

Digital signal processing and communications.

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Executive summary

An interrogation of the application of digital signal processing (DSP) techniques including amplitude shift keying (ASK), phase shift keying (PSK), quadrature phase shift keying (QPSK) and quadrature amplitude modulation (QAM) in respect to the application of noise and the ability to continue to deliver an accurate portrayal of the transmitted signal. Given some basic background information considerations were made in respect to the channel parameters, signal bit rate of each application, volume of data and data and carrier wave amplitude. The requirement of the DSP application will ultimately define what system technique is most suited to enable the capability.

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1 INTRODUCTION

Contained herein is an interrogation of the application of ASK, PSK, QPSK and QAM in respect to the application of noise and the ability to continue to deliver an accurate portrayal of the transmitted signal. This critical comparison explored each model type and its construct within MathWorks MATLAB Simulink 2020a; simulations were executed initially to confirm the relevance and functionality of the block system then additive white gaussian noise (AWGN) was implemented in incremental levels to ascertain the system's ability to tolerate noise within transmission. The Tabulated results were recorded within Excel due to the nominal familiarity with MATLAB Simulink software package. Graphical representations were compiled, and comparisons made with respect to noise tolerance, capability of transfer rate and the implied power to noise ratio required to deliver a transmission with reduced susceptibility to noise. A relevant compilation of background information was recorded in addition to potential explorative research and a review of the delivery of this report.

2 BACKGROUND INFORMATION

2.1 Digital Signal Processing Communication system

In respect of digital signal processing (DSP) a communication system is the transfer of data from one point to another but with usually involving some element of encoding and modulation to ensure the signal can be decoded and demodulated respectively at the receiver. The Data source is usually in the form of an analogue or sinusoidal format. It must be discretely sampled through an antialiasing filter demonstrating Nyquist- Shannon sampling theorem that essentially defines the sampling rate is to be twice the amplitude of the maximum required frequency. This is then represented in digital format as a discretised set of Binary numbers, modulated prior to transmission then sent. It is at this point the signal is most susceptible to noise in transit from external power sources et.al. the Signal is received and filtered before being demodulated with a coherent system should the signal be designed to be received. This signal is then converted back to a sinusoidal format and adequately processed for delivery as alluded to in **Figure 1**. [1, 2, 3, 4, 5, 6, 7, 8]

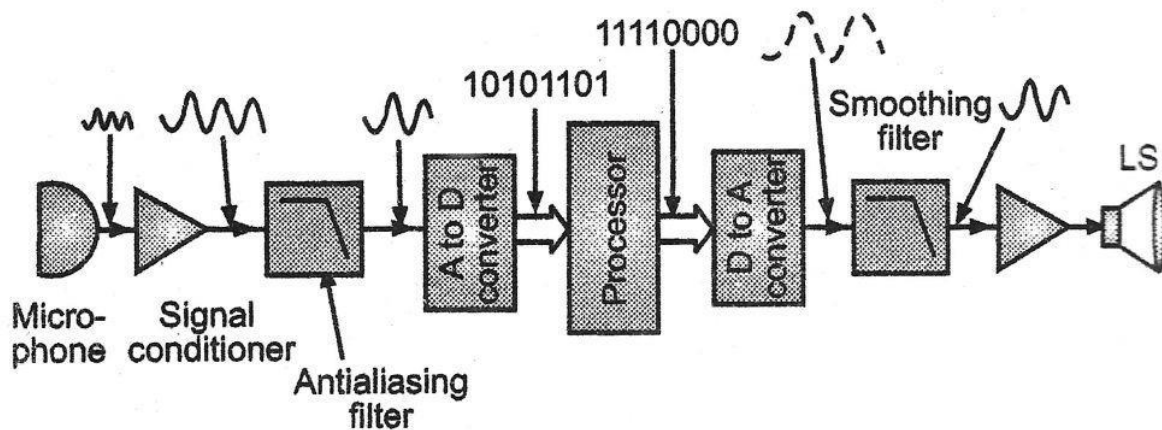


FIGURE 1 representative DSP communications system [4]

2.2 Modulation and demodulation

In the transmitter section of the system there are multiple components that will process the dataset prior to transmission but the modulator provides the carrier wave to physically send the signal. The generated waveform is suitable to carry the encoded dataset through the remnants of the DSP communication channel before transmission to the receiver. A modulated signal is when a signal property is modified such as phase, frequency, or amplitude whilst the remnant properties remain unaltered. Demodulation of a signal is the removal of this modification from the signal as it is received. [1, 9,]

Housed within the receiver elements of the system is a demodulation block. In coherent systems the demodulator will typically generate an identical waveform to negate the transmitted carrier wave. A typical application of this sort of system could be a modem used to receive data from an external source.

Non coherent demodulators have a wider operational bandwidth and adjustable amplitude and frequency; these are often applied to signal interception albeit espionage or late 80's Irish radio. [1, 10, 11]

2.3 Channel characterisation

To adequately assess a DSP system, the channel in which it operates must be assessed; notation should be taken to available bandwidth, level of noise, any attenuation or delay caused through transmission through its given media. In mobile DSP systems the movement of and relative proximity between the transmitter and receiver according to Maxwells equations. [1, 12]

Channels and signals can be categorised into two types:

1. Baseband:
 - Signals centred around 0Hz DC value
 - channel uses low pass filter to receive DC signal
2. Bandpass:
 - signals centred around different frequency other than DC i.e. palpable high and low values
 - channel uses high pass filter to receive the signal

2.4 Fourier transform

The Fourier transform is the mathematical relationship between the time domain and frequency domain and their relative modification and is represented by the equation: [1, 13]

$$g(t) \leftrightarrow G(f)$$

$$G(f) = F[g(t)] = \int_{-\infty}^{\infty} g(t)e^{-j2\pi ft} dt$$

The Fourier transforms intent is to be applied to a continuous signal wherein a DSP type signal can be directly assessed through the application of Discrete Fourier Transform due to its application to a discretised sample with adequate sampling rate.

The Fast Fourier transform is another way to ascertain information of discretised data in both frequency and time domains. in the time domain the initial step is to sort data through bit reversal followed in the frequency domain by ascertaining the spectrum of each of the signals before synthesizing them into a single frequency spectrum output. [1, 13, 14, 15, 16, 17]

2.5 Digital modulation techniques

2.5.1 ASK

Amplitude shift keying (ASK) is often referred to as on off keying phase and frequency remain unchanged whilst the amplitude is modified essentially the carrier wave will be rapidly switched on and off to create the signal data the differing amplitudes representing a 1 or a 0 and prevailing digital bit stream. [1, 9, 18, 19, 20, 21].

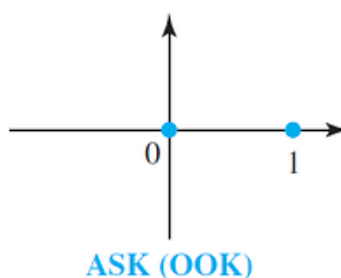


FIGURE 2 ASK Constellation diagram [18]

2.5.2 FSK

With the application of frequency shift keying (FSK) the carrier wave frequency is varied by a very small amount to represent the data whilst amplitude and phase remain constant the two independent frequencies will be established to represent a 0 or a 1 within the data. [1, 9, 18, 22]

2.5.3 PSK

Phase shift keying (PSK) as suggested retains constant frequency and amplitude and is subject to phase change, each phase angle will represent a 1 or 0 meaning the bit rate and modulation rate are equal however additional phase angles may be added to increase the bit rate and amount of data able to be transferred within the available bandwidth. [1, 9, 18, 22]

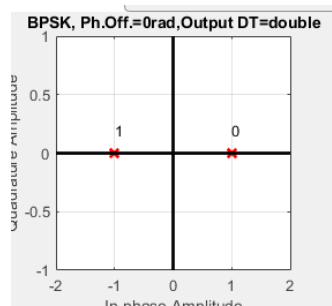


FIGURE 3 PSK constellation diagram [MATLAB]

2.5.4 QPSK

Quadrature phase shift keying (PSK) is the culmination of two separate binary PSK operations: one operating in phase the other in the quadrature phase. Following conversion from a series to parallel signal that divides the data between the two modulators the data is transmitted and then demodulated before being returned to a series signal. QPSK operates four phase angles in its most basic form to demonstrate two bits of data at each phase angle: 00, 01, 10, 11. QPSK retains the ability to increase its number of phase angles at the cost of tolerance to noise. [1, 9, 18, 22, 23 24, 25]

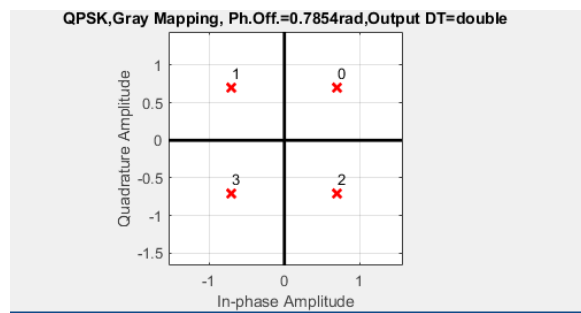


FIGURE 4 QPSK Gray coded constellation diagram [MATLAB]

2.5.5 QAM

Quadrature amplitude modulation (QAM) is the conglomerate of both ASK and PSK systems operating the same in-phase and quadrature phase operation. These phases are represented by a sinewave and cosine wave respectively. As with most higher order modulation techniques QAM retains the ability to operate additional phase angles at a cost of noise tolerance. Operation QAM systems can be 16QAM, 64QAM and 256QAM the latter being commonly employed with in UK telecommunications infrastructure. With the application of more channels there is a requirement to increase power to the system to balance the signal to noise ratio (SNR). [1, 26, 27, 28, 29, 30, 31, 32, 33, 34]

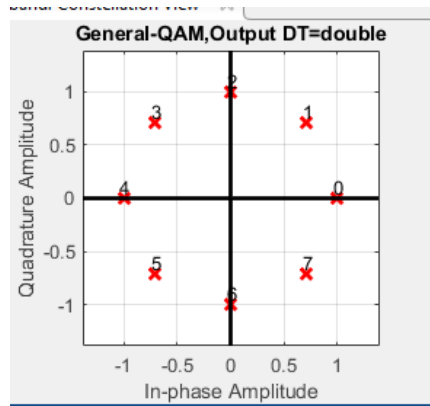


FIGURE 5 QAM Gray coded constellation diagram [MATLAB]

3 SIMULATION MODELS

[1]

3.1 ASK

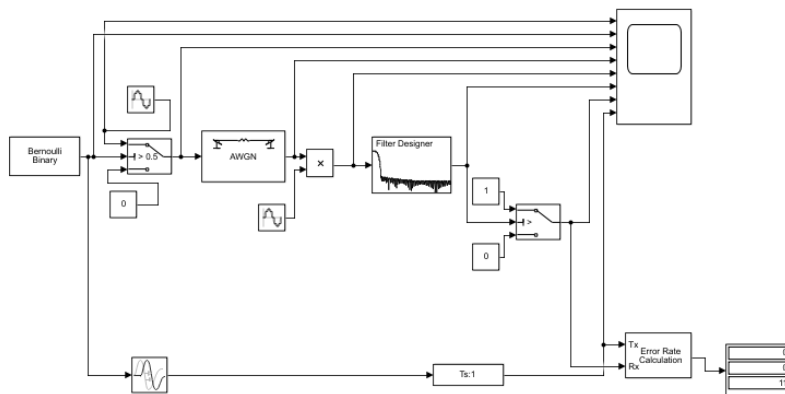


FIGURE 6 ASK block diagram MATLAB screen capture

ASK simulation set up description

Binary Bernoulli (0.5 probability of 0) data feed into modulator switch with 0.5 threshold driven by sign wave of $2\pi \times 100$ frequency and 0 phase with sample time of 1/1000 and constant block. AWGN block set as SNR with initial seed of 67 and variation was made to the SNR noise output is then multiplied by a copy of the modulators sign wave before running through the low pass filter.

Low pass filter settings

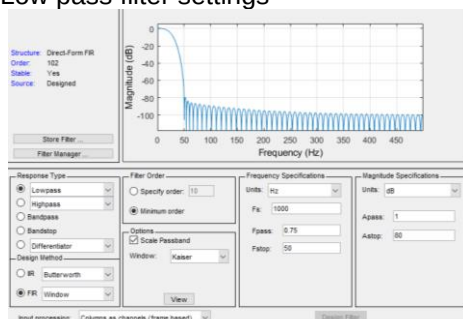


FIGURE 7 ASK Filter designer block parameters MATLAB screen capture

Demodulator switch threshold set to 0.25 to scope and Rx Error rate feed

Tx error rate feed is taken from Bernoulli source through a time delay (0.055) and a signal specification block to migrate to discrete signal data

Stop time 500

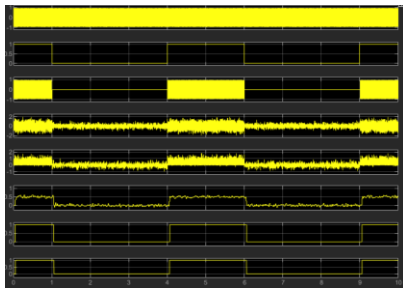


FIGURE 8 ASK initial scope output (stop time =10) MATLAB screen capture

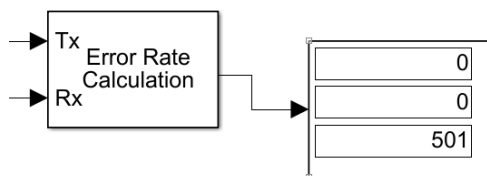


FIGURE 9 ASK Initial Error rate calculation output MATLAB screen capture

3.2 PSK

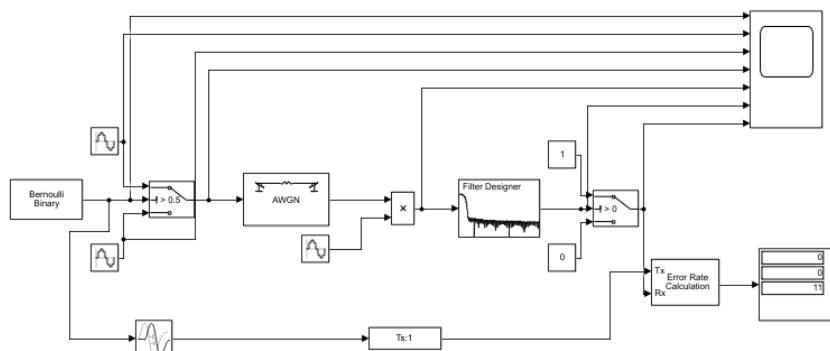


FIGURE 10 PSK block diagram MATLAB screen capture

PSK simulation set up description

Binary Bernoulli (0.5 probability of 0) data feed into modulator switch with 0.5 threshold driven by 2 sign waves of $2\pi \times 100$ frequency with sample time of $1/1000$ one with phase setting of 0 the second with phase setting of π

AWGN block set as SNR with initial seed of 67 and variation was made to the SNR noise output is then multiplied by a copy of the modulators sign wave before running through the low pass filter.

Low pass filter settings

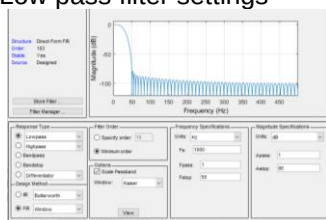


FIGURE 11 PSK Filter designer block parameters MATLAB screen capture

Demodulator switch threshold set to 0 to scope and Rx Error rate feed

Tx error rate feed is taken from Bernoulli source through a time delay (0.053) and a signal specification block to migrate to discrete signal data

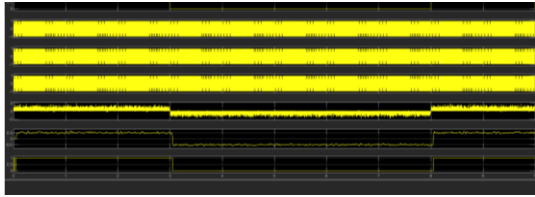


FIGURE 12 PSK initial scope output (stop time =10) MATLAB screen capture

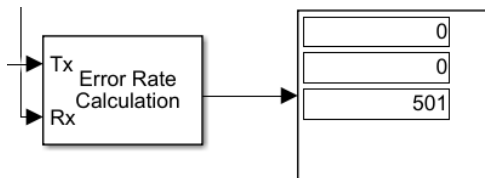


FIGURE 13 PSK Initial Error rate calculation output MATLAB screen capture

3.3 QPSK

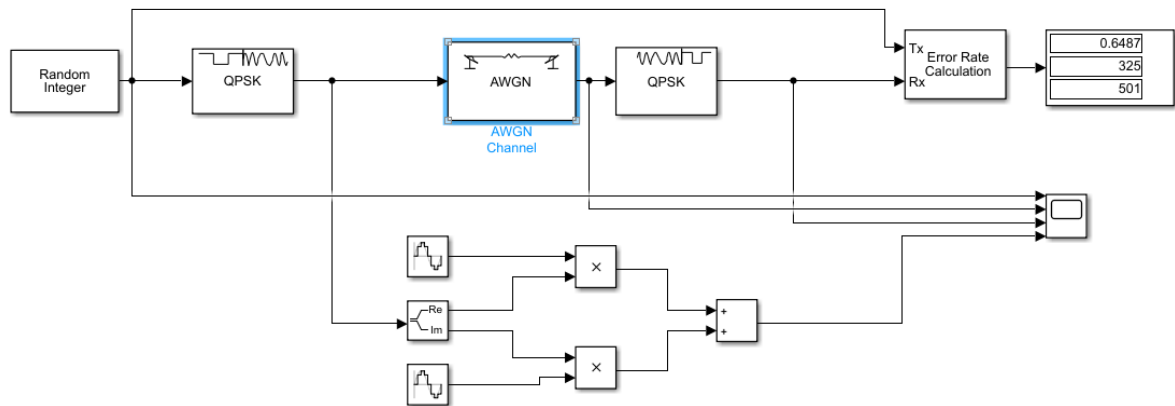


FIGURE 14 QPSK block diagram MATLAB screen capture

N.B. due to hardware limitation alternate methods to build the simulation were implemented in the form of Simulink standard QPSK modulation and demodulation blocks [35]

QPSK simulation set up description

Random integer generator was used to enable 4 bit data entry transferred through QPSK modulation AWGN as set in PSK with SNR values to be modified this was then fed through QPSK demodulation block that was set to the same as modulator
To confirm QPSK modulation output of QPSK modulator was run through products of in phase and quadrature phase sign wave generators and a complex to real imagery splitter, this signal was added together and observed in the scope to be a QPSK signal

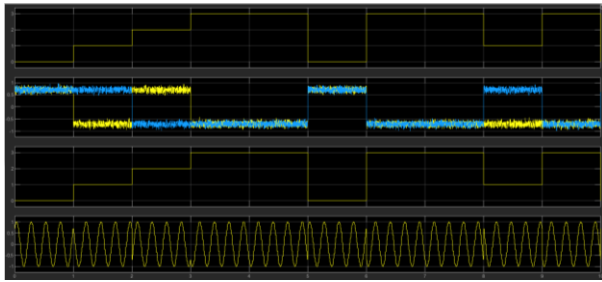


FIGURE 15 QPSK initial scope output (stop time =10) MATLAB screen capture

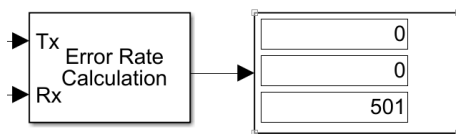


FIGURE 16 QPSK Initial Error rate calculation output MATLAB screen capture

3.4 QAM

As was the case with the QPSK simulation Simulink standard QAM blocks were implemented,

QAM simulation set up description

Random integer generator was used to enable 8 bit data entry transferred through QAM modulation AWGN as set in PSK with SNR values to be modified this was then fed through QAM demodulation block that was set to the same as modulator

To confirm QAM modulation output of QAM modulator was routed through an identical system as implemented on QPSK demonstrating QAM signal as shown in initial scope output.

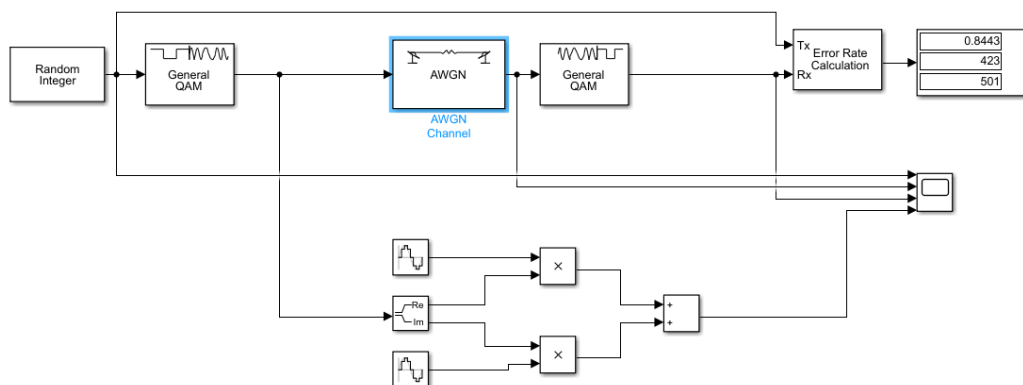


FIGURE 17 QAM block diagram MATLAB screen capture

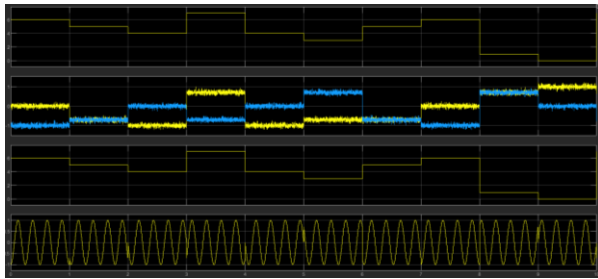


FIGURE 18 QAM initial scope output (stop time =10) MATLAB screen capture

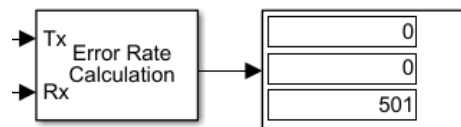


FIGURE 19 QAM Initial Error rate calculation output MATLAB screen capture

4 RESULTS

4.1 Definition of system failure

Definition of failure parameters are key in determining just what constitutes system failure as can be seen from ASK table shown in 4.2 simulation will continue beyond what could be determined a realistic amount of interference for the purpose of these applications the failure rate will be set at a Bit Error rate (BER) of 40% when applied to a varying signal to noise ratio (SNR)

4.2 Simulation notes

4.2.1 Note 1

Due to naivety parameters for the simulations were arbitrary figures obtained through trial and error methodology.

4.2.2 Note 2

Due to the random element of binary data it was suggested a multi simulation average should be demonstrated for each setting of snr the simulation was ran in triplicate then the average figure ascertained for use within these results

4.3 MATLAB; Simulink Error

Requirement to annotate the output constellation diagram from each circuit was to remain omitted from this results section as result of software error:

The fielding of Simulink constellation diagram block within any models would culminate in its visualisation but attempt to modify/operate the block would result in simulation crash and MATLAB failure as evidenced in **Figure 20**. Following repeated attempts and multiple emails to MathWorks Technical support and erroneous connections via remote desktop to university facilities the omission of the results remained to be the only viable delivery given time constraints.

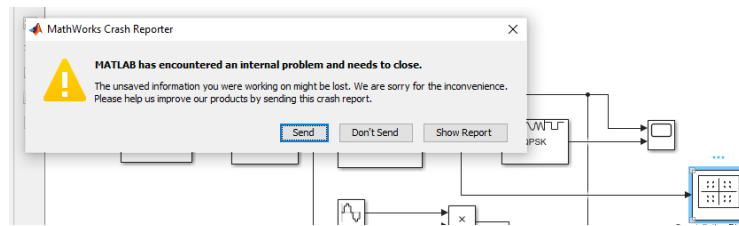


FIGURE 20 MATLAB Error Screen capture

4.4 ASK

TABLE 1 ASK simulation raw data output

SNR (dB)	Sim1 ER	Sim 1 NoErr	Sim2 ER	Sim 2 NoErr	Sim3 ER	Sim 3 NoErr	ave ER	ave NoErr
10	0%	0	0%	0	0%	0	0.00%	0.00
0	4%	21	4%	20	4%	21	4.00%	20.67
-1	6%	31	6%	29	6%	31	6.00%	30.33
-3	10%	51	8%	45	11%	53	9.67%	49.67
-6	19%	97	17%	87	21%	104	19.00%	96.00
-9	25%	124	25%	125	25%	125	25.00%	124.67
-12	27%	133	31%	156	29%	143	29.00%	144.00
-15	34%	170	38%	190	40%	200	37.33%	186.67
-18	41%	207	40%	198	40%	198	40.33%	201.00
-21	40%	200	43%	217	41%	207	41.33%	208.00
-24	48%	238	46%	229	39%	193	44.33%	220.00
-27	46%	230	47%	233	47%	233	46.67%	232.00
-30	51%	255	45%	225	45%	226	47.00%	235.33
-40	47%	236	47%	237	49%	245	47.67%	239.33
-50	48%	238	50%	252	50%	248	49.33%	246.00
-60	50%	252	52%	258	53%	267	51.67%	259.00
-70	52%	261	49%	244	50%	254	50.33%	253.00
-80	53%	266	52%	259	53%	263	52.67%	262.67
-100	47%	236	49%	247	53%	266	49.67%	249.67
-1000	50%	252	51%	253	51%	253	50.67%	252.67
-10000	50%	254	50%	252	49%	247	49.67%	251.00

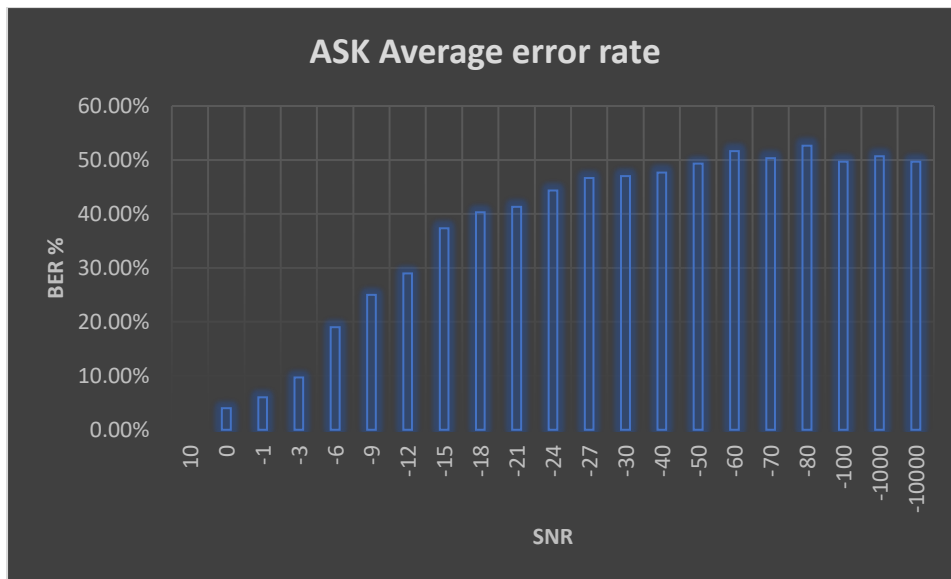


FIGURE 21 Graphical representation of ASK average data

The ASK simulation yielded evidence of a relatively high tolerance to noise against incremental increase of the Signal to noise ratio not achieving failure until average SNR was at a value of -18.

4.5 PSK

TABLE 2 PSK simulation raw data output

SNR (dB)	Sim1 ER	Sim 1 NoErr	Sim2 ER	Sim 2 NoErr	Sim3 ER	Sim 3 NoErr	ave ER	ave NoErr
10	0%	0	0%	0	0%	0	0.00%	0.00
0	0%	1	0%	1	0%	1	0.00%	1.00
-1	0%	0	0%	0	0%	1	0.00%	0.33
-3	1%	5	1%	5	0%	4	0.67%	4.67
-6	5%	23	4%	21	4%	19	4.33%	21.00
-9	10%	50	11%	55	12%	62	11.00%	55.67
-12	16%	82	19%	97	20%	104	18.33%	94.33
-15	25%	126	26%	128	25%	125	25.33%	126.33
-18	32%	162	31%	156	33%	165	32.00%	161.00
-21	36%	182	34%	169	38%	188	36.00%	179.67
-24	38%	192	39%	197	43%	219	40.00%	202.67
-27	42%	208	47%	234	43%	215	44.00%	219.00
-30	49%	243	42%	211	46%	229	45.67%	227.67

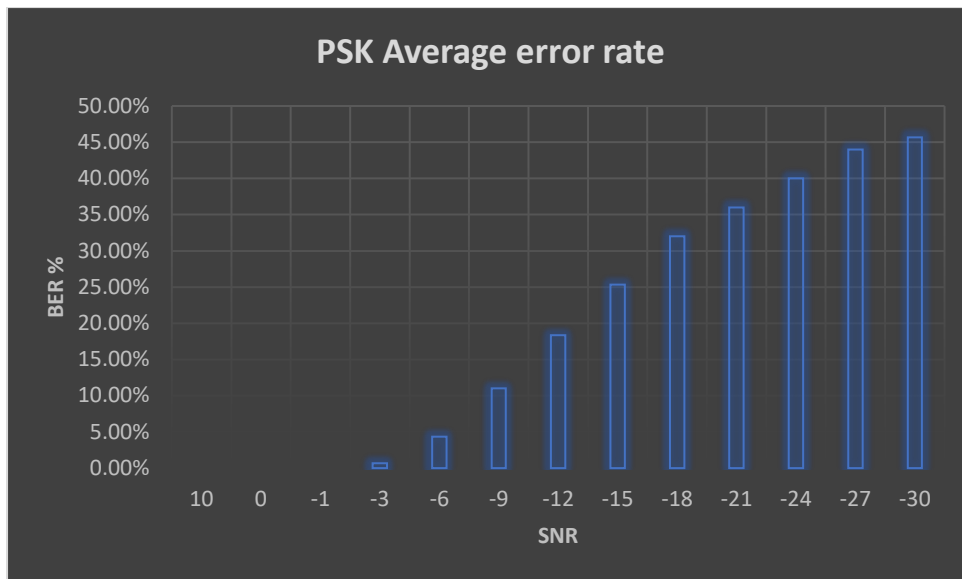


FIGURE 22 Graphical representation of PSK average data

The PSK simulation yielded evidence of a relatively higher tolerance to noise against incremental increase of the Signal to noise ratio not achieving failure until average SNR was at a value of -24.

4.6 QPSK

TABLE 3 QPSK simulation raw data output

SNR (dB)	Sim1 ER	Sim 1 NoErr	Sim2 ER	Sim 2 NoErr	Sim3 ER	Sim 3 NoErr	ave ER	ave NoErr
12	0%	0	0%	0	0%	0	0.00%	0.00
10	0%	1	0%	0	0%	1	0.00%	0.67
8	1%	6	1%	5	1%	5	1.00%	5.33
6	6%	28	3%	18	5%	25	4.67%	23.67
4	9%	45	11%	56	10%	51	10.00%	50.67
2	17%	84	18%	91	19%	94	18.00%	89.67
0	29%	143	27%	136	30%	149	28.67%	142.67
-2	39%	195	40%	199	38%	189	39.00%	194.33
-4	46%	230	47%	235	46%	232	46.33%	232.33
-6	53%	263	53%	267	52%	257	52.67%	262.33
-8	61%	306	61%	304	55%	277	59.00%	295.67
-10	59%	295	58%	293	62%	314	59.67%	300.67
-12	64%	323	67%	335	65%	325	65.33%	327.67

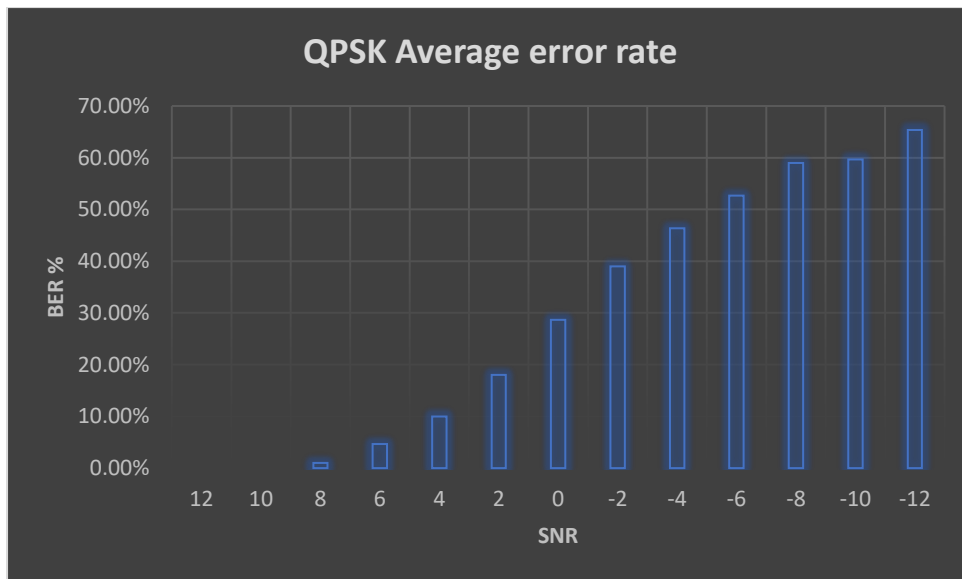


FIGURE 23 Graphical representation of QPSK average data

The QPSK simulation demonstrated very deficient tolerance to noise against incremental increase of the Signal to noise ratio achieving failure when the average SNR was at a value of just over -2.

4.7 QAM

TABLE 4 QAM simulation raw data output

SNR (dB)	Sim1 ER	Sim 1 NoErr	Sim2 ER	Sim 2 NoErr	Sim3 ER	Sim 3 NoErr	ave ER	ave NoErr
16	0%	0	0%	0	0%	0	0.00%	0.00
14	1%	6	0%	3	1%	5	0.67%	4.67
12	3%	20	3%	15	3%	16	3.00%	17.00
10	8%	38	9%	47	9%	46	8.67%	43.67
8	18%	92	18%	89	16%	79	17.33%	86.67
6	29%	143	23%	116	28%	138	26.67%	132.33
4	37%	185	39%	193	39%	197	38.33%	191.67
2	50%	251	50%	251	52%	260	50.67%	254.00
0	59%	293	57%	287	58%	292	58.00%	290.67
-2	65%	325	64%	321	65%	325	64.67%	323.67
-4	68%	343	72%	359	71%	356	70.33%	352.67
-6	75%	375	74%	372	73%	368	74.00%	371.67
-8	80%	400	77%	384	78%	391	78.33%	391.67

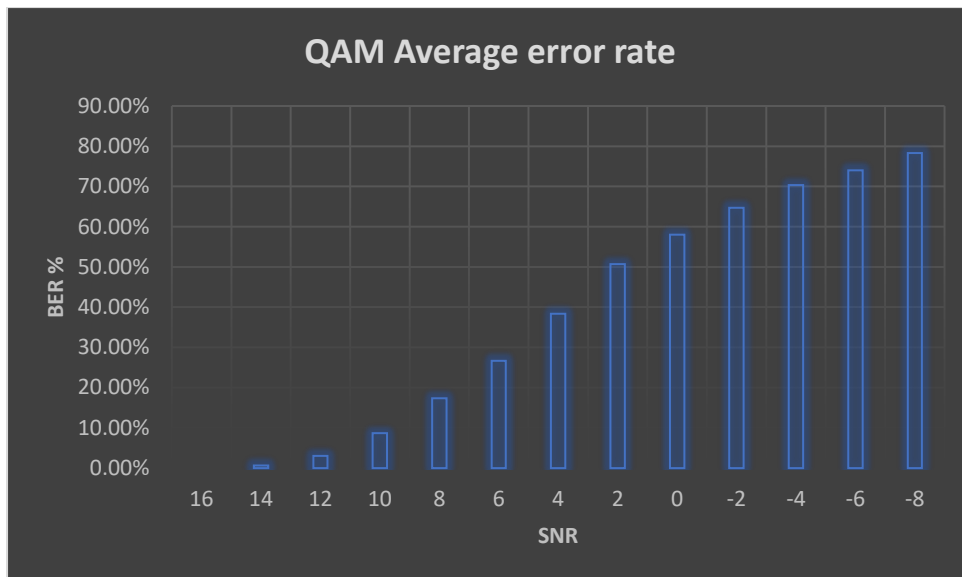


FIGURE 24 Graphical representation of QAM average data

The QAM simulation bore evidence of a feeble tolerance to noise against incremental increase of the Signal to noise ratio achieving failure with an average SNR value of +4.

5 DISCUSSION

5.1 Comparison of BER results

TABLE 5 simulation Average data output

SNR (dB)	ASK Ave	PSK Ave	QPSK Ave	QAM Ave
16	0.00%	0.00%	0.00%	0.00%
14	0.00%	0.00%	0.00%	0.67%
12	0.00%	0.00%	0.00%	3.00%
10	0.00%	0.00%	0.00%	8.67%
8		0.00%	1.00%	17.33%
6		0.00%	4.67%	26.67%
4		0.00%	10.00%	38.33%
2		0.00%	18.00%	50.67%
0	4.00%	0.00%	28.67%	58.00%
-1	6.00%	0.00%		
-2			39.00%	64.67%
-3	9.67%	0.67%		
-4			46.33%	70.33%
-6	19.00%	4.33%	52.67%	74.00%
-8			59.00%	78.33%
-9	25.00%	11.00%		
-10			59.67%	
-12	29.00%	18.33%	65.33%	
-15	37.33%	25.33%		
-18	40.33%	32.00%		
-21	41.33%	36.00%		
-24	44.33%	40.00%		

-27	46.67%	44.00%		
-30	47.00%	45.67%		

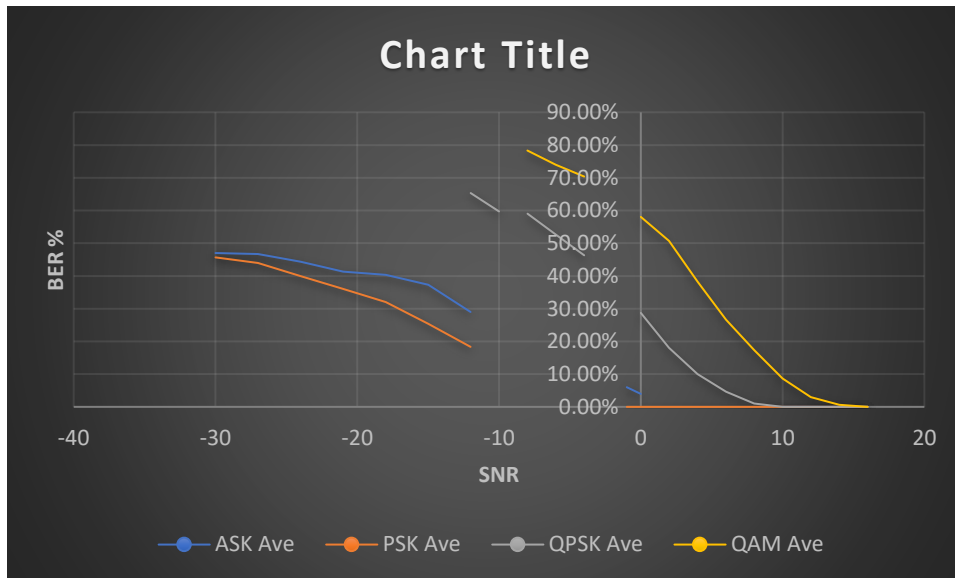


FIGURE 25 Graphical comparison of all simulation average data

5.2 Observation Discussion

From interrogation of the data in **5.1** it was observed that relatively speaking PSK has the highest tolerance to SNR holding the lowest point. Following further investigation, the channel parameters were considered; both ASK and PSK systems retain a low bit rate and binary output, from interrogation of a constellation diagram it would demonstrate how in spite of noise in the signal, it is easy to set boundary parameters for allocation of either a 1 or 0 signal. Specifically, in the case of PSK the central axis of the constellation can be set as a boundary. This can be visualised in **Figures 2** and **3** located in **2.6**.

QPSK retains a Bit rate of 4 meaning there is four points that will require allocated parameter boundaries to ascertain output at either 00, 01, 10 or, 11. Constellation diagram located in **2.7 Figure 4**

QAM has a bit rate of 8; further constraining parameter boundaries (visualisation in **2.8 Figure 5**) its circular layout around the Axes origin being constrained diametrically by signal amplitude meaning that the smaller the signal amplitude as is demonstrated in these results; then the higher susceptibility to noise interference with the signal.

5.3 Constellation diagram parameter boundary mapping

Following the unfortunate software failure defined in **4.3** demonstration was unobtainable within MATLAB with regards to signal noise output on a constellation diagram. Within the resultant output of non-linear applications of Quadrature modulation systems software algorithms will demonstrate decision boundaries wherein the parametric positioning of the point will allocate its signal output. Mapping of different Quadrature decision boundaries will be reliant on software algorithms far beyond the spectre of this report however for perusal **Figure 26** demonstrates different higher order modulation constellation target diagrams **Figure 27** demonstrates an example of QAM decision boundary. [36]

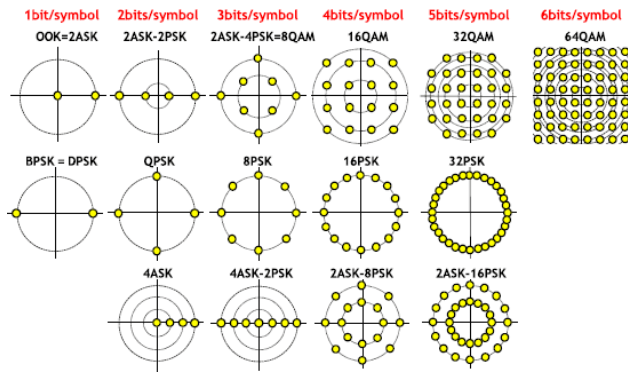


FIGURE 26 Higher order modulation constellation target diagram [37]

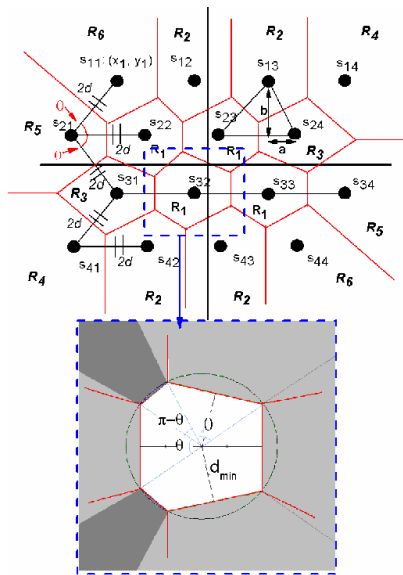


FIGURE 27Example QAM decision boundary [38]

A typical output would be a culmination of points contained within these boundaries as alluded to in **Figure 28**, these signals will be defined by the limitation set by the decision boundary as will any spurious signals that may fall outside the perimeter of the boundary. In higher order modulation such as 64QAM decision boundaries of a 6-bit system can be annotated to show binary output **Figure 29**.

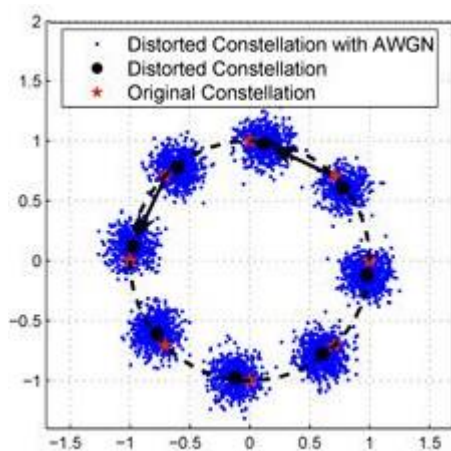


FIGURE 28 example output from noise on a constellation diagram [39]

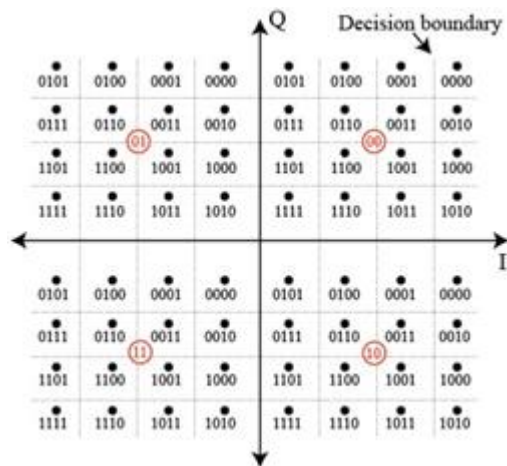


FIGURE 29 64 QAM 6-bit Binary output mapping [40]

6 CONCLUSION

6.1 Report conclusion

To appropriately conclude contextual definition was given to the application of Bit Rate within modulation systems. A fair conclusion could have been that PSK is the best operational modulator to combat a high level of white gaussian noise; however, ASK FSK and PSK are a 2 bit process meaning volume of data within the transfer is comparatively minimal when higher order modulation systems are considered. The requirement of application will lead in the decision to deploy each capability. If a PSK where to be applied to an unsuitable application such as modem operation although its capability to handle noise would be unchallenged its rate of data delivery would be exponentially poor in competition with a 254QAM system.

From the data and research undertaken regarding output through constellation diagrams, it would imply that data and carrier wave amplitude may undertake a large part in signal to noise ratio balance suggesting that greater amplitude may in the case of higher order modulation allow for a larger boundary area to compensate for noise. Meaning if a tighter boundary were to be applied on a larger amplitude signal it could potentially be a methodology to isolate spurious data from the output.

Each modulation system that has been briefly probed by this report has a suited application and tolerance to noise should not be the only decision in the application of a new DSP system. All of the systems require certain parameters to be met. An ideal application for instance ASK systems are susceptible to non-linear distortion and FSK systems are reliant of high stability within the systems source and PSK benefits from a high phase tolerance.[9]

6.2 Further exploration

In order to fully ascertain an understanding of the application of noise on signals further research should be undertaken on higher order modulation techniques and assessment into the reduction of noise interference through increased amplitude of the carrier wave and data signal to balance the signal to noise ratio in the favour of the data signal.

6.3 Review of activity

The approach to this report resounded in immaturity, naivety, and unpreparedness. The foundation knowledge to deliver such a report in a short time frame was not achieved and there was no level of intimacy in the operation of MathWorks MATLAB and Simulink. Retrospection would deliver knowledge of the depth of intimacy required with the operation of MathWorks software to have undertaken external training ahead of time; meaning the delivery of course led material would not be fraught with menial software issues such as not having appropriate tooling within MathWorks products and focus could be applied to the delivery of a suitable content.

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