

ACDA5008 – Digital Signal Processing & Communications

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Abstract

This assignment looks at the differences between Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and their variations. Both are methods of encoding digital data onto an analog transmission.

The comparison is made using simulations of all methods on a piece of software called Simulink. The simulations can provide a realistic example of how these transmission methods work.

The differences being analysed are the error rates of each transmission method when a certain amount of noise is inserted between the modulation and demodulation stages. The inserted noise serves as a method of simulating the real-life disadvantage of transmitting data over long distances or in a noisy environment. The noise will interfere with the signals amplitude and can cause a difference between the transmitted data and the received data. By gradually increasing the amount of noise the number of errors should also increase. The rate at which the errors increase and the point at which the noise causes the data to be considered useless will differentiate between the transmission methods.

Introduction

All the following modulation techniques are methods of transmitting digital data over an analogue carrier signal. The digital data will be a signal made up of binary voltage levels, for example, 2V is a binary 1 and 0V is a binary 0. The analogue carrier signal is a continuous signal in the form of a sine wave. For example, the voltage continuously varies between +2V and -2V. Each method modulates the analogue signal in a different way. Modulation is when the characteristics of the analogue signal are varies in reference to a digital signal [1].

Amplitude Shift Keying (ASK)

ASK is a form of modulation which varies the amplitude of the carrier signal based on the value of the message signal. When the digital signal has a value of 1, the analogue sine wave is transmitted. When the digital signal has a value of 0, the analogue sine wave is not transmitted. The phase and frequency of the carrier signal are not altered, only the amplitude [2]. This is demonstrated in the screenshot below. The screenshot is of an oscilloscope attached to the output of the simulated ASK modulator in Simulink.

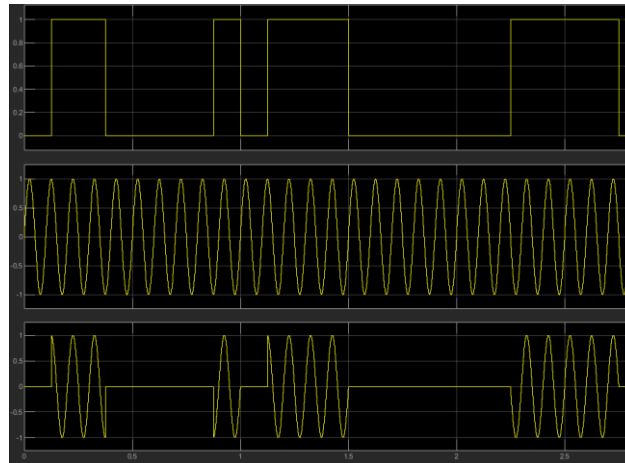


Figure 1. ASK Modulation in Simulink

The advantages of ASK is that it offers higher bandwidth efficiency, can be used to transmit digital messages over optical fibre and the modulation method is very simple and inexpensive.

However, ASK has a major disadvantage. Noise interference only affects the amplitude of a signal, therefore, because the ASK modulation method only depends on the variation in amplitude it is much easier for noise to corrupt the transmitted signal to a point in which the received data is different. [3]

Phase Shift Keying (PSK)

PSK is another method of modulation which varies the phase of the carrier signal based on the value of the message signal. The amplitude and frequency of the carrier signal are unaltered. This modulation technique always outputs a signal, however, whenever the message value is a binary 1, the phase of the carrier signal is shifted by 180° . When there are only two options for the message value, a 1 or a 0, there are only two phases being used. Therefore, this method of modulation is also referred to as BPSK or Binary Phase Shift Keying [4]

The operation of this modulation technique can be seen in the screenshot below. Once again, this is the output of a simulated BPSK modulator in Simulink.

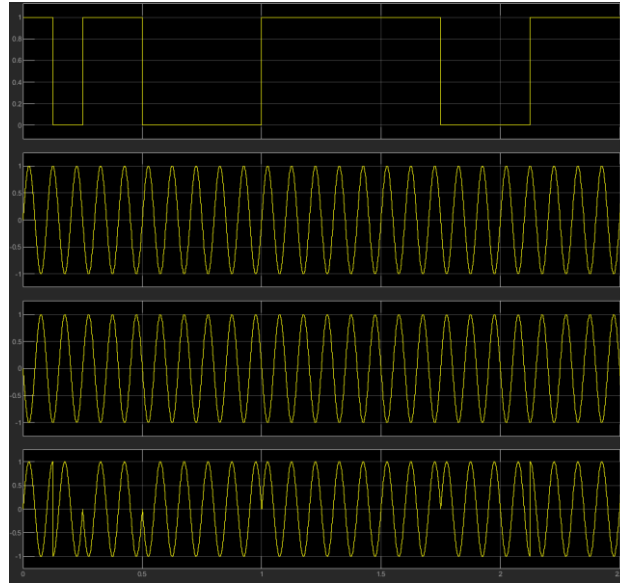


Figure 2. PSK Modulation in Simulink

BPSK can transmit data more efficiently than ASK, this means it has a higher power efficiency. It is also less susceptible to noise than ASK due to the phase of the signal being the varied attribute.

However, BPSK is much more complex to demodulate than ASK. This is because the receiver can never be perfectly synchronized with the transmitter. This means it must guess which phase is a 1 and which is a 0 [5].

Quadrature Phase Shift Keying (QPSK)

QPSK is a form of PSK which means the carrier wave's phase is varied based on the value of the message signal. QPSK differs from BPSK with the fact that QPSK can transmit two bits of binary information at the same time. This means that the data transmission rate is doubled. [6]

This modulation technique alters the carrier signal through 4 different phases: 0° , 90° , 180° and 270° .

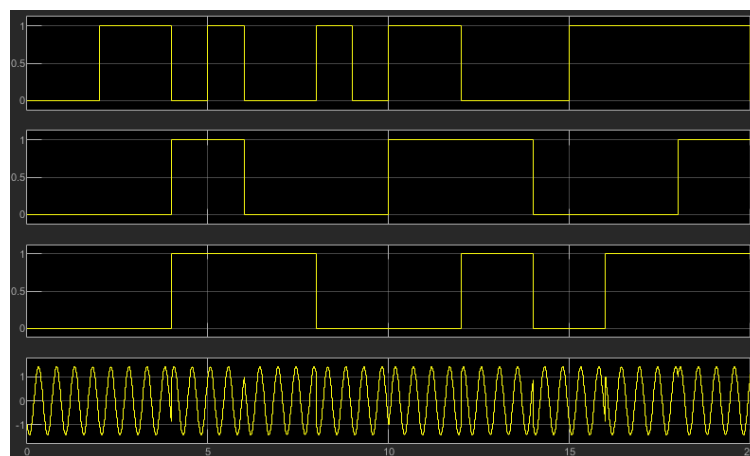


Figure 3. QPSK Modulation in Simulink

Whilst QPSK is twice as efficient as BPSK in terms of bandwidth, it is less power efficient. This is because the transmitter and receiver require more complex modulation and demodulation techniques. Therefore, the power per bit of information is greater for QPSK than BPSK.

Furthermore, because QPSK uses 4 states of input rather than two, the gap between the levels is less than in the other modulation techniques. This means that a smaller amount of noise is required to cause a bit to be incorrectly read. Making it more susceptible to a noise filled transmission environment. [7]

Simulation Models

Amplitude Shift Keying (ASK)

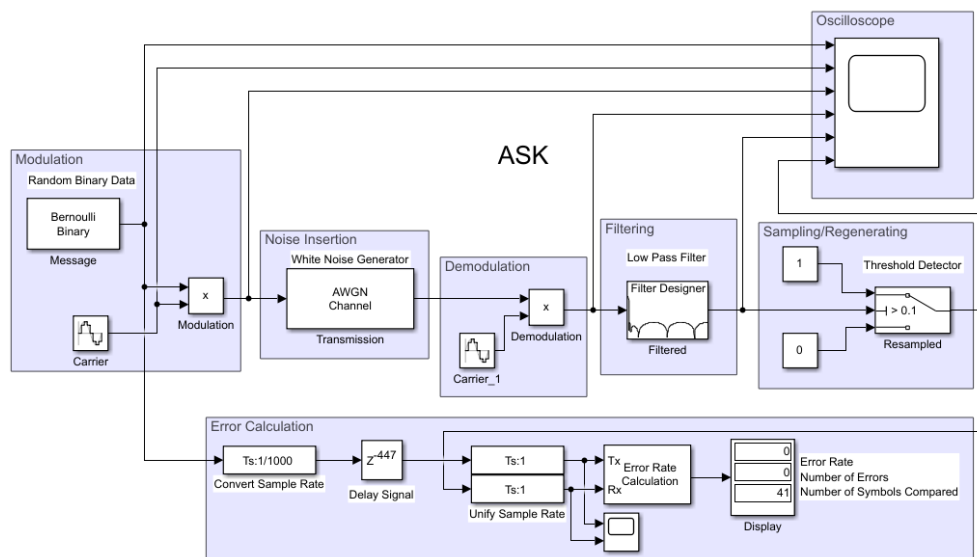


Figure 4. ASK Simulation in Simulink

The easiest way to implement ASK modulation is via an On-Off-Keying (OOK) modulator. This is essentially allowing the carrier signal to transmit on a binary 1 and transmitting nothing on a binary 0. This simulation uses a multiplication block to achieve this. When the message data is 1, the carrier signal is multiplied by 1 and stays the same. When the message data is 0, the carrier signal is multiplied by 0 and is nulled.

The simulation then uses an Additive White Gaussian Noise (AWGN) Channel block to create the noise observed during transmission in real life.

For demodulation, it is as simple as multiplying the transmitted message by the carrier wave again, filtering out the higher frequency of the carrier wave and then resampling. By multiplying the message signal by the carrier wave again it converts the signal from oscillating between positive to negative to staying positive. This also doubles the frequency of the signal blocks which needs to be accounted for when designing the filter.

A lowpass filter is used to remove the carrier wave and isolate the active blocks from the 0 state. However, the output of this filter is close to being a square wave, but the rising and leading edges are too pronounced. An edge detector is used to toggle between peak amplitude and 0 when a voltage level is detected. This straightens the edges of the wave and form an ideal square wave containing the data of the input signal.

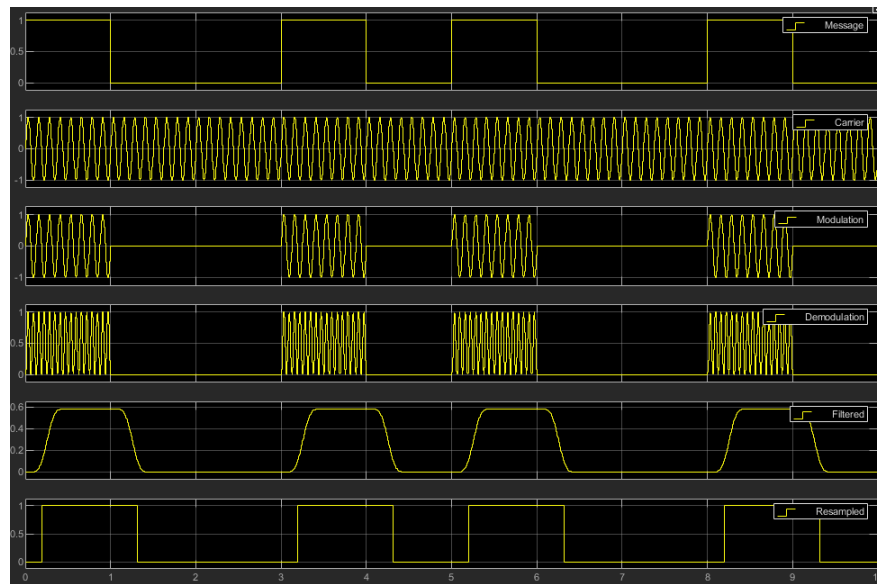


Figure 5. ASK Simulation Output

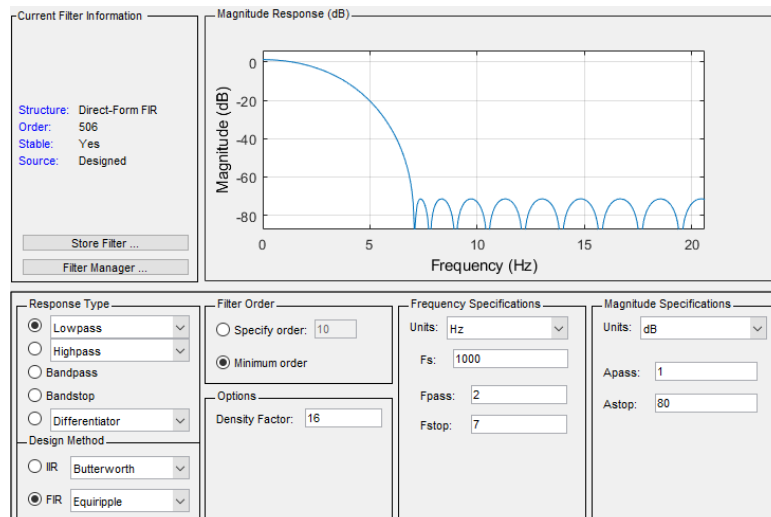


Figure 6. ASK Digital Lowpass Filter

The above figure shows the digital filter designer block within Simulink. The selected filter is a lowpass, FIR Equiripple filter. The specifications of the filter are chosen based on the specification of the carrier wave. F_s refers to the sample rate of the signal within the simulation this is set to the 1000Hz sample rate of the carrier wave. The F_{pass} and F_{stop} values determines the curve of the filter and it chosen based on the frequency of the carrier wave. The frequency of the carrier wave in this case is 4Hz, however, during demodulation the frequency is doubled. Therefore, the filter needs to be set to pass anything below 8Hz. The chosen values allow for a smooth output and has a wide range to ensure the order of the filter stays small. The order of the filter determines the delay caused by the filtering process. The final filter has an order of 506, this combined with the sample frequency of 1000Hz means the output is delayed by 256ms.

Phase Shift Keying (PSK)

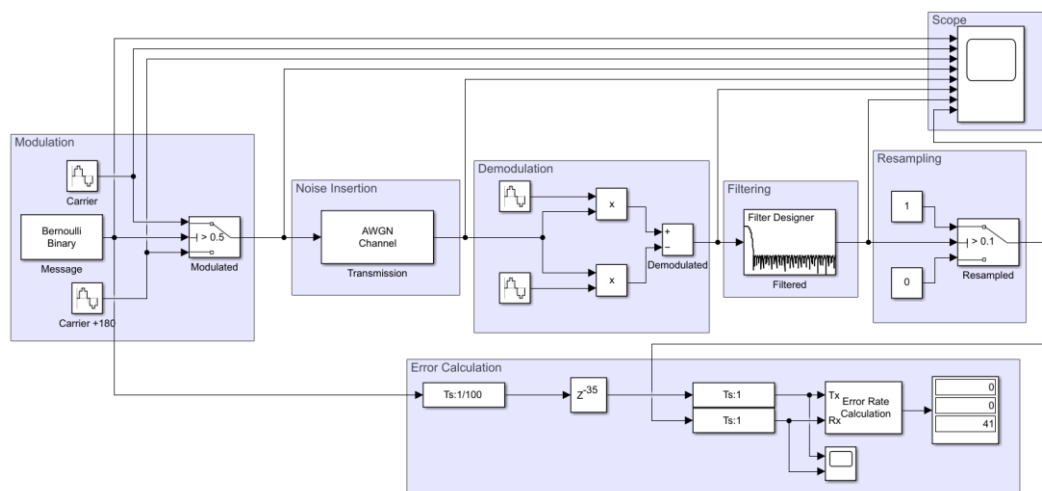


Figure 7. BPSK Simulation in Simulink

BPSK modulation can be seen as switching between two carrier signals, one at 0° phase and one at 180° phase. In Simulink this can be done using a digital switch that is triggered by the input signal. When the input is a binary 1, the switch toggles to pass the 180° out of phase signal. The effect of this can be seen in the first 4 signals seen in the oscilloscope output in figure 8.

This simulation also includes an AWGN channel block to simulate the noise required for the comparison.

Demodulation is slightly more complex but relies on the same principle of multiplying the signal by the carrier again. This time, because there are two carrier waves the signal is multiplied by both carrier waves and the difference of the two is the output of the demodulator. The output is then filtered based on the frequency of the carrier wave, the frequency of the two carriers is the same so only one filter is required. It is then resampled using the same process as the ASK simulation.

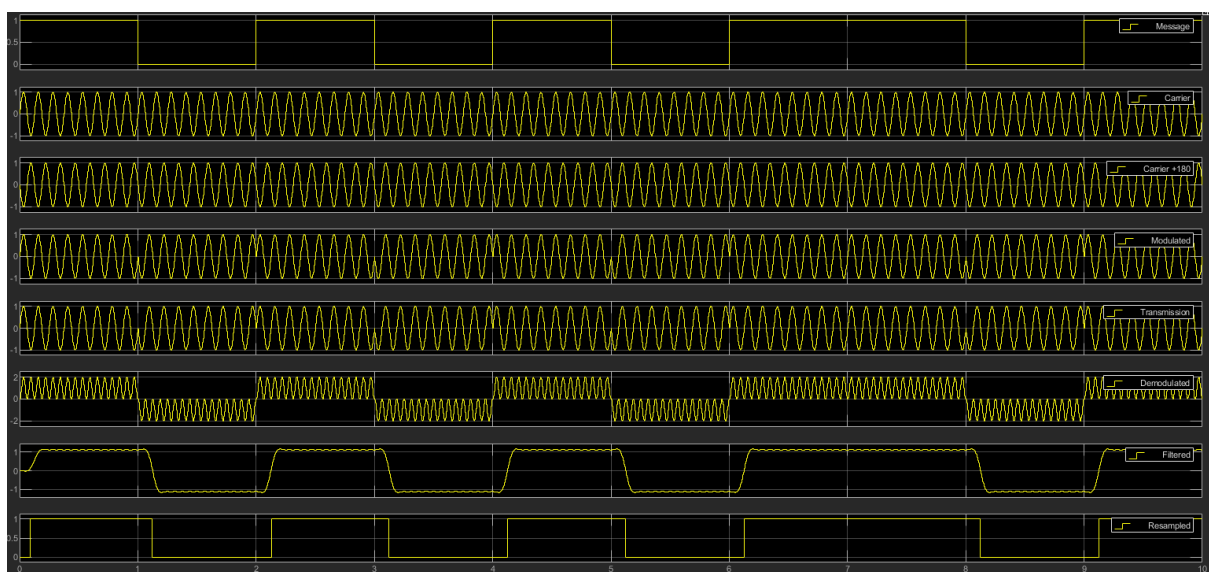


Figure 8. BPSK Simulation Output

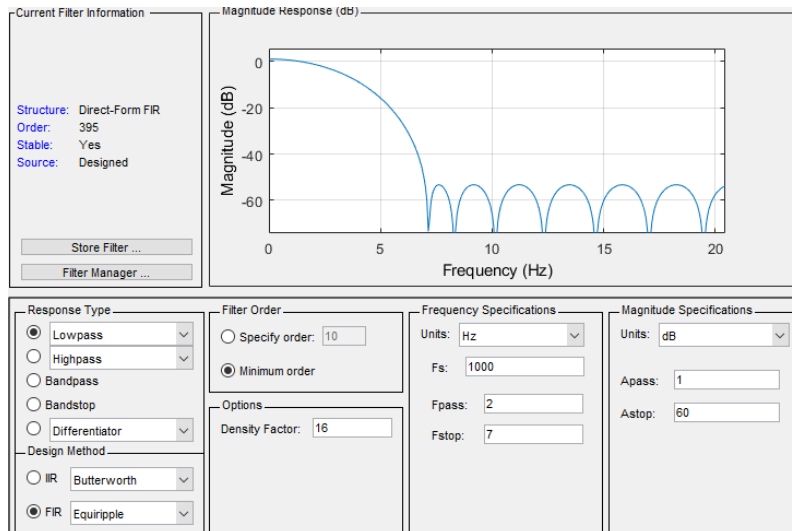


Figure 9. BPSK Digital Lowpass Filter

Quadrature Phase Shift Keying (QPSK)

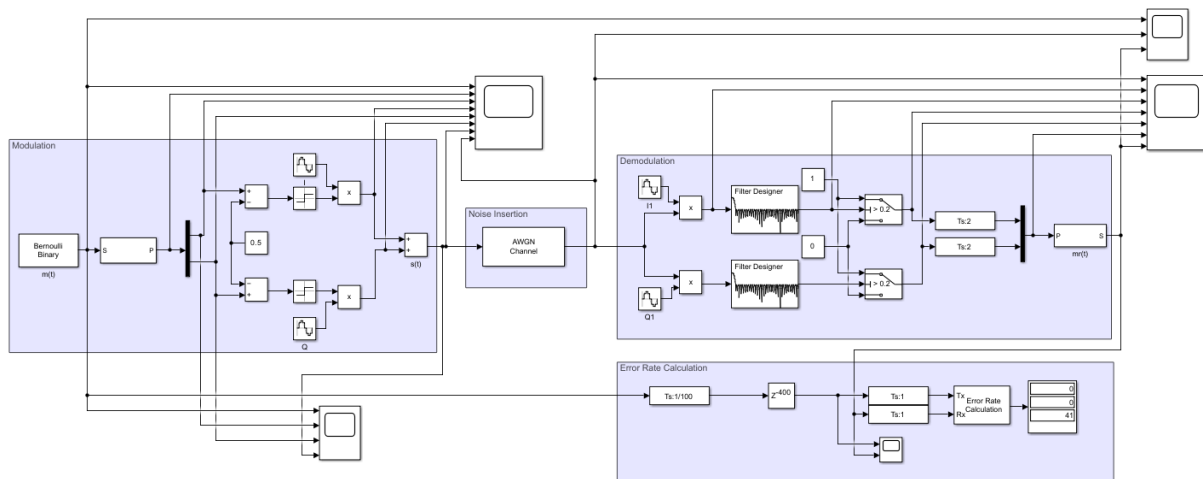


Figure 10. QPSK Simulation in Simulink

The simulation model for QPSK is much more complex than the other two. This is due to the input being two bits at a time rather than one. The input must first be converted from serial to parallel and then passed into a demux to split the matrix into two separate outputs. Each output is then used for half of the phase changes. There are two carrier wave signals, one is 180° out of phase of the other. The two separate signals are then combined and form the output of the modulator.

The output contains 4 different phases and is once again subject to the AWGN channel. The demodulator follows the sample principles as the previous two but split into two copies for the two channels. Each channel is demodulated by multiplying the transmitted signal with the carrier wave and then passed through a filter. The filter design can be seen in Figure 13 and is focused on the carrier frequency of 2Hz.

The output of each filter is resampled using an edge detector and then needs to be muxed back together and converted from parallel to serial. This serial output should then be the same as the output of the binary generator.

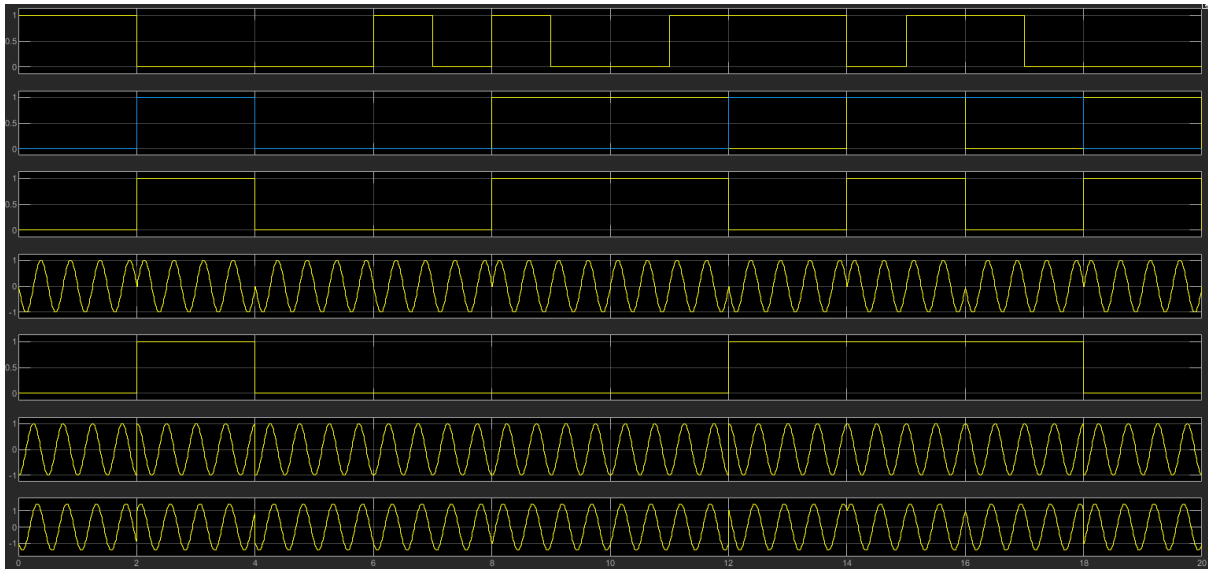


Figure 11. QPSK Modulation Output

Figure 11 shows the conversion between serial and parallel, the two channels being BPSK modulated and then combined into a QPSK signal.

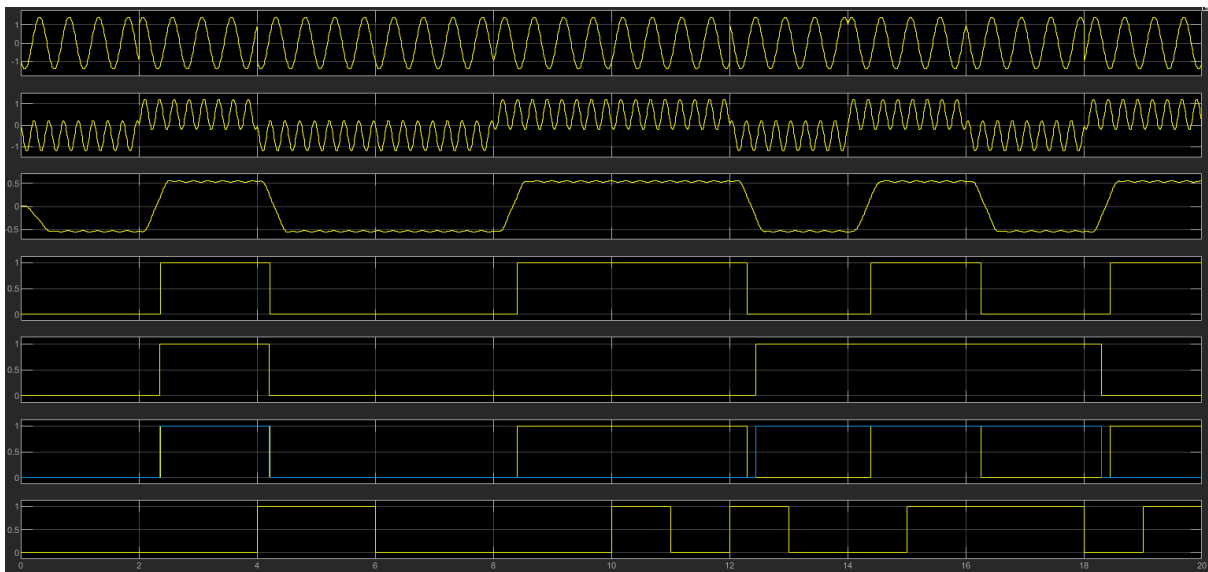


Figure 12. QPSK Demodulation Output

Figure 12 shows the demodulation process focusing on one channel only. The demodulation, filtering and resampling looks the same as the BPSK output because it is functionally identical. The final three signals show the conversion back from two channels to one and then converted from parallel to serial. Because two filters are used in the demodulation process the final output has a considerable delay compared to the other two techniques.

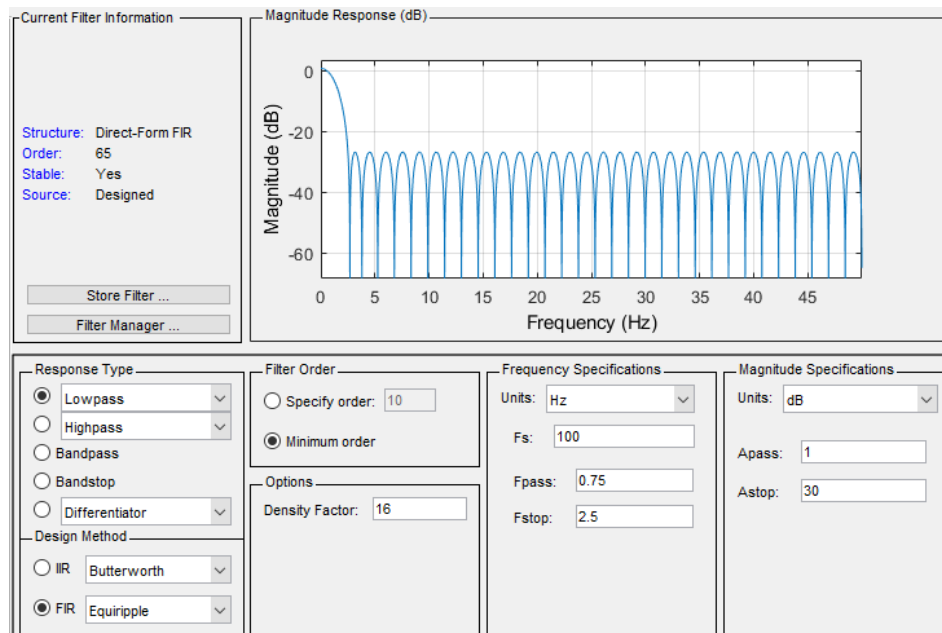


Figure 13. QPSK Digital Lowpass Filter

Error Calculation

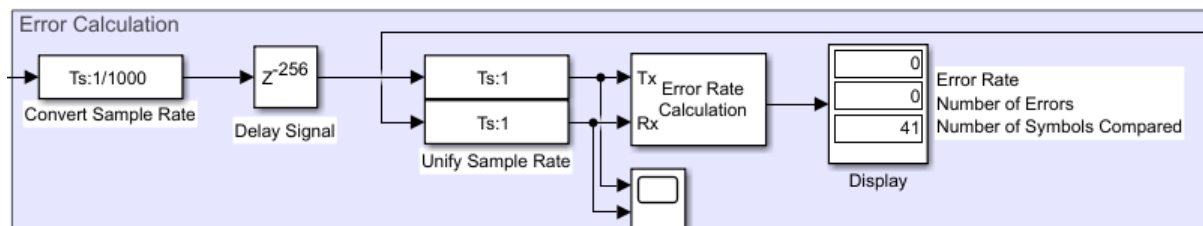


Figure 14. Error Calculation Function in Simulink

Figure 13 shows the error calculation block used in all simulations to determine the amount of errors between the transmitted signal and the received signal. The far left input is connected to the output of the binary generator and needs to be converted to the same sample rate as the carrier wave. This is because the delay from the filter will need to be compensated to line up the two signals. Once the delay has been accounted for the sample rate is unified and input into the error rate block. This block compares the two bit streams and detects if there is a difference in value at a given bit. The output of this block shows the Bit Error Rate (BER), the number of errors and the total number of bits compared. The BER output for each simulation is recorded at several different noise levels and recorded to compare the 3 modulation techniques.

Due to the large variation of error rates each time a simulation is run, the simulation is ran 6 times for each SNR so a mean BER can be calculated.

Results

The following three figures showcase the tables created from the data gathered during the simulations. As mentioned previously, for each SNR level the simulation is ran 6 times. A mean BER is

then calculated for accuracy. The standard deviation of this mean is also calculated so error bars can be included in the graph to indicate the variation of the simulations.

ASK								
Signal to Noise	BER						Mean BER	STD
10	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
-5	0	0	0	0	0	0	0	0
-10	0	0	0.04878	0.04878	0	0.07317	0.02846	0.02740
-12.5	0.09756	0.07317	0.02439	0	0.02439	0	0.03659	0.03387
-15	0.1463	0.09756	0.1951	0.1707	0.09756	0.09756	0.13413	0.03628
-17.5	0.2195	0.2439	0.1951	0.1463	0.1707	0.2195	0.19917	0.03035
-20	0.1951	0.3171	0.2439	0.2439	0.2439	0.2195	0.24390	0.03451
-22.5	0.3171	0.2683	0.3659	0.3171	0.3415	0.3902	0.33335	0.03609
-25	0.2683	0.3415	0.3171	0.3902	0.4634	0.4146	0.36585	0.05973
-27.5	0.3415	0.2927	0.439	0.4878	0.3902	0.4146	0.39430	0.05889
-30	0.4146	0.3659	0.4146	0.3415	0.3902	0.4146	0.39023	0.02604
-32.5	0.3659	0.5122	0.4634	0.5366	0.3659	0.5122	0.45937	0.06440
-35	0.4878	0.3415	0.6098	0.4634	0.3415	0.3902	0.43903	0.08746
-40	0.5122	0.439	0.3902	0.439	0.5122	0.5366	0.47153	0.04822
-45	0.561	0.561	0.439	0.561	0.439	0.561	0.52033	0.05325

Figure 15. ASK BER Table

BPSK								
Signal to Noise	BER						Mean BER	STD
10	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
-5	0.122	0.07317	0.04878	0.02439	0.04878	0.02439	0.05692	0.03105
-10	0.09756	0.2439	0.122	0.122	0.2927	0.1707	0.17481	0.06572
-12.5	0.2439	0.3902	0.2927	0.2195	0.2439	0.1951	0.26422	0.05890
-15	0.1951	0.3171	0.3415	0.2683	0.3659	0.3171	0.30083	0.05162
-17.5	0.2927	0.2683	0.3415	0.2195	0.2439	0.3902	0.29268	0.05375
-20	0.3415	0.2927	0.2439	0.4146	0.3902	0.3415	0.33740	0.05281
-22.5	0.3415	0.4146	0.3171	0.3171	0.4146	0.3902	0.36585	0.03908
-25	0.3902	0.3171	0.3902	0.3171	0.439	0.3171	0.36178	0.04402
-27.5	0.439	0.3415	0.4146	0.5366	0.4146	0.4146	0.42682	0.05336
-30	0.2927	0.4878	0.4878	0.5366	0.439	0.5854	0.47155	0.08516
-32.5	0.3659	0.4146	0.5366	0.4878	0.4878	0.4878	0.46342	0.05214
-35	0.3659	0.439	0.439	0.5854	0.3659	0.4878	0.44717	0.06980
-40	0.4634	0.439	0.5366	0.5854	0.6829	0.6098	0.55285	0.07787

Figure 16. BPSK BER Table

QPSK								
Signal to Noise	BER						Mean BER	STD
10	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
0	0	0	0.07317	0.02439	0.04878	0	0.02439	0.02607
-5	0.1707	0.1707	0.09756	0.07317	0.2439	0.122	0.14634	0.05214
-10	0.2927	0.2195	0.1951	0.1707	0.2195	0.1463	0.20730	0.04276
-12.5	0.1951	0.2195	0.3171	0.3902	0.2927	0.2683	0.28048	0.05938
-15	0.439	0.3415	0.3415	0.439	0.2439	0.439	0.37398	0.06731
-17.5	0.3902	0.3659	0.3659	0.3659	0.3902	0.3415	0.36993	0.01549
-20	0.3415	0.3659	0.3659	0.4146	0.4634	0.3902	0.39025	0.03685
-22.5	0.2683	0.5366	0.4146	0.439	0.3902	0.3902	0.40648	0.07337
-25	0.2927	0.5122	0.561	0.439	0.4634	0.561	0.47155	0.08516
-27.5	0.4146	0.2683	0.3415	0.4146	0.561	0.3659	0.39432	0.08288
-30	0.4634	0.3415	0.5122	0.561	0.4878	0.6098	0.49595	0.07786
-32.5	0.4634	0.3902	0.439	0.5854	0.561	0.561	0.50000	0.06746

Figure 17. QPSK BER Table

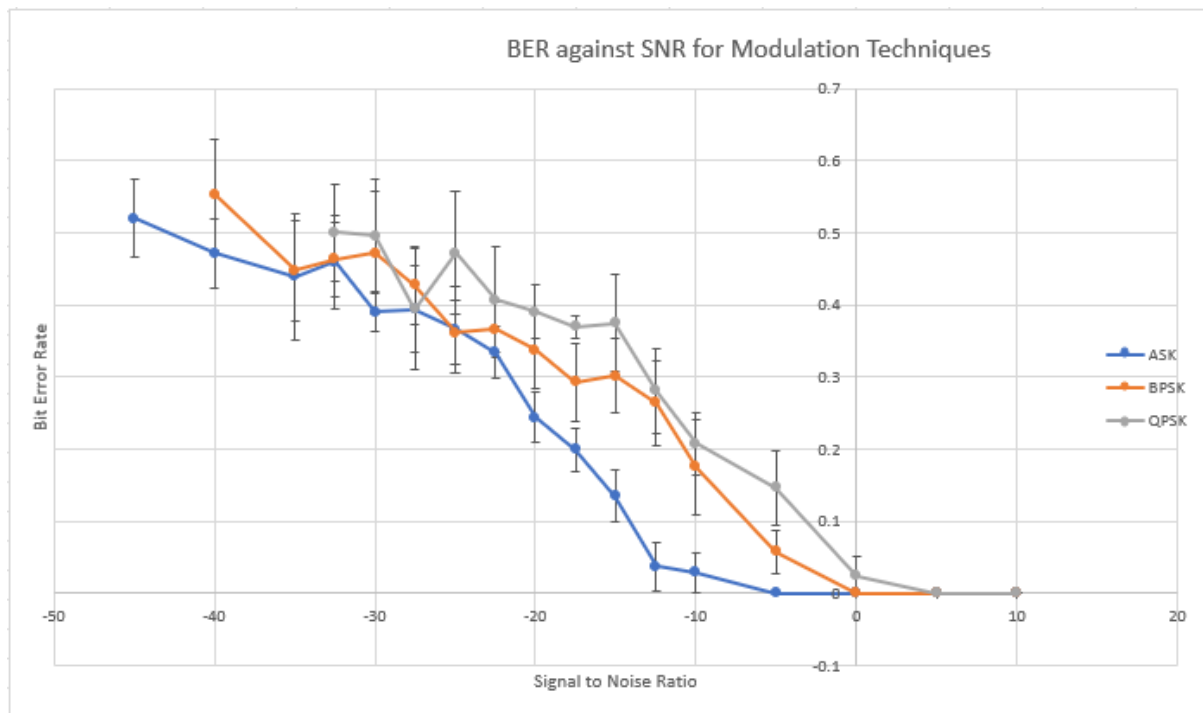


Figure 18. BER against SNR Graph

Figure 17 displays the graph generated from the mean BERs of the three modulation techniques against the SNR. Included are error bars at 1 standard deviation.

Discussion

The graph in figure 17 shows that as the SNR ratio decreases, the BER for all modulators increase. This is to be expected as the noise disrupts the signal.

The data gathered from the simulation disputes the claim in the introduction that ASK is more prone to noise errors than BPSK. It is evident that there is a reasonable difference between the two between 0 SNR and -20 SNR. During this period BPSK consistently has a higher bit error rate than ASK. Whether the cause of this disparity is due to a factor within the simulation or not is unknown.

One thing which lines up with the expectation is the fact that QPSK almost always had a higher BER than the other two. However, I believe that the difference should have been greater. Between this and the previous disparity it may indicate that the BER values for the BPSK simulation are inflated, and its simulation was faulty but there is no definitive evidence indicating this.

Conclusion

In this report, it has been determined that BPSK modulation may be more noise resilient than ASK modulation. Further analysis of the BPSK simulation model and comparison with other models will provide further evidence if the above theory is correct or false.

It has been confirmed that QPSK has the worst noise resilience of the three techniques, however, in a low noise environment the data transmission rate is double that of the other techniques.

References

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