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DIGITAL COMMUNICATION LAB (EC39001)

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Title Of Experiment: Eye Diagram for Inter Symbol Interference
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Introduction

This experiment in purely **MATLAB** based. The experiment intends to explain the **Inter Symbol Difference** for channels given their Impulse Response. For simplicity sake, we observe only 4 basic filters and understand how **Noise** affects them differently.

Key Objectives

For this experiment, out key objectives are:

- Generating a PN Sequence and performing BPSK Modulation on it.
- Applying filters on the modulated signals. .
- Studying Inter Symbol Interference(ISI) with the help of Eye Diagram.
- Observing the effect of noise on the Eye Diagrams and therefore ISI.

Results

We begin by first generating the PN Sequence. This can be done by using the built in module in **Communications Toolbox**. Once it is generated, we need to transform the Sequence from {0, 1} to {-1, 1}. After that, the Signal is upsampled to **Symbol Rate**

$$\text{Symbol Rate} = \frac{1}{\text{Symbol Duration}}$$

This is done by **inserting 0s between the symbols**(not repeating the symbol, I learnt this the hard way). Let us ahve a look at how the PN Sequence signal looks.

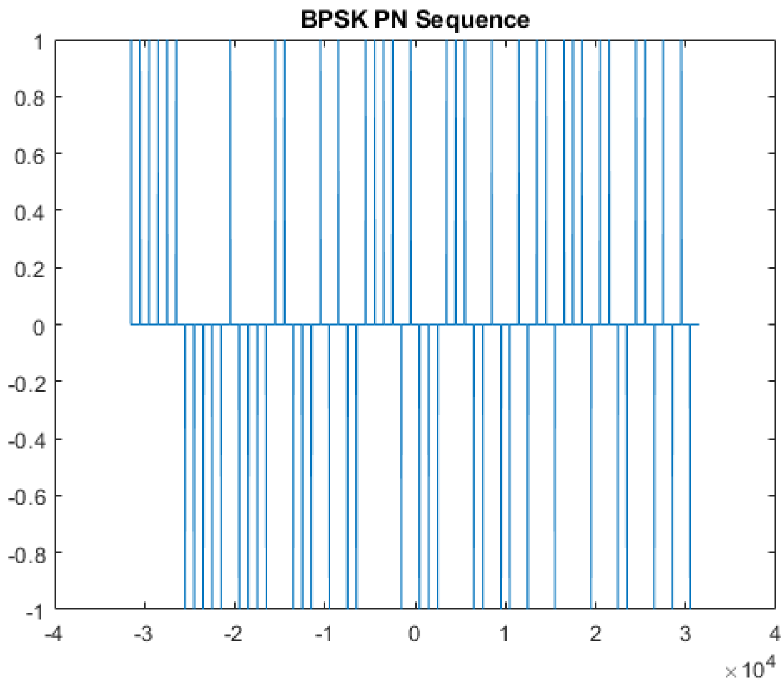


Figure 1: Modulated PN Sequence Signal

Notice how the time is centered. Now let us look at generating the Time Domain Response of Filters. We have to make the following Filters:

- Rectangle

$$\mathsf{h}(t) = \mathsf{abs}(t) < \frac{\mathsf{T}}{2}$$

- Triangle

$$\mathsf{h}(t) = \begin{cases} \mathsf{T} - \mathsf{abs}(t) & \text{when } \mathsf{abs}(t) < \dfrac{\mathsf{T}}{2} \\ 0 & \text{otherwise} \end{cases}$$

- Raised Cosine Pulse

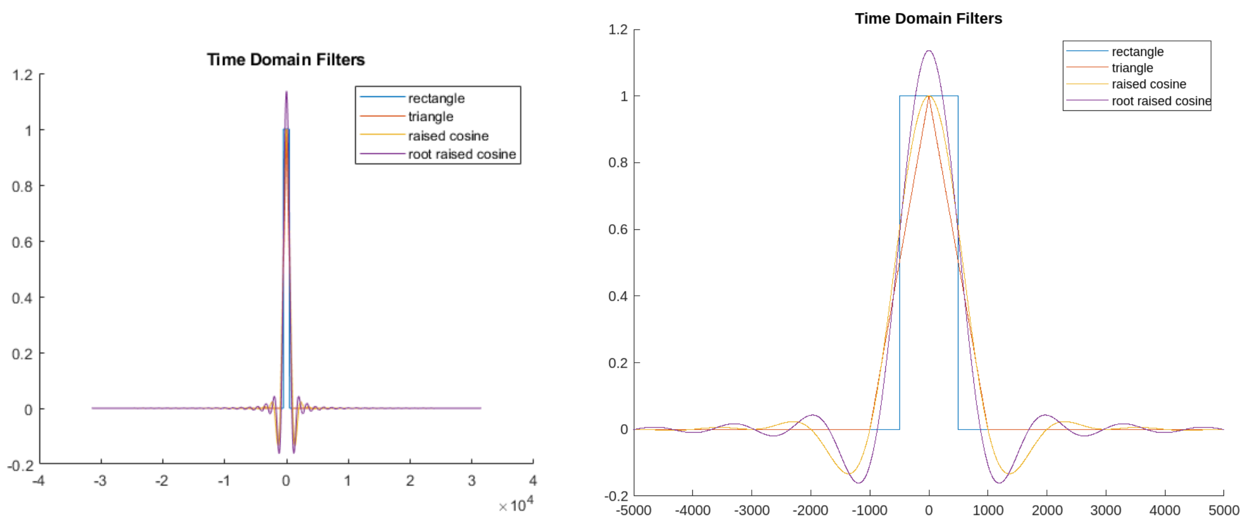
$$\mathsf{h}(t) = \mathsf{T} \text{ x } \begin{cases} \dfrac{\pi}{4\mathsf{T}} sinc\left(\dfrac{1}{2\beta}\right) & \text{when } t = \pm\dfrac{\mathsf{T}}{2\beta} \\ \dfrac{1}{\mathsf{T}} sinc\left(\dfrac{t}{\mathsf{T}}\right) \dfrac{cos(\frac{\pi\beta t}{\mathsf{T}})}{1 - (\frac{2\beta t}{\mathsf{T}})^2} & \text{otherwise} \end{cases}$$

- Root Raised Cosine Pulse

$$\mathsf{h}(t) = \mathsf{T} \text{ x } \begin{cases} \dfrac{1}{\mathsf{T}}\left(1 + \beta(\dfrac{4}{\pi} - 1)\right) & \text{when } t = 0 \\ \dfrac{\beta}{\mathsf{T}\sqrt{2}}\left[\left(1 + \dfrac{2}{\pi}\right) sin\left(\dfrac{\pi}{4\beta}\right) + \left(1 - \dfrac{2}{\pi}\right) cos\left(\dfrac{\pi}{4\beta}\right)\right] & \text{when } t = \pm\dfrac{\mathsf{T}}{4\beta} \\ \dfrac{1}{\mathsf{T}} \dfrac{sin\left[\pi\frac{t}{\mathsf{T}}(1-\beta)\right] + 4\beta\frac{t}{\mathsf{T}} cos\left[\pi\frac{t}{\mathsf{T}}(1+\beta)\right]}{\pi\frac{t}{\mathsf{T}}\left[1 - \left(4\beta\frac{t}{\mathsf{T}}\right)^2\right]} & \text{otherwise} \end{cases}$$

Note: Definitions of Raised Cosine and Root Raised Cosine differ from the Wikipedia definitions in order to make all the Filters have same order of magnitude at $t = 0$.

Let us have a look at how these filters look:



(a) Impulse Response of Filters

(b) Zoomed View

Figure 2: Filters

We now apply the filters on the Modulated PN Sequence and observe how they look.

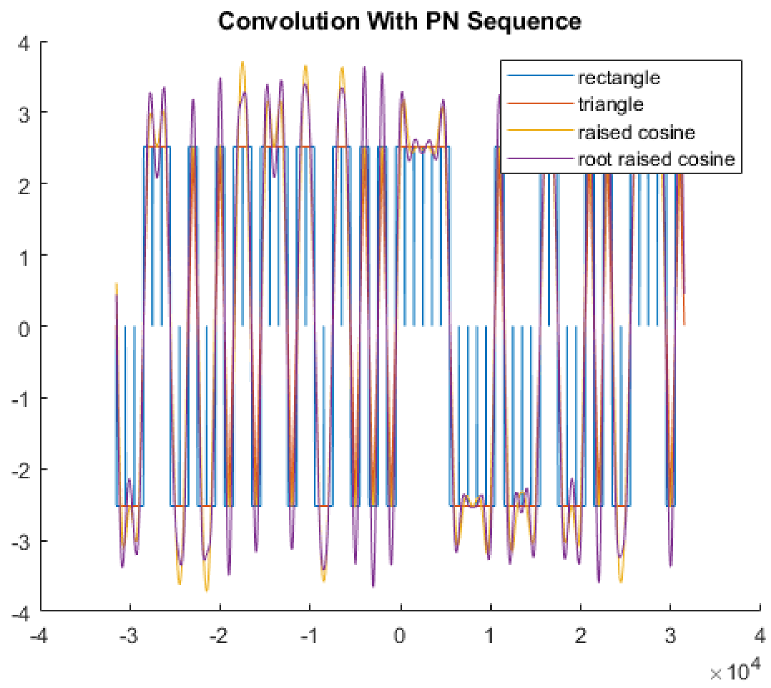


Figure 3: Filtered PN Sequence

They look just as expected. We will now look at the Eye Diagram for each of the Filters.

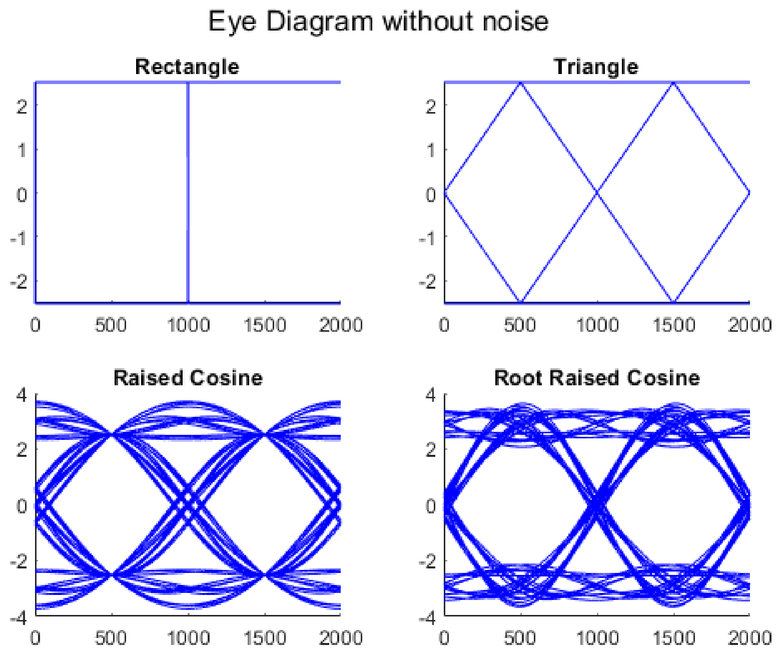
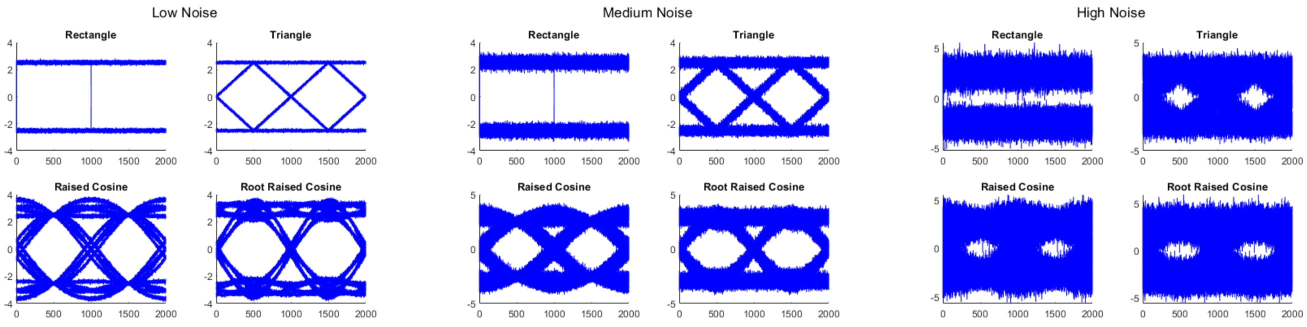


Figure 4: Eye Diagrams

We will also add a **White Gaussian Noise** on top of the filtered PN Sequence in order to mimic a Noisy Channel. Let us look at how they affect Eye Diagrams under three settings:

- Low Noise
- Medium Noise
- High Noise



(a) SNR = 30 dBW (b) SNR = 20 dBW (c) SNR = 10 dBW

Figure 5: Eye Diagrams with Noise

Discussion

Answering the questions given in Lab Manual:

- **Question 1**

  The Eye Diagram allows us to visualize the Signal over multiple periods, by overlaying them on top of each other. Looking at the Eye Diagram, we can find the time point t_0 where the Eye is **most open(or wide open)**. In order to understand the reason behind it, let me first explain what the Height and Width of Eye Diagram convey. **Height** of the Eye Diagram **signifies the Amplitude**. Now the point where the Eye is most widely open t_0 is the point where the difference/distance between the symbols(Symbol 1 represents the Upper part of Eye whereas Symbol 0 represents the Lower part of Eye) is largest. This means we can easily distinguish between symbols due to the large **Noise Margin**. Therefore, the receiver should sample the signal at time point t_0 in each period where the Eye is most open. Width of the Eye signifies the **range of values Receiver is seeing during a Symbol Period**. Therefore, **wider Eye** indicates **more ISI**. Since Height of the Eye signifies Amplitude, it is also a proxy for **Signal to Noise Ratio(SNR)**.

- **Question 2**

  Yes, there are pulse shaping filters which can completely eliminate ISI. They must satisfy **Nyquist Pulse Shaping Criteria**. The criteria goes like:

$$p(t) = \begin{cases} 1 & \text{when } t = 0 \\ 0 & \text{when } t = \pm\mathrm{T}, \pm 2\mathrm{T} \ldots \end{cases}$$

  The idea is to **not** have the **spectral response spread beyond Nyquist Frequency**. Therefore, **Sinc Filter** can ideally have 0 ISI. However, we have consider factors like Frequency-Selective Attenuation, Noise etc and come up with a **Trade-off between ISI and Spectral Efficiency**.

- **Question 3**

  Although easy to generate(Low Complexity), Rectangular Filter has a Frequency Response that is spread, causing high ISI. The side lobes cause ISI and should decay in order to minimize ISI. Formalizing the requirements for a good pulse shaping filter:

  - The Frequency Response should lie within the Channel's available bandwidth, i.e, **Good Spectral Confinement**.
  - Sidelobes, if present, should be as **low** as possible in order to minimize the ISI.
  - The filter should be easy enough to generate, i.e, **Low Complexity**.

Conclusion

In this experiment, we learnt about Eye Diagrams and how they are related with Inter Symbol Interference(ISI). We observed how Eye Diagrams are helpful in studying the properties of Channel and how the noise affects it.

References

- MATLAB Official Documentation
- Wikipedia
- ChatGPT
- Lab Manual