EXPERIMENT NO. 06

TITLE: Eye Diagram for communication with inter-symbol interference (ISI)

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PROBLEM STATEMENT: In this software experiment, you need to construct the so-called eye diagrams for different pulse-shaping transmit filters. Plot the eye diagram along with the transmit time domain waveform for different pulse shaping filters and comment on the key differences. Finally, introduce additive white Gaussian perturbations to the output of the pulse shaping filters and analyse, if any, the degradation of the eye diagram.

KEY COMPONENTS: This is a software experiment. You can use standard functions in MATLAB.

BRIEF THEORY:

What is an eye diagram? In simple terms, an eye diagram is a graphical representation of a digital signal that helps to analyze the quality of the signal. For a given long time series of the waveform, the eye diagram is a plot of a sequence of shorter waveform cycles superimposed on each other, with the amplitude of the signal represented on the y-axis and time represented on the x-axis. The name "eye diagram" comes from the shape of the plot, which looks like an open eye. The plot is created by overlaying many identical waveform cycles, with each cycle shifted slightly in time relative to the others.

The eye diagram is used to determine the signal's performance by examining the openings and closures of the "eye" in the plot. Certain eye parameters of the eye are very useful: the *width of the opening of the eye* indicates the signal's noise margin, and the *height of the opening* indicates the signal's amplitude margin. A narrower opening or a lower height can indicate a signal with a higher probability of errors or clock jitter.

The eye diagram is commonly used in telecommunications and digital signal processing to analyze and optimize signal performance in a variety of applications, including high-speed data transmission and signal modulation.

Pulse shaping and eye pattern: In digital communications, the transmitted signal is typically in the form of a series of pulses, with each pulse representing a digital symbol. However, due to the limited bandwidth of the communication channel, the pulse shape may get distorted, resulting in ISI. ISI occurs when the energy from one symbol spills over into adjacent symbols, making it difficult to correctly decode the transmitted symbols at the receiver. A pulse shaping filter is a digital filter used to modify the shape of a transmitted signal so that it conforms to certain requirements, such as minimizing intersymbol interference (ISI) or meeting spectral efficiency requirements.

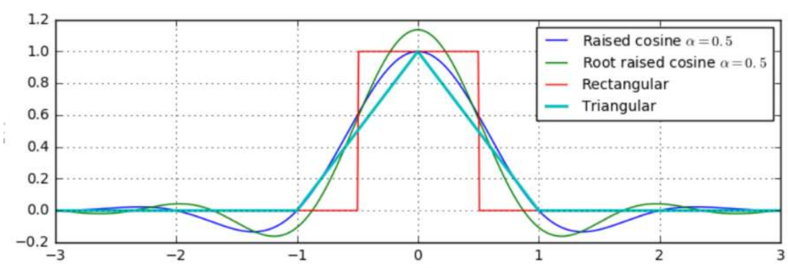
To mitigate ISI, a pulse shaping filter is often used to shape the transmitted pulse so that it has a specific spectral profile that is better suited for the communication channel. The filter modifies the shape of the pulse by applying a time-domain filter to the input signal. The most commonly used pulse shaping filter is the raised cosine filter, which is designed to have a flat frequency response in the passband and a steep roll-off outside the passband. The raised cosine filter has a parameter, known as the roll-off factor, that determines the sharpness of the roll-off. Other types of pulse shaping filters include the Gaussian filter, the root-raised cosine filter, and the sinc filter. Each of these filters has its own characteristics and trade-offs, depending on the specific communication system requirements. Overall, a pulse shaping filter is an essential tool for improving the quality and efficiency of digital communication systems, particularly in high-speed data transmission applications.

FORMAL DESCRIPTION OF THE EXPERIMENT:

1. Generate a PN sequence (our proxy for data) using a 6-stage linear feedback shift register (LFSR). Use appropriate LFSR structure (you can look at references). Let this PN sequence denote our data $d(t)$.
2. Use two methods for synthesizing the transmit time domain signal $x(t)$
   a. **Simple line coding:** map the PN sequence data to +1 and -1 (simple BPSK signaling)
   b. **Pulse-shaping filter:** use a pulse shaping filter $p(t)$ and generate the time domain signal as follows: $x(t) = \sum_{k=-\infty}^{\infty} d(k)p(t-kT)$, where T is the inter-symbol time. Let us fix T=1 for convenience. Note that x(t) is the superposition of several different pulse components (this will be more apparent for raised cosine and root raised cosine filters later). For this experiment, you will need to construct the following filters (seen in the time domain):
      1. Simple rectangular pulse filter
         $p(t) = 1$ for $t \in [-1/2, 1/2]$ and 0 otherwise.

      2. Triangular pulse
         $p(t) = 1 - |t|$ for $|t| \leq 1$ and 0 otherwise.
      3. Raised-cosine pulse
         (see standard formula vis-à-vis rectangular function defined above and set roll off factor ½)
      4. Root raised cosine pulse
         (see standard formula vis-à-vis rectangular function defined above and set roll off factor ½)

3. Generate time domain pulses for each of the different filters and plot them. You will need to look up references to know the exact functional form and parameters for the last two filters. Remember to define the functions with respect to the same inter symbol time T. See below figure for representative time domain pulse representations.



Ref.: dspillustrations.com

4. For a fixed inter-symbol time $T = 1$, plot the following:
   a. data waveform $d(t)$
   b. time domain waveform $x(t)$ for each choice of the simple line coding and different pulse-shaping filters.
5. *Generation of the eye diagram:* To construct the eye diagram for each time domain pattern (under different pulse shaping choices), you will need to overlay chunks of a long time series corresponding to the time domain signal $x(t)$. The chunks should be of size $2T$ (i.e., two times the symbol period). However, successive chunks have offset of T. For example, if the first chunk is for the time period [0,2], the next chunk should be for the period [1,3], followed by the chunk for [2,4], then for the chunk for

[3,5] and so on. Plot the eye for the time domain waveform under the simple line coding as well as other pulse shaping filters.

6. *Degradation of the eye under additive Gaussian noise:* Generate zero mean Gaussian noise samples $n(t)$ under three different variances (very low, small and large) and perturb the time domain signal $x(t)$ additively to generate $y(t)$. Now repeat the previous step and plot the eye diagram under the noisy signal $y(t)$.

OUTCOMES AND RESULTS

1. Include step-by-step results and detailed plots in the report (as per the previous section).
2. Comment (in your own words) on the following in your report:
   1. How would the receiver use the eye diagram to decide sampling times? What does the width of the eye and the height of the eye convey about the ISI or other channel characteristics? Explain in more detail than in the introductory text of this experiment.
   2. In an ideal scenario, can one design pulse shaping filters to completely avoid ISI? If so, what is the condition one should look for?
   3. Why are rectangular pulses not *good* pulse waveforms? How would you characterize *good* pulse characteristics? Among the four choices listed, does any waveform best fit the characteristics required?