

DSP

by James Hunt

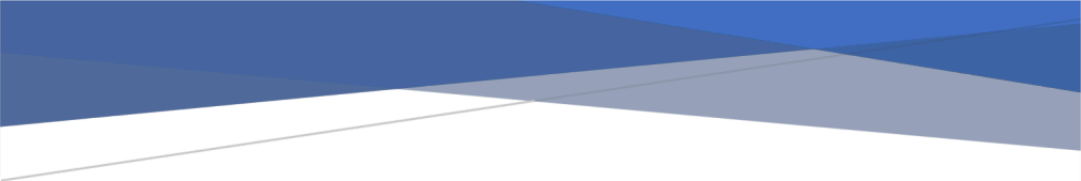
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DIGITAL SIGNAL PROCESSING AND COMMUNICATIONS

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Abstract

This study examines the performance of four digital modulation schemes: Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM), under different noise conditions, using Additive White Gaussian Noise (AWGN). The Bit Error Rate (BER) was measured for each scheme at various Signal-to-Noise Ratios (SNR).

Results showed that ASK and PSK had high BER values at low SNR levels, indicating they were noise-sensitive. In contrast, QPSK and QAM performed better due to their stronger encoding methods. At high SNR levels, all schemes showed very few errors. Overall, ASK and PSK work well in high-SNR scenarios where simplicity is key, while QPSK and QAM are better for low-SNR situations that require higher data rates. This research highlights the importance of matching modulation schemes to their environments and suggests paths for future work on noise models and error correction.

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Introduction



In modern communication systems, there is a need to transmit increasing amounts of digital data to provide a seamless connection for various services society has come to rely on. This requirement for data massively influences the choice of modulation scheme to achieve reliable and efficient data transmission. Modulation is the process of varying a carrier signal's properties, such as amplitude, phase, and frequency, to encode information. To transmit digital data, the most widely used schemes are Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and their advanced variants, such as Quadrature PSK (QPSK) and Quadrature Amplitude Modulation (QAM). Each scheme has distinct characteristics, making it suitable for different applications and operating conditions.[1]-[4]

A fundamental challenge in communication systems is signal noise, which can distort transmitted signals and, therefore, degrade the performance of the chosen modulation scheme. This report will use Additive White Gaussian Noise (AWGN) as the mathematical model to represent random noise caused by thermal, interference, or impulse effects typically observed in authentic transmissions. It can be characterised by its constant power spectral density and Gaussian amplitude distribution and serves as a standard model to evaluate the robustness of modulation schemes. The impact of AWGN will be measured using key performance metrics such as Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER). The SNR indicates the relative strength of the signal compared to the noise, while the BER shows the degree of errors in the received data. [1], [2]

The primary objective of this study is to compare the performance of these modulation schemes in the presence of AWGN. This will be achieved by modelling each scheme in Simulink, simulating their behaviour across a range of SNR values, and analysing their BER performance. The findings from this analysis can provide insights into the trade-offs between complexity, efficiency, and reliability. This can help in guiding the selection of an appropriate modulation scheme for various real-world communication scenarios.[5], [6]

Simulation Models



Below are the Simulink implementations of the four digital modulation schemes. Alongside the MATLAB script, which sets some of the simulation parameters, the carrier signal frequency was set at 5Hz with a phase difference of 90° when required for a quadrature (Q) sine wave source.

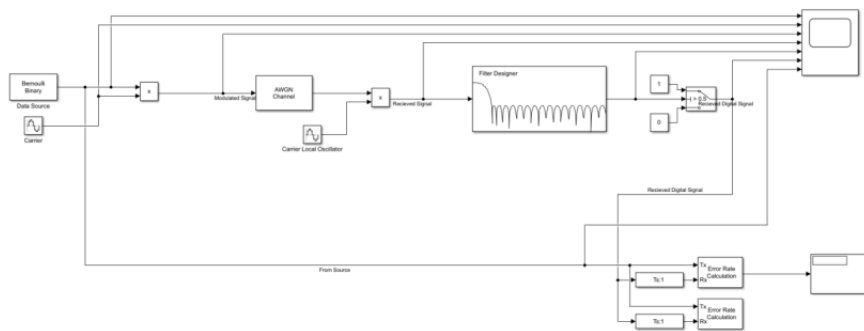


Figure 1 - ASK Simulink Model

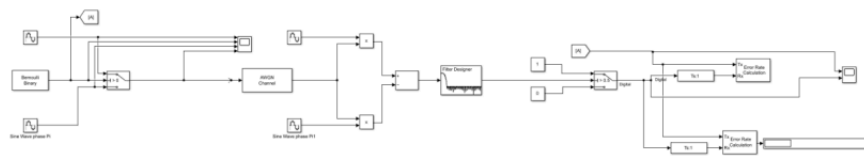


Figure 2 - PSK Simulink Model

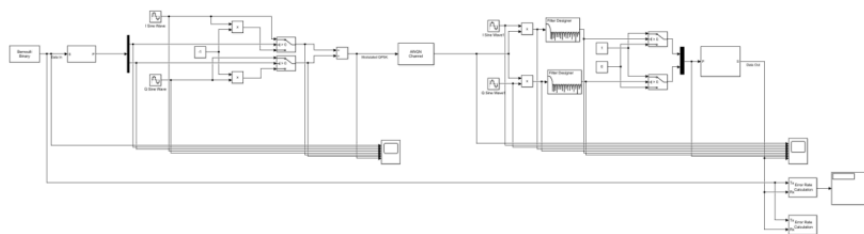


Figure 3 - QPSK Simulink Model

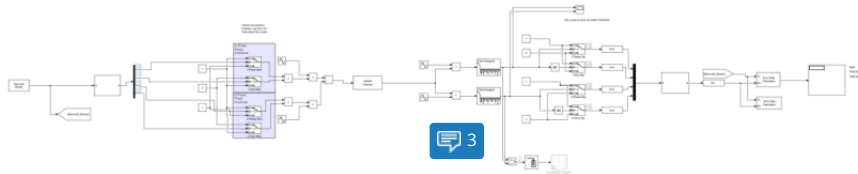


Figure 4 - QAM Simulink Model

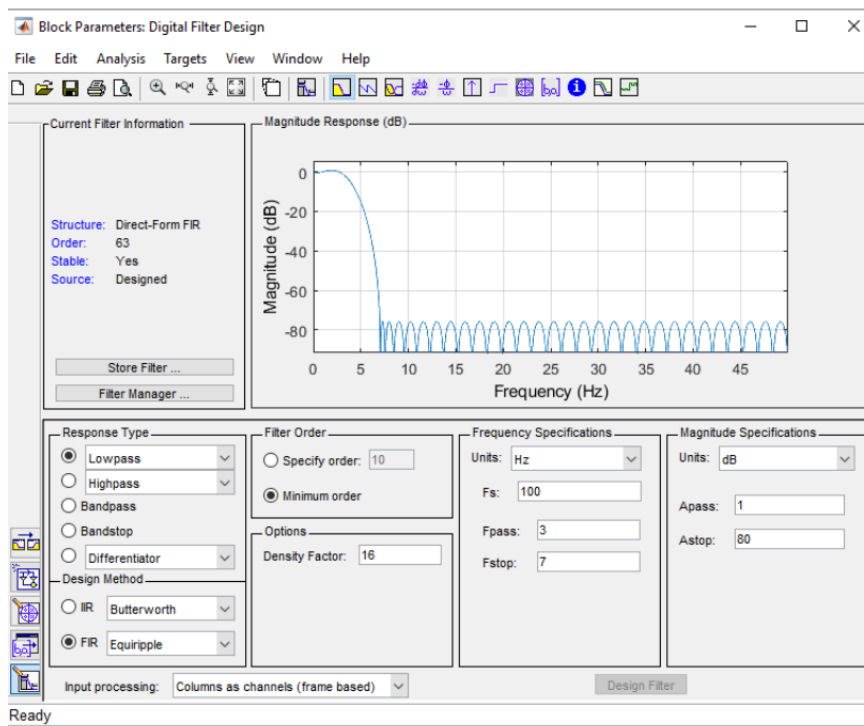


Figure 5 - Filter Designer Details

For all the modulation scheme models, a method is required to prevent aliasing [1], [7], [8] This is where sampling errors are created by the high frequency components of the carrier signal (5Hz) are misrepresented. This is achieved by implementing a lowpass filter as an anti-aliasing filter. A lowpass filter is a signal processing tool that allows signals with frequencies below a specified cut off frequency to pass through while attenuating higher frequencies. The figure details the specifications of the lowpass filter used with all the modulation schemes.

The design specifications shown for the filter in Figure 5 - Filter Designer Details outline its key characteristics. The passband frequency is set at 3 Hz, the maximum frequency at which the signal can pass with minimal attenuation. The stopband frequency is designated at 7 Hz, marking the point where significant attenuation begins. Within the passband, a ripple of 1 dB is permitted, indicating the allowable variation in gain. The filter design must provide a stopband attenuation of 80 dB, guaranteeing that signals within this range are effectively removed. The filter's complexity was calculated to have an order of 63, indicating a sharper transition between the passband and the stopband. To ensure that it was only the effects of AWGN on the various modulation schemes that are being investigated, a stable and linear phase response is required. One of the best ways to achieve this is by using a Finite Impulse Response (FIR) filter. As the name suggests, these filters require a fixed number of input samples, allowing the response to reach zero. In contrast to Infinite Impulse Response (IIR) filters, which rely on feedback and therefore can be unstable, fixed sample input filters offer inherent stability in their design. This advantage ensures consistent performance without the complications that feedback may introduce. This produces an excellent lowpass filter, but this has a computational cost. The calculation requires knowledge of the previous output. This means that the calculation complexity increases for each output sample.[7], [8]

Results

BER vs. SNR Plots

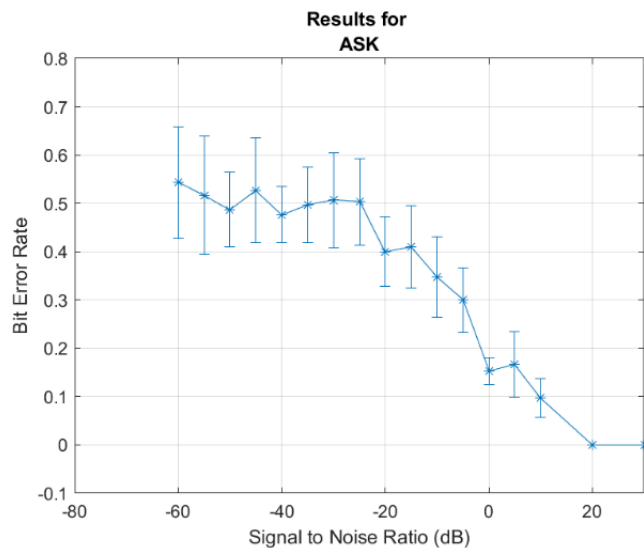


Figure 6 - ASK BER to SNR Plot

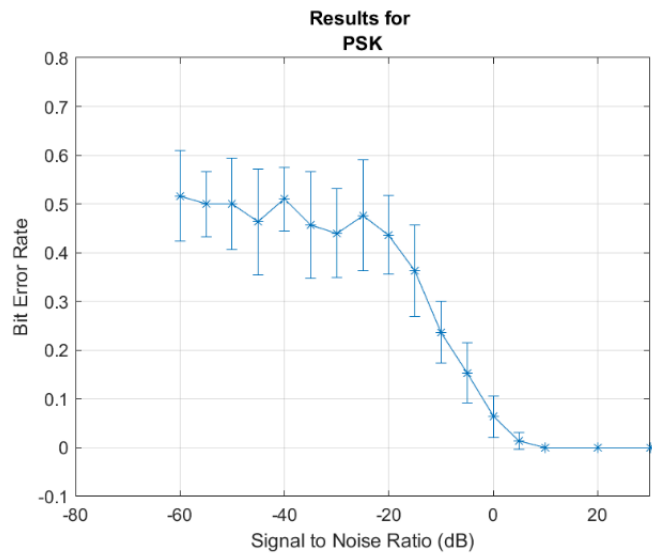


Figure 7 - PSK BER to SNR Plot

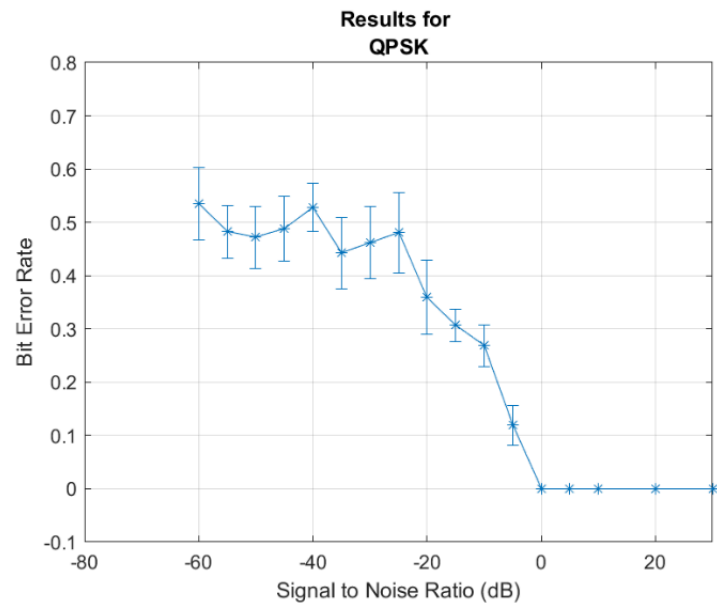


Figure 8 - QPSK BER to SNR Plot

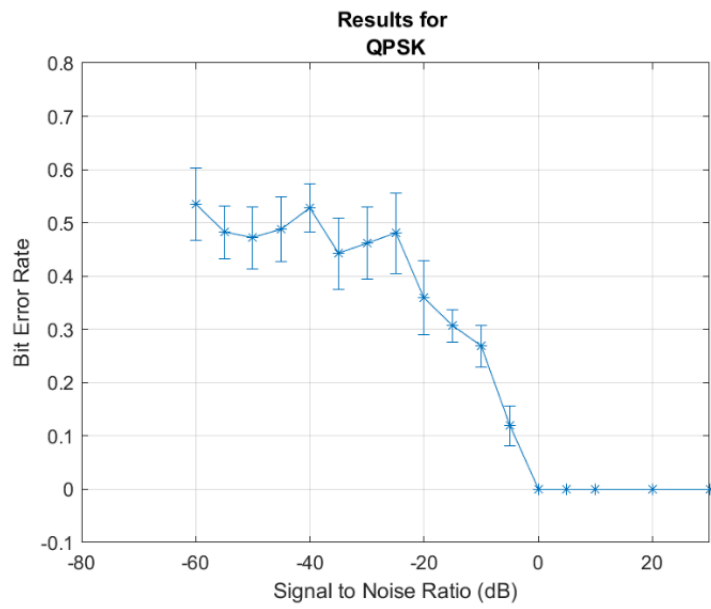


Figure 9 - QAM BER to SNR Plot

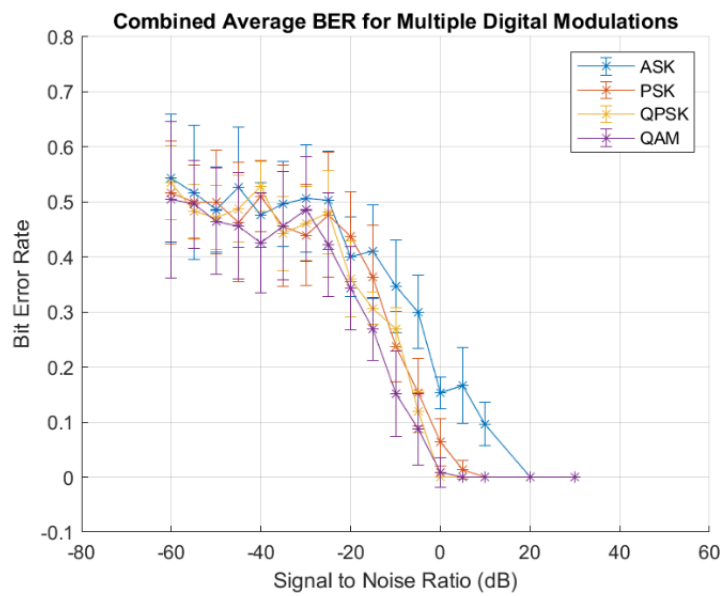


Figure 10 - Combined Modulations Plot

BER vs. SNR Table

SNR_dB	Avg_BER_ASK	Avg_BER_PSK	Avg_BER_QPSK	Avg_BER_QAM
30	0	0	0	0
20	0	0	0	0
10	0.096667	0	0	0
5	0.166667	0.013333	0	0
0	0.153333	0.063333	0	0.008696
-5	0.3	0.153333	0.119298	0.086957
-10	0.346667	0.236667	0.268421	0.152174
-15	0.41	0.363333	0.307018	0.269565
-20	0.4	0.436667	0.359649	0.343478
-25	0.503333	0.476667	0.480702	0.421739
-30	0.506667	0.44	0.461404	0.486957
-35	0.496667	0.456667	0.442105	0.456522
-40	0.476667	0.51	0.52807	0.426087
-45	0.526667	0.463333	0.487719	0.456522
-50	0.486667	0.5	0.47193	0.465217
-55	0.516667	0.5	0.482456	0.495652
-60	0.543333	0.516667	0.535088	0.504348

Figure 11 - BER to SNR Table

The BER versus SNR plots demonstrate the efficiency of the four digital modulation techniques (ASK, PSK, QPSK, and QAM) under various noise environments from -60 dB to +30 dB.

Trends in the Plots

At low SNR levels, the BER for all digital modulation methods increases sharply, indicating their growing vulnerability to noise. ASK and PSK are especially sensitive to errors, with BER values approaching 0.5, suggesting a performance similar to random guessing.

All modulation techniques reach BER values close to zero at higher SNR levels. However, the level at which they approach near-zero BER varies, with more straightforward methods (ASK, PSK) needing lower SNR (10 -20 dB) thresholds than QPSK and QAM (approx. 0 dB, i.e. the same level of power of signal and noise)

The BER for QPSK shows better performance than ASK, and PSK shows enhanced noise resistance.

Although QAM's performance at higher SNR is similar to that of QPSK, its BER at lower SNR levels is greater.

Discussion

ASK is very susceptible to noise because it depends on amplitude changes, which AWGN can easily influence. However, PSK demonstrates greater robustness since it is based on phase changes, which are less susceptible to amplitude interference caused by adding AWGN. However, in real-world scenarios, the effects of reflections can create multipath routes leading to phase noise. [4]

Quadrature Phase Shift Keying (QPSK) offers significant advantages in digital communication by encoding two bits of information per symbol. This increased bit density allows for a more efficient

bandwidth use compared to traditional Phase Shift Keying (PSK), where only one bit is represented by each symbol. This dual-bit encoding effectively doubles the data transmission rate without requiring additional bandwidth, which is a critical factor in environments with limited frequency resources.

This increased complexity of the QPSK signal constellation enhances its performance, particularly in challenging conditions characterised by noise and interference. By spreading the symbols across four distinct phase shifts, QPSK can maintain signal integrity more effectively than single-bit PSK schemes. As a result, it demonstrates improved robustness against bit errors caused by environmental factors. Overall, QPSK's ability to offer higher data rates while performing well in noisy environments makes it a helpful choice in modern communication systems to fall back on in these situations. [9]

While higher-order QAM techniques (like the 16-bit QAM model) offer improved data rates. However, they have diminished noise resilience due to the need to vary both the phase and amplitude to place the symbols within the constellation correctly. This is an increasing issue when the data rate increases as the distance between symbols is reduced. However, this increase in data has created high-speed data communication systems, such as 4G/5G networks and WiFi, because of its capacity to achieve high spectral efficiency. This does present other challenges in designing effective noise mitigation strategies and error correction to manage the BER when working in congested electromagnetic environments.

Conclusion

This report assessed the efficiency of four digital modulation techniques, Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM)—under varying Signal-to-Noise Ratio (SNR) conditions with Additive White Gaussian Noise (AWGN).

Due to its use of amplitude changes, ASK is highly susceptible to noise, making it suitable only for environments with a high SNR and applications that have low data rate requirements. However, PSK, which utilises phase changes, offers improved noise resilience and greater reliability in environments with moderate interference.

QPSK enhances phase-based modulation by encoding two bits per symbol, effectively doubling the data rate without requiring additional bandwidth. This, combined with its ability to maintain signal integrity (Low BER) as the SNR increases, allows it to be valuable in bandwidth-constrained applications where higher data rates are critical, such as in wireless communication systems.

QAM combines amplitude and phase variations to encode multiple bits per symbol, achieving higher data throughput and greater spectral efficiency. While it requires higher SNR to maintain low BER, QAM is a fundamental part of modern high-speed communication systems like 4G, 5G, and WiFi. [4], [9] This performance, however, does introduce other issues, such as forward error correction, to address challenges in congested or noisy electromagnetic environments.

In summary, each modulation technique has advantages and trade-offs. ASK and PSK are ideal for simpler systems with high SNR and low data rate demands. QPSK balances higher data rates with noise resilience, making it versatile for challenging environments with limited bandwidth. QAM offers outstanding spectral efficiency for high-throughput systems but requires higher SNR and robust error correction mechanisms.

These insights show the importance of selecting the correct modulation scheme based on specific application needs and balancing data rate, noise resilience, and spectral efficiency to optimise performance in various communication scenarios.

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Appendix

MATLAB Live script for controlling the Simulink models

Digital Signal Processing and Communications ACDA5008

Simulation of Digital Modulation Techniques

This live script forms part of the overall laboratory report, especially for the method and results sections.

Each section will break down the steps and stages required to calculate the Bit Error Rate of different digital modulation schemes as Additive White Gaussian Noise is introduced into each of the Simulink models.

Stage One - Setup

This section creates all the variables needed to control a script capable of automating the data collection on how additive white Gaussian Noise (AWGN) affects the Bit Error Rate (BER) across a range of digital modulations.

The author created all the simulated models and proved them to have a zero BER at a signal-to-noise ratio of 30 dB before this control script was written.

This initial stage of the script involves initialising and setting up all necessary variables and parameters to standardise the simulation environment and facilitate automation throughout the investigation.

A variable representing the SNR for the AWGN channel was defined, along with a range of SNR values that extended from +30 dB to -60 dB, allowing for an assessment of performance in both clear signal channels and extremely noisy conditions. Each modulation model was first checked to ensure a ratio of +30 dB, 1000 times greater than the noise level, was sufficient to have a zero BER. The number of simulation runs per SNR value was set to ten to ensure statistically significant results. The array, `model_array`, was created to reference the modulation schemes under examination: ASK, PSK, QPSK, and QAM. The sampling time was set to 1/100 seconds, and memory-efficient arrays were pre-allocated to store the BER results for each combination of SNR value and modulation scheme.

```
clear all
close all

% Stage One - Setup
SNR = 30; %creates variable in the base workspace for AWGN block for when
the Simulink model 1st opens
SNR_Ratios = [30,20,10,5,0,-5,-10,-15,-20,-25,-30,-35,-40,-45,-50,-55,-60];
%set ratios for SNR
simulated_runs = 10; % how many data points are required
model_array = ["ASK","PSK","QPSK","QAM"];
sample_time = 1/100 ; %used in all models to setup sine wave generators
```

```

% Preallocate data arrays
data = zeros(length(SNR_Ratios), simulated_runs, length(model_array));
avg = zeros(length(model_array), length(SNR_Ratios)); % Average BER array
err = zeros(length(model_array), length(SNR_Ratios)); % Standard deviation array

% Setup x-axis
graph_x = SNR_Ratios;

```

Stage Two - Main Control Loop

In Stage Two, the data collection process is structured using a nested loop framework to simulate each modulation scheme across a range of signal-to-noise ratio (SNR) values. The loop loads and simulates the corresponding Simulink model and then outputs the results into the workspace for each modulation scheme. All the simulation's stop times are set to 30 seconds to ensure consistency across all models.

The inner loop controls the SNR parameter and is called iteratively according to the predefined values in the SNR_Ratios array. For each SNR value, the simulation was executed ten times, allowing for random variations in noise to be accounted for. Each run's output bit error rate (BER) was recorded in a designated data array. Following this, the average BER and standard deviation were calculated for each SNR value using the mean and standard deviation functions built into Matlab.

```

% Stage Two - Main Control Loop
for m = 1:length(model_array)
    model_name = model_array(m); % Get the current model name
    load_system(model_name); % simulates model but without opening simulink GUI
    set_param(model_name, "StopTime", "30");

    for i = 1:length(SNR_Ratios)
        SNR = SNR_Ratios(i);
        for test = 1:simulated_runs
            simOut = sim(model_name, 'ReturnWorkspaceOutputs', 'on'); %
            % BER = simOut.get('output_BER'); % Retrieve the BER output from
            % the simulation
            data(i, test, m) = BER(1); % Store the first value of BER
        end

        % Calculate the average and standard deviation for each model
        avg(m, i) = mean(data(i, :, m)); % Average for the current model
        err(m, i) = std(data(i, :, m)); % Standard deviation for the current
    end
end

```

```
end
```

Stage Three - Plotting

After the main simulation loop, the collected BER data is organised into arrays. Each modulation scheme generates a plot using the mean BER (average) and its standard deviation (err) across multiple runs for each SNR value. These plots also use the errorbar function in MATLAB to highlight the variability in performance due to random noise. Larger bars show a greater sensitivity to noise, while smaller bars indicate a more resilient modulation scheme. The plots are then labelled, titled for recognition, and saved.

Observed performance trends

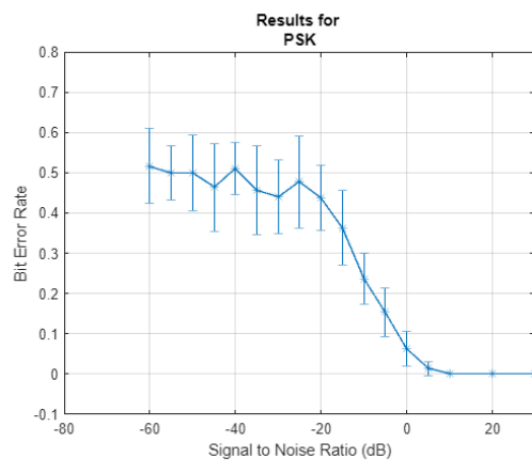
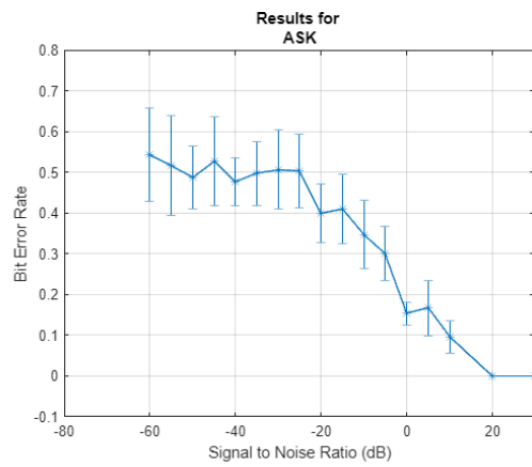
The plots demonstrate how BER changes as SNR increases. At low SNR (IE high noise), BER approaches 0.5, which shows the demodulation is random guessing for binary schemes

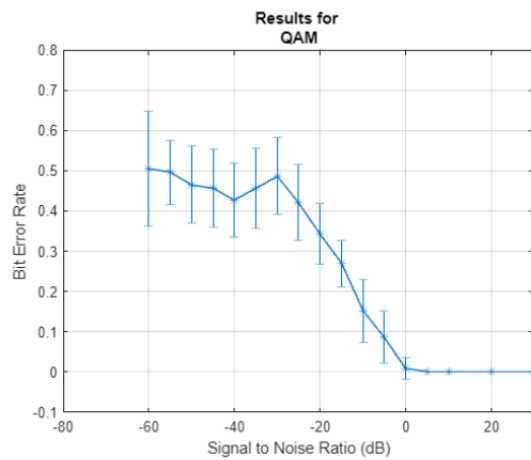
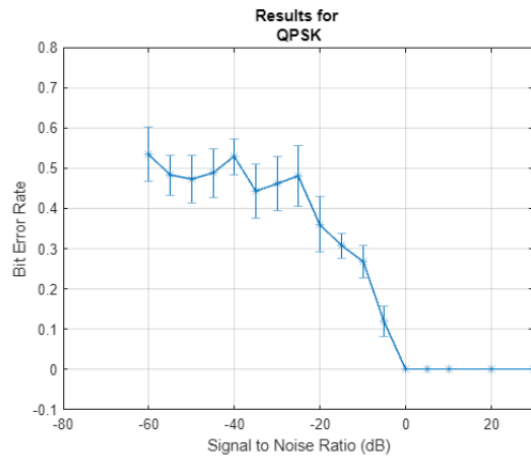
The plots illustrate the direct influence of SNR on BER. At low SNR (IE, high noise), BER approaches 0.5, indicating that the demodulation performs no better than random guessing for binary schemes such as ASK and PSK.

The BER drops significantly at high SNR (low noise), approaching zero for schemes like QPSK and QAM. This contrasts with the performance of ASK and PSK at low SNR, highlighting the impact of noise conditions on different scheme's performance.

```
for m = 1:length(model_array)
    figure;
    errorbar(graph_x, avg(m, :), err(m, :), '-*');
    ylabel('Bit Error Rate');
    xlabel('Signal to Noise Ratio (dB)');
    title(['Results for ', model_array(m)]);
    grid on;
    xlim([-80 30]);
    ylim([-0.1 0.8]);

    % Save each individual plot
    saveas(gcf, ['BER_results_', char(model_array(m)), '.png']);
end
```





Stage Four - Combined Plotting

Stage Four combines the individual BER vs. SNR plots for all modulation schemes, ASK, PSK, QPSK, and QAM, into a single graph. This combined representation allows for a direct comparison of the performance of different schemes under identical noise conditions. The aim is to identify trends, highlight differences, and derive conclusions about the robustness and efficiency of each modulation technique.

Performance at Low SNR (High Noise)

- ASK typically performs poorly, with BER values remaining high due to its limited noise resilience.

- PSK and QPSK may perform slightly better due to phase encoding and are less susceptible to amplitude variations.
- QAM exhibits intermediate performance in low SNR conditions, balancing amplitude and phase modulation.

Performance at High SNR (Low Noise)

- All schemes converge to near-zero BER as noise becomes negligible, but the rate at which they achieve this differs.
- More complex schemes like QAM require higher SNR to achieve error-free performance than simpler schemes like ASK.

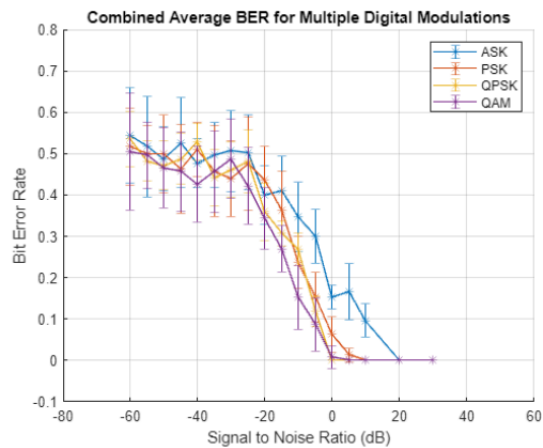
Error Bars and Variability

- The error bars provide insights into the stability of each modulation scheme. At high SNR levels, all the schemes have smaller error bars, indicating better consistency.
- Larger error bars at low SNR suggest greater sensitivity to noise, especially for amplitude-based schemes like ASK.

```
% Combined Plotting
figure;
hold on;
for m = 1:length(model_array)
    errorbar(graph_x, avg(m, :), err(m, :), '-*', 'DisplayName',
model_array(m)); % Plot each model's average BER
end
hold off;

% Add labels and legend for combined graph
ylabel('Bit Error Rate');
xlabel('Signal to Noise Ratio (dB)');
title('Combined Average BER for Multiple Digital Modulations');
legend show;
grid on;
xlim([-80 60]);
ylim([-0.1 0.8]);

% Save combined plot
saveas(gcf, 'Combined_BER_results.png');
```



Stage Five - Create a simple table of results

Stage Five organises the results of the average Bit Error Rates (BER) for each modulation scheme into a table format. This table provides a structured summary of the performance data across varying signal-to-noise ratio (SNR) levels, making it easy to analyse, compare, ready to incorporate into the final report.

```
% Create a table for results
results_table = table();

% Add columns for SNR
results_table.SNR_dB = graph_x';

% Add columns for each modulation scheme
for m = 1:length(model_array)
    col_name = strcat("Avg_BER_", model_array(m));
    results_table.(col_name) = avg(m, :);
end

% Display the results table
disp(results_table);
```

SNR_dB	Avg_BER_ASK	Avg_BER_PSK	Avg_BER_QPSK	Avg_BER_QAM
30	0	0	0	0
20	0	0	0	0
10	0.096667	0	0	0
5	0.16667	0.013333	0	0

0	0.15333	0.063333	0	0.0086957
-5	0.3	0.15333	0.1193	0.086957
-10	0.34667	0.23667	0.26842	0.15217
-15	0.41	0.36333	0.30702	0.26957
-20	0.4	0.43667	0.35965	0.34348
-25	0.50333	0.47667	0.4807	0.42174
-30	0.50667	0.44	0.4614	0.48696
-35	0.49667	0.45667	0.44211	0.45652
-40	0.47667	0.51	0.52807	0.42609
-45	0.52667	0.46333	0.48772	0.45652
-50	0.48667	0.5	0.47193	0.46522
-55	0.51667	0.5	0.48246	0.49565
-60	0.54333	0.51667	0.53509	0.50435

Stage Six - Save the results

The final stage ensures that all simulation data and academic documentation are saved for future reference. This involves saving the results table in a universally accessible format (CSV) and preserving the workspace variables for additional analysis or reproducibility of results. This practice is essential for maintaining data integrity, to either enable further exploration or for academic requirements.

```
% Save the table as a CSV file for easy access
writetable(results_table, 'BER_results_table.csv');

% Save the data for future analysis
save('BER_results.mat', 'data', 'avg', 'err', 'SNR_Ratios', 'model_array');
```

72/100

PAGE 1

QM

Abstract - results

Good abstract, although you should include a statement of your results.

Additional Comment

you should quantify your results - exactly how much better were they?

PAGE 2

PAGE 3



Comment 1

digital data



Comment 2

Shown in figures 1 - 4 are the simulink

direct the reader to the right images. Don't let them guess by only saying "below" - there are quite a few images in this report.

PAGE 4

PAGE 5



Comment 3

Too small to see detail. Would have been better split into chunks

PAGE 6



Comment 4

No - there is no analogue to digital conversion going on, therefore no aliasing will happen. The filter is there to remove the carrier from the data.

PAGE 7

PAGE 8

PAGE 9

PAGE 10



Comment 5

There is a change in the spectral footprint between PSK and QPSK. This is caused by the sharp edges present in the signal at the point of the phase change.



Comment 6

Good, but what does the distance between the symbols in the constellation diagram signify?

PAGE 11

QM

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

Additional Comment

missing page numbers

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

GRADING FORM: SMU GENERIC_SMOSEY

JAMES HUNT

71.50

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."

6.8

KNOWLEDGE & UNDERSTANDING

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



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

15

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."

19.8

Sound, convincing conclusions / recommendations

A stronger link between constellation diagrams, noise level, and your simulation results would have improved this section.

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, with extensive use of relevant examples.

Application and deployment extend beyond established conventions. Innovation and creativity evident throughout.

23.4

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 well, confidently and consistently in a suitable format.

Can work very well as part of a team, with very good contribution to group activities.

Work is coherent and fluent and is well structured and organised.

6.5

You included figures without referring directly to them in the text, tell the reader where to look.

Doing this would have increased your mark here.