1 Introduction

A transmitter is a device to send message data as radio waves or a form suitable for a particular channel. The transmitter can be divided into several steps as shown in figure 1.

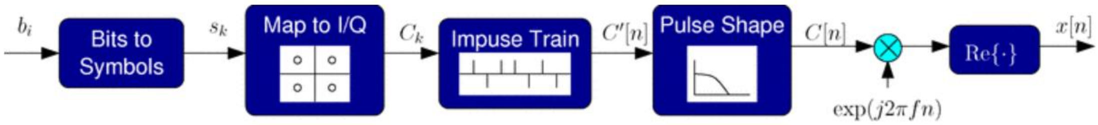
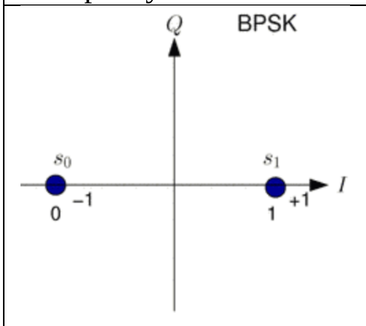
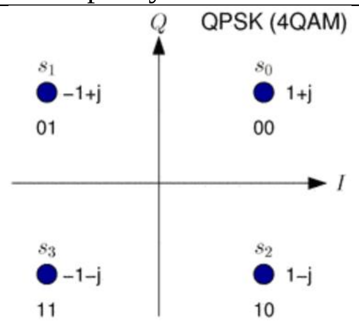
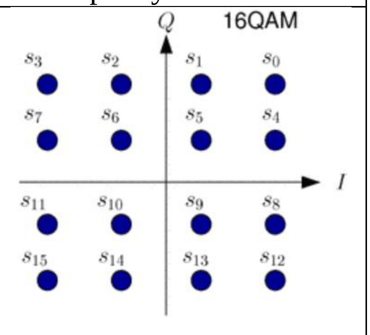


Figure 1: Transmitter steps of a phasor representation

<u>Bits to symbols</u>
A symbol is a waveform that persists for a fixed period of time. A transmitter places symbols at a fixed symbol rate and the receiving device detects the symbol and reconstructs the transmitted data. Each symbol encodes one or several bits. N bits require 2^N symbols represented at figure 1 as s_k which are usually integers.

<u>Map to I/Q</u>
To transmit multiple independent signals in the same transmission medium, frequency division multiplexing is used. Frequency division multiplexing divides separate signal into non- overlapping frequency bands. This is usually done by modulating with a sine wave carrier with a particular frequency. Signals can be sent by using phase and amplitude. Signals in the complex plane can be represented in terms of I/Q components. I (In phase, sinusoid in same frequency) component shows the real part and Q (Quadrature, sinusoid with 90º off phase.) component shows the imaginary part. I/Q mapping maps the symbol (s_k) to complex baseband value C_k in complex plane. There are several ways to map in a complex plan depending on the number of bits per symbol as shown in table 1.

Table 1: I/Q mapping

BPSK	QPSK (4QAM)	16 QAM
1 bit per symbol	2 bits per symbol	4 bits per symbol
		

<u>Pulse Shaping</u>
When C_k is transmitted as rectangular pulses $C'[n]$, a wide sinc-like spectrum is produced. A wider spectrum than the channel's spectrum causes distortion of signals, creating intersymbol interference. To avoid this, pulse shaping is done by filtering the pulse to a desired shape making the signal fit in its frequency band.

Up-conversion

Up conversion is a process that moves the frequency of individual signals up to a different frequency for better transmission. This is done by multiplying by $e^{j2\pi fn}$. In addition, only the real part of the complex signal is taken because the channels only support real signals.

Real Processing

Signals can be represented in complex baseband (phasor) representation but also in real value quantities. This is more efficient to perform DSP operation. This is shown in figure 2.

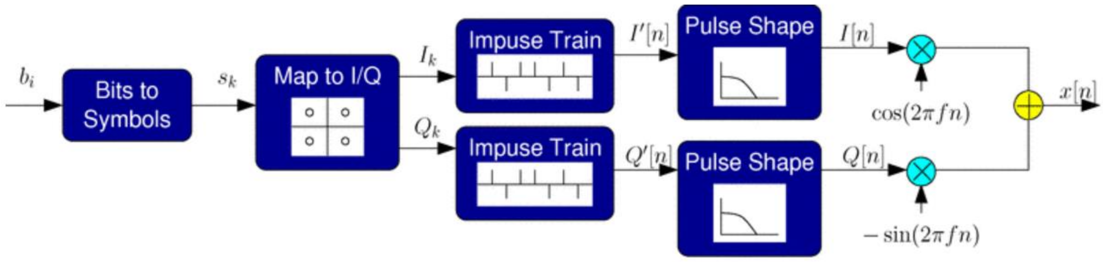


Figure 2: transmitter steps of real value representation

2 Execution/Evaluation

Input

The input stream gets the data from a file named 'rand.mat' with bit period 10 samples and output width 1. 'rand.mat' files contains 1000 random bits.

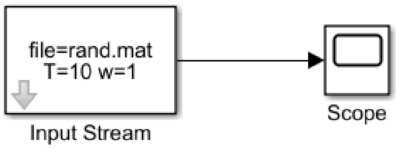


Figure 3: Simulink setup 1

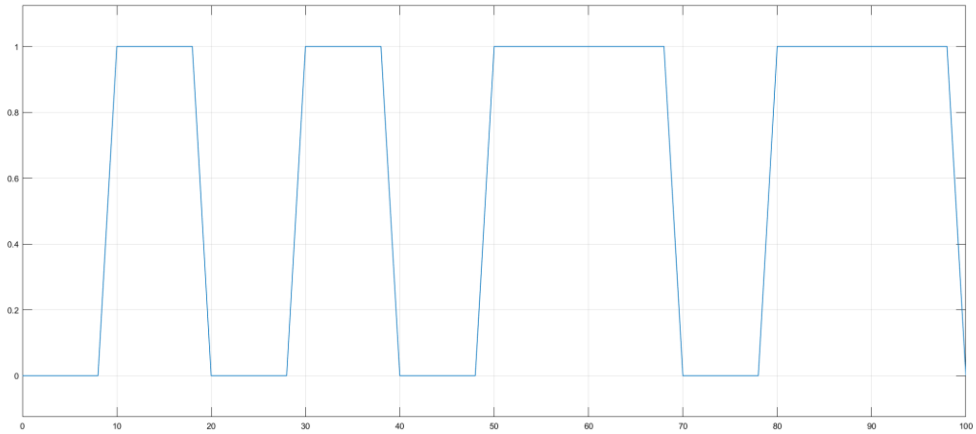


Figure 4: Output of setup 1

BPSK (Binary Phase Shift Keying)

Binary bits (0, 1) map to I values of (-1, 1). Symbol mapper takes a vector of N bits input to 0 to $2^N - 1$(LSB first). The lookup table contains a vector of output that needs to be mapped by each symbol. Lookup table is changed to [-1 1]: 0 is mapped to -1 and 1 is mapped to 1. Which gives a result of the graph with the same shape but with range -1 to 1. (Figure 6)

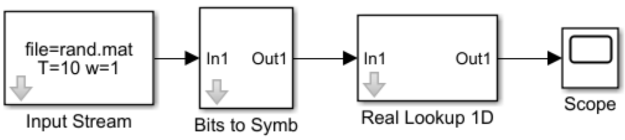


Figure 5: Simulink setup 2

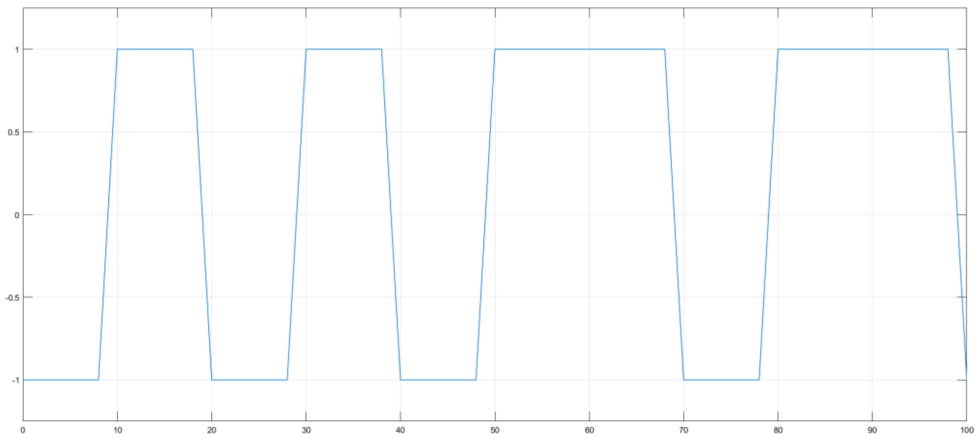


Figure 6: Output of setup 2

Rectangular pulses and PSD (Power spectral density)

PSD block gives a FFT (Fast Fourier Transform) of input stream and averages it to show the spectrum of the signal. The length of buffer (size of buffer) is set to 128; Number of points for FFT to 512; plot after how many points to 128, this controls degree of power averaging.

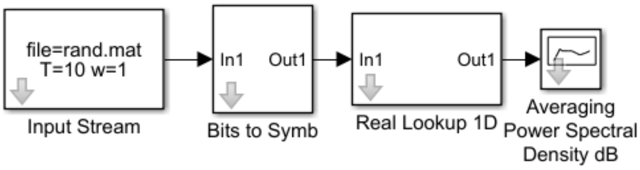


Figure 7: Simulink setup 3

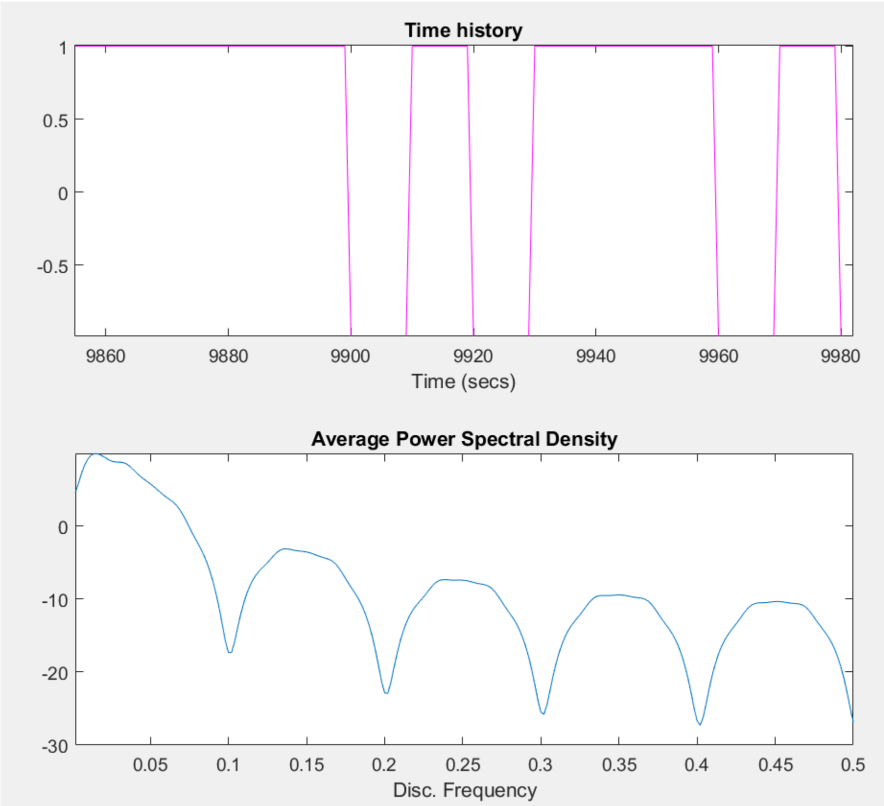


Figure 8: Output of setup 3

The setup has a discrete symbol frequency of 0.1. If the PSD plot falls sharper, it indicates higher efficiency. Therefore figure 8 is not efficient. The plot would be more efficient if the sampling time is narrower.

Spectrally-Efficient Pulse Shaping

To improve PSD, pulse shaping method is used. Pulse train of period 10 and RC (Raised Cosine) filter with roll of $\beta = 0.5$, filter length 128, symbol period of 10 is used. The change of RC filter according to roll of factor (β) is shown in figure 9. The result is shown in figure 11, which shows higher efficiency compared to figure 8.

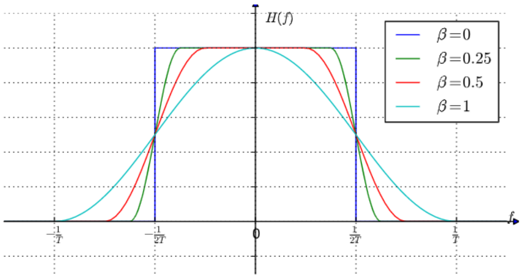


Figure 9: Raised cosine and beta $\beta = 1$ is a pure cosine

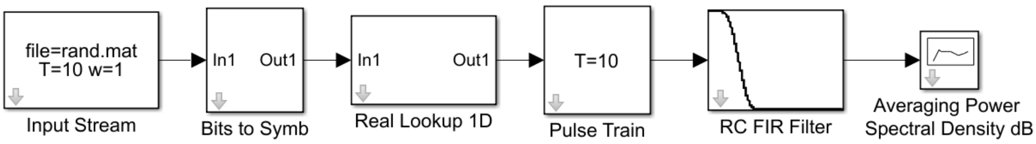


Figure 10: Simulink setup 4

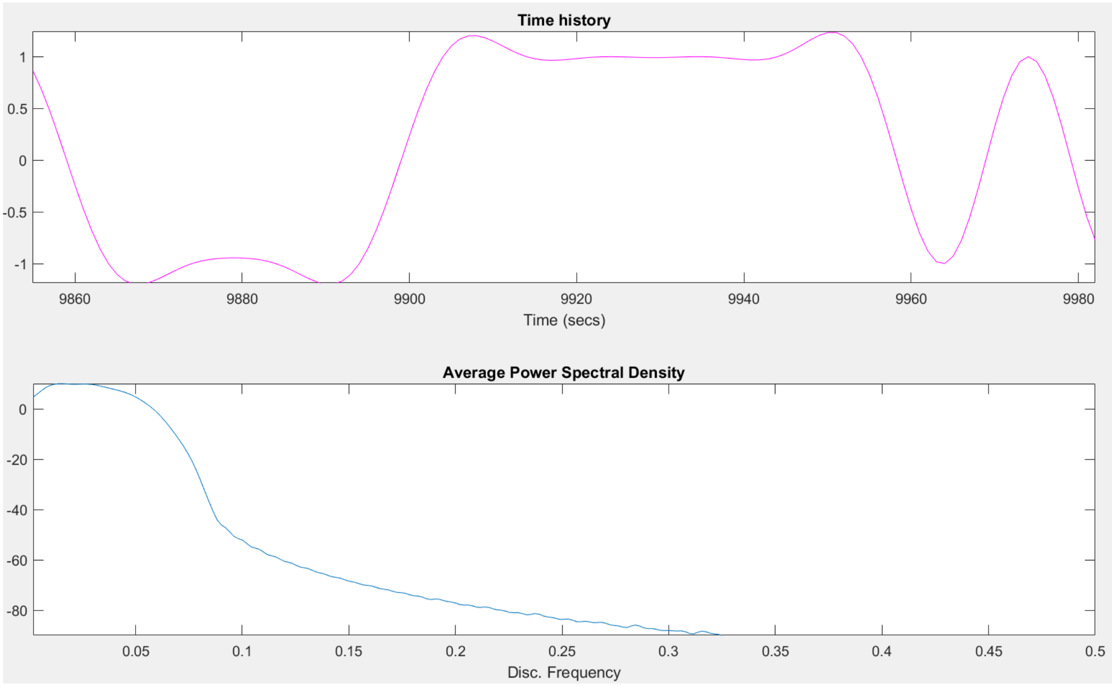


Figure 11 Output of setup 4

Decoding Pulses

To compare the pulses, setup 5 is used. Because the filter has an extra delay, a delay block is added for better comparison. The multiplexer is used to show the plot of two signals on the same plot. The sampler block is set to sample the signal at symbol period. RC filter minimizes the intersymbol interference (ISI) property. If it is sampled at an optimal form, it gives no ISI because the waveform goes to 0 at an integer multiple of the symbol period. Therefore at the zero points, multiple pulses doesn't interfere. Thus for RC filter pulses, the optimal sample points need to be sampled. Which is a big difference comparing to rectangular pulses that can be sampled anywhere through the symbol period. In figure 13, it is shown that the output of the decoded pulse showed an equivalent result to the actual pulse.

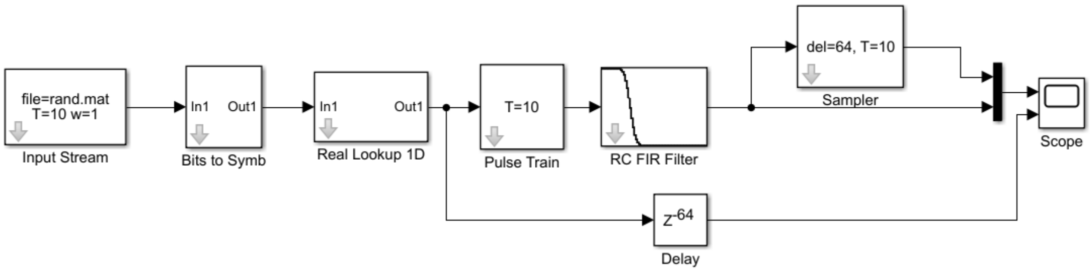


Figure 12: Simulink setup 5

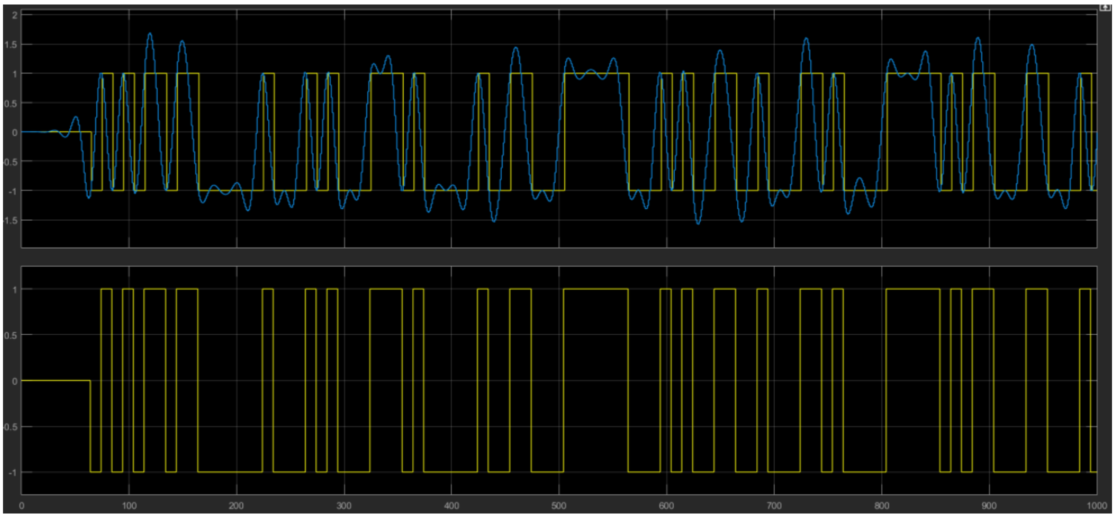


Figure 13: Output of setup 5

Up-Conversion

The signal is up converted to a higher frequency by multiplying sine wave of frequency $2 \cdot \pi \cdot 0.1$ rad/sample. In figure 15, the baseband signal (yellow), up converted signal (red), and unmodulated sine wave (blue) is shown. The BPSK signal and phase is either in phase with the carrier or 180 degrees out of phase.

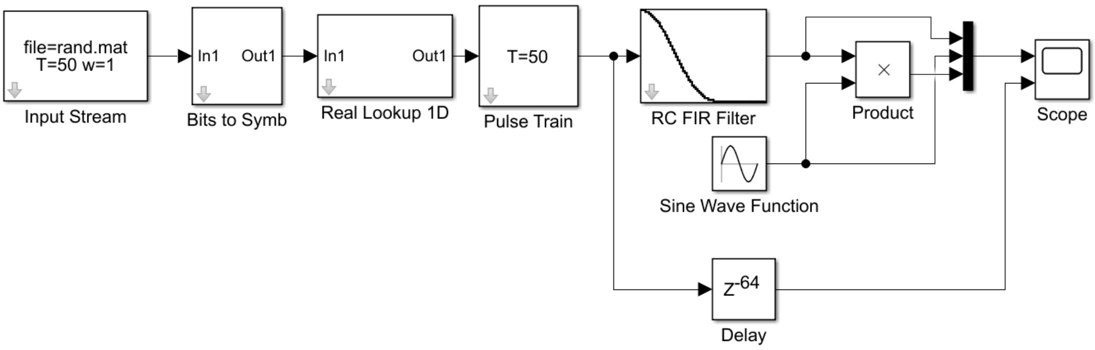


Figure 14: Simulink setup 6

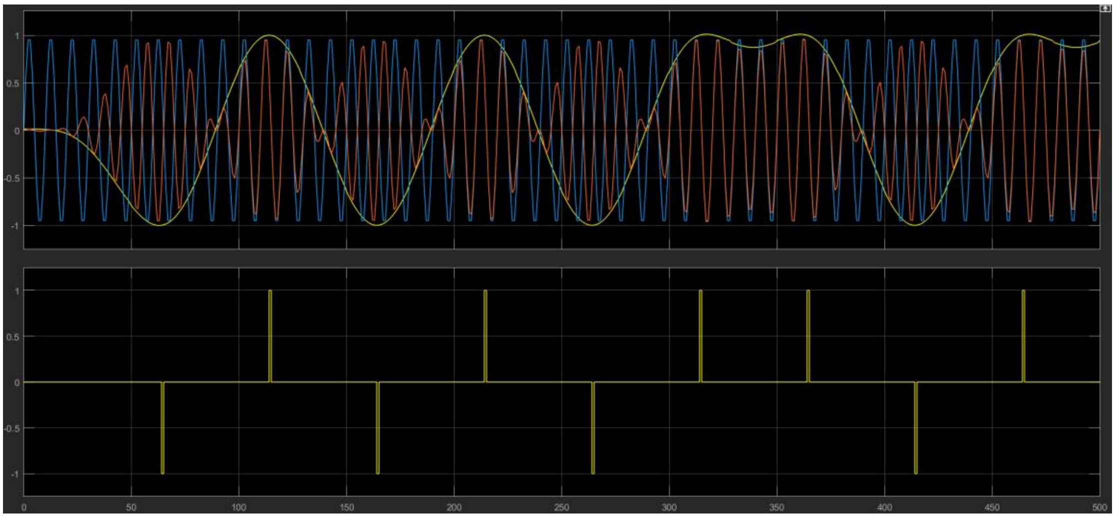


Figure 15: Output of setup 6

Lab Write up

<u>(1) Explain in one or two paragraphs what you learned about communications systems that you didn't know before.</u>

The general insight of how communication systems work and different steps of transmission and reception processes was learned. In the experiment, the transmission side in depth- mainly modulation part since it was focused on 'uncoded' transmission, which considers the encoding part/block as a trivial pass through was learned. Input signals were also assumed to be digital so that A/D conversion in not taken into consideration in the experiment.

To be more detailed, the different steps of the modulation part of a digital signal transmission was studied. At first, bits are mapped to symbols (s_k). Then, to support problems like frequency division multiplexing, constellation mapping is used. The latter maps the s_k's to the complex plane and the number of points in the arrival set depends on the symbols' number of bits. The next step is pulse shaping, which is discussed in (3). Subsequently, the resulting complex baseband waveform are shifted to a higher frequency since signals are not transmitted at baseband. The last step is real processing, which is more efficient to perform DSP operations. Phasor domain representation is more compact on the mathematical level, but it is harder and less effective on the computational level.

<u>(2) Show a picture of your final QPSK transmitter. Explain briefly what the different blocks are for. Explain how you checked that it was working correctly. A plot of the output showing important signals would be very helpful.</u>

QPSK Transmitter

<u>Input stream</u> has an input signal with 'rand.mat' file with period 50 and output width of 2. The input is converted to digital by *<u>bits to symbol</u>* and because it is QPSK, the *<u>look up</u>* is changed to [1 j -1 -j]. Which encodes 00 to 1, 01 to j 10 to -1 and 11 to –j. (for simplicity, it is chosen as [1 j -1 –j] rather than [1+j -1+j 1-j -1-j]). *<u>Complex to Real imaginary</u>* block splits the complex signal to real and imaginary parts. The *<u>pulse train</u>* does pulse shaping and *<u>RC filter</u>* avoids ISI and puts the signal to baseband giving delay of 64 samples. *<u>Sine wave</u>* function is *<u>multiplied</u>* for the up conversion of the signal. The sine wave function has a phase of $-\frac{\pi}{2}$ giving cosine function. (Cosine carrier for real part of the function (I)) *<u>Delay</u>* block is set to compensate for the filter.

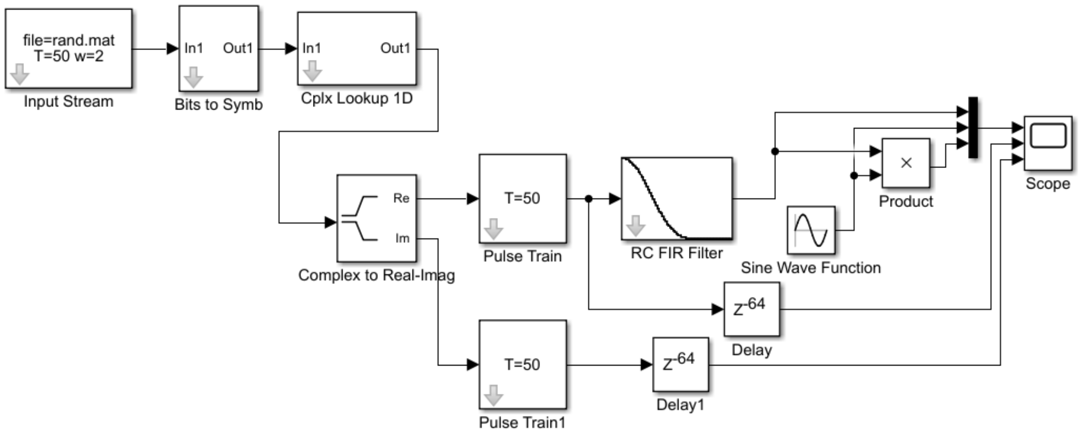


Figure 16: Simulink setup of QPSK

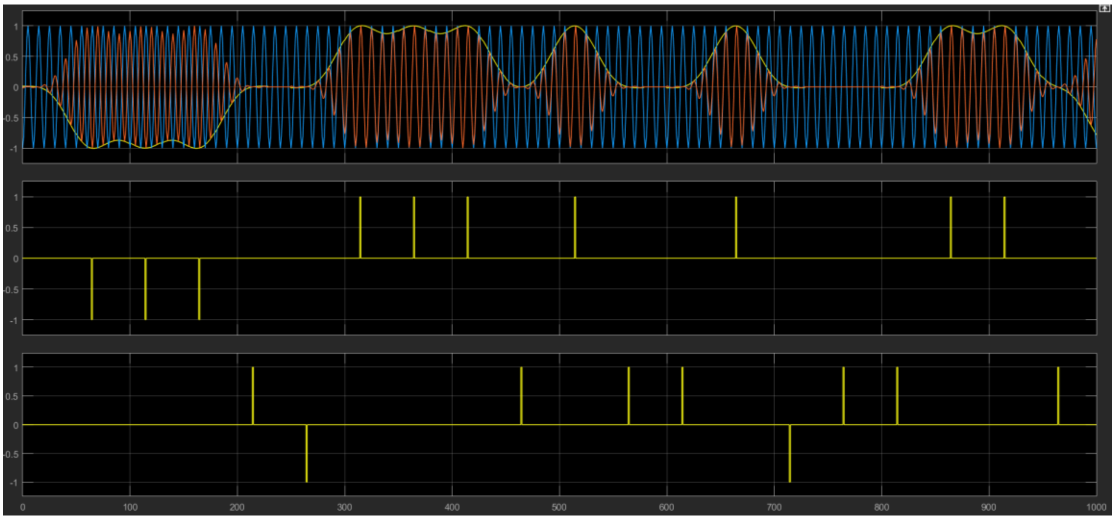


Figure 17: Simulink diagram of QPSK

Upper figure: Up converted signal (red)
Cosine carrier signal (blue)
Baseband signal (yellow)
Middle figure: Real part of pulse train
Bottom figure: Imaginary part of pulse train.
The pulses in the middle (real part of the pulse train) follows the peaks of the baseband signal in the first graph. Therefore the QPSK transmitter is working correctly.

(3) Explain why we do pulse-shaping in communications systems, rather than just sending rectangular pulses.

Transmitting rectangular pulses without pulse shaping results in a sinc-like spectrum whose bandwidth is larger than our band-limited transmission channel, which will cause a distortion shown as intersymbol interference (ISI). For wireless applications with limited bandwidth, sinc spectrum is not preferred. Thus the need of pulse-shaping aims to limit the transmission's effective bandwidth. This can be implemented by the use of filters that satisfy certain criterions, commonly the Nyquist ISI criterion. One of the mainly used filters are the boxcar/sinc filter, the raised cosine filter and the Gaussian filter.

(4) Tell why synchronization (e.g. sampling the received signal at the right place) is critical in a communications system that uses pulse shaping.

Synchronization is the most widely used method to recover the sampled functions at the receiver side. Some phase error can cause high intersymbol interference. Therefore synchronization is critical. Some conditions are necessary for synchronization to be maintained; for instance, convenient propagation conditions. What makes synchronization-based receivers critical and extremely advantageous over non-coherent ones is their noise performance and bandwidth efficiency.

(5) Describe any difficulties you experienced in getting your design to work and how you fixed these problems. I will be really surprised if everything worked perfectly!

Most of the problems faced were linked to the first exposure to Simulink and relating the results obtained to what should be obtained in theory. These problems were fixed by simply changing some of the given numbers to see what effect it will have on the final result: shape, amplitude and delay to name a few. The simulations are improved by making them less ‘complicated’.

The main problem encountered was in the last problem where the final result looked a bit weird compared to the desired outcome. The problem occurred because we were not plotting the real part of the output, instead plotting a sum of both the real and (j*)imaginary parts-the whole complex signal. However, the problem was quickly detected by observing that the signal obtained was the sum of the real and $\frac{\pi}{2}$ phase shifted imaginary signal. Necessary changes were made afterwards and expected results were achieved.

3 Conclusion

The operation of transmitter Simulink was examined throughout the experiment; from A/D conversion to modulation and transmission. The functioning of an ‘uncoded’ transmission system-transmission side was studied. The results obtained mached with the expected theoretical results to a high degree. The errors expected is perceived in the receiver side of the transmission where the absence of a synchronization component such as a PLL will result in distortion due to a non-efficient bandwidth and a bad signal to noise ratio. The simulation showed how the BPSK and QPSK works in transmitter systems.

4 References

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