

EthanAndersonDSPAssignment Final

by Ethan Anderson

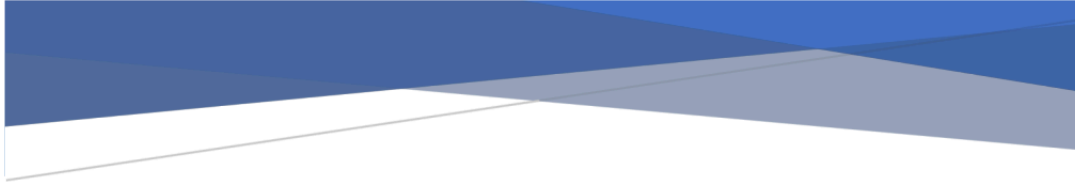
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DIGITAL SIGNAL PROCESSING

Laboratory Report

BENG2-PT Embedded Electronic Systems
Distributed Intelligence Systems ACDA5008

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Abstract

This report investigates the design and performance of four select digital modulation schemes: Amplitude Shift Keying (ASK), Quadrature Amplitude Modulation (QAM), Binary Phase Shift Keying (BPSK), and Quadrature Phase Shift Keying (QPSK). Each modulation scheme was modelled in Simulink, beginning with pseudo-random bit streams, modulation, transmission over a simulated free space with Additive White Gaussian Noise (AWGN) and demodulated to produce an estimation of the original bitstream, including a measurement of the Bit Error Rate (BER).

The basic operating logic and structure of the modulator and demodulator of each modulation scheme is detailed, including key differences between each scheme.

The results indicate that modulation complexity plays a significant role in vulnerability to interference as the Signal to Noise Ratio (SNR) is decreased. The trade-off between higher order modulation schemes, to increase spectral efficiency and data bandwidth, and robust communications in the presence of high ambient noise is discussed.



Introduction

Digital communication systems are the backbone of modern wireless communications, allowing data bandwidth over long distances, whilst remaining spectrally efficient. The fundamental operation of digital modulation systems (typically over free space) is to encode digital information (expressed as discrete values) onto an analogue carrier (expressed as a continuous stream of values of infinite resolution) and vice versa. Modulation of digital information onto a free space analogue carrier wave allows the transmission of digital information over free space, enabling transmission of discrete data over long distances in the presence of noise and interference.

The principles of digital modulation revolve around controlling specific analogue attributes of the free space carrier to encode discrete information. These include the control of phase, amplitude and frequency. The simplest of methods will select two analogue values, such as two frequencies, to represent a binary 0 and 1, however these methods are relatively restrictive on the rate that information can be transmitted (in this instance only one bit is represented per symbol). Modern modulation schemes such as QAM are inherently scalable with multiple bits per symbol to dynamically control data bandwidth depending on the SNR of the free space carrier.

This report focuses on four specific schemes: ASK, QAM, PSK and QPSK. ASK and PSK, at their core, are the least complex. As detailed previously, these two schemes select two distinct signals to represent a binary 0 or 1. This can be specifically referred to with the '2-' prefix or 'B' for Binary to represent the number of distinct signals which are used. In the instance of BPSK, two distinct signal phases are used to encode the digital information, such as 0° and 180° . One of the most common applications of BPSK is the 868.0 – 868.8MHz and 902.0 – 928.9MHz bands of ZigBee, a low-power close-proximity wireless communication protocol [1]. ASK is often even simpler, only requiring a single analogue signal to represent a 1 bit and simply its off state to represent 0. This specific instance is referred to as On-Off Keying (OOK) and was originally used in communication protocols such as Morse Code [2].

QAM and QPSK, by comparison, have an increased complexity. No longer is one signal state representing a single bit, and instead multiple bits are encoded to a single signal state to increase data bandwidth. QAM functions by controlling the amplitude of two separate carrier waves 90° apart in phase (known as orthogonal or in Quadrature) and summed prior to transmission. By controlling the amplitude of the In-phase (I) and Quadrature (Q) waves separately, a greater number of bits can be

encoded onto the carrier wave. In its simplest form, 4-QAM, there are 4 distinct signal states which can be achieved with each signal state representing two bits. Hence, 4-QAM can achieve twice the data rate of BPSK because each transmitted symbol has represents twice the number of bits. QAM is inherently scalable to higher orders of modulation when it is feasible to do so, allowing for a greater number of signal states (with modulated phase) and each symbol representing a greater number of bits, increasing data rate. However, for the same spectral bandwidth, higher order modulation schemes become more susceptible to bit errors induced by noise interference as each signal state is less distinct from its neighbouring states. The signal states are represented on a constellation diagram, with each point representing a desired symbol and number of bits.

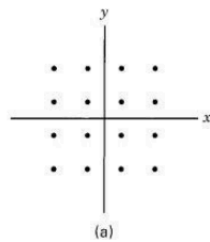


Figure 1: 16-QAM Constellation Diagram [1]

QAM is employed in the IEEE 802.11p standard for wireless communications, regularly implemented under the Wi-Fi brand name [3]. QPSK is an upscaled version of BPSK, using four signal states to represent two bits, similar to 4-QAM. In fact, 4-QAM and QPSK output the same modulated carrier wave, although the underlying concepts are different, and the outputs diverge on higher orders of modulation.

Ultimately, the demodulated information received from these modulated carrier waves can only ever be considered an estimation of the original signal, as random additive noise is constantly present and will interfere with the carrier signal in real world conditions. The performance of these modulations in the presence of noise can easily be characterised by the Bit Error Rate. This is achieved by comparing the original, pre-transmit bitstream to the bitstream that has been decoded by the demodulator. Dividing the two achieves a BER, ranging from 0 to 1. It is important to note that, in a functioning digital modulation system, it is not feasible for the BER to increase much past 0.5 as 0.5 represents every single binary value being incorrect. A value of 0.5 is equivalent to randomly guessing each bit, without any information being transmitted. Therefore, a measured value significantly greater than 0.5 indicates an issue with the function of the modulator or demodulator.

This report will explain the process of modelling each of the aforementioned modulation schemes in Simulink, including the addition of white noise (AWGN) and measure its effect on the resultant BER.

Simulation Models

The modulators and demodulators of the ASK, QAM, BPSK and QPSK modulation schemes were modelled using block-based functions in Simulink. Noise interference introduced by transmission over free space was modelled using an AWGN Channel block, with the SNR being varied as an independent variable to measure its effect on BER. The BER value is obtained using an Error Rate Calculation block. A secondary Error Rate Calculation block was used to output the BER value to the workspace, where a separately written MATLAB code runs the simulation 20 times for an array of SNR values. These values are averaged in an Excel document to plot a final BER response to a varying SNR.

The free space signal, with added noise, was filtered using a bespoke designed Finite Impulse Response (FIR) digital lowpass filter. This filters out higher frequency repetitions of the information signal, introduced as a mathematical byproduct of modulation. In the interest of accuracy and repeatability, the design of the filter was constant with each modulation scheme. The filter parameters are detailed in Figure 2 below.



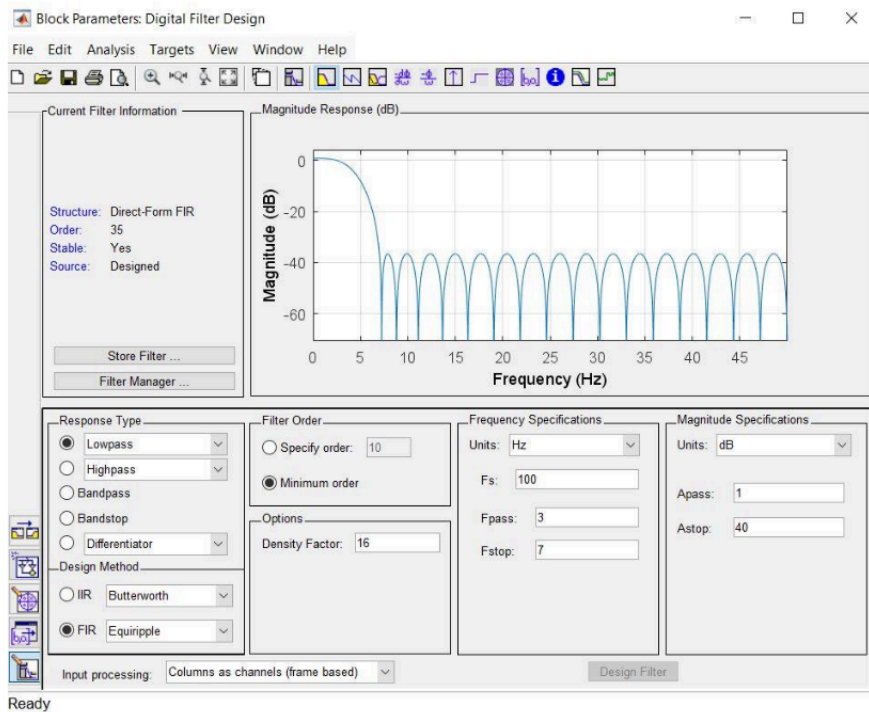


Figure 2: Filter design

It is also important to note that the same stop time (60) and bits per sample (1) was used for each model. This ensures the same number of bits are passed through each modulator for the sake of reliability in the results.

ASK

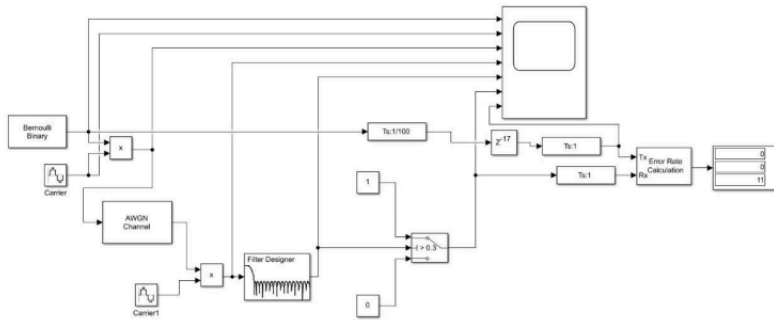


Figure 3: ASK modem in Simulink

Figure 3 shows the modulator/demodulator for ASK model. A Bernoulli Binary generator block is used to generate a pseudo-random bitstream. This bitstream is multiplied by a carrier signal to transmit over free space. The AWGN channel adds white noise to the signal, which is then multiplied by another sample of the carrier wave before being filtered. The switch serves as a threshold-based detector to determine the state of the signal (on or off) based on its amplitude. The switch will output a binary 0 or 1 based on this input to create an estimation of the bitstream, which is then compared to achieve a BER value.

QAM

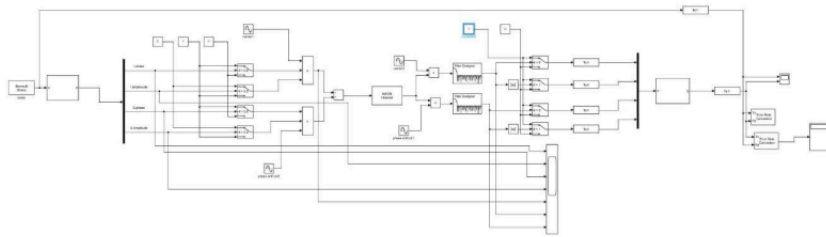


Figure 4: QAM modem model

Figure 4 shows the QAM modulator/demodulator model. This model is significantly more complex than ASK, however the underlying principles are similar. A pseudo-

random bitstream is generated and distributed to control the phase and amplitude components of the I and Q signals, which are then applied to the I and Q carrier signals and summed to transmit over free space with added noise. The same filter is used to sample the signal and perform the inverse operation to produce the bitstream estimation.

BPSK

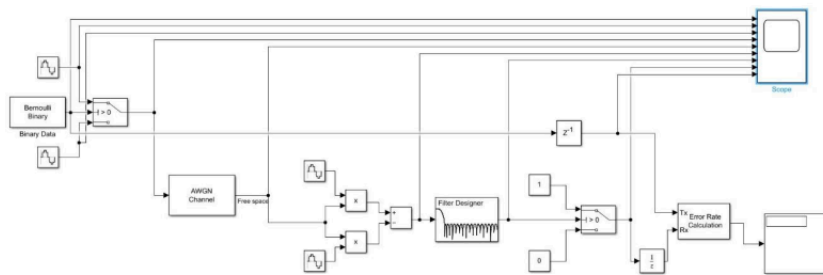


Figure 5: BPSK modem model

Figure 5 details the BPSK modulator/demodulator. A bitstream is used to toggle a switch between two carrier signals, 90° in phase, to modulate the signal. An inverse sum is then performed to demodulate the signal and filter it to be sampled. Because of the buffer applied by the digital filter, a pair of delay blocks are needed to re-align the sampled bitstream with the transmitted stream.

QPSK

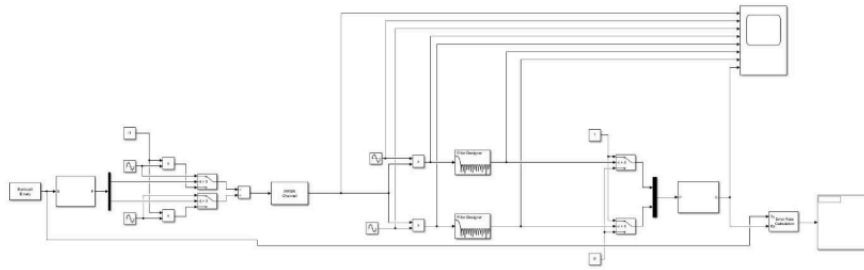


Figure 6: QPSK modem model

Figure 6 displays the modulator/demodulator model for QPSK. Similar to BPSK, two orthogonal carrier waves are used as inputs to modulate the bitstream, however in QPSK the waves are also multiplied by the constant -1 to produce four possible signals. These signals are selected by the switch based on the bitstream input and summed to produce the carrier wave. The inverse is performed at the demodulator and filtered/sampled to find the BER.

Results

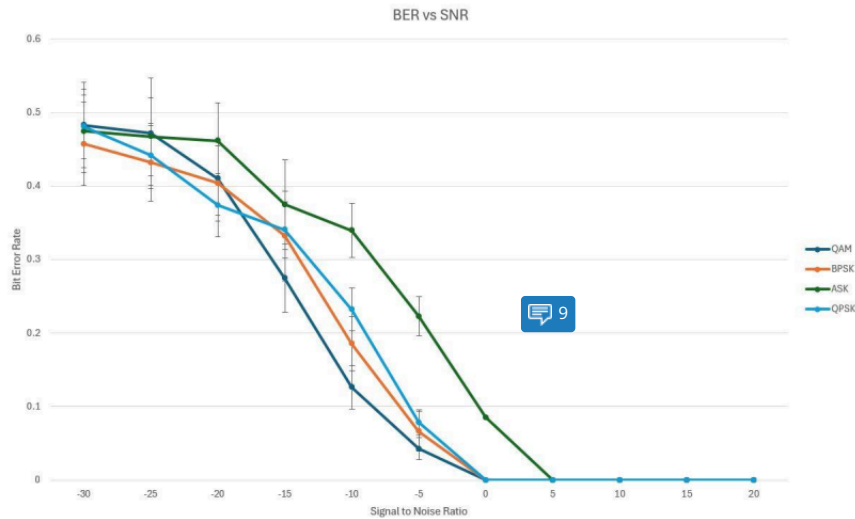


Figure 7: Bit Error Rate vs Signal to Noise Ratio for all four modulation schemes

Figure 7 displays the final collected BER performance of each modulation scheme for a changing SNR. It is notable that all four schemes followed a similar pattern of degradation as the SNR increased, however QAM clearly outperformed the other schemes in robustness against noise.

Discussion

Figure 7 displays the final results measuring the performance of each digital modulation scheme against an increasing Signal to Noise Ratio. As mentioned, performance was measured as the value of the Bit Error Rate, a comparison of the received bitstream as an estimation of the originally generated pseudo-random bits. A higher BER indicates a higher amount of information received.

All four modulation schemes followed a similar pattern of degradation as the SNR was increased. This is to be expected, as increased noise will effectively inject randomness to the received bit stream, and a lesser ratio of signal to noise will mean the added noise has a greater impact on the original signal. A lower SNR makes it more difficult to effectively distinguish between different signal states, increasing confusion between states and inserting bit errors.

At extremely low Signal to Noise Ratios, from roughly -30dB to -20dB, there is little disparity between the average BERs of each scheme. All four modulations had a BER of nearly 0.5, producing effectively random and useless received data.

As the SNR increased, within the range of -20dB to 5dB, a greater disparity between each method becomes apparent. Amplitude Shift Keying maintains a higher BER across this SNR range. This is to be expected as ASK is a relatively simple method of digital modulation and its simple OOK ¹¹ can more easily be affected by pseudorandom additive noise. Both BPSK and QPSK outperformed ASK within this SNR range and were roughly equivalent to each other in BER. This is likely due to their use of phase modulation as opposed to amplitude modulation, which is less affected by the addition of gaussian noise and so a lower BER is achieved. While there was little disparity in BPSK and QPSK, ¹² imagined that higher orders of Phase Shift Keying may have degraded performance. It may be useful to note that there are other sources of noise within a real digital modulation system, such as clock jitter which was not modelled in this exercise. Clock jitter can directly introduce phase noise into the signal, of which phase-keying modulation schemes may be more susceptible to [4].

Ultimately Quadrature Amplitude Modulation was the highest performing modulation scheme, owing to its complexity and control of both amplitude and phase components, making single noise multiplications less impactful on the transmitted bit stream.

Conclusion

This report has explored the performance of four digital modulation schemes – ASK, QAM, BPSK and QPSK under the presence of Additive White Gaussian Noise, modelled using Simulink. The underlying operating principles of these systems were explored and compared. The simulations show that BPSK and QPSK outperform ASK in noisy environments owing to their inherent resilience against amplitude fluctuations. QAM maintained the highest performance against added noise due to its use of phase and amplitude modulation and In-phase and Quadrature signals. QAM was also the most spectrally efficient method, using two bits per symbol.

These findings emphasize the importance of selecting the appropriate digital modulation scheme for the application, taking into account performance against noise, modulator and demodulator complexity and required spectral efficiency and data bandwidth.

References

- [1] H. Schmitt and D. F. Ramian, "EVM Measurements for ZigBee Signals in the 2.4GHz Band Application Note," Rohde & Schwarz, 2014.
- [2] B. Lathi and Z. Ding, Modern Digital and Analog Communication Systems, New York: Oxford University Press, 2010.
- [3] A. M. Abdelgader and L. Wu, "The Physical Layer of the IEEE 802.11p WAVE Communication Standard: The Specifications and Challenges," in *Proceedings of the World Congress on Engineering and Computer Science 2014 Vol II*, San Francisco, 2014. Refs missing in: Ref Qty
- [4] cts corp, "Jitter and Phase Noise in Timing References," cts corp.

FINAL GRADE

GENERAL COMMENTS

64/100

PAGE 1

PAGE 2

PAGE 3



Comment 1

Excellent abstract although a quantified statement of your results would have improved it.

PAGE 4



Comment 2

Usually 0 and 180 are used for BPSK

PAGE 5



Comment 3

Excellent



Comment 4

The probability of getting a bit wrong (or right), purely by guessing is 0.5. Therefore when receiving badly corrupted data and guessing its value will likely lead to a BER of approximately 0.5

PAGE 6



Comment 5

How do these parameters relate to the carrier frequency and data rate you have chosen? Why did you design the filter like this?

PAGE 7

PAGE 8



Comment 6

This description is a bit short. More detail is needed



Comment 7

BPSK



Comment 8

They should be 180 degrees apart, not 90.



Comment 9

It is difficult to determine which error bars belong to which series of data



Comment 10

Looking at the graph, I would say BPSK performed best with the noise as at the highest noise level BPSK's error rate is lowest while QAM's is highest



Comment 11

Why?

You should give a reason to support your argument.



Comment 12

Again, why? You need to provide reasons for your arguments.



Refs missing info

Some of your references are missing information. To understand what information should be included, see the university IEEE referencing handbook on the library website.

https://uwtssd.ac.uk/media/uwtssd-website/content-assets/documents/library-and-learning-resources/infoskills/IEEE-eng_v.1.2.pdf



Ref Qty

I was hoping for more references

ETHAN ANDERSON

64.40

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.

5

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

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, but you must close the loop between the background information and your discussion section. You talk about noise causing bit errors in the background section but don't make that connection in your discussion.

18

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.

Better descriptions of your models would have improved this.

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.

8