

DSP assignment

by Cameron Fitze

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Digital Signal Processing
Assignment – Cameron Paul Fitze
2111737

Digital Signal Processing Assignment

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Course Number:

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Abstract

This assignment explores modulation techniques, specifically digital modulation techniques including ASK, BPSK, QPSK, and QAM.

Each technique varies a different property of the signals during the modulation stage.

ASK varies the amplitude, whilst BPSK and QPSK both  the phase. However, the BPSK constellation consists of two points, 180 degrees out of phase of each other, whereas, QPSK has four constellation points, 90 degrees out of phase of each  QAM varies the amplitude and phase, so combines ASK and PSK, and comes in variants such as 16 QAM, and 64 QAM.

Low data rate applications would suit simpler techniques such as ASK and PSK, whereas higher data rate applications would require more sophisticated techniques such as QPSK or QAM, increasing the order level, e.g., 16QAM,  etc., for increasing data rate requirements.

This assignment investigates how bit error rate changes with channel noise, or signal to noise ratio. Each modulation technique was tested and compared to what was found out through background research.

The results showed that whilst PSK did have an increase in BER with noise, ASK and QPSK appeared to show the reverse. This could be due to errors  analysis state. If the graphs had been configured to show BER vs SNR, then the results observed would be as expected.

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1. Introduction

This aim of this assignment is to create various radio frequency (RF) modulation techniques using MATLAB, and evaluate at what point these systems fail as they experience an increase in noise on the channel. This will be determined by their bit error rate (BER) values.

This assignment involves a design stage and an analysis stage.

The overarching concepts explored in this report are modulation techniques and signals.

Modulation involves varying the properties of something like noise (for example, making something louder).

Signals are used to carry information, and for the purpose of RF modulation, there are two types of signals: carrier signal and message signal.

The carrier signal is usually a sinusoidal waveform used to convey data from a message signal. The message signal is the signal bearing the data to be transmitted.

RF modulation involves varying at least one of a carrier signal's properties (phase, amplitude, frequency, for example), in relation to the message signal.

1.1 Design stage

The design stage is carried out using Simulink – a graphical-based modelling environment for simulating and analysing, built on top of MATLAB.

1.2 Analysis stage

The analysis stage involves observing the spectrum output at various stage of the modulator and demodulator of the systems designed, as well as observing the IQ data.

There are two types of sampling signals observed in DSP: continuous time, where it can be an infinite array of possible numbers, and discrete time, where it has to be a specific/ whole number.

IQ data describes a complex baseband signal with a discrete time series that can be transformed to a corresponding real valued RF signal. The real component is in phase, and the imaginary component is out of phase. [1].

1.3 Modulation techniques

There are two types of modulation techniques: analogue and digital. Analogue consists of techniques such as Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM). Applications include radio transmission using AM and FM.

The modulation techniques explored in this assignment are digital, and include the following techniques:

- Amplitude-Shift Keying (ASK)
- Phase-Shift Keying (PSK)
- Quadrature-Phase-Shift Keying (QPSK)
- Quadrature Amplitude Modulation (QAM)

2. Digital Modulation

ASK is a modulation technique that varies the amplitude of the message signal. ASK is used in binary data transmission, for instance, data transmitted over an optical cable. The benefit of ASK is it is low cost and simple to implement, thus it is used in low data-rate applications.

PSK is a modulation technique that varies the phase of the message signal. PSK is used in applications such as Bluetooth and RFID. PSK is more efficient than Frequency Shift Keying (FSK) [2] and has a simpler transmitter and receiver design due to there being no amplitude modulation. There are various types of PSK including:

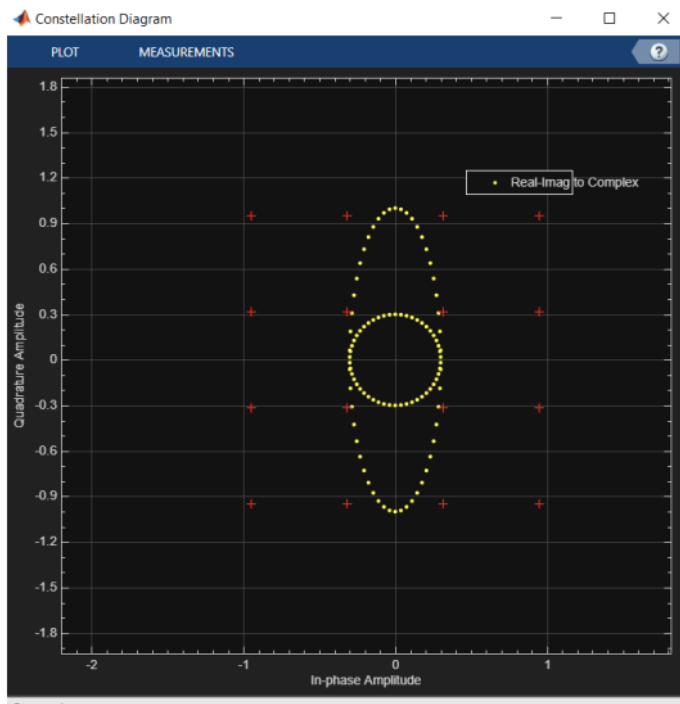
- Binary PSK (BPSK)
- QPSK
- Offset QPSK (O-QPSK)
- 8 PSK
- 16 PSK

QPSK is a modulation technique that varies the phase of the message signal in four constellation points. Each constellation point is 90 degrees out of phase of each other, with the possible carrier phase shifts being 0, 90, 180, or 270 degrees. This allows for a higher data rate than BPSK or ASK (As more data can be transmitted over the same bandwidth link). However, a higher SNR is required for high data rate, low bit error rate (BER) applications QPSK is used in satellite communications and LTE. Data rate requirements will determine what order QPSK is used or whether another modulation schema such as QAM is used.

QAM is a modulation technique that essentially combines ASK and PSK, varying the amplitude and phase of the message signal, but in 4 constellation points. Types of QAM include 16 QAM and 64 QAM. QAM is used in telephone modems and LTE. Like with QPSK, what order level of QAM is used will depend on the data rate requirements. The benefits of QAM over ASK and PSK is that it increases the number of bits available, thus increasing the bit rate [3]. The negative of QAM is that it requires a more complex transceiver than ASK or PSK as it needs to receive data from 4 different phases simultaneously. This adds cost to the process.

As mentioned above, a modulated signal can be represented on a constellation diagram. Figure 1 shows the constellation for 16 QAM. As shown, there are four constellation points per quadrant. Each constellation point represents a symbol. Different modulation techniques have different number of bits per symbol. With QAM, the number of bits per symbol is 2^n , so for 16-QAM, this number is 2^4 which equals 16, hence 16 QAM. Therefore, 16 QAM can hold 4 bits per symbol. For 64 QAM, it would be 2^6 , so 6 bits per symbol.

ASK and PSK are binary, so can only transmit either a 1 or 0 at one time. QPSK can transmit twice as much, so 2 bits per symbol.



6

Figure 1 - 16-QAM constellation diagram

2.1.1 Choosing a digital modulation technique

When selecting a digital modulation technique, consideration should be afforded to power efficiency and bandwidth efficiency [4].

Power efficiency is the number of bits per thermal noise energy unit (TNEU). This is the number of bits transmitted within a signal that has the same power spectral density (PSD) as the AWGN received at the receiver. [5]

Bandwidth efficiency is the rate of bits that can be transmitted per one hertz of bandwidth.

Other properties of a digital transmission include BER and SNR.

BER is the rate of bits that have errors at the receiver compared to the total number of bits transmitted. External factors that affect BER include noise – a high noise channel can result in a high BER. BER needs to be low for applications such as voice as a high BER will result in scrambled communications. BER is calculated as energy per bit to the noise PSD, E_b/N_0 .

SNR is the relationship of signal gain to noise power, measured in db. A high SNR is required for high data rate applications and for a good communications channel, both of which would require a low BER as well.

QPSK can carry twice as much data as BPSK along a communications link of equal bandwidth as it can hold two bits per symbol, whereas BPSK holds one bit per symbol. QPSK would therefore require a higher SNR as it is a high data-rate modulation technique.

Another measurement to consider PSD mentioned within this section. PSD is the measure of a signal's power against frequency.



First use

2.1.2 Channel Modes

As seen in the modulation models in section 3, additive white Gaussian noise (AWGN) channel is added to the end of the modulators. This is a standard model that adds noise to the modulated signal passing through it, enabling the model to experience characteristics typical in nature, and would not otherwise be observed in a perfect medium, as experienced in simulation software. The PSD for white noise is constant through all frequencies.

3. Simulation Models

The digital modulation techniques were modelled and simulated on MATLAB Simulink.

The models all consisted of the following components:

- Bernoulli Binary Generator – generates random binary numbers using Bernoulli distribution
- Demux – extract component of input signal and outputs separate signals
- Product – provides mathematical operations to the simulation, used to multiply the message signal with the carrier signal for most modulation techniques
- Sign – accepts signals of any data type, outputs a +/-, depending on sign of input signal
- AWGN Channel
- Deserialiser – converts the fast and scalar input data stream into a slower vector signal
- Digital filter(s) – for removing unwanted noise, and filtering out any out-of-band signals

3.1 ASK

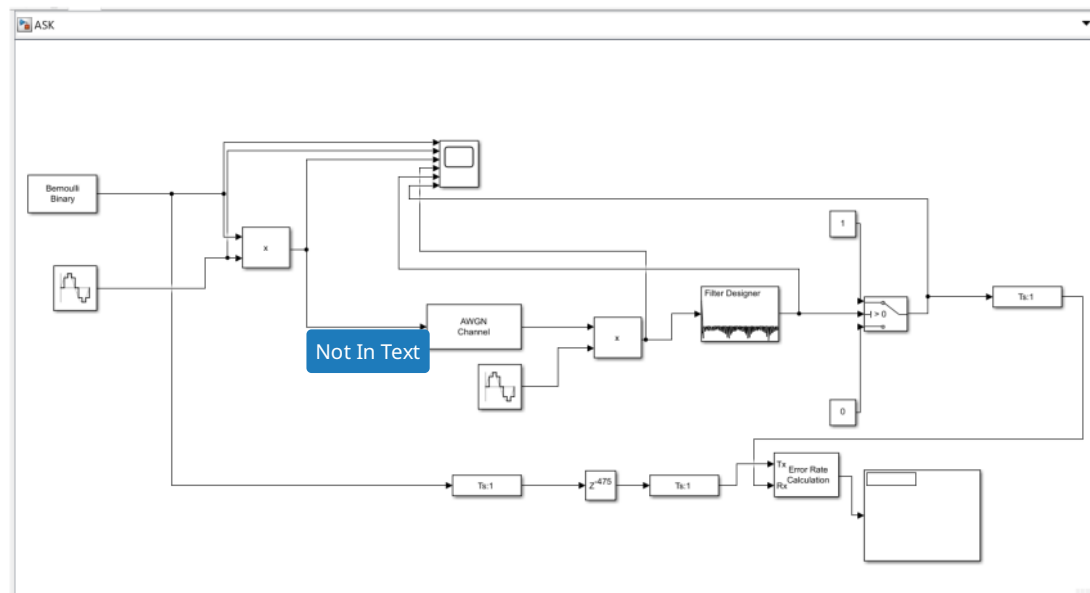


Figure 2 - ASK model

For ASK, the message signal is determined by the formula, $\cos(2\pi f_c t)$.

The ASK demodulator passes the signal through a low pass filter as you will need to remove the high frequencies from the signal in order to obtain the message signal from the modulated signal.

2.2 PSK

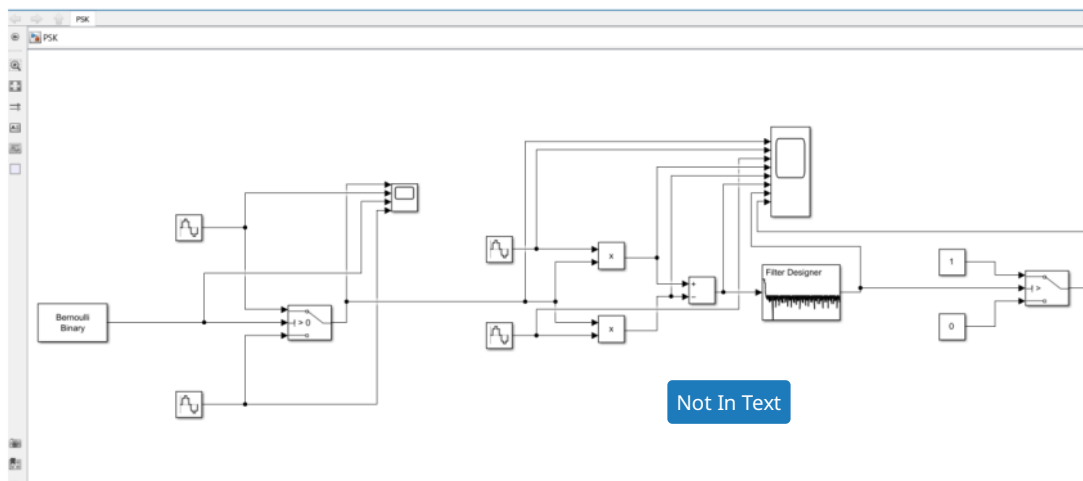


Figure 3 - PSK model

For PSK, the message signal is determined by the formula, $s(t) = \pm A_c \cos(2\pi f_c t)$.
 Sep. Eqn.

The PSK modulator consists of an oscillator, and a half wavelength delay to alter the phase of the modulated signal to the value of π . For this model, a simple switch was used instead of a conventional modulator.

The PSK demodulator consists of a low pass filter. Both the reference signal and the received modulated signal must be in phase at this stage.

2.3 QPSK

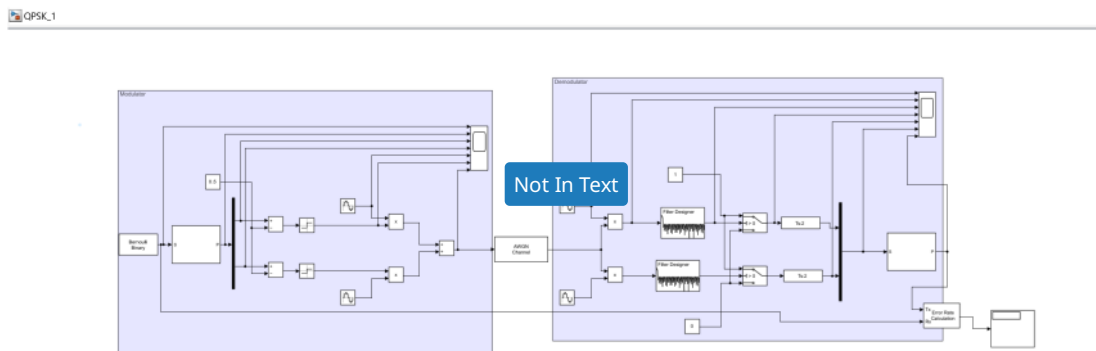


Figure 4 - QPSK model

Four-level PSK, or QPSK, the message signal, is comprised of four elements, each one determined by the following formulas:

$$s(t) = A \cos(2\pi f_c t + \frac{\pi}{4}).$$

$$s(t) = A \cos(2\pi f_c t + \frac{3\pi}{4}).$$

$$s(t) = A \cos(2\pi f_c t + \frac{5\pi}{4}).$$

$$s(t) = A \cos(2\pi f_c t + \frac{7\pi}{4}).$$

In the model, QPSK combines two BPSK signals in the modulation section. When the signal is demodulated, it uses two low pass filters to remove out-of-band signals or spurious signals resulting from the modulation stage.

2.4 QAM

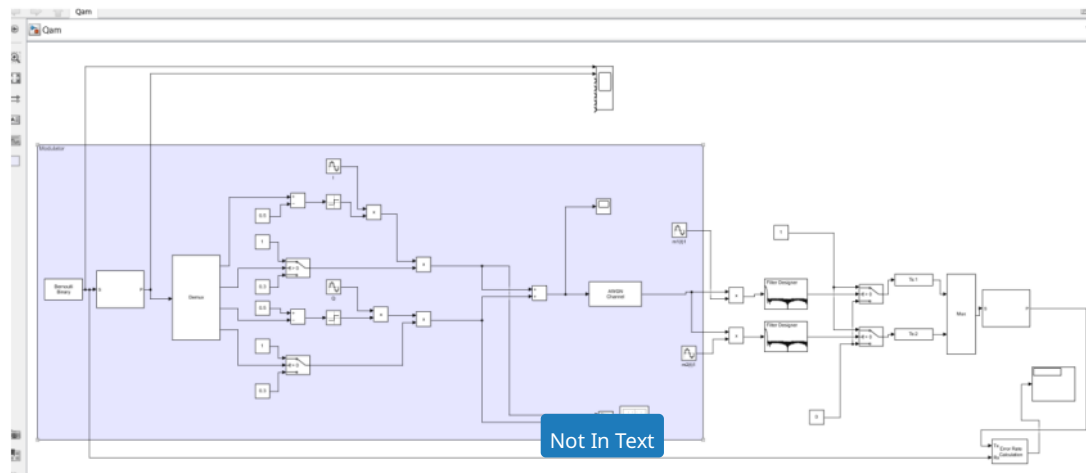


Figure 5 - QAM model

QAM combines ASK and PSK, with two signals, of varying amplitudes, using the same carrier frequency. The message signal is determined by the formula, $s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$.

Sep. Eqn.

4. Results

This section analyses the BER results for each modulation technique. In theory, a noisy communications channel results in less symbols being received compared to transmitted, therefore a higher BER. For the following test, analysis was conducted into how BER changes as the noise within the AWGN channel varies.

The first test was with no noise, to identify a benchmark BER figure, then the noise was gradually increase, using AWGN, until system failure.

The graphs in the following section show how BER changes with SNR. BER is inversely proportional to SNR, so the testing should reflect this by way of a line of positive correlation graph.

4.1 ASK

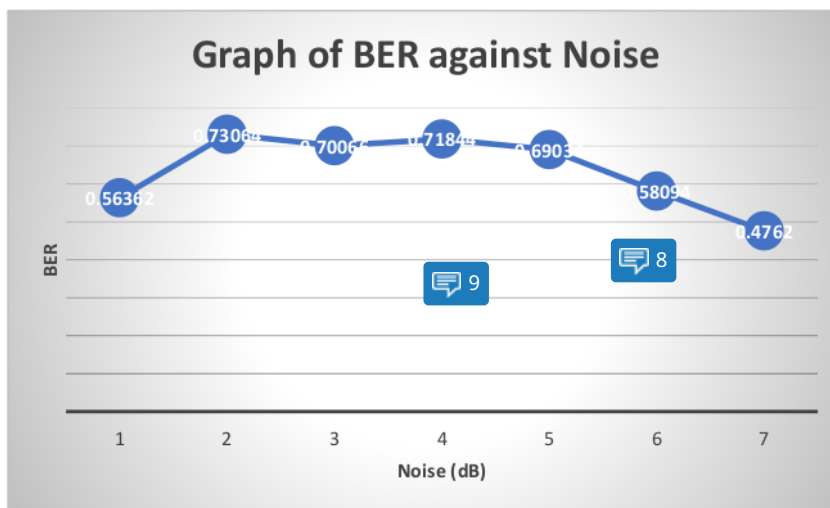


Figure 6 - ASK BER graph

4.2 PSK

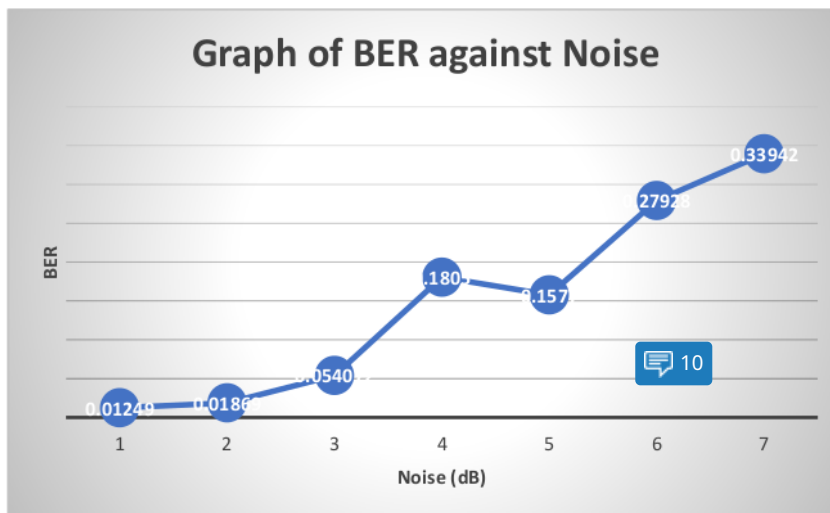
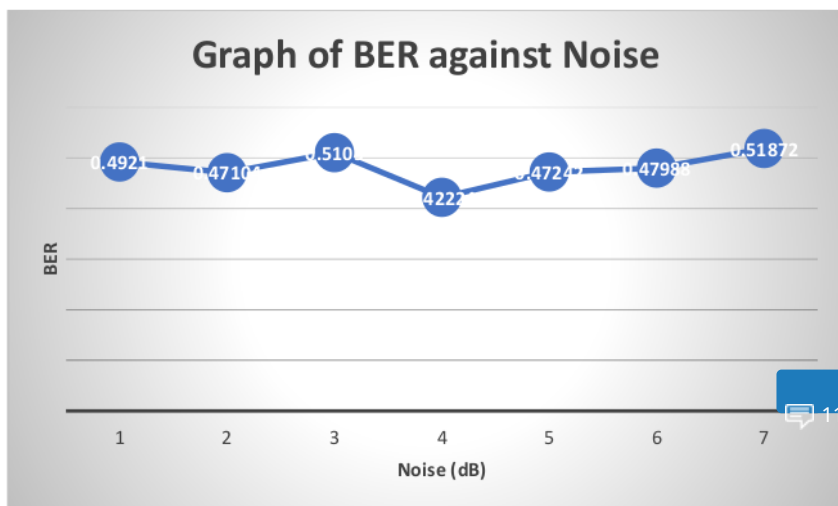


Figure 7 - PSK BER Graph

4.3 QPSK



4.4 QAM

Due to the QAM demodulator not working, it was not possible to conduct the BER test for QAM.

However, background research suggests that QAM, which supports a higher data rate than ASK and PSK, would require a lower BER than both of those techniques.

4.5 methodology

The results were all captured into a table. For the BER evaluation, each noise level was executed five times. The final column of the table featured a BER average and a standard deviation column.

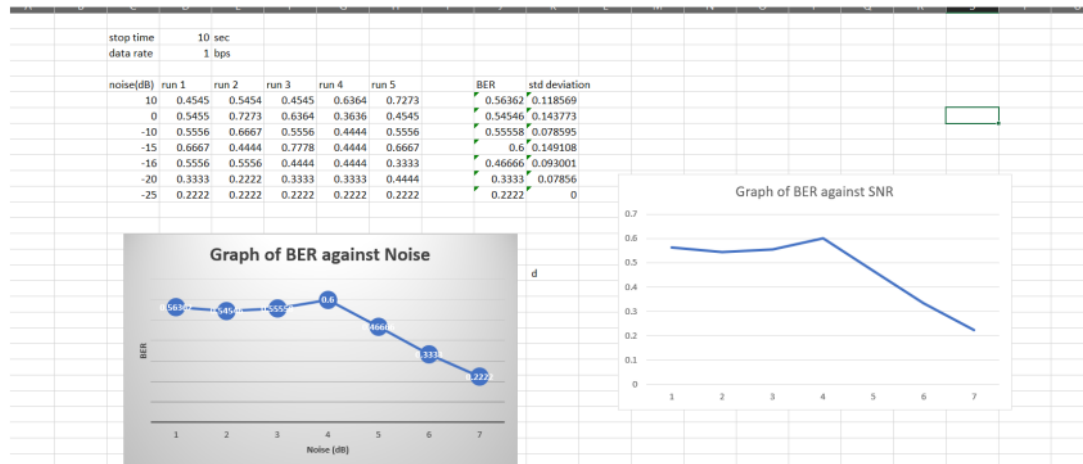


Figure 8 - BER testing spreadsheet

5. Discussion

These results show how the BER changes as noise is increased on the channel. If SNR was on the x-axis then the graphs would be inversely proportional to the graphs shown in the previous section.

The result for PSK shows a positive correlation with an increase in BER, however, the results for ASK and QPSK show a negative or negligible correlation. This is contrary to what should have happened. It was expected that ASK and PSK should have positive correlations, but would be outperformed by QPSK. This could be due to the graphs for ASK and QPSK being configured to show E_b/n_0 (energy per bit) on the x-axis. If this is correct, then these graphs would be closer to what was expected.

The testing was repeated five times for each noise level. To gain a greater fidelity of data, the testing should be repeated more times.

Figure 9 [6] shows research by Abdul Haq, et al, of the expected BER vs E_b/N_0 for QPSK. As shown, there is a negative correlation between BER and E_b/N_0 , until at a point where $E_b/N_0 = 13\text{dB}$, the BER becomes negligible.

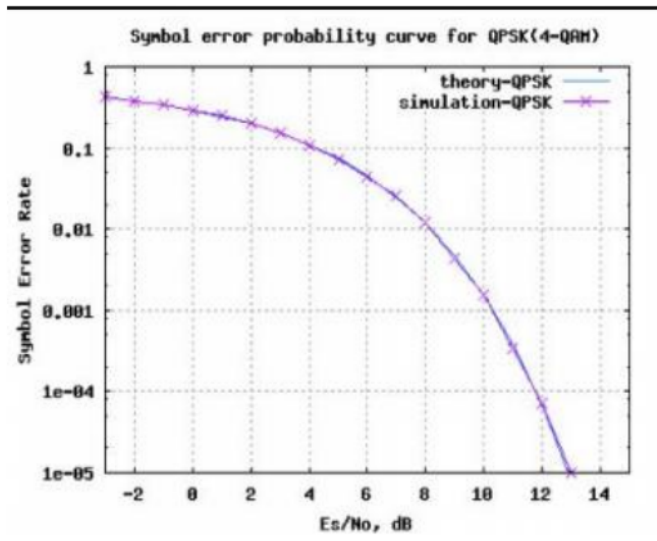


Figure 9 - Expected BER vs E_b/N_0 for QPSK [6]

6. Conclusion

There are various findings to report from this investigation.

Firstly, BER does increase with increase levels of RF noise on a communications link for at least one of the modulation simulations, PSK. However, this trend appears to be reversed with QPSK and ASK. This must be due to either modulator design errors, bit error rate calculator being incorrectly connected, or an error in the analysis stage.

Background research revealed that most modulation testing analyses the BER against SNR, so the graph would show a negative correlation, thus the graphs for QPSK and ASK would be correct, to varying degrees of accuracy. Further investigation would have to be conducted into the BER analysis spreadsheets to identify whether this had been inadvertently the case.

Ultimately, the type of digital modulation technique used depends on the application. A simple, low power, low data rate application could suit an ASK or PSK deployment, which is likely to require a low cost and simple option, afforded by these techniques.

Conversely, a high data rate application, such as LTE networks, would require a more sophisticated technique capable of carrying more bits per symbol, such as QPSK or QAM.

References

- [1] International Telecommunication Union (ITU), "Data format definition for exchanging stored IQ data for the purpose of spectrum monitoring," ITU, 2018.
- [2] elecontrincs-notes.com, "What is PSK, Phase Shift Keying," elecontrincs-notes.com, [Online].
Ref Qual le: <https://www.electronics-notes.com/articles/radio/modulation/phase-modulation-shift-keying-what-is-psk.php>.
- [3] Open Uni, "Exploring communications technology," The Open University, [Online]. Available: <https://www.open.edu/openlearn/digital-computing/exploring-communications-technology/content-section-1.7#:~:text=QAM%20is%20based%20on%20the,in%20a%20quadrature%20phase%20relationship..>
- [4] F. Xiong, "Digital Modulation Techniques (Second Edition)," Artech House, Inc, Norwood, MA, 2006.
- [5] J. Akhtman and L. Hanzo, "Power Versus Bandwidth Efficiency in Wireless Communications: The Economic Perspective," Southampton, 2009.
- [6] A. Haq, R. Katiyar and P. K, "BER PERFORMANCE OF BPSK AND QPSK OVER RAYLEIGH CHANNEL AND AWGN," International Journal of Electrical and Electronic Engineering and Telecommunications, 2014.

Ref Qty

DSP assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

43/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

180 degrees out of phase WITH EACH OTHER



Comment 2

EACH OTHER



Comment 3

QAM



Comment 4

Good abstract although you should quantify your results.

PAGE 4

PAGE 5

PAGE 6

PAGE 7



Comment 5

each other



First use

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

PAGE 8



Comment 6

This constellation diagram is not correct. The yellow dots (your system's data) should line up with the red crosses (reference constellation)

PAGE 9



Comment 7

You would think, but as the spacing of the points in the constellation diagrams for BPSK and QPSK are identical, their noise immunity should be very similar.



First use

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

PAGE 10



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.



Sep. Eqn.

Separate Equations:

Equations should be given their own line and caption to allow you to discuss them in your text. You should also identify and describe each of the variables in the equation.

PAGE 11



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.



Sep. Eqn.

Separate Equations:

Equations should be given their own line and caption to allow you to discuss them in your text. You should also identify and describe each of the variables in the equation.

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 12

QM

Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....

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.

QM

Sep. Eqn.

Separate Equations:

Equations should be given their own line and caption to allow you to discuss them in your text. You should also identify and describe each of the variables in the equation.

PAGE 13



Comment 8

This graph is unreadable. It looks like you have selected the wrong graph to display your data - the horizontal axis should have the Signal to Noise Ratio (dB) on it, which should correspond to the settings you put into the simulation.

I also suspect that your system is not working as your BER is very very high.



Comment 9

error rates of 0.5 are indicative of a failed system. As the data is binary, i.e. only having two states, the probability of *guessing* what the next bit of data is going to be is 0.5, demodulators should be a lot better than this. With no noise i.e. high SNR the BER should be 0. I would expect the BER to start increasing as the SNR became negative (noise power greater than signal power)



Comment 10

See figure 6



Comment 11

See figure 6



Comment 12

This section should be before your results.



Comment 13

SNR *should* be on the X axis. Why isn't it?



Comment 14

You *could* have done more runs.



Comment 15

It appears as though none of your systems worked. As a result all the data you have captured is not representative of the modulation techniques you were investigating.

If in doubt you should ask for help.



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.



Ref Qty

I was hoping for more references

CAMERON FITZE

43

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a wide range of research-informed literature, including sources retrieved independently.

Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.

6

KNOWLEDGE & UNDERSTANDING

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



Evidence of basic knowledge and understanding of the relevant concepts and underlying principles.

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 some attempts to synthesise, albeit with some weaknesses.

Some evidence to support findings/ views, but evidence not consistently interpreted.

Some relevant conclusions and recommendations, where relevant

12.6

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Rudimentary application of methods, materials, tools and/or techniques but without consideration and competence. Flawed appreciation of the context of the application.

11.4

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.

5