Mid - Term report

Implementation and testing of digital modulation and demodulation schemes for underwater acoustic modems

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Abstract

Aim of this project is to design, implement and test a robust communication system for underwater modems. To design the communication system we will choose source coding technique, channel coding technique and modulation scheme suitable for underwater channel. For implementing the communication system, we will program two stm32f746ng boards to perform the functions of transmitter and receiver. In addition, we will be using transducers at the end of transmitter and beginning of receiver for conversion between electrical signal and audio signal. To test the communication system, we will use model of propagation of audio signal in underwater medium. Finally, to gauge the performance, we will measure the bit error rate and throughput of the communication system. Lastly, we would want to extend our work to underwater networks

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1 Objectives

2 Applications

Lower data rate modems for scuba divers higher rate for under water vehicles.

3 Simulations

3.1 Introduction

The under water channel is a pass-band channel at 25KHz-35KHz for acoustics communication. The rate at which data is generated in 80bps. Modulation is used to center the energy of the signal to center around 27KHz so that there is less loss in the communication link. We tried 4-PSK and BPSK modulation schemes and checked the BER for different underwater scenarios. The range in all of the cases discussed below is between 100-150m and depth of Tx and Rx is 60m and 2m respectively.

3.2 Noise Simulation

The under water noise doesn't fallow AWGN noise as in typical communication systems. The noise in underwater channels is discussed by Yasin and his team in the paper [1]. As mentioned in the paper we generated noise using the below equations.

$$Nt(f) = 17 - 30logf$$

$$Ns(f) = 40 + 20(s - 5) + 26logf - 60log(f + 0.03$$

$$Nw(f) = 50 + 7.5w^{1/2} + 20logf - 40(logf + 0.4)$$

$$Nth(f) = -15 + 20logf$$

$$N = Nt + Ns + Nw + Nth$$

$$R(t) = T(t) + N(t)$$

Here N(t) is the ifft of N(f) and R(t) is received signal and T(t) is the transmitted signal.

$$F\ in\ kHz$$

$$s\ is\ a\ shipping\ factor\ usually\ ranges\ from\ 0\ to\ 1$$

Nt, Ns, Nw, Nth are noises due to turbulance, shipping, wind, and surface movment. IN the paper the discussion is only on the PSD of the noise, to generate noise we need to do an inverse fourier transform. From PSD we will be able to get the amplitude of the noise and for the phase a random generator is used to generate phase between 0 to 360 degrees and ifft is done. The noise added signals can be seen in Figure-1 and Figure-2.

3.3 Effect of Reflected Signals on the received data

The implementation of modulator and de-modulator is briefly explained from section5.4 to section5.8. Considering those techniques the effect of the reflected signals is derived. The reflected signals can be considered as two types

- Immediate Reflection arrival at bitPeriod/10
- Delayed Reflection arrival at bitPeriod/2

3.3.1 Immediate Reflection

The received signal can be shown as in the figure-3

$$For\ ease\ of\ caluclations\ we\ assumed\ that\ the\ transmitted\ signal\ is\ sumof\ two\ signals$$

$$Also\ amplitude\ is\ assumed\ to\ be\ same\ to\ concentrate\ on\ phase\ change\ effect$$

$$T(t) = cos(\theta) + cos(\theta + \phi) + j * (sin(\theta) + sin(\theta + \phi))$$

$$T(t) = 2cos(\theta + \phi/2)cos(\phi/2) + 2jsin(\theta + \phi/2)cos(\phi)$$

$$T(t) = 2cos(\phi/2)(cos(\theta + \phi/2) + jsin(\theta + \phi/2)$$

$$T(t) = 2cos(\phi/2)e^{\theta+\phi/2}$$

From the above equations we get to know that the symbols phases will be shifted and amplitude changes. So the data points will be rotated in the constellation diagrams by a certain phase and get amplitude changed, this can be observed in the figure4.

3.3.2 Delayed Reflection

If there is a delayed reflection then the effect of previous bits also come into the picture and giving different phase shifts based on the previous bits, in this case the data points rotate and also diverges by some phase, this can also be proved mathematically by usind the same steps used for immediate reflection. The effect of Delayed reflections can be seen in figure-5

3.4 Channel Simulations

Oalib's bellhop model is used for ray tracing and getting the channel's impulse response. If H(t) is the channels impulse response then the received signal R(t) is given by

$$R(t) = T(t) * H(t)$$

From our observations the channel can be mainly divided into three

- Shallow water - Many Reflections
- Deep water - Less Reflections
- No line of site

3.4.1 Shallow Water

In this case there will be many reflections from the bottom and surface of the ocean. The reflected signals are comparable to the received direct signal and causes intern symbol interference. And are spread across multiple bit periods.
The effect of the reflected signals can be seen by plotting the constellation diagram of a demodulated signal, the same is shown in Figure7.

3.4.2 Deep water

In this the reflections from the bottom of the oceans are none and only reflections are from the surface, these reflections are also arrive immediately after the LOS signal. So the data points are rotated by a fixed phase on the constellation diagram. The same can be observed in the figure-9. The channel model used can be seen in the figure-8

3.4.3 No Line of Site

Here the original signals are reflected signals it self, in this case the data points may rotate depending on number of reflected signals arriving. Here the margin for noise is low, so noise may cause high BER's, by using high Tx amplification we can increase the margin for noise and achieve giid BER. A typical scenario of no LOS communication is shown in the figure-11. The channel model used can be seen in the figure-10

3.5 Modulation and Demodulation using 4-PSK

3.5.1 Introduction

Initially we implemented 4-PSK schema with higher bit rates, but due to many reflected signals in the underwater channel we were not able to achieve good BER, so we reduced the bit rate to 80bps and were able to get better results compared to higher bit rates. We simulated the model for different underwater scenarios and tabulated the average BER in each case.

3.5.2 Shallow waters

The depth of the ocean is kept 150m and the range of Tx is varied from 10 to 300m. The average BER achieved in this case was 0.176, which is very high and communication is not possible. The data points can be seen in the figure-12.

3.5.3 Deep Waters

The depth of the ocean is 1500m and the range of Tx is varied from 300 to 2000m. Since the reflections are less dominant in the Deep waters scenario we extended the range of Tx upto 2000m and calculated the BER's for different scenarios. The BER achieved is 0.03, which is not a reliable communication link. The data points can be seen in the figure-13

3.5.4 No LOS Communication

In no LOS site scenario the received signals are highly effected by the noise in the channel and the signals were not able to be demodulated. So 4-PSK is not suitable for no LOS communication.

3.5.5 Optimization

As seen in the figures-13 and 12, the data points in the top row are rotated due to the reflected signals. But the data points are grouped at one place, so we introduced one byte of training data to know the locations of the symbols in the constellation diagram. The position of training data is at center of the data packet as shown in figure-16. Using the new referance points obtained from the training byte we were able to demodulate the signals with less BER. The decision boundary before and after the training is shown in the figure-14. With the help of the training byte we were able to overcome the effect of channel modulation, but the average BER after training is 0.002 for shallow water cases and 0.00031 for deep water cases. This high BER is due to the noise in the under water channels. So to improve the BER we need to use high amplification at transmitters, which makes the circuit to consume high power.

3.6 Modulation and Demodulation using BPSK

3.6.1 Introduction

We implemented BPSK for a data rate of 80bps. The average BER is calculated for different under water scenarios. The average BER obtained using BPSK is very good compared to the results of 4-PSK.

3.6.2 Shallow waters

The depth of the ocean is kept 150m and the range of Tx is varied from 10 to 300m. The average BER achieved in this case was 0.0214375, which is very high and communication is not possible. The data points can be seen in the figure-12.

3.7 Conclusion

4 Hardware Used

STM32F746-DISCO is used as digital signal processor which has a cortexM7 processor in it. With ADC and DAC between 0 to 3.3V. There are also many timers for configuring the rate at which ADC or DAC is done.

5 Implementation on the Board

5.1 Introduction

We implemented a pipeline which can transmit and receive data at a rate of 80bps using Binary phase shift keying(BPSK). The 80bps is enough for the underwater modems because we can transmit 5 readings of sensors in a second with half word size. The digital modems is used for transmitting information such as oxygen percentage available to diver or pressure in divers suits etc(which doesn't require high data capture rates to extract useful information). The digital signal processing code is in such a way that it can be extended to m-PSK with equalization or other BER reduction techniques.

5.2 Data Acquisition

Initially we developed a keyboard which can be used to input data to the processor. But underwater conditions doesn't allow users to type data and transmit. Therefore modems main goal is to obtain data from the wearable sensors on the diver and transmit the data.To simulate this type of conditions we used an Arduino board which randomly generated data and it is collected by the processor and further processing is done.

5.3 Data Frame Format

64bytes of data is transmitted at a time in which 1byte is used for training data. The training data can be used for better demodulation as discussed in the section Equalization.

5.4 Line Coding

As we discussed in the section3.7 We chose BPSK to be our modulation technique.Therefore NRZ line coding owas used on the data generating 80 complex codes per second. These are further up-sampled. The In-phase part of the signal will be 1 for 1 and -1 for 0, Quadrature phase part of the signal is zero. The NRZ codes plotted on an imaginary axis would like below.

5.5 Up Sampling

Since the frequency range of the transmitting signal is 25-35KHz we kept sampling rate at 100KHz which satisfies the nyquist criteria. So each sample is replicated 100000/80(=1250) times to get a sampling rate of 100KHz.

5.6 Modulation

The up Sampled signal is multiplied with

$$e^{2\pi ft}$$

The real part corresponds to the signal that we transmit. Therefore the transmitted signal can be given as

$$T(t) = I(t) * cos(2\pi ft) + Q(t) * sin(2\pi ft)$$

Where I(t) + j*Q(T) is the complex envelope of the signal.

5.7 Transmitting

The output of the multiplier is connected to a DAC which runs at a frequency of 100KHz using timer trigger events. The DAC of the board used only supports conversions from 0 to 3.3V so the data is shifted by 1 to get a range between 0 to 3.3V the signal then can be given to a hydrophone for transmission.

5.8 Demodulation

The demodulation is done by coherent detection. Received signal is multiplied by cos and sin waves and then are integrated to extract the complex envelope of the signal.

$$R(t) = T(t) * cos(2\pi ft) - jT(t) * sin(2\pi ft)$$

$$R(t) = I(t)*cos^2(2\pi ft)+I(t)cos(2\pi ft)sin(2\pi ft)-Q(t)*sin^2(2\pi ft)-Q(t)cos(2\pi ft)sin(2\pi ft)$$

$$R(t) = I(t)+I(t)cos(2*2\pi ft)+I(t)sin(2*2\pi ft)/2+jQ(t)+jQ(t)sin(2*2\pi ft)-Q(t)sin(2*2\pi ft)/2$$

On integrating the R(t) over a time period of T=1/f all the cos and sin terms will become zero leaving behind the complex envelope. Low pass filtering also can be used instead of integration.

$$\int_0^T R(t)\,dt = I(t) + jQ(t)$$

The output of the integral can be used for getting the data. The whole demodulation pipeline is shown in the below figure. The down-conversion from 100000bits to 80bits is done by integration. The output can be further processed for better BER.

6 Testing

The hardware testing is not done in the underwater environment, but the modulation and demodulation is done in the memory of the processor without transmitting and tested.

7 Future Scope

In this paper only PSK modulation techniques are explored with out any complex equalization and error detection techniques. In future other modulation techniques can be explored and complex equalization and error detection techniques can be used for achieving higher data rates. In case of higher data rates the applications of the modems can be extended to underwater autonomous vehicles.

References

[1] Sha'ameri, A.Z. Al-Aboosi, Yasin Khamis, Nor. (2014). Underwater Acoustic Noise Characteristics Of Shallow Water In Tropical Seas. 10.1109/ICCCE.2014.34.

List of Figures

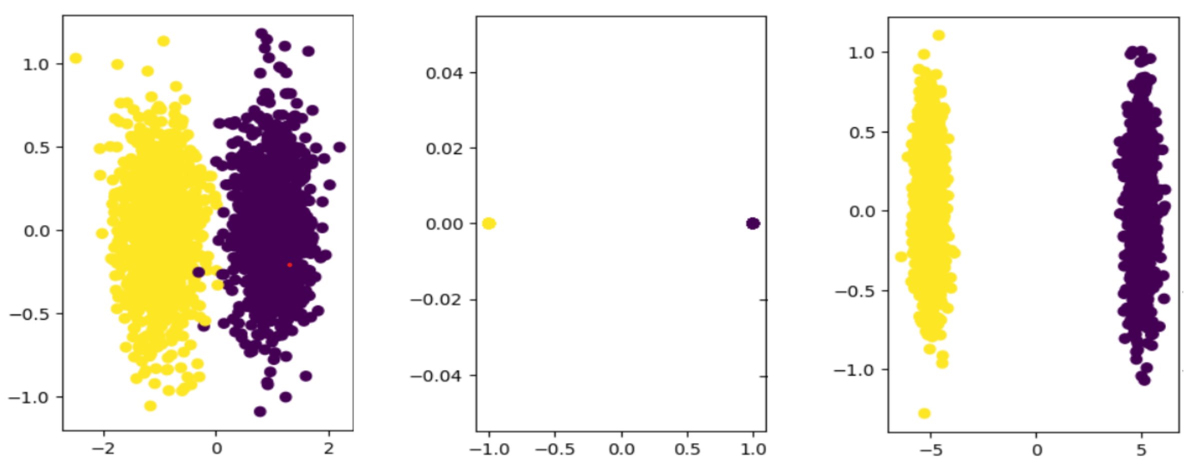


Figure 1: Noise added BPSK signals with 0dB amplification on left and 25dB amplification on right and no noise signal in the middle

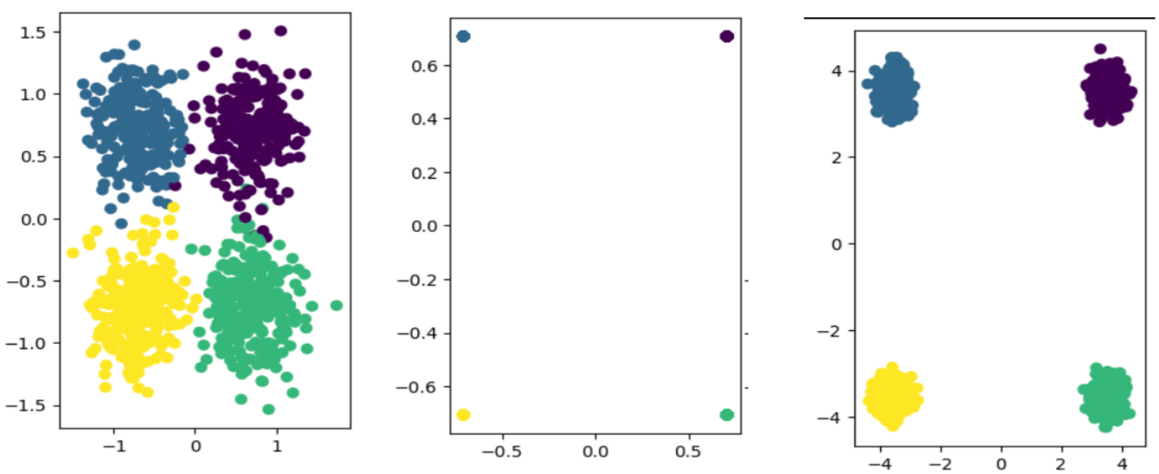


Figure 2: Noise added 4-PSK signals with 0dB amplification on left and 25dB amplification on right and no noise signal in the middle

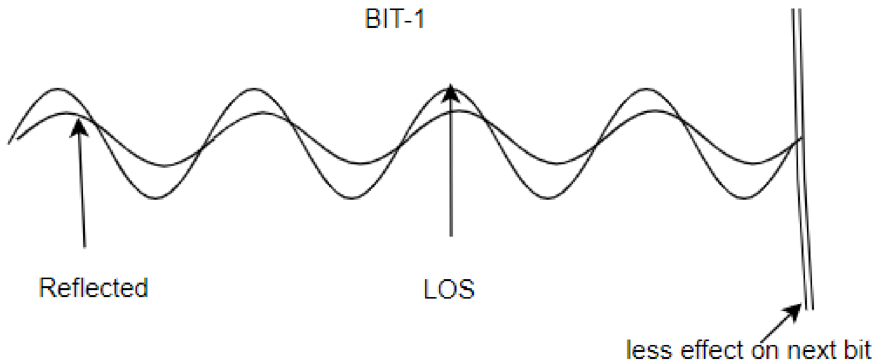


Figure 3: Immediate Reflection

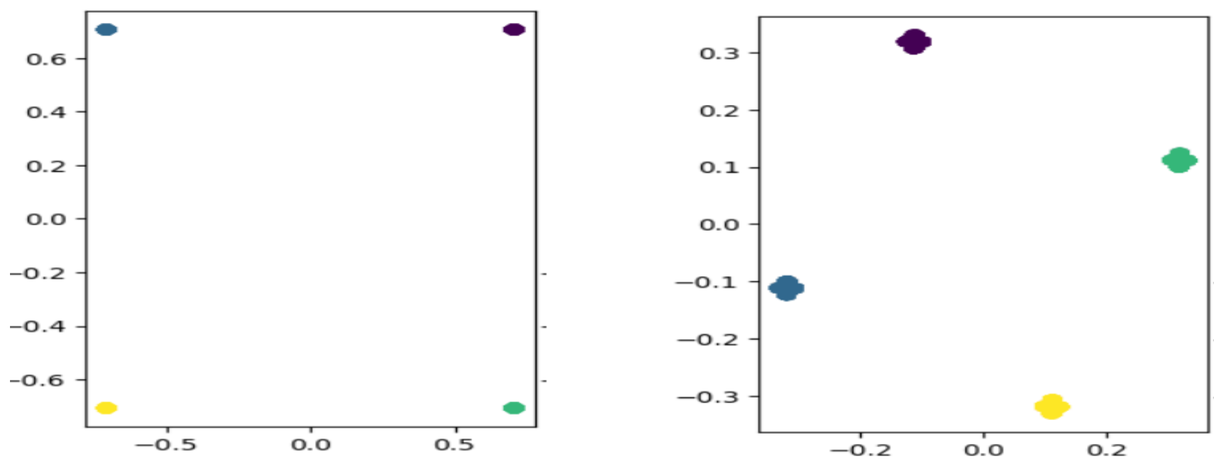


Figure 4: Effect of immediate reflection

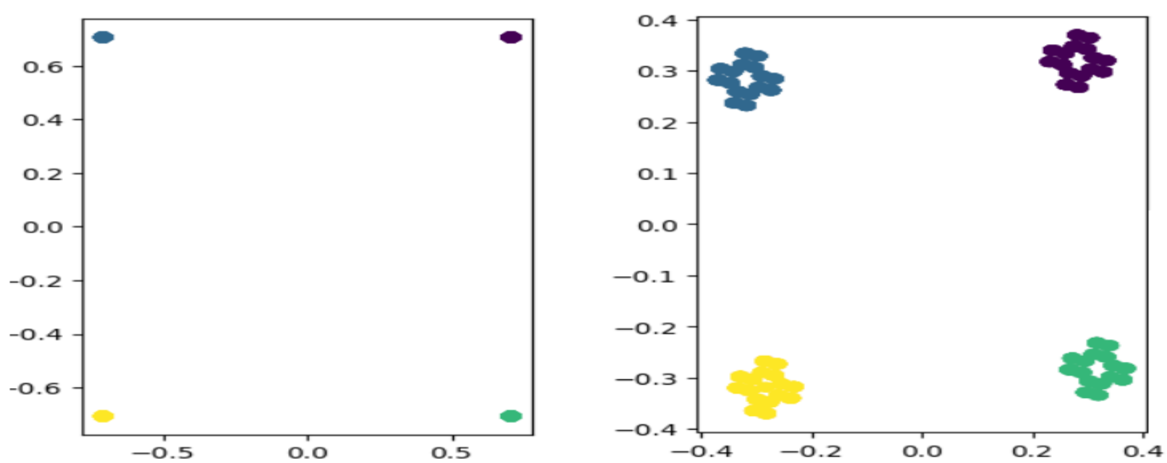


Figure 5: Effect of Delayed reflection

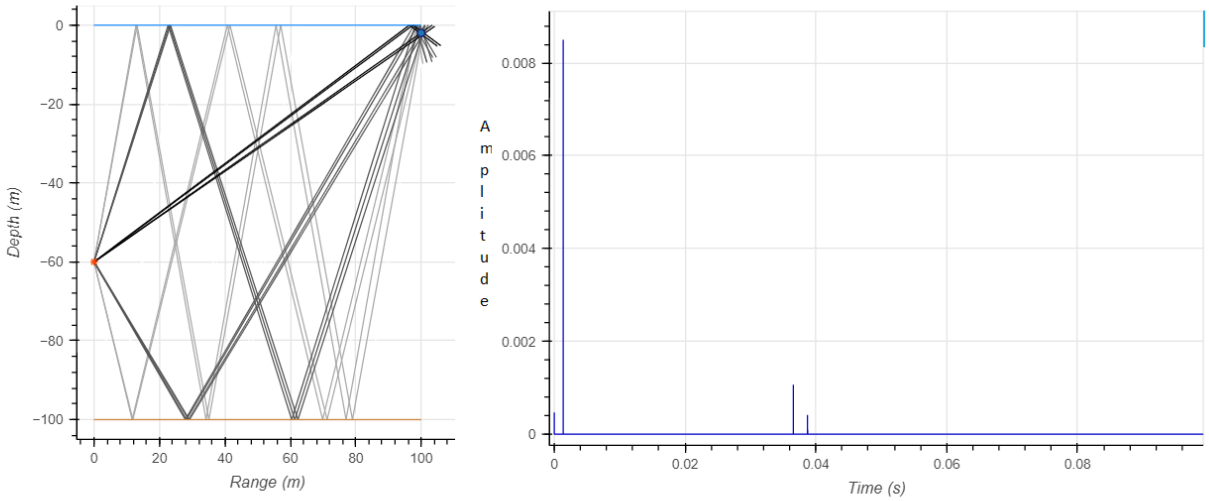


Figure 6: Channel model and it's impulse response on right

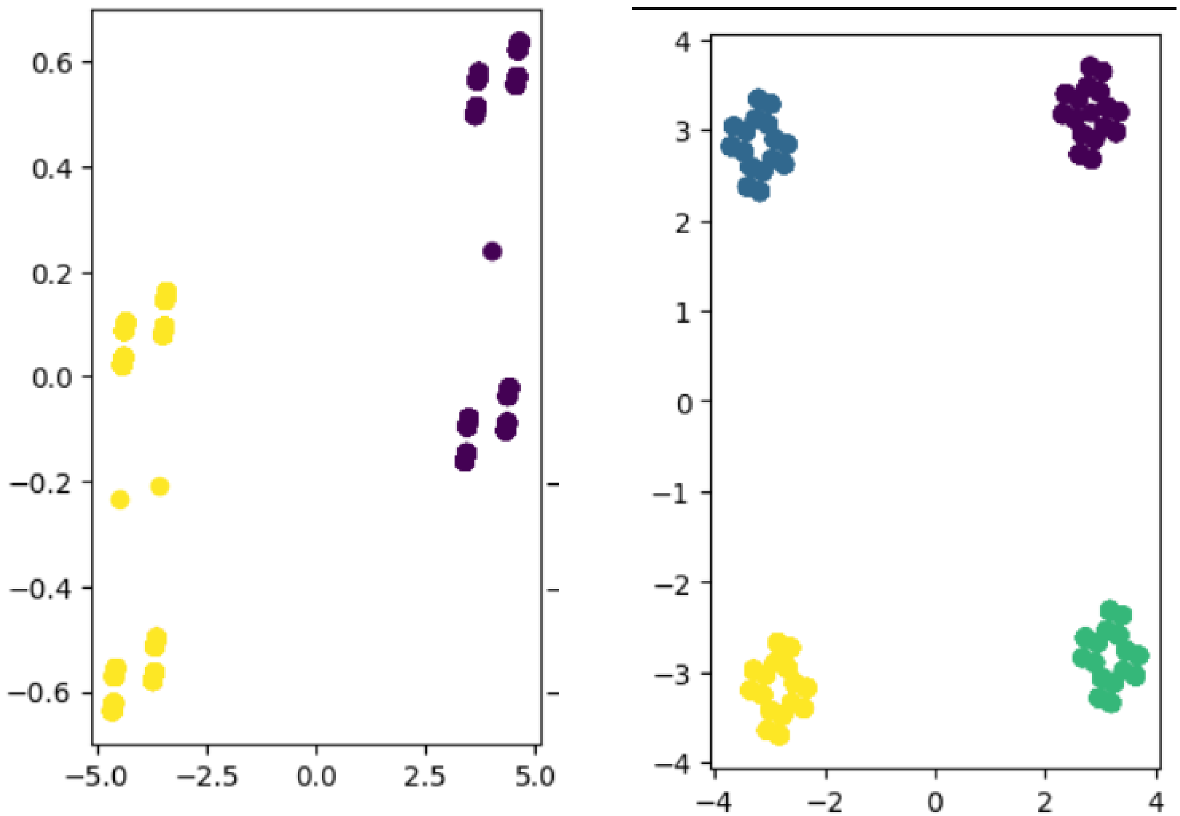
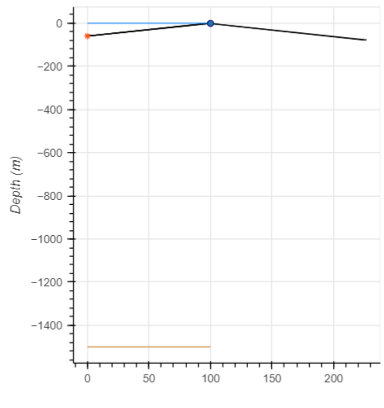


Figure 7: Effect on signal due to shallow water left is a BPSK signal and right is 4-PSK



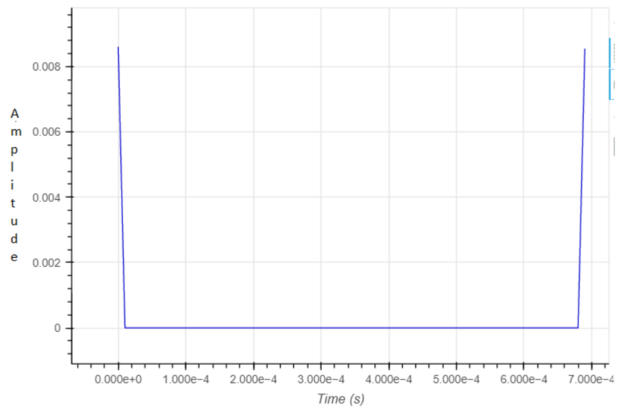


Figure 8: Deep water Channel model

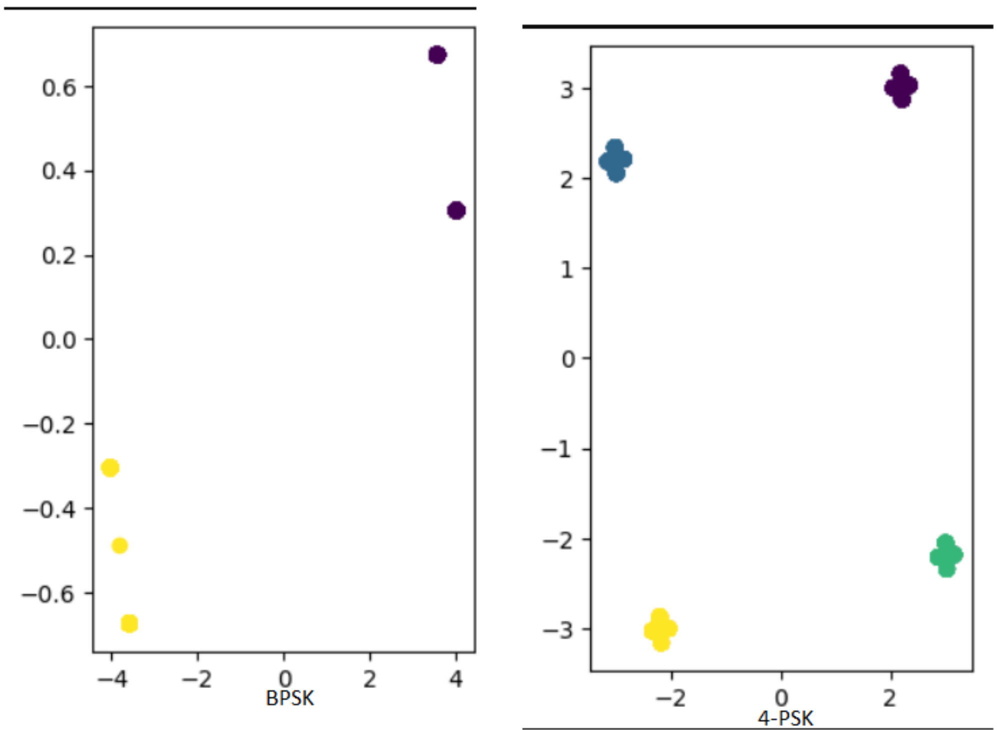


Figure 9: Effect on signal due to deep water left is a BPSK signal and right is 4-PSK

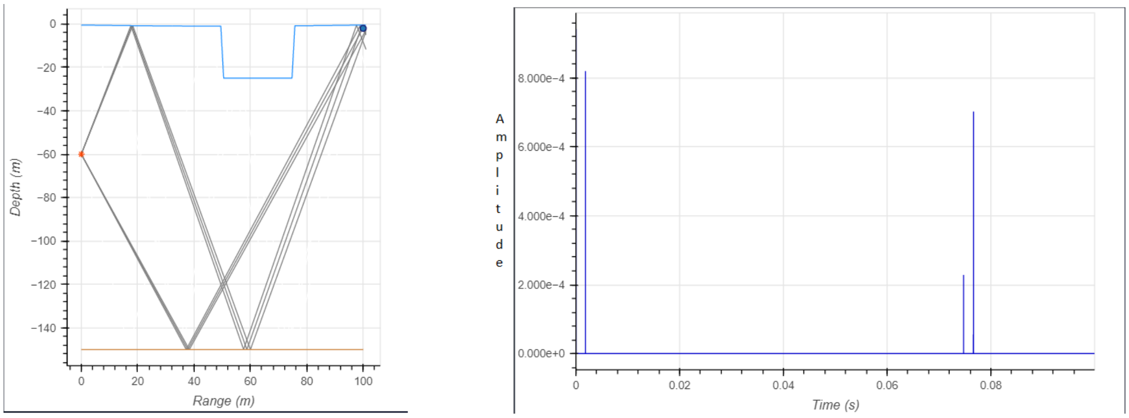


Figure 10: No LOS channel model

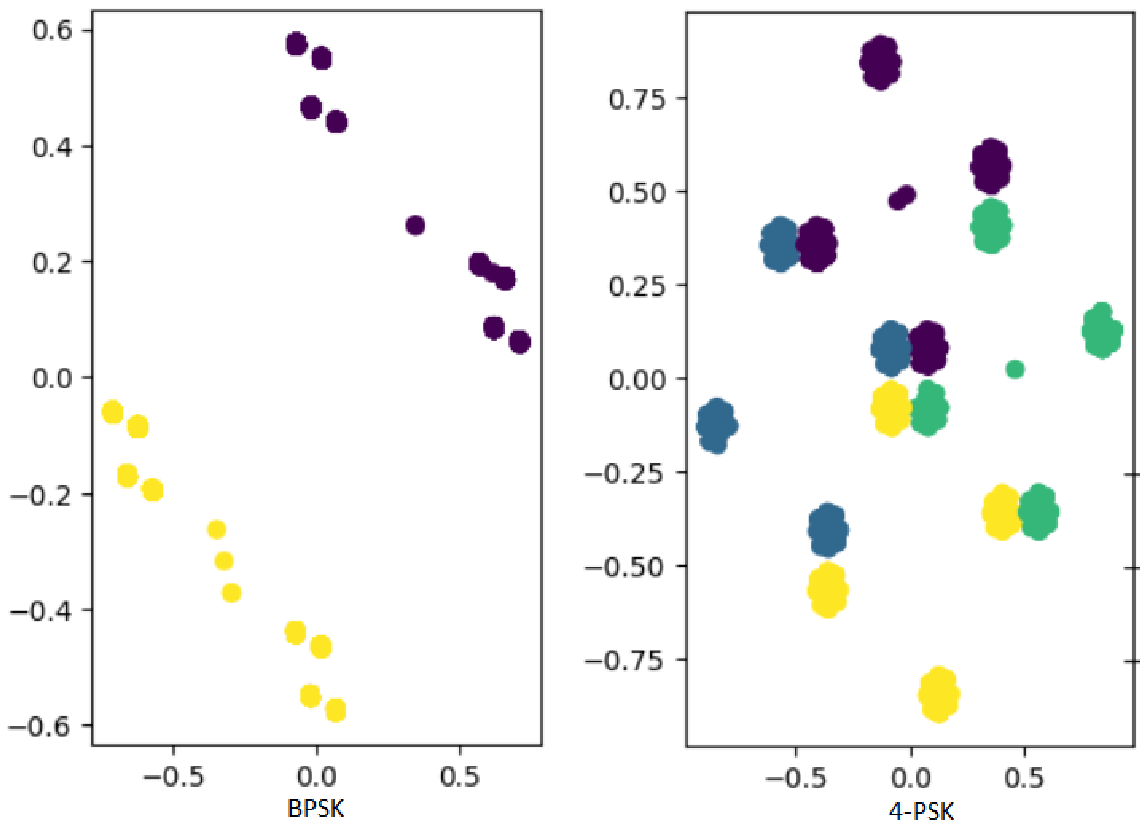


Figure 11: Effect on signal due to lack of LOS left is a BPSK signal and right is 4-PSK

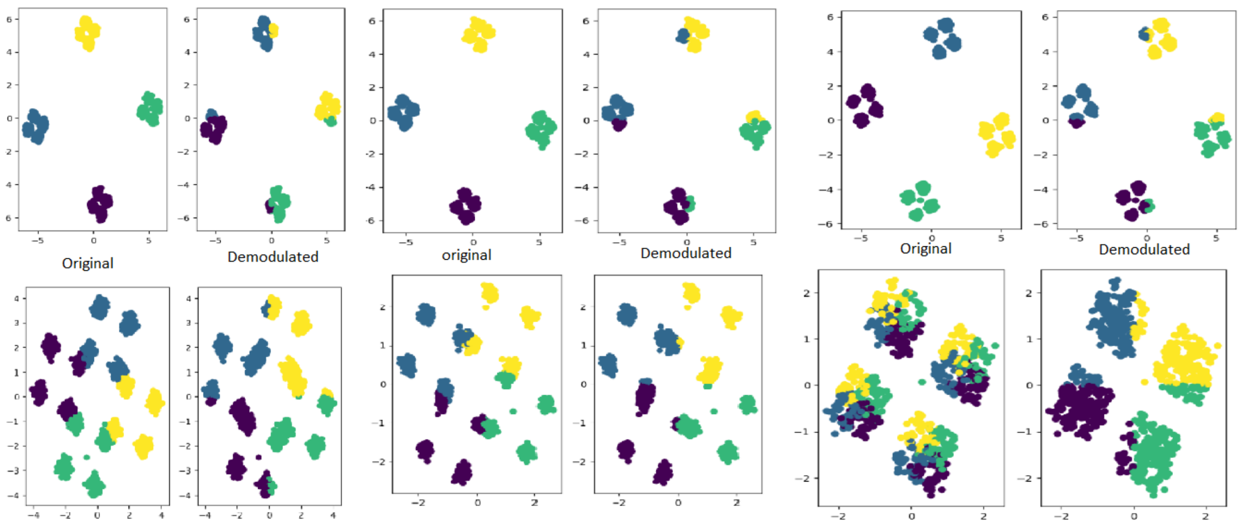


Figure 12: 4-PSK modulated and demodulated signals with channel and noise simulations

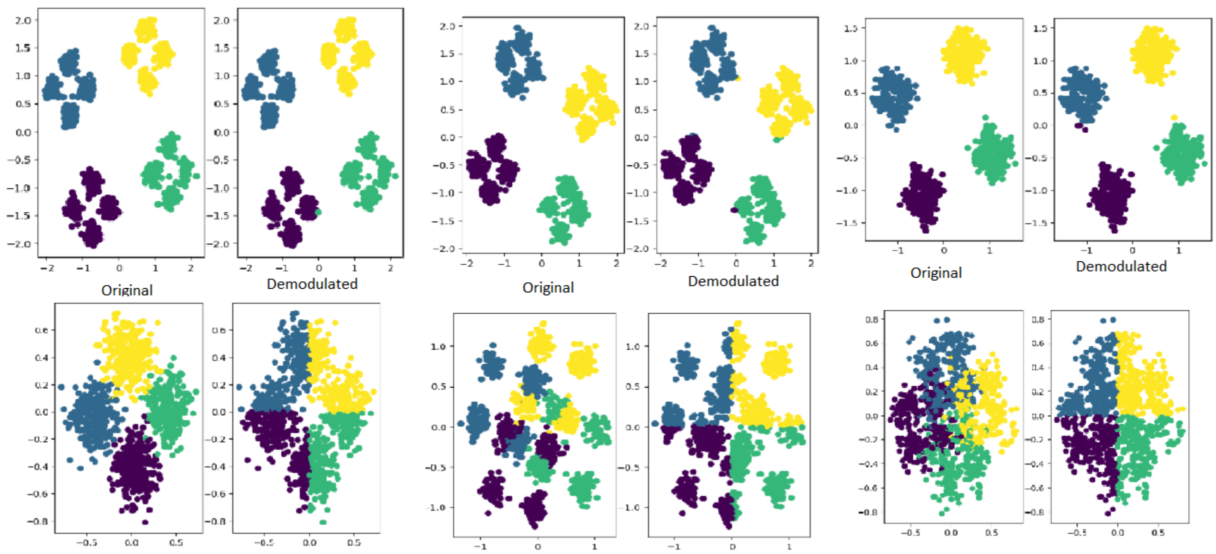


Figure 13: 4-PSK modulated and demodulated signals with channel and noise simulations in Deep water

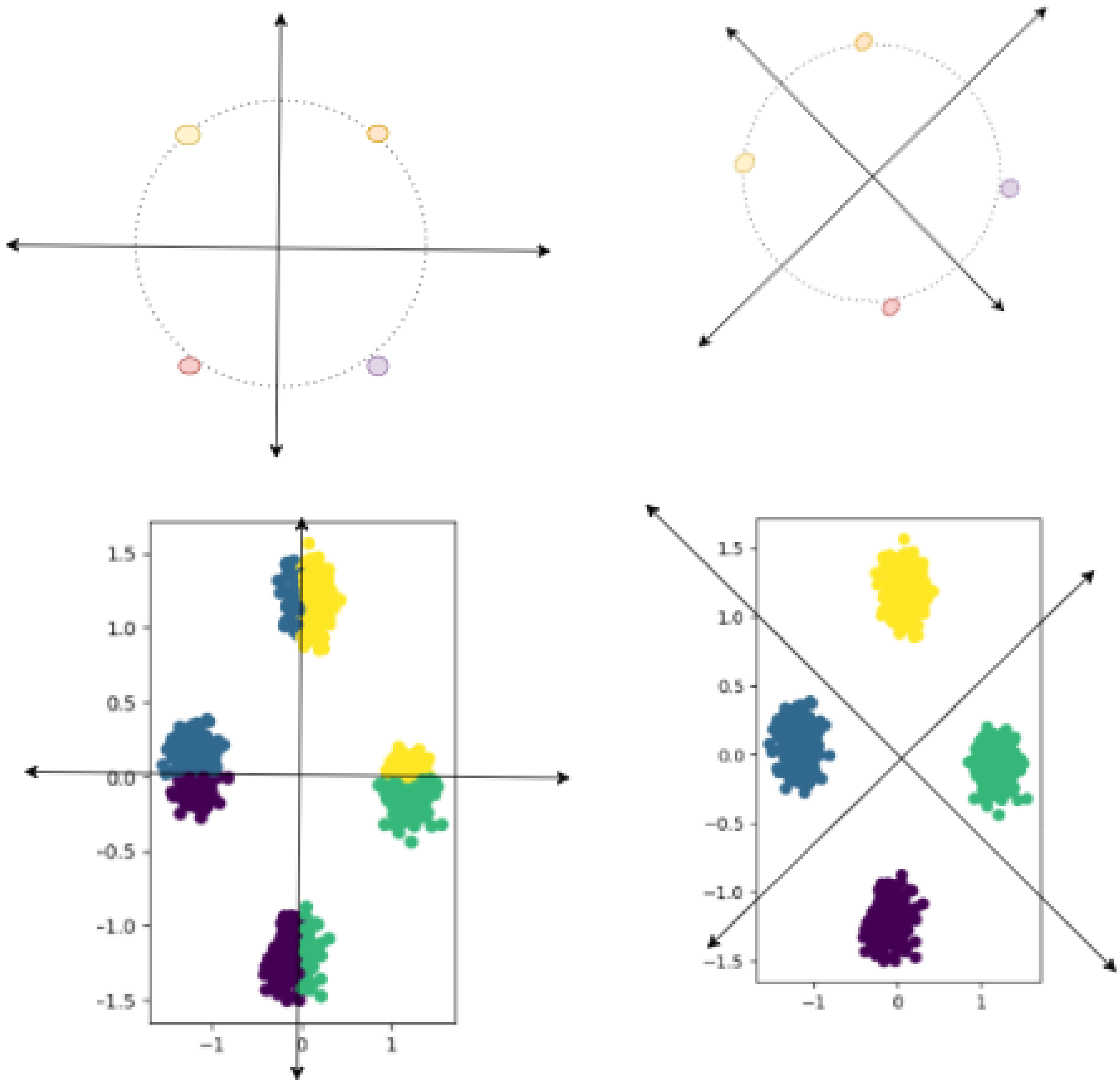


Figure 14: Left depicts the demodulation with out training and right with training

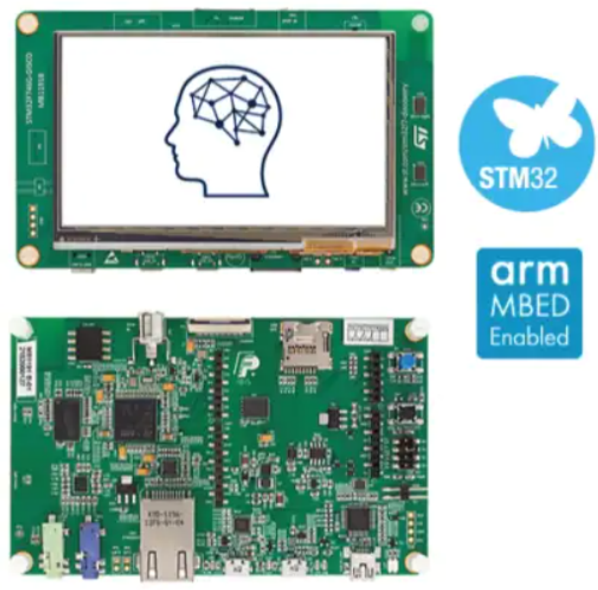


Figure 15: STM32F746NG

31bytes data	8bits 0xAA	30bytes data

Figure 16: Data Frame

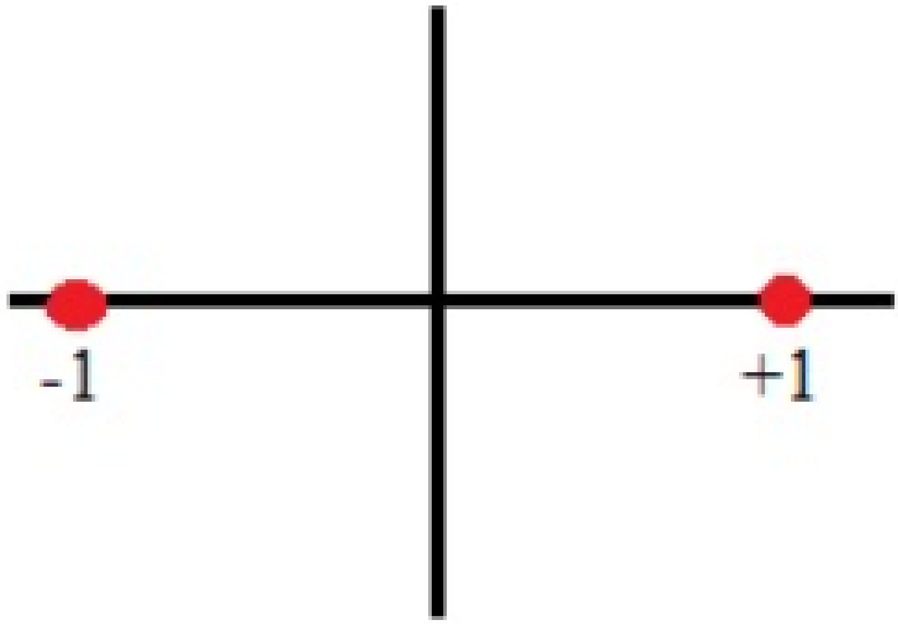


Figure 17: Complex Envelope/Codes

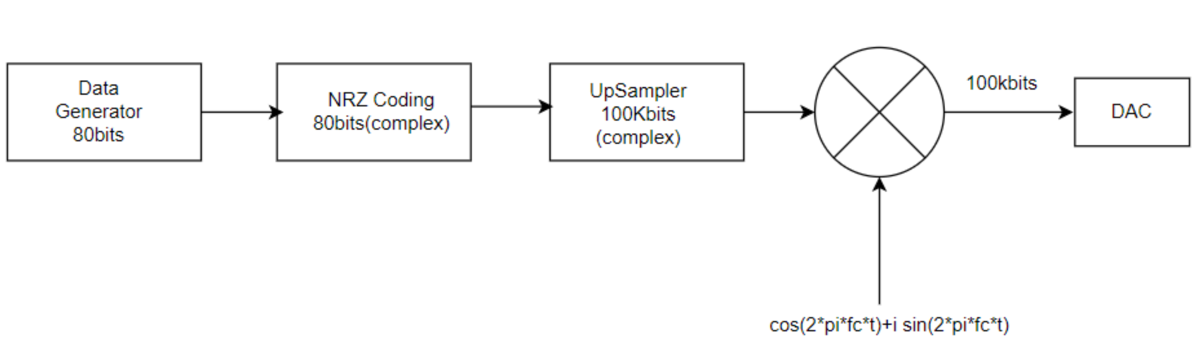


Figure 18: Modulation Pipeline

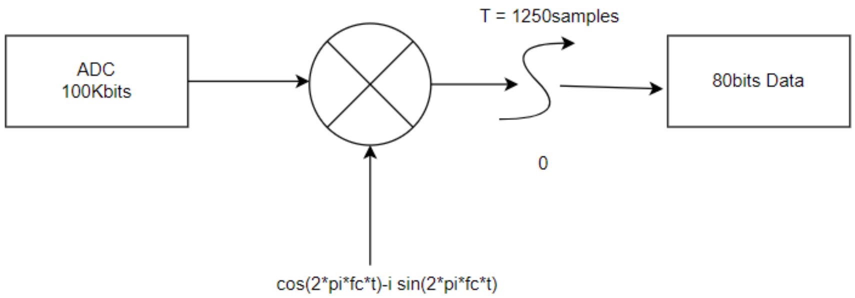


Figure 19: Demodulation pipeline