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Simulation of Digital Modulation Techniques

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Table of Contents

Abstract	3
Introduction	3
Simulation Models	3
ASK Model	4
PSK Model	4
QPSK Model	5
QAM-16 Model	5
Simulation Parameters	5
Results	6
Discussion	7
Conclusion	8
References	8

Table of Figures

Figure 1 - ASK Simulink Model	4
Figure 2 - PSK Simulink Model	5
Figure 3 - QPSK Simulink Model	5
Figure 4 - QAM-16 Simulink Model	5
Figure 5 - Comparison of Modulation Technique Performance with AWGN	6
Figure 6 - Individual Modulation Techniques with Vertical Error Bars	7

Table of Tables

Table 1 - Modulation Technique Simulation without Additive White Gaussian Noise	4
Table 2 – Control Variable Parameters	6

Abstract

This report details the comparison of digital modulation techniques in the presence of Additive White Gaussian Noise (AWGN). The modulation techniques compared were that of Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). This has been conducted by modelling and simulating these techniques using MathWorks MATLAB Simulink R2022b Version 9.13.

From this experiment, it was determined that ASK modulation is the least resilient to noise, and therefore would provide the worse data integrity out of all the modulation schemes tested when used in a noisy electromagnetic environment. It was also determined that QAM-16 modulation has the highest noise immunity until a Signal to Noise Ratio (SNR) of -20 dB is achieved; beyond which PSK and QPSK offer similar performance.

Introduction

In this report, the following digital modulation techniques have been analysed using data collected from models developed using MATLAB Simulink:

ASK

Amplitude Shift Keying is a digital modulation technique where data is transmitted by varying the amplitude of a constant frequency carrier wave. [1] The ASK modulation technique is commonly used for wireless communication, for instance in Radio Frequency Identification (RFID) cards and tags for access control systems. It is also used for transmitting data over long distance fiber optic cables, and for short range radio communication at low to medium data rates. [2]

PSK

Phase Shift Keying is a digital modulation technique where data is transmitted by varying the phase of a constant frequency carrier wave. [4] PSK modulation is applied in wireless Local Area Network (LAN) applications for devices that operate using Bluetooth/Bluetooth Low Energy (BLE). PSK is also applicable for keyless entry such as contactless payments and RFID. [3]

QPSK

QPSK modulation is a type of Phase Shift Keying where two bits of information are modulated at the same time, with the carrier signal being phase shifted by either $0, \pi/2, \pi, 3\pi/2$ radians. Therefore the signal is quadrature as the carrier signal can be one of four phases at a given time. This enables greater efficiency as the signal carries twice as much data as a PSK modulated signal, while using occupying the same bandwidth. [5] The QPSK modulation technique used in this assignment is commonly used for cellular network communication and video broadcasts from satellites. [5]

QAM-16

QAM modulation is where two sinusoidal waves of the same frequency are transmitted simultaneously, having changes in both phase and amplitude. These make up the real 'I' and imaginary 'Q' components of the waveform. These sinusoidal waves are orthogonal, having a phase difference of 90 degrees. QAM16 has sixteen different possible states, comprised of variations of amplitude and phase of these signals; with each time slot having four bits of information encoding this data. [6]

This digital modulation technique is commonly used for Digital Video Broadcasting (DVB) and television broadcasting applications. However, more dense QAM constellation schemes, such as QAM-256 or QAM-1024 provide higher spectral efficiency, therefore being suitable for wireless cellular applications and video streaming using Internet Protocol (IP). [7]

Simulation Models

MATLAB Simulink was used to design models for and simulate ASK, PSK, QPSK and QAM-16 modulation techniques individually, while introducing AWGN to the system. This enabled the generation of Bit Error Rate (BER) data that can be analysed to provide comparison of the performance of these schemes.

Firstly all modulation techniques were simulated without the presence of any AWGN to ensure a BER of 0 was achieved repeatedly. This test was conducted for three runs per modulation scheme, as shown by Table 1. This validated that the models were designed correctly within the MATLAB Simulink, before we add noise into the system to assess performance.

ASK	Run 1	Run 2	Run 3
Bit Error Rate (BER)	0	0	0
Number of Wrong Symbols	0	0	0
Number of Symbols Received	120	120	120

PSK	Run 1	Run 2	Run 3
Bit Error Rate (BER)	0	0	0
Number of Wrong Symbols	0	0	0
Number of Symbols Received	1198	1198	1198

QPSK	Run 1	Run 2	Run 3
Bit Error Rate (BER)	0	0	0
Number of Wrong Symbols	0	0	0
Number of Symbols Received	237	237	237

QAM-16	Run 1	Run 2	Run 3
Bit Error Rate (BER)	0	0	0
Number of Wrong Symbols	0	0	0
Number of Symbols Received	113	113	113

Table 1 - Modulation Technique Simulation without Additive White Gaussian Noise

ASK Model

Figure 1 shows the block diagram model produced to simulate Amplitude Shift Keying (ASK) using MATLAB Simulink R2022b.

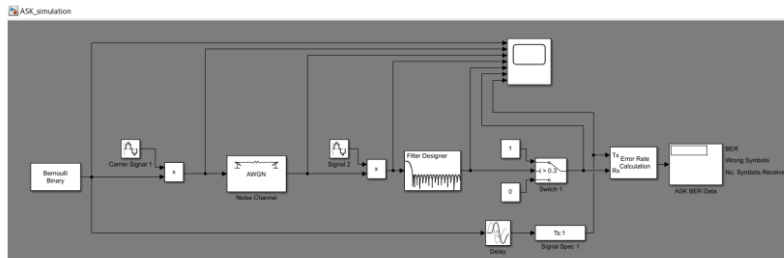


Figure 1 - ASK Simulink Model

PSK Model

Figure 2 shows the block diagram model produced to simulate Phase Shift Keying (PSK) using MATLAB Simulink R2022b.

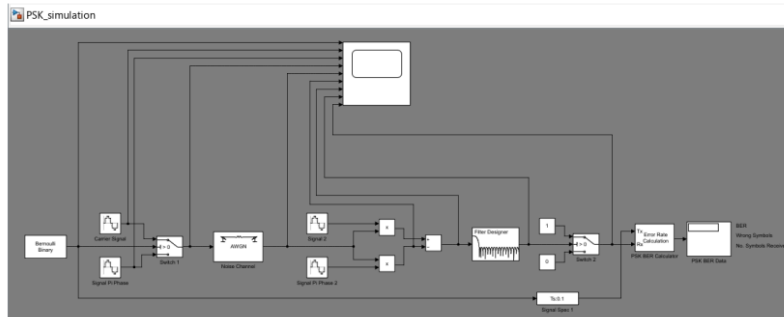


Figure 2 - PSK Simulink Model

QPSK Model

Figure 3 shows the block diagram model produced to simulate Quadrature Phase Shift Keying (QPSK) using MATLAB Simulink R2022b.

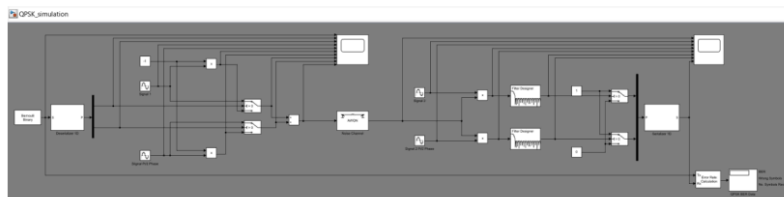


Figure 3 - QPSK Simulink Model

QAM-16 Model

Figure 4 shows the block diagram model produced to simulate Quadrature Amplitude Modulation (QAM) where the carrier signal can be acting as one of sixteen different states, using MATLAB Simulink R2022b.

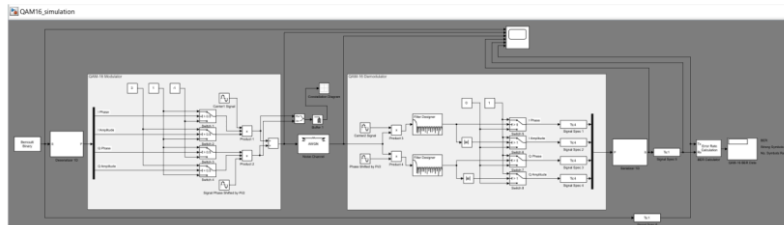


Figure 4 - QAM-16 Simulink Model

Simulation Parameters

To ensure this is a fair comparison and valid experiment we must consider the simulations variables. For this experiment, we can group the variable under three main categories:

Control Variables

During this experiment the control variable must remain constant for all modulation techniques investigated. [8] Therefore each simulation was conducted for a simulated time period of 120 seconds, with the constant variables shown by Table 2.

Filter Design Parameters		Bernoulli Binary Generator - Input Stimuli	
Structure	Direct-Form FIR	Probability of Zero	0.5
Order	35	Source of Initial Seed	Auto
Response Type	Low Pass	Sample Time (s)	1
Design Method	FIR Equiripple	Samples per Frame	1
Frequency Specifications		Output Data Type	Double
F_s (Hz)	100	Carrier Signal Characteristics	
F_{pass} (Hz)	3		
F_{stop} (Hz)	7		
Magnitude Specifications		Amplitude (m)	1
A_{pass} (dB)	1	Frequency (rads/s)	10π
A_{stop} (dB)	40	Sample Time (s)	0.01

Table 2 – Control Variable Parameters

Independent Variables

The independent variables are what we are adjusting to produce data that enables us to assess the performance of each modulation scheme. [9] For this experiment, the independent variables are that of Signal to Noise Ratio (SNR) and the modulation technique investigated; being either ASK, PSK, QPSK or QAM-16.

Signal to Noise Ratio (SNR) is adjusted by introduce Additive White Gaussian Noise (AWGN) to the system. This noise channel was set to have an initial seed of 67, with 'Signal to Noise (SNR)' mode selected and having an Input of 1 Watt, referenced to 1Ω . This enables the SNR value to be gradually incremented in 5 dB steps from 10 dB to -55 dB.

Dependant Variables

The dependant variable is the output we are measuring in this experiment, this being the 'Bit Error Rate (BER)' of the modulation technique investigated. [9]

Results

Figure 5 is a scatter graph showing how Bit Error Rate varies in response to a change in the level of AWGN for ASK, PSK, QPSK and QAM16 modulation techniques.

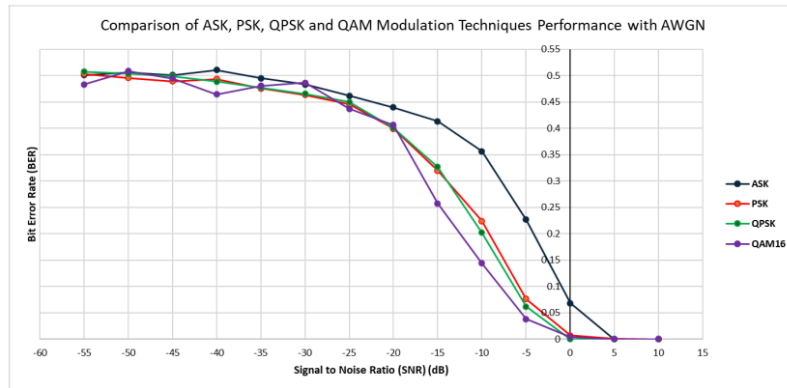


Figure 5 - Comparison of Modulation Technique Performance with AWGN

Figure 6 shows how Bit Error Rate varies in response to a change in the level of AWGN for individual ASK, PSK, QPSK and QAM16 modulation techniques, with the addition of vertical error bars.

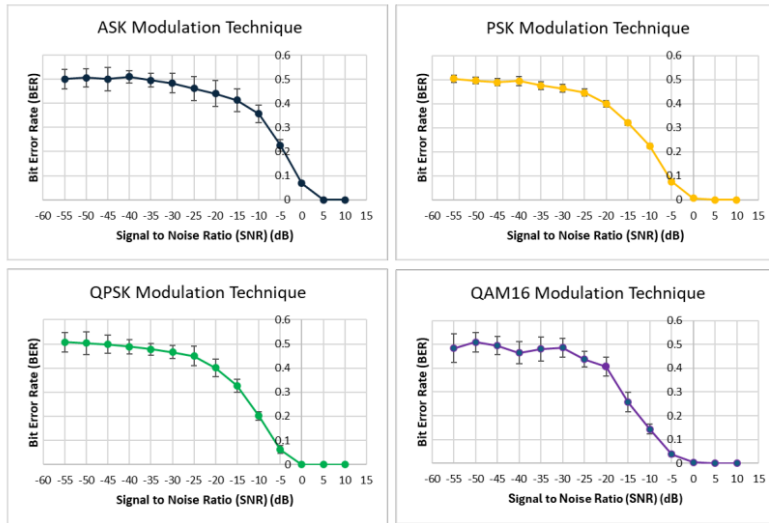


Figure 6 - Individual Modulation Techniques with Vertical Error Bars

Figure 5 shows that ASK digital modulation model is the fastest to respond to an increase in Additive White Gaussian Noise, outputting higher BER values per SNR value than each comparative modulation scheme. Therefore this indicates that ASK modulation is the most susceptible to noise, out of the techniques tested in this experiment. Conversely, QAM-16 modulation appears to have the highest immunity to noise being slower to respond to an increase in AWGN. Alongside this, at first glance it appears that PSK and QPSK have performed similarly, having low variance between the curves plotted in the scatter graphs shown by Figure 5.

By calculating standard deviation for each of the 10 data points recorded per Signal to Noise Ratio (SNR) value, vertical error bars were plotted for each modulation scheme shown by Figure 6. This provides an indication of the confidence we have in the data collected. Larger error bars correspond to lower confidence and certainty in the data recorded.

Discussion

Figure 5 and Figure 6 show how Bit Error Rate varies in response to an increase in Additive White Gaussian Noise for the ASK, PSK, QPSK and QAM16 modulation techniques. Bit Error Rate was recorded at 5 dB increments, for Signal to Noise Ratios in the 10 dB to -55 dB range.

When comparing the performance of these modulation techniques, we can observe that ASK has the highest susceptibility to noise, while QAM-16 modulation appears to have the highest immunity to noise being the slowest to respond to an increase in AWGN. Therefore, ASK digital modulation is the worst choice for providing resilience to noise and good data integrity.

To determine at which noise level system failure occurs for the modulation schemes, a Bit Error Rate for failure needs to be determined. For telecommunications it is considered that a BER of 10^{-9} is an acceptable BER to maintain good Quality of Service (QoS). This would mean that there is 1 erroneous bit per 10^9 bits of data received. [10] In comparison a BER of 10^{-3} is considered to be acceptable for Wireless Fidelity and Bluetooth

applications; expecting 1 bit error per 1000. Therefore failure BER of 0.45 appears to be far beyond good data integrity and acceptable performance. Received signals at this BER would be unreadable for the user due to the high signal degradation caused by noise. However, Figure 5 shows that the modulation techniques have asymptotic behaviour, having diminishing variance towards a BER of 0.45.

In this experiment, ASK modulation reaches a BER of 0.45 the soonest, at a SNR value around -25 dB. ASK modulation may be failing sooner than that of PSK and QPSK as **amplitude is less robust to noise than phase**. ASK modulation is reliant on changes of amplitude to provide a signal with good data integrity. Amplitude fluctuations may be easier to detect and interpret than a phase shift; therefore causing signal degradation resulting in worse performance under noisy conditions. 

This experiment shows PSK, QPSK and QAM-16 first cross this 0.45 BER threshold at an identical SNR of -27 dB, not allowing for comparison at this point. However from this experiment it has been determined that QAM-16 has the lowest BER values of all modulation techniques across the SNR range of 0 to -20 dB. Therefore it can be argued that QAM-16 is the most preferable to use in applications where resilience to noise is required. However when the Additive White Gaussian Noise is beyond this -20 dB threshold, the benefits of using QAM-16 as opposed to PSK/QPSK modulation seems diminished, as performance is similar to the PSK and QPSK modulation schemes past this point. Although, QAM-16 may offer higher throughput of data, albeit at the cost of having a more complex modulation process than PSK variations.

Figure 5 also shows that PSK and QPSK perform similarly, with scatter graphs curves showing minimal variance. Therefore it could be said that both PSK and QPSK modulation have a nearly matched response to a change in AWGN. However we must also consider that the QPSK data shown by Figure 6 cannot be directly compared to the PSK data, as the data received through testing has greater uncertainty. This is shown by the larger error bars on the individual QPSK scatter diagram, corresponding to larger standard deviation in results. There is less confidence in the QPSK dataset, when compared to the PSK data. The smaller variation in the PSK data points provides a higher level of certainty and confidence in the dataset, appearing more consistent.

Conclusion

In this experiment, it has been determined that Amplitude Shift Keying (ASK) is the least effective digital modulation techniques in the presence of Additive White Gaussian Noise (AWGN). ASK is the least immune to noise and failed the soonest, not providing the same level of data integrity as PSK, QPSK and QAM-16 in noisy environments.

The 16-Quadrature Amplitude Modulation (QAM-16) technique used in this experiment provided the highest noise immunity of all modulation schemes tested; being the best option for use in highly contested and noisy electromagnetic environments. However, beyond a Signal to Noise Ratio of -20 dB, where the wanted signal is below the noise floor; Phase Shift Keying (PSK) and Quadrature Phase Shift Keying (QPSK) provided similar system performance.

This experiment could be further improved by conducting more test serials to gain a larger dataset for each digital modulation scheme. This may reduce the uncertainty in the data collected, therefore providing a more direct comparison for system performance between techniques. This could be implemented by producing a script to automate MATLAB Simulink to record more datapoints with a smaller resolution of SNR/AWGN. This data could be exported as a .csv file enabling time efficient analysis of these modulation techniques.

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65/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

Excellent abstract



Comment 2

Usually the phases:

$\pi/4$, $3\pi/4$, $5\pi/4$, and $7\pi/4$ are used as these are easier to generate from quadrature signals



Comment 3

Excellent background information



Comment 4

You should try to ensure headings are not the last thing on a page

PAGE 4

PAGE 5



Comment 5

Nice clear models, although a more detailed description of each would have been beneficial.

PAGE 6



Who is "We"

Who is "we"?

Additional Comment

The independent variables are those that are adjusted to produce data....



Comment 6

Nice graph

**Comment 7**

Why?

You need to link back to the distance between points in the constellation diagram

**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 Qual**

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.

GRADING FORM: SMU GENERIC_SMOSEY

ALISTAIR LOUNDS

64.50

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.

6.5

More high quality sources would have improved your mark here.

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

More detail in your descriptions would have improved your mark here

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



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

16.5

You need to explain why the results are the way they are. I know you said that amplitude is more susceptible than phase, but why is this the case?

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.

20.4

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 professionally and, confidently in a suitable format.

Work is coherent, very fluent and is presented professionally.

7.5