

DSP-SL

by Sam Lloyd

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Samuel Jay Lloyd
2110666
Digital Signal Processing and
Communication
ACDA5008

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Abstract

The documentation will describe how to test ASK (amplitude-shift keying), PSK (Phase-shift Keying), QPSK (Quadrature Phase-Shift keying) and 16-state QAM (Quadrature Amplitude Modulation), how this is done and the differences in the systems and how they deal with gradually increasing levels of additive white Gaussian noise. This testing will be completed by creating simulations within Simulink and comparing the results when a random binary input is made and testing the output. The results will show that QPSK and PSK are the best systems but also discuss the advantages to QAM and ASK in situations.

Introduction

Before creating the simulations, it was important to carry out research on each of the modulation's methods to understand how they work and how to build the systems.

ASK Research

For ASK the formula for the modulation for the binary of 1 & 0 is:

$$\text{logic 1} - X_{ASK} = A_1 x \cos \omega_c t$$

$$\text{logic 0} - X_{ASK} = A_2 x \cos \omega_c t$$

Equation 1: ASK Formula [1]

Amplitude

$\omega_c t$ = frequency in rad/s

This formula states that the value that varies between the logic 1 and 2 messages are Amplitude example in Figure 1.

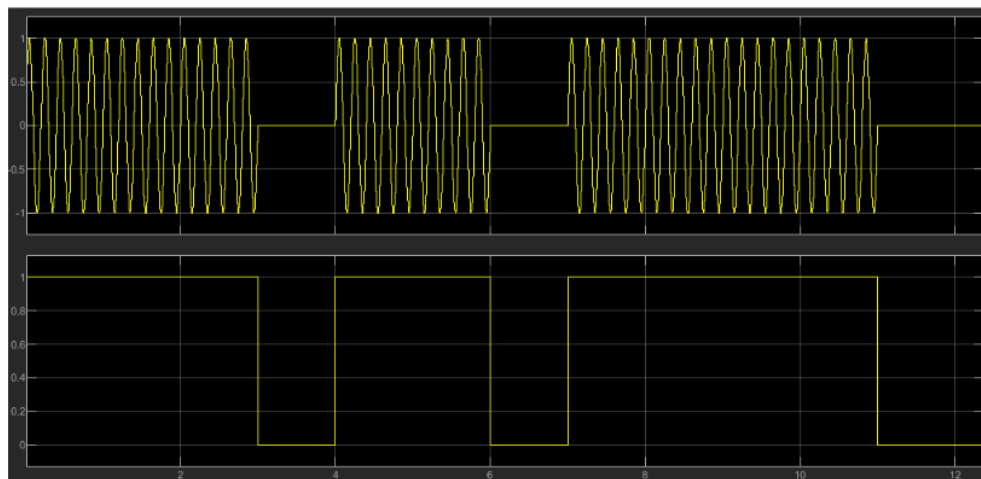


Figure 1: ASK Example

This shows ASK where when in state logic 1 the Amplitude is equal to 1 and during Logic 0 the Amplitude is equal to 0 [2]. The principle of ASK is it's a very simple modulation technique and is easy to set up which is seen later but the negative is its very susceptible to noise. This is due to the fact the main thing effected by noise is the amplitude, noise will create large spikes in the amplitude

making it more inaccurate of a modulation much easier than other methods, this will be seen later in the results section. ASK can be used for more than 1 bit per message [3] but in this case it is just 1. ASK is used in optical cables to transmit data [4].

PSK Research

For PSK the formula for the modulation for the binary of 1 & 0 is:

$$\text{logic 1} - X_{PSK} = Ax \cos(\omega_c t)$$

$$\text{logic 0} - X_{PSK} = Ax \cos(\omega_c t - \theta)$$

Equation 2: PSK Formula [1]

A = Amplitude

$\omega_c t$ = frequency in rad/s

θ = phase

When looking at Equation 2 this shows the clear difference being the phase, an example of how this would look is Figure 2.

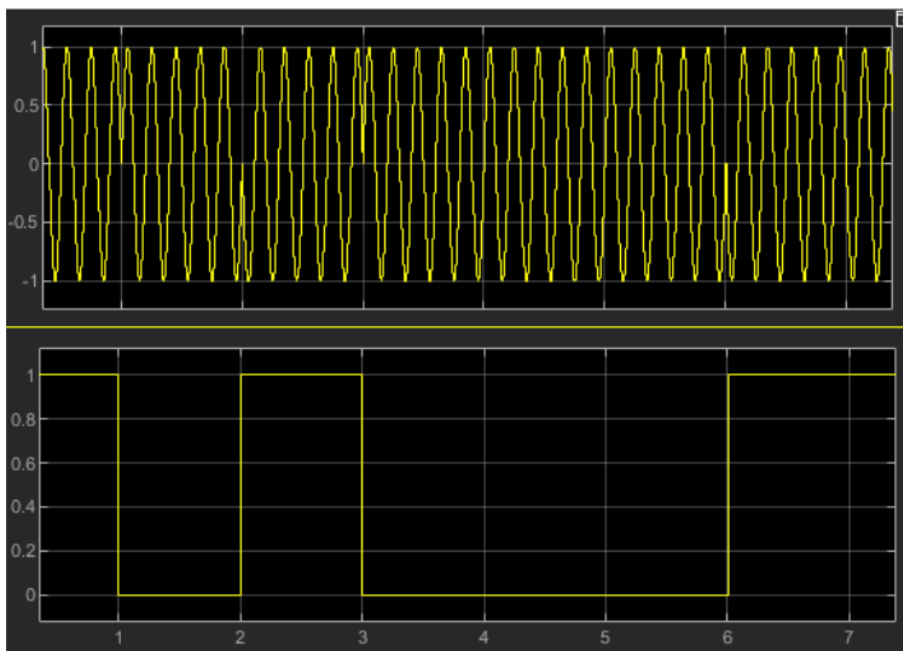


Figure 2: PSK Example

In this example you can see when the logic changes between 1 and 0 there is a clear switch in Phase as the wave appears to reverses [5]. The advantage to using PSK is its less susceptible to noise as phase cannot be affected by noise but still will be at some point as this can loss the data when the noise is high enough levels. The negative of this is compared to ASK modulation the demodulation is more complicated which can be seen later. BPSK is commonly used in Bluetooth [6].

QPSK Research

For QPSK the formula for the modulation for the binary of 00 -> 11 is:

$$X_{QPSK} = Ax \cos(\omega_c t - \theta)$$

Equation 3: QPSK Formula [1]

A = amplitude

$\omega_c t$ = frequency in rad/s

θ = phase

Where:

$$\text{Logic 11} \rightarrow \theta = \frac{\pi}{4}$$

$$\text{Logic 01} \rightarrow \theta = \frac{3\pi}{4}$$

$$\text{Logic 00} \rightarrow \theta = \frac{-3\pi}{4}$$

$$\text{Logic 10} \rightarrow \theta = \frac{-\pi}{4}$$

QPSK is very similar to PSK with main difference being there are 4 different phases instead of 2, this allows for 2 bits to be passed instead of 1 per cycle. An example of how this modulation would look can be seen in Figure 3, the 2 input waves can be seen in Figure 4, and An example of what the output waves would look like can be seen in Figure 5. The output waves can also be seen in the constellation graph in Figure 6 which plots Quadrature amplitude against in-phase amplitude, this clearly shows the 4 points, one for each of the 4 binary states (11, 10, 01, 00).

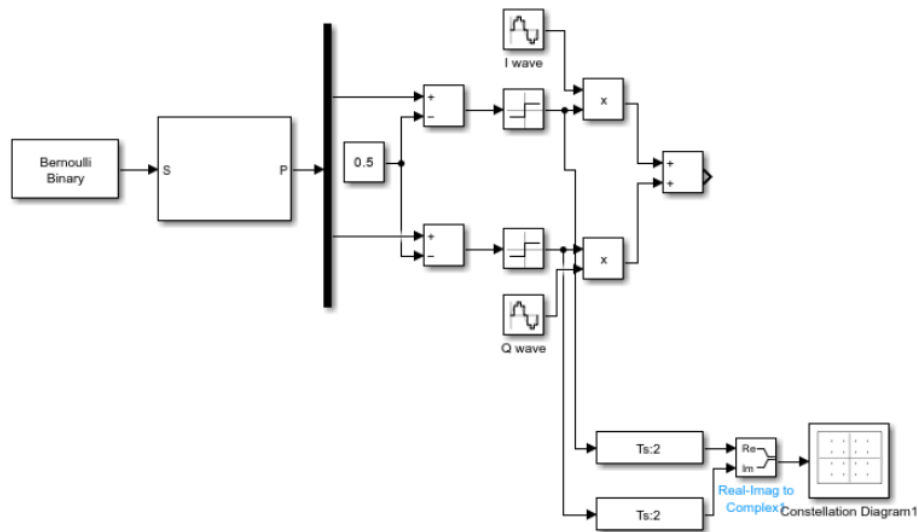


Figure 3: QPSK Modulation

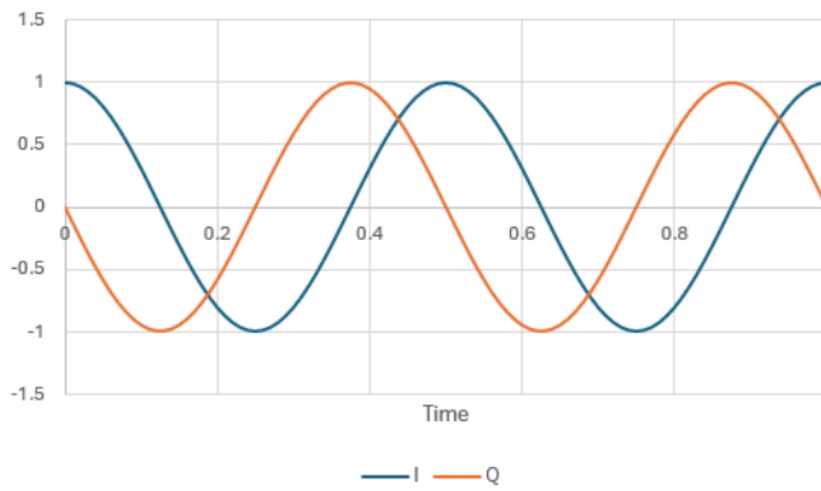


Figure 4: I & Q wave

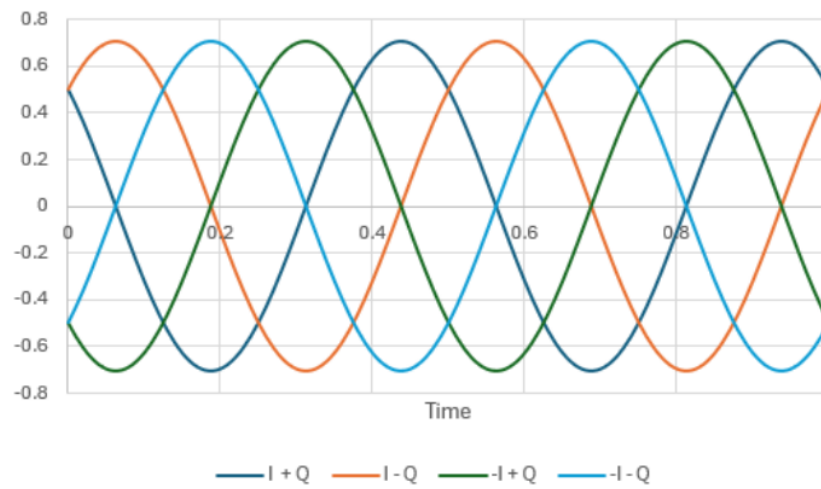


Figure 5: QPSK Outputs

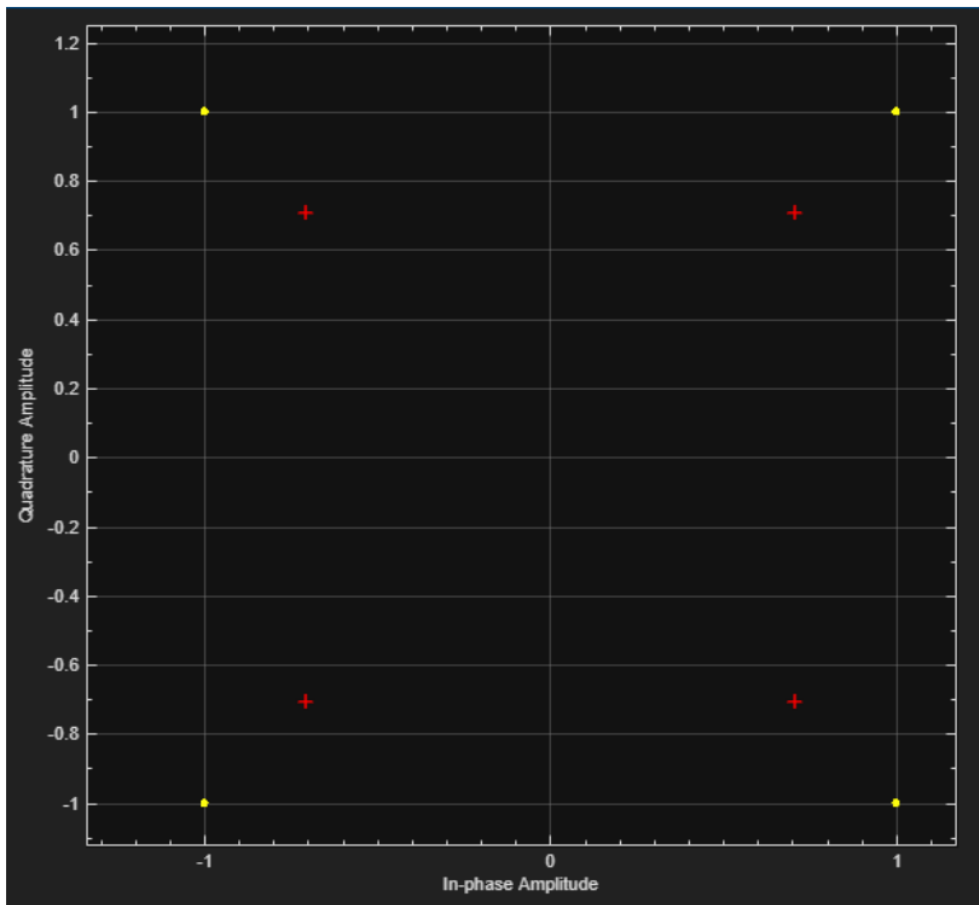


Figure 6: QPSK Constellation Graph

All this information means that the QPSK has the advantage that it can send more data than the PSK and is almost as good at transmitting data, this has the advantage of being very complicated to setup. QPSK is commonly used in cellular signals, such as 2G and 3G [6]

16-State QAM Research

The QAM is a combination FSK and ASK modulation techniques looked at before [7], it uses the varying amplitude and phase to be able to pass more data while keeping it as safe from noise.

For a QAM modulator the formula is:

$$X_{QAM} = Ax \cos(\omega_c t + \theta)$$

Equation 4: QAM Formula [7]

16 amplitude
 $\omega_c t$ = frequency in rad/s
 θ = phase

To create a 16-state QAM this means having 4 Amplitudes and 4 varying phases, this is done using:

A: 1, 0.3, -0.3 & -1

$\theta: \frac{\pi}{4}, \frac{3\pi}{4}, \frac{-3\pi}{4} \text{ \& \& } \frac{-\pi}{4}$

This creates 16 variants which are assigned to 1111 -> 0000 depending on the setup, an example can be seen in the constellation graph in the Figure 7 bellow.

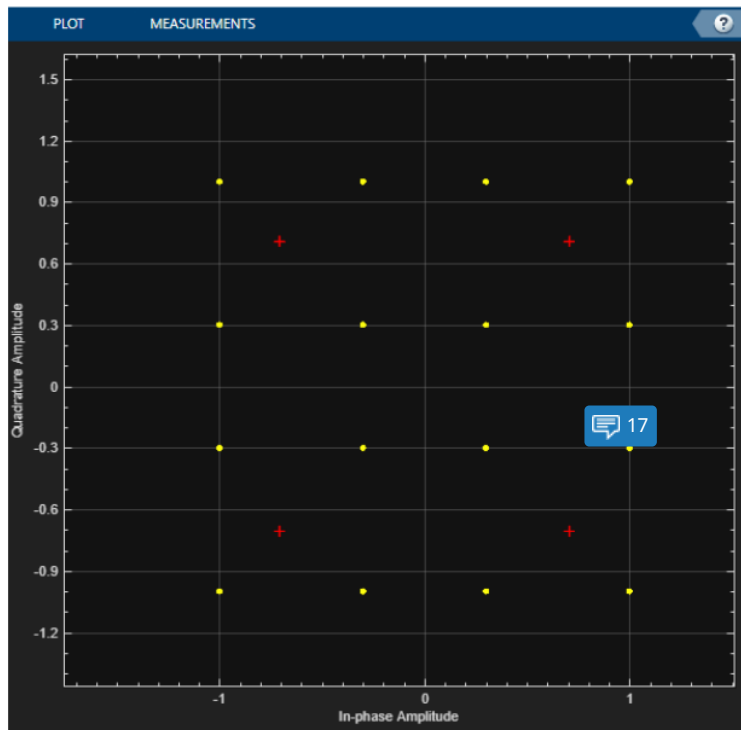


Figure 7: Constellation Graph for 16-state QAM

QAM advantages of QAM is the ability to pass larger amounts of data then the other techniques, this is because it gives more variables being able to alter the Amplitud and Phase. If you tried to pass 16 states of data using just an ASK or PSK method, the data would be very easily lost to noise, whereas using the QAM this spreads out the data, so it is more : 18 This makes the devise a lot more complicated than the others that can be seen bellow in Figure 16. QAM is commonly used in cellular and Wi-Fi [8].

Simulation Models

For Simulating the models Simulink was used, [9], Simulink is a part of MATLAB used for graphical programming, modelling, and analysing of multi dynamical systems. This is perfect for the job as will allow creation of the models and then simulating the models to ensure they are outputting the expected results. Once decided on I then took the next steps into building the models.

Bellow in Figure 8 you can see the standard filter I decided to use, this was done as it was a order I thought wasn't too high and the filter wouldn't create a massive delay in data, but would still do the expected job in the output removing an appropriate level of noise.

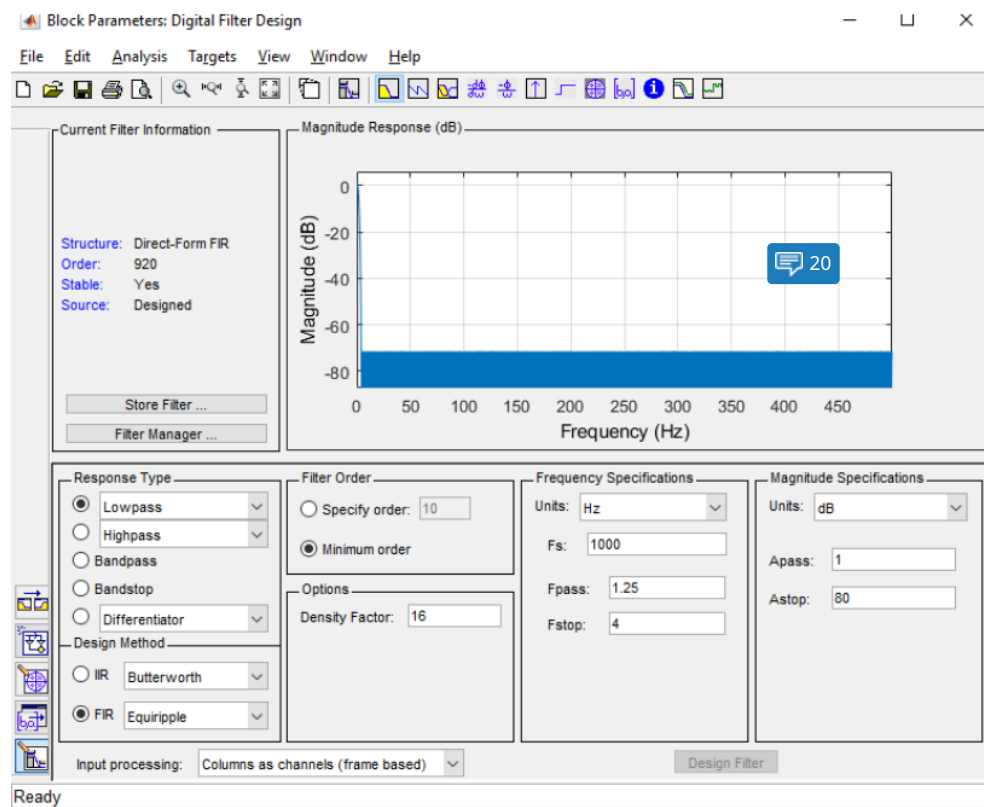


Figure 8: Standard Filter

Once the Filter was decided on, I then began building the models. At this point it was also decided that the carrier waves would be of a standard amplitude of 1 and a frequency of 5Hz, and the binary data will be transmitted at 1 Hz.

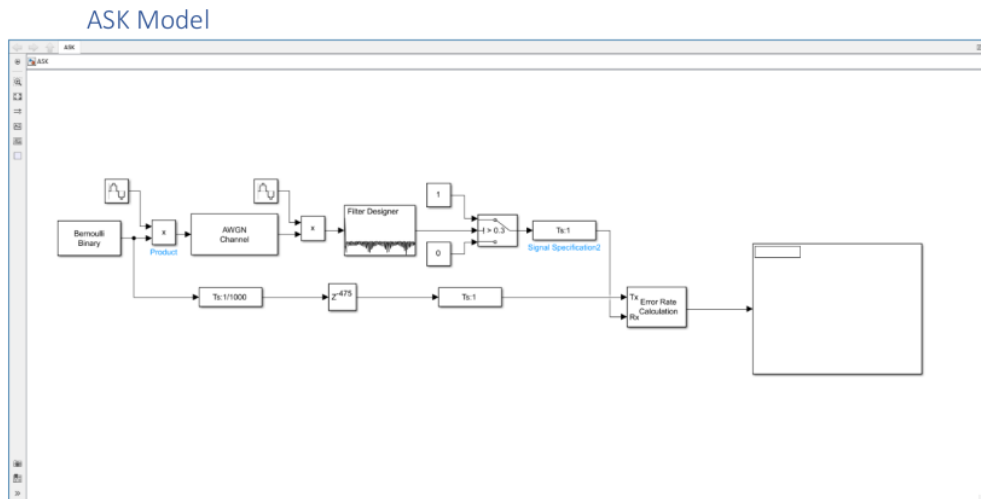


Figure 9: ASK Simulink Model

Figure 9 above shows the model of an ASK system, the Bernoulli Binary random outputs 1 or 0 then multiplies this with the carrier, this creates the modulation, seen in Figure 10 top 3 scopes (1- sine wave in, 2- Bernoulli Binary, 3- modulated wave). This then passes through the AWGN channel, Figure 10 scope 4, which adds white noise then starts the demodulation. In the demodulation this is then multiplied by the carrier again to remove it, then passes through the filter which smooths out the noise, then goes into a switch which will detect if the value input is above or below 0.3, if above the switch outputs 1 else 0. The output is then compared to the input, the input is delayed, and then compared using the error rate calculations then displayed next to it, Figure 10 scopes 5->7.

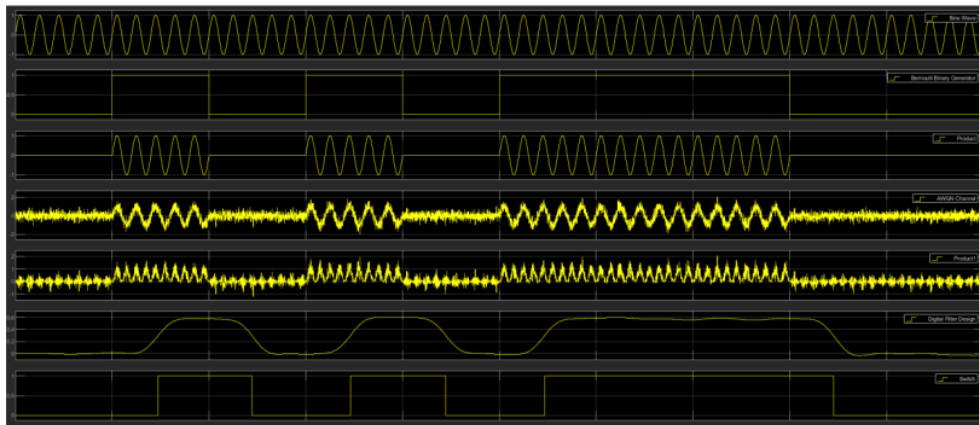


Figure 10: ASK Scope output

PSK Model

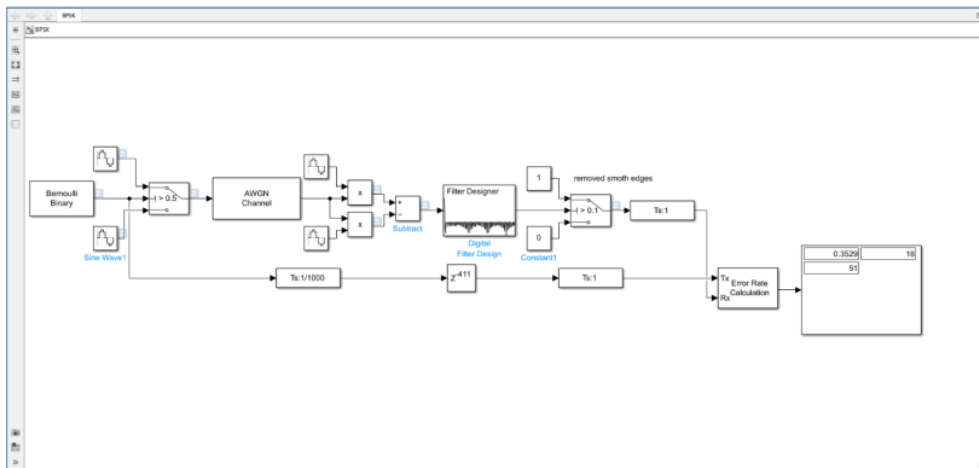


Figure 11: PSK Simulink model

Figure 11 above shows the model of a PSK system, the Bernoulli Binary random outputs 1 or 0 then using a switch this then output wave 1 or 2, these are identical waves just wave 2 is 180° out of phase, Figure 12 channels 1-4. This signal then passes through the AWGN channel, Figure 12 channel 5, adding noise then needs to be demodulated. The signal received is multiplied with wave 1 and wave 2 then the outputs are subtracted, and this is the end out, this then passes through the same end as the ASK and tested the same way, Figure 12 channel 6-10.

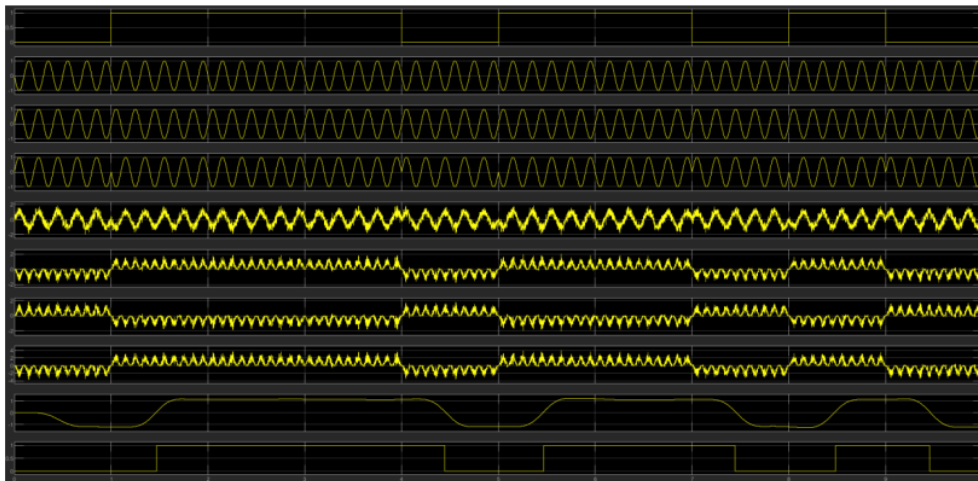


Figure 12: PSK Scope output

QPSK Model

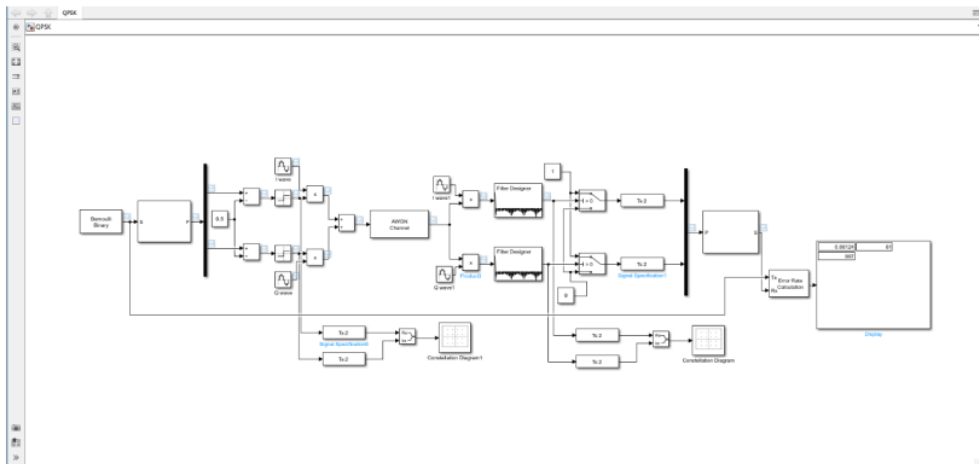


Figure 13: QPSK Simulink Model

Figure 13, this is like PSK just with an additional bit of data being passed at once, to do this the binary is backed up and then output on the de-mux with 2 bits of data at the same time. 1 bit of data is then output from the mux then 0.5 is subtracted, meaning 1 $\rightarrow$ 0.5 and 0 $\rightarrow$ -0.5. So when you then multiply this with the wave if it's a 0 the wave is inverted/ phase changed by 180. For the second bit this is the same, but the wave is 90° out of phase, when these 2 waves are added together this creates the phases discussed in the research phase, seen in Figure 14. This is then passes through the AWGN channel. The demodulator works like the PSK just with 2 separate waves. Once demodulated this works the passes into the mux and then the output is tested the same as before, seen in Figure 15.

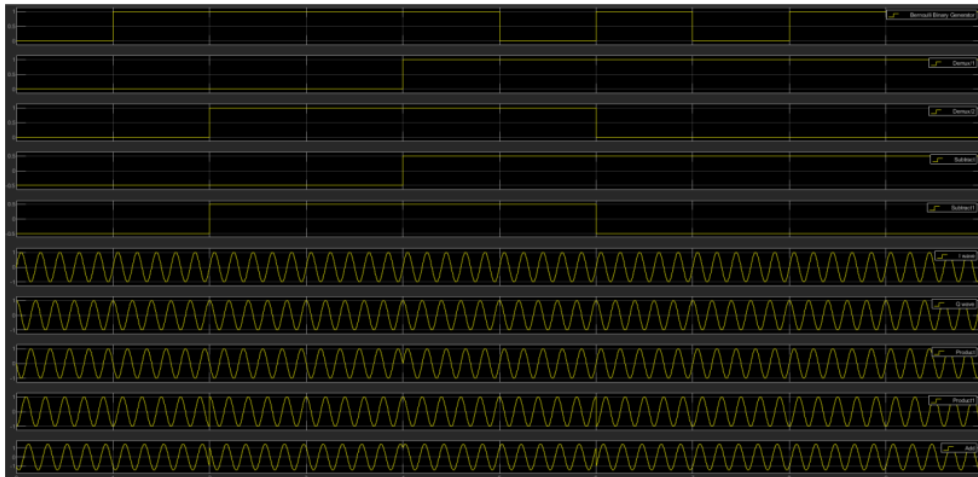


Figure 14: QPSK Modulation

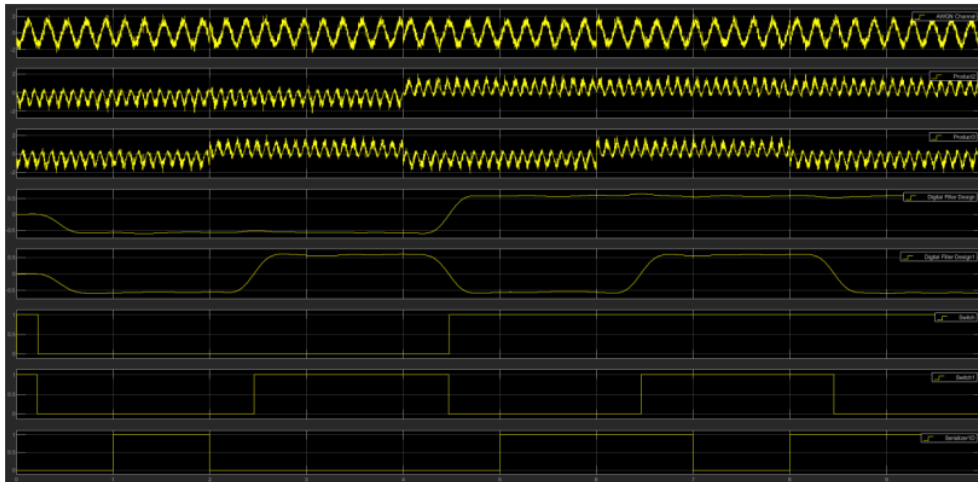


Figure 15: QPSK Noise & Demodulation

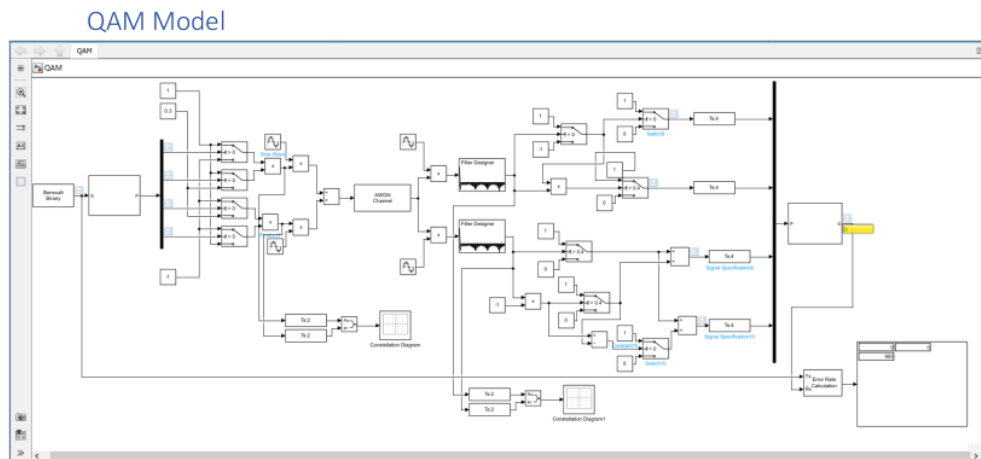


Figure 16: QAM Simulink model

Figure 16 shows the QAM, this is a combination of both the QPSK with ASK included as well. 4 bits are passed through the de-mux they are passed into a switch which creates varying outputs using the constants 1, 0.3 and -1 creating a range of outputs of 1, 0.3, -0.3 and -1 which are then multiplied with the I wave and Q wave (I wave 90° out of phase), then adding these 2 waves together creates 16 varying outputs, this can be seen in Figure 17, Figure 18 and Figure 19. This then passes through the AWGN channel. Then needs to be demodulated this, is done by first using the QPSK technique to remove the 2 waves, then uses the ASK technique to get the individual bits, seen in Figure 20 and Figure 21.

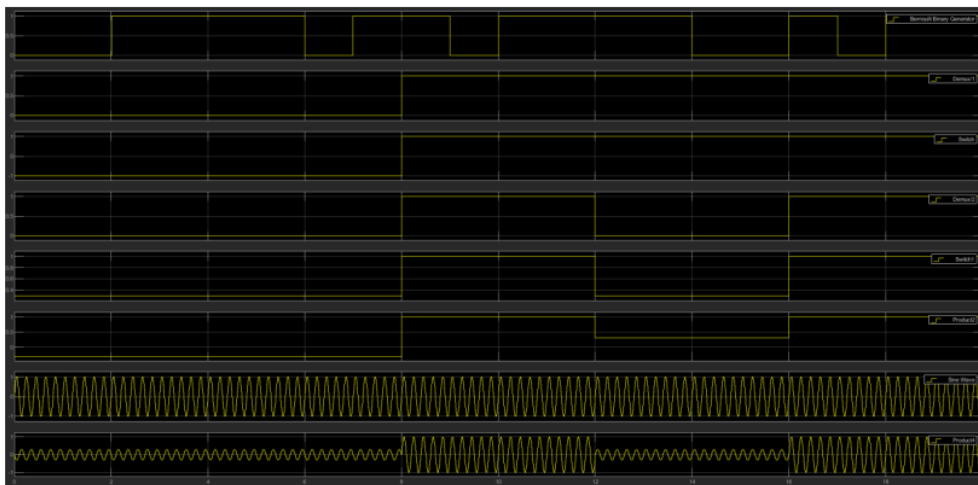


Figure 17: QAM I Wave Modulation.

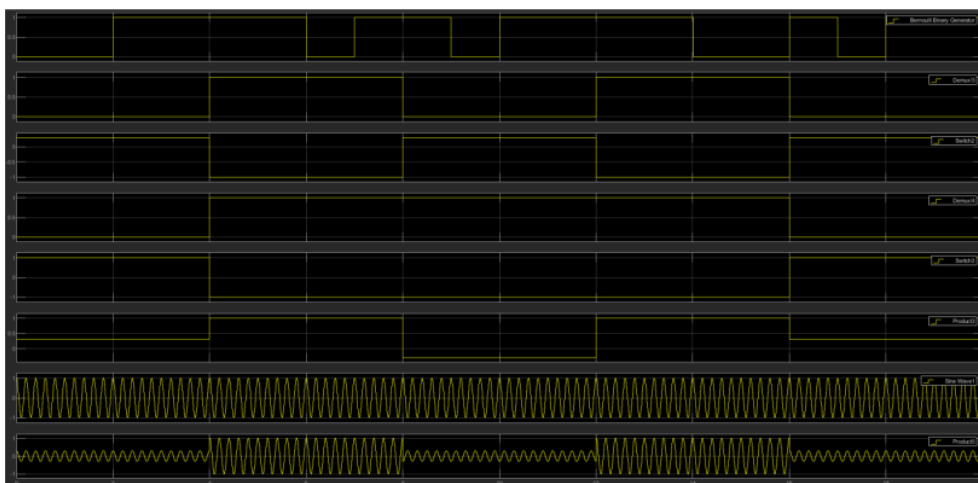


Figure 18: QAM Q Wave Modulation.

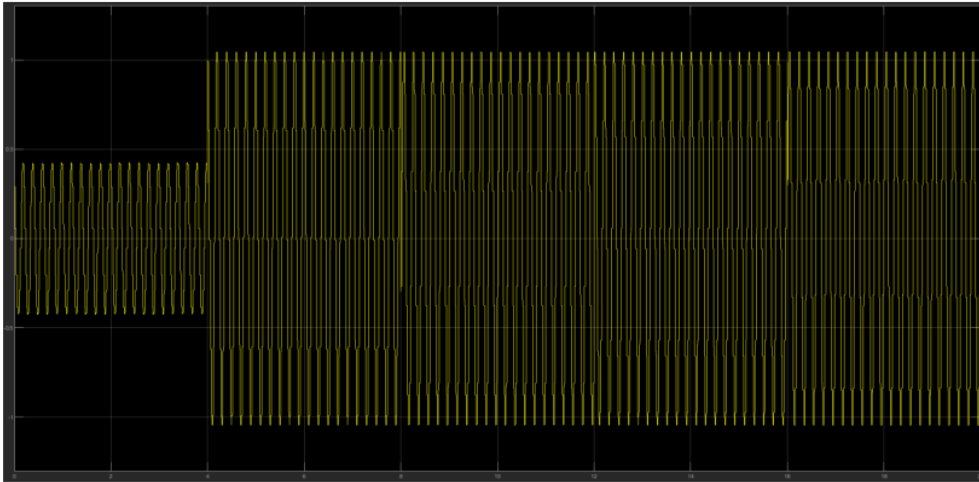


Figure 19: QAM I&Q Wave Combined- Final Modulation.

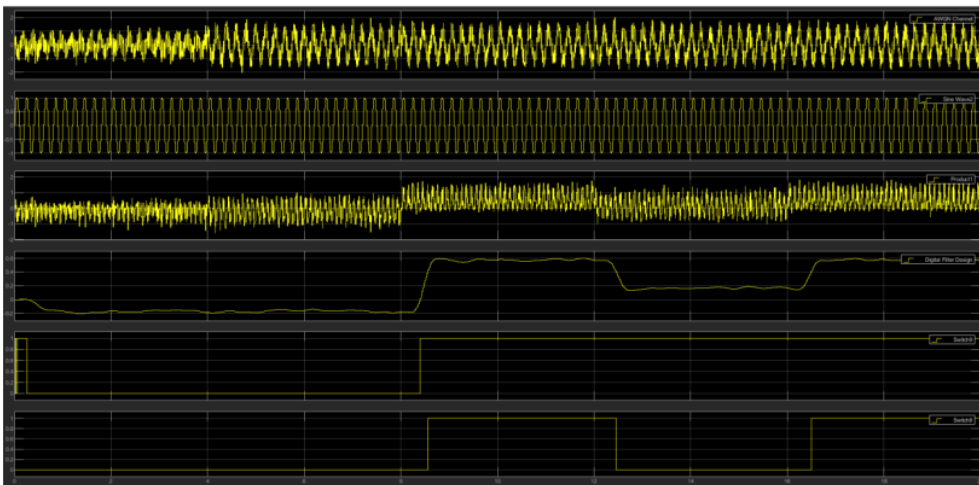


Figure 20: I Wave Demodulation.

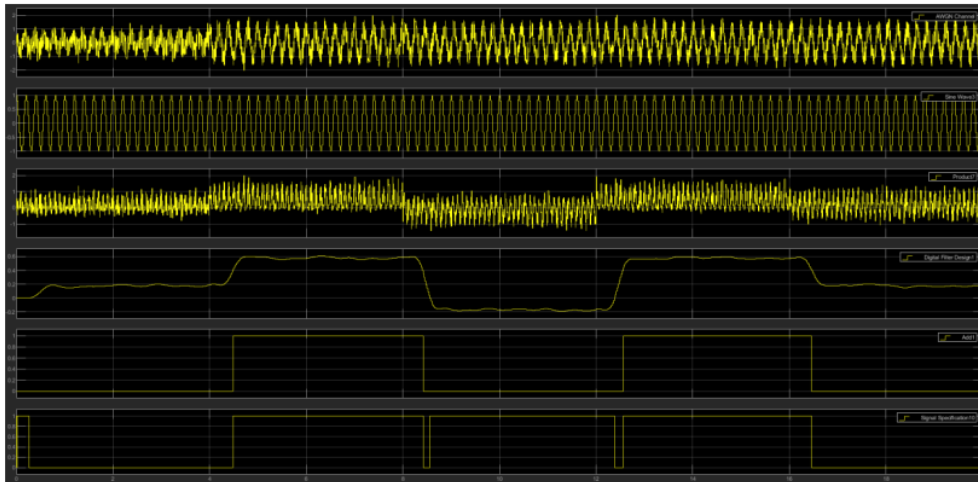


Figure 21: Q Wave Demodulation.

Testing Methodology

After carrying out the task of building each of the modulation methods in Simulink the next part is to carry out the testing on each one. This will be done by altering the value in the AWGN (Additive White Gaussian Noise) channel then using an error rate calculator work out the BER (Bit Error Rate) with each noise level. [10] BER is a method to examine the performance of the modulator, this is done by looking at the binary at one both ends of the device and testing them against each other to see how many errors occur, this will mean using a delay method as it is not instant to pass 1 bit through modulation. Attempting to get a more accurate test result, each test would be carried out in as similar conditions as possible, for example: as similar inputs as possible and the same filter. Then when testing the tests were ran 20 times and these values were used to create an average and then the standard deviation which would be used to create error bars on the final graph.

Results

Bellow, Figure 22, the final graph can be seen which is a direct comparison between all 4 of the modulation techniques. This graph is plotting the data collected from the test ran using the test methodology stated above.

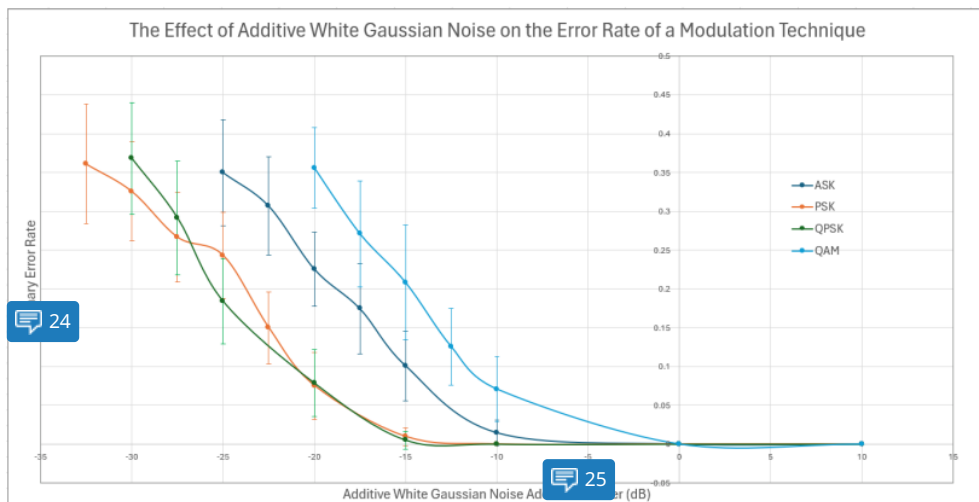


Figure 22: Test Results graphed.

The Below images Figure 23, Figure 24, Figure 25 and Figure 26 are photos of the constellation graph for a QAM with varying levels of noise started in there captions. Figure 27, Figure 28, Figure 29 and Figure 30 are for the QPSK, this also shows the data displaying with varying noise. The Graphs plot the Quadrature Amplitude against the In-Phase amplitude. In all these images each central point, shown best on the 10dB noise graphs, relate to one of the binary outputs, an example of this can be seen in Figure 31 where the binary for each point is displayed next to the point.

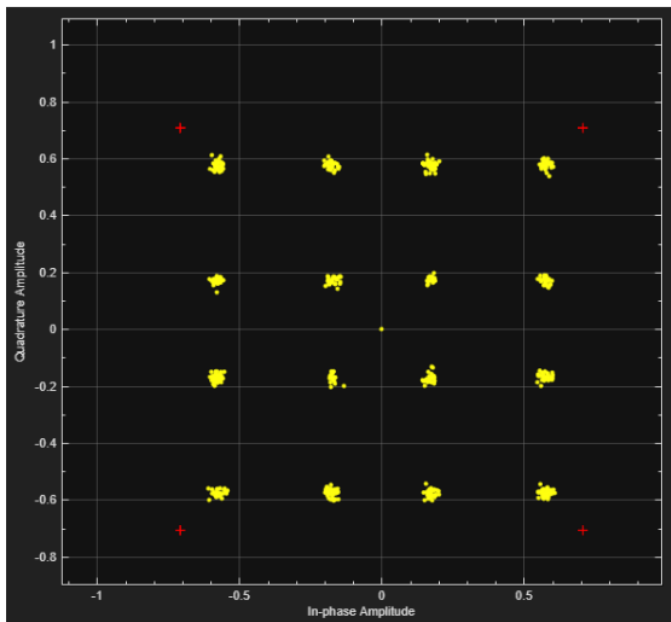


Figure 23: QAM Constellation with 10dB

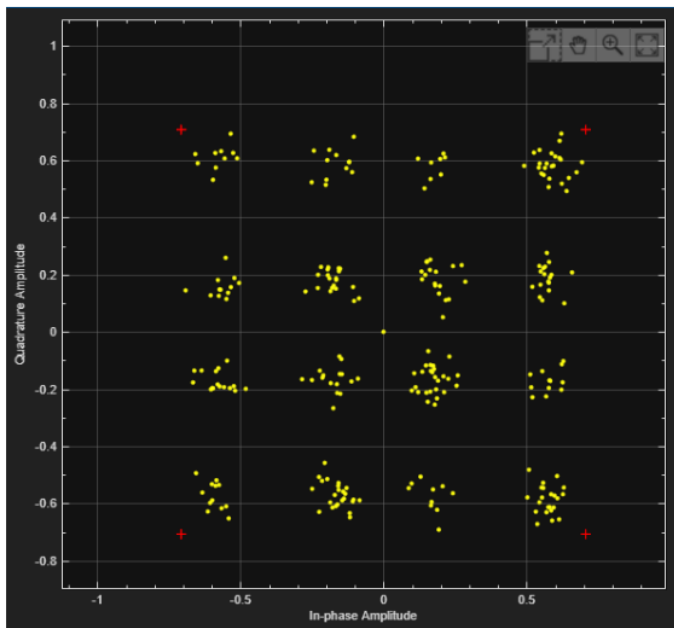


Figure 24: QAM Constellation with 0dB noise

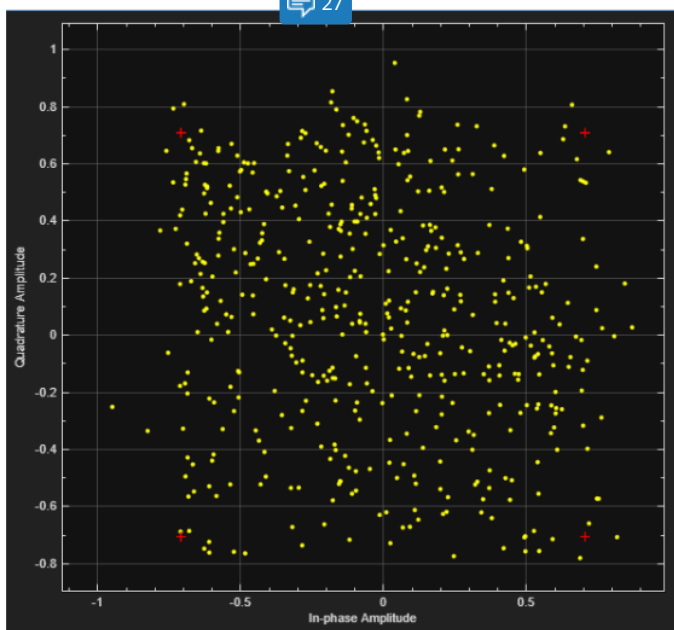


Figure 25: QAM Constellation with 28 dB noise

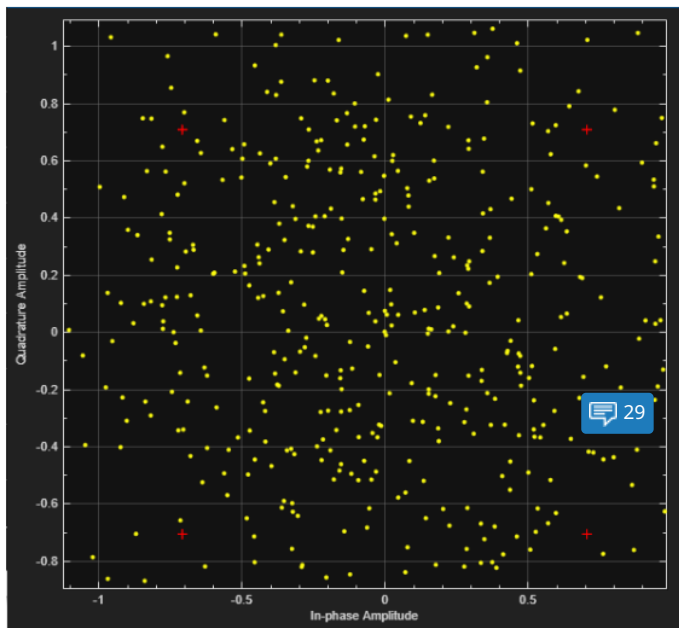


Figure 26: QAM Constellation with -20dB noise

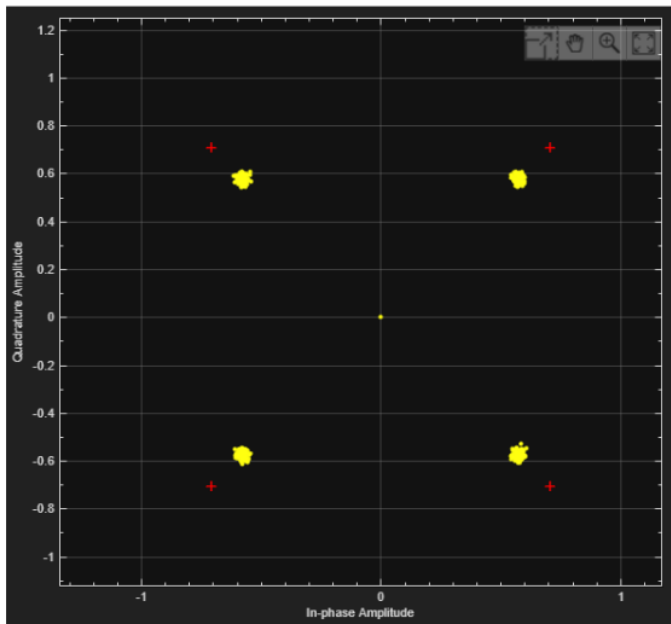


Figure 27: QPSK Constellation with 10dB noise

30

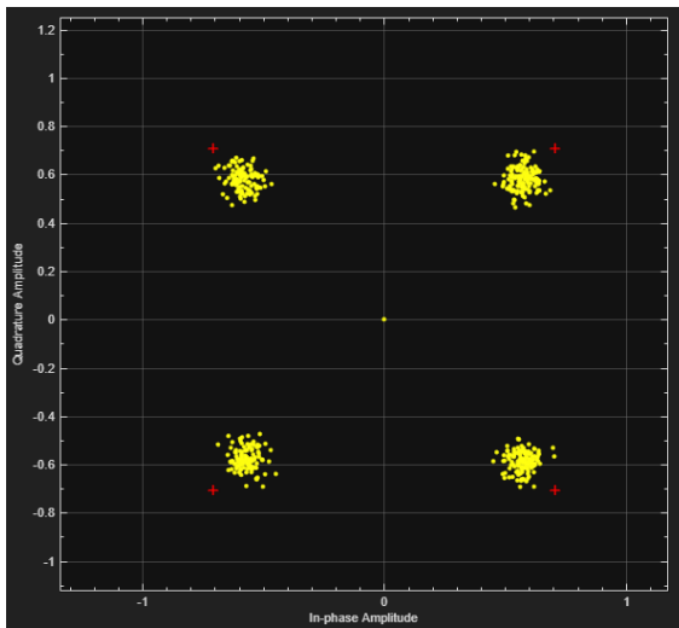


Figure 28: QPSK Constellation with 0dB noise

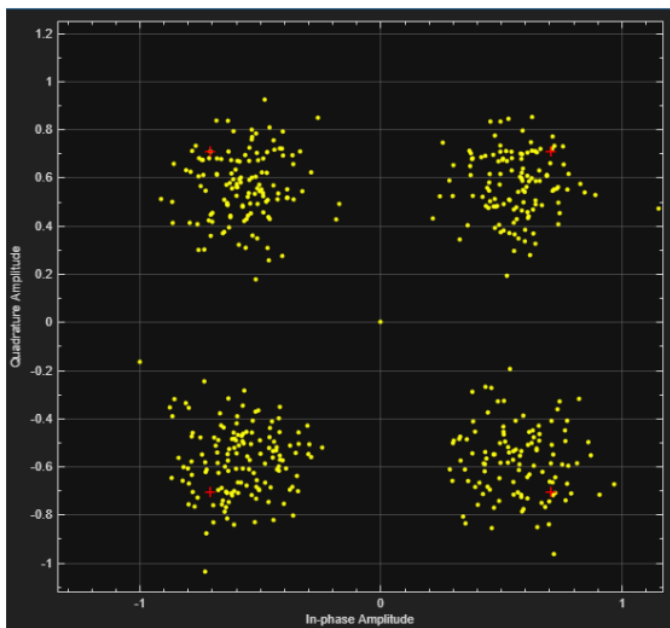


Figure 29: QPSK Constellation with -10dB noise

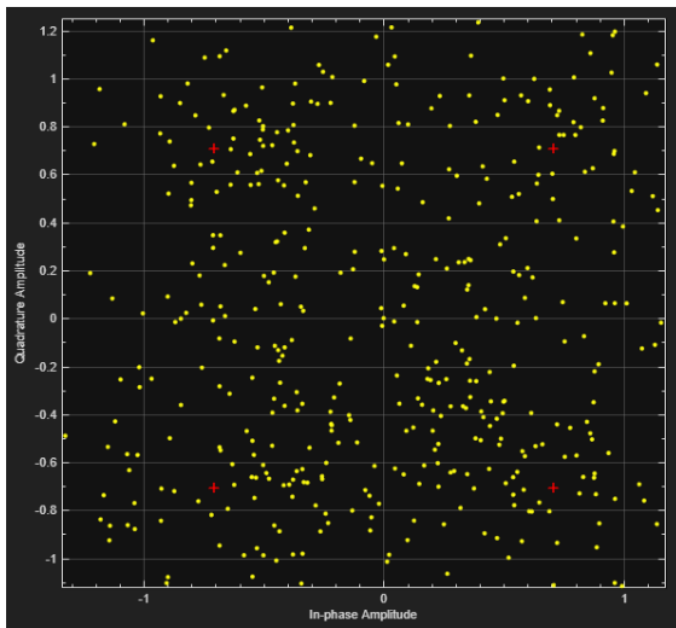


Figure 30: QPSK Constellation with -20dB noise

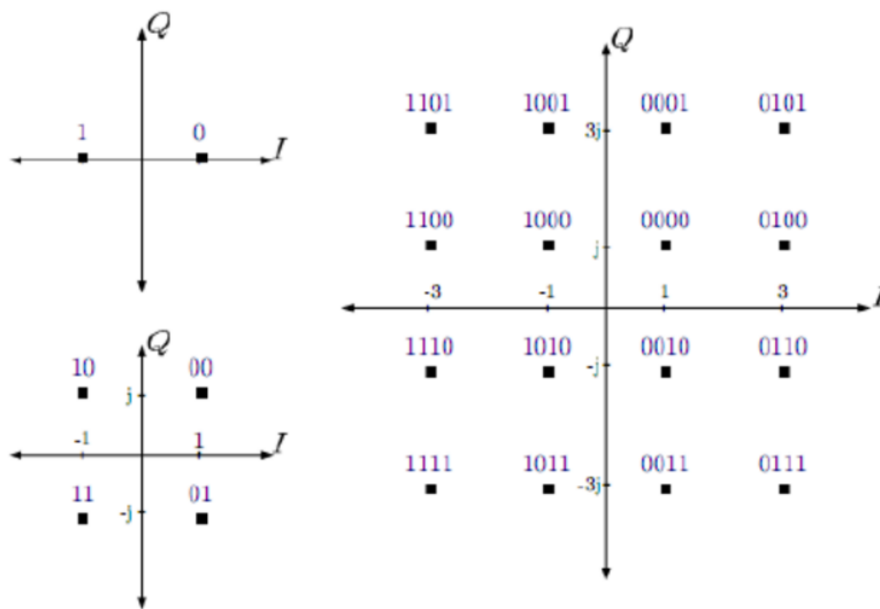


Figure 31: Binary Example [11]

Discussion

In Figure 31 can see how the different systems coped with the addition of noise, the best performing being the PSK and QPSK with the PSK performing slightly better as expected with it carrying only 1 bit of data rather than 2 bits of data. Both these systems are not highly affected by noise, as discussed before, due to phase not being affected by noise meaning the errors start occurring a lot later when the noise is a lot higher. They are both complicated systems, PSK seen in Figure 11 and the QPSK seen in Figure 13, compared to the ASK, seen in Figure 9.

It was expected that QAM would have the worst result, even though this is a combination of ASK and PSK methods due to carrying much more data with 4 bits. This can be seen when comparing the Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, Figure 29 and Figure 30 which are of the QAM and QPSK outputs to a constellation graph, this shows the massive difference noise creates for QAM interfering with the data where this only happens which much more noise for the QPSK. This is also very complicated to demodulate which can be seen in Figure 16. There are a lot of steps which when compared to the ASK in Figure 9 is very dramatic.

Finally, the 3rd best performing was ASK, this was expected to be far from the best due to how ASK's work, due to using the amplitude to pass the data this is a bad method as this is very susceptible to additive white Gaussian noise.

Conclusion

In conclusion all these modulations systems have their uses, each one has a reason to be selected for a different task. ASK is good for simple transmissions where you know the noise levels are low as it's an easy system to create and demodulate the signal. PSK and QPSK are very good in an area you know there is a higher level of noise as there is a reduced chance in data loss with QPSK being able to carry a larger amount of data in a message, this does make it slightly more susceptible to noise but only by a small amount, this can be seen in Figure 22 at the end of the graph. With QAM although it was the most susceptible to noise it can pass much more data in a short period of time compared to the other systems, so would be useful if you need to pass a large amount of data in a less noisy area but are a lot more complex system.

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67 /100

PAGE 1

PAGE 2

PAGE 3

PAGE 4



Comment 1

The abstract should be written in past tense, so instead of "The results will show..." you could say "The results show..."



Comment 2

Good abstract, but a more quantitative statement of results should be given.

The abstract is like the blurb on the back of a book, except it tells you who the killer is before you open the book.



Comment 3

Should be centered



Comment 4

You should put this in a sentence.

Where A is the amplitude, ω is the frequency, and t is time.



Comment 5

Which formula? It has a label, you should refer to it by its label.

"Equation 1 shows that the value..."



Comment 6

The feels a bit clunky. I think it could have been said better.

"Equation 1 shows that the amplitude of the modulated signal changes dependent on the binary value of the data to be transmitted. This is illustrated in Figure 1."



Comment 7

Do you mean benefit?

PAGE 5



Comment 8

Should be centered



Comment 9

You should put these into a sentence

PAGE 6



Comment 10

Should be centered



Comment 11

Put into sentence



Comment 12

This is the modulator (device), not the modulation (variations in the signal controlled by the data)

PAGE 7

PAGE 8



Comment 13

You should qualify this comment.

"...it can send more data than PSK *in a given amount of time*."



Comment 14

Be more precise in your language. Do you mean one of these:

disadvantage

shortcoming

encumbrance



Comment 15

Should be centered



Comment 16

Should be in a sentence

PAGE 9



Comment 17

Good as it illustrates how the QAM points are spread, although you should have changed the reference constellation (red crosses) to QAM too.



Comment 18

QAM is no more secure than any other of the techniques you've looked at

PAGE 10



Use of 1st Person Voice

When writing technical reports, do not use first person voice. Instead, use the third person passive voice.

You should not use words like "I", "you", "we" etc..



Comment 19

You should be writing more formally. Maybe consider phrases like:

"Figure 8 illustrates..."

"Shown in Figure 8 is...."

"Presented in Figure 8 is...."



Comment 20

This is a very severe filter



Comment 21

This is the wrong way around. First you decide the carrier frequency, then the data rate, and finally the filter characteristics once you know what it is you're filtering.

PAGE 11



First use

You should introduce acronyms and symbols the first time you use them so the reader understands what you are talking about.

PAGE 12



Comment 22

This feels like it could have been written better

PAGE 13



Colloquialism

You should not use colloquialisms in formal writing.

PAGE 14

PAGE 15

PAGE 16

PAGE 17



Comment 23

Which value? What effect does this have on the simulation?

Do you mean...

"This will be done by altering the Signal to Noise ratio (SNR) control in the channel, and then using an error rate calculator to compute the Bit Error Rate (BER)



Comment 24

Should be "Bit Error Rate"



Comment 25

Should be Signal to Noise Ratio (dB)



Comment 26

I think this should be..

QAM Constellation diagram with a SNR of +10dB



Comment 27

I think this should be..

QAM Constellation diagram with a SNR of 0dB



Comment 28

I think this should be..

QAM Constellation diagram with a SNR of -10dB



Comment 29

Do you really need these figures? I think Figs 23 - 25 told enough of the story.



Comment 30

See comment on Fig 23



Comment 31

Figure 22 shows...

You need to be more formal in your writing style



Comment 32

You should explicitly state what it is about the constellation diagrams which helped you draw these conclusions. Tell the story to the reader, don't let them guess.

PAGE 24



Comment 33

While you have some good quality reference sources, you should try to stay away from websites such as electrical4u.com and electronicscoach.com. Try to use more textbooks, we have a wonderful library which has a very large online catalogue.

PAGE 25

GRADING FORM: SMU GENERIC_SMOSEY

SAM LLOYD

66.80

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

6

good use of referencing conventions, consistently applied.

KNOWLEDGE & UNDERSTANDING

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



Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.

13.6

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.



"Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity and significance of evidence. Ability to communicate ideas and evidence accurately and convincingly.

Sound, convincing conclusions.

You need to explicitly state facts instead of allowing the reader to guess. - Join the dots for them.

20.4

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,

21.6

with extensive use of relevant examples.
Application and deployment extend beyond
established conventions. Innovation and creativity
evident throughout.

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 effectively in a suitable format, but may have minor errors.

Mostly coherent work and is in a suitable structure.

Take care with your writing style. - Try to be more formal and precise with your language

5.2