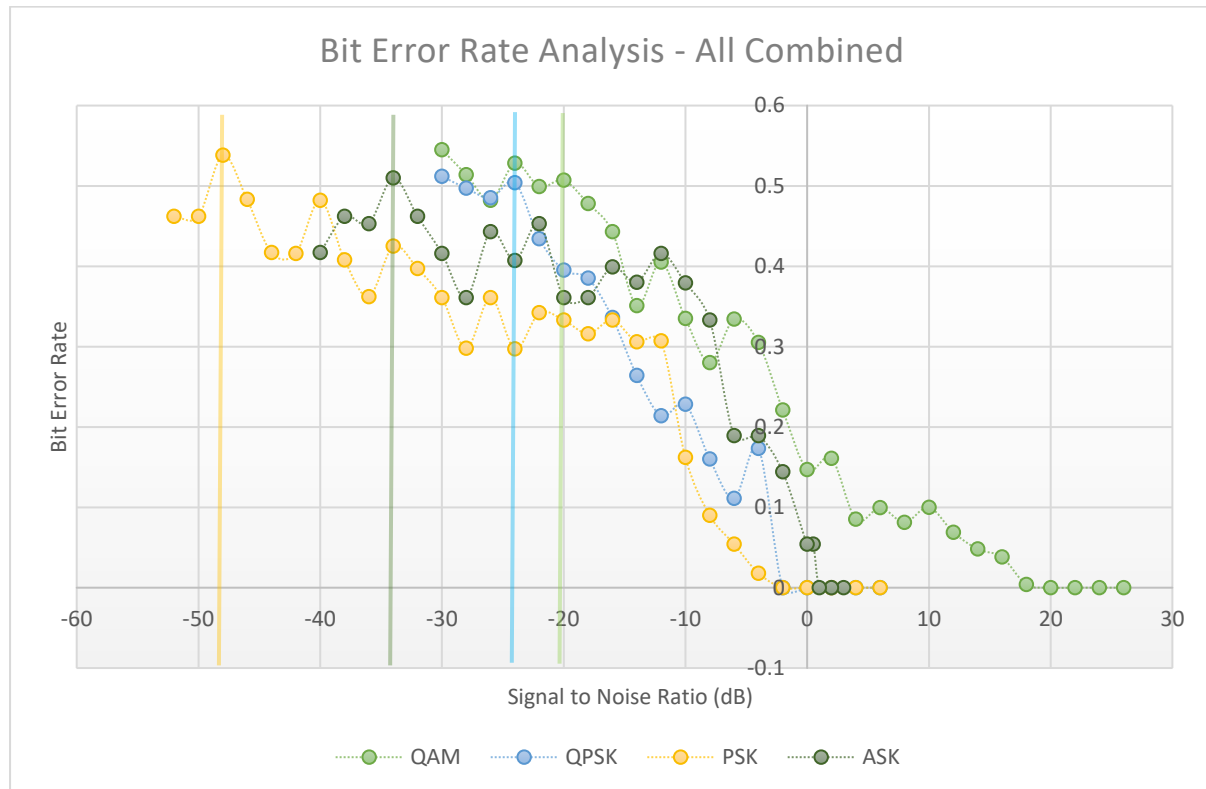


Figure 31 All Simulations Combined

Failure Points

- PSK - SNR -48dB, BER 0.583
- ASK – SNR -34dB, BER 0.510
- QPSK – SNR -24dB, BER 0.504
- QAM – SNR -20dB, BER 0.507

Once all of the test results are combined into the graph shown in figure 31, the different communication variants can be easily compared. The PSK showed the greatest resistance to noise. ASK failed with less noise. Then the QPSK failed with even less noise. The QAM performed the worst, with the noise beginning to have a negative effect on signal reliability much sooner with the BER beginning to increase at around 20dB, whereas the other three begin to fail at around 0dB SNR.

Conclusion

The PSK was the most resistant to noise because when the two potential signals are shown on a constellation diagram, the distance between the two possible states is greater. Noise causes the signal's received position on the graph to deviate from the normal position. If this occurs to a great enough extent, the signal can be mistaken as being in the wrong data bit, causing an error. The graphs in figure 32 show how the distance between the different data bits varies for each. QPSK is closer than both so this should have worse resistance to noise.

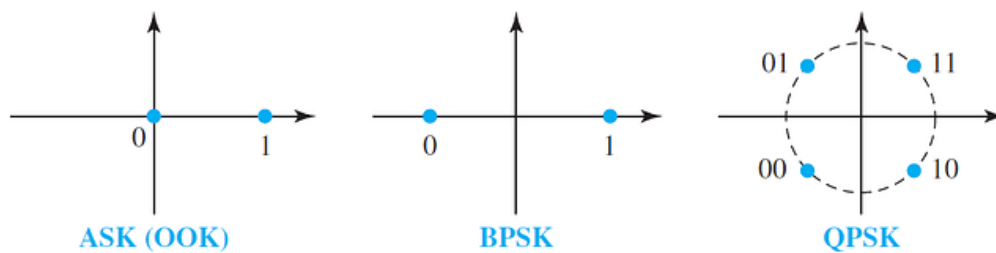


Figure 32 [4] ASK, PSK & QPSK Constellation Diagrams

Figure 33 shows an example of testing the effects of noise on a 16QAM modem, identical to the variation tested in this report. The top image shows less noise and the bottom shows increased noise (lower SNR). Significant variation in the received signals can be seen and the more spread out the signal bits are, the more they get mistaken for the other bits, which is an error in transmission. The bottom QAM has a lower SNR than the top. Due to each point in the QAM being closer together than the ASK, PSK, and QPSK, the resistance to noise is worse.

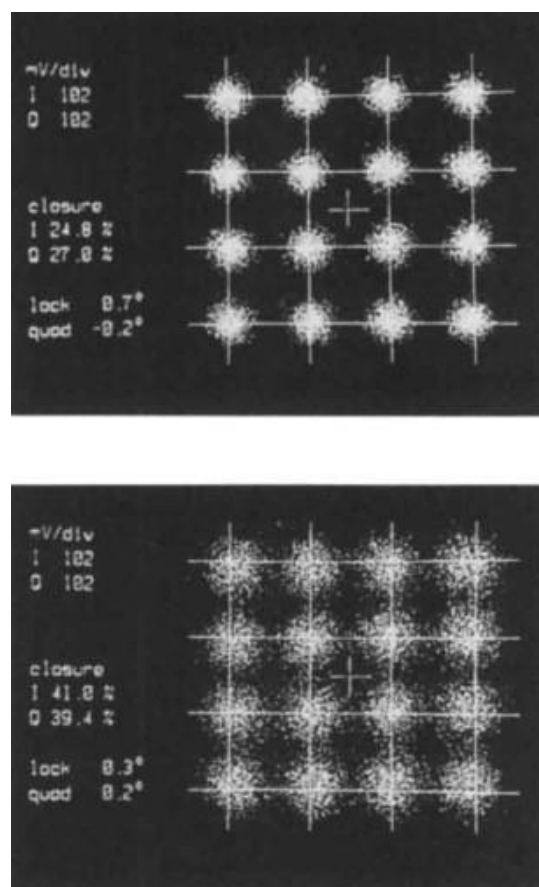


Figure 33 QAM Constellation Diagram

[5]

This was proven in this report as the 16QAM did indeed have the highest SNR, the QPSK following in second. .

References

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- [2] J. J. M. C. L. A. D. N. a. S. R. T. W. Aaron Don M. Africa, "DESIGN OF AN ASK MODULATION DIGITAL SIGNAL CONVERSION SYSTEM," *ARPJ Journal of Engineering and Applied Sciences*, vol. 15, no. 2, p. 179, 2020.
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