DIGITAL COMMUNICATION

In this project, we will investigate baseband and bandpass digital communications via MATLAB. **PLEASE NOTE THAT YOU ARE NOT ALLOWED TO USE MATLAB MODULATION FUNCTIONS AS WELL AS SPECIFIC FUNCTIONS MENTIONED IN EACH PROBLEM.**

We will first experiment with a root raised cosine filter, which is a variant of the most widely used pulse shaping filter, raised cosine filter, that satisfies the Nyquist criterion for zero inter-symbol interference (ISI). We will observe how changing the design parameter affects the signal decay in time and signal bandwidth.

Digital pulse amplitude modulation (PAM) is a form of baseband modulation in which message is encoded into amplitude of serial pulses. It can be unipolar, where amplitudes can take only positive values, or bipolar, in which amplitudes can be positive or negative. The number of possible amplitude levels determine the bits per symbol rate. For instance, if we want to transmit 4 bits/symbol, then there will be 16 different pulse amplitude levels.

Eye diagram is an indicator of the quality of received digital PAM signals. It depicts a superposition of digital PAM signals for time samples of input digital data sampled at the rate f_s. A properly constructed eye diagram should contain every possible sequences of received pulses for different combinations of transmitted symbols. In this project, we will also learn how to construct an eye diagram properly.

Finally, we will experiment with quadrature amplitude modulation (QAM) of digital PAM signals for bandpass communications.

Problem 1 (*Root Raised Cosine Pulse Design*)

IN THIS PROBLEM, YOU ARE NOT ALLOWED TO USE MATLAB FUNCTION `rcosdesign` AS WELL AS ANY FILTER DESIGN FUNCTION.

Root raised cosine pulse, $g(t)$, is defined as

$$g(t) = \frac{1}{T_s} \frac{\sin\left(\dfrac{\pi t(1-\beta)}{T_s}\right) + \dfrac{4\beta t}{T_s}\cos\left(\dfrac{\pi t(1+\beta)}{T_s}\right)}{\dfrac{\pi t}{T_s}\left(1-\left(\dfrac{4\beta t}{T_s}\right)^2\right)}$$

where $0 \leq \beta \leq 1$.

For this problem, you can choose T_s as you wish, but make sure that the requested plots are clearly visible and distinguishable from each other. Also, you have to normalize every pulse such that energy of each pulse should be unity.

1. Plot $g(t)$ for $\beta \in \{0, 0.25, 0.5, 0.75, 1\}$ on a single plot. What can you say about the time domain properties of $g(t)$ as β varies? Which β value provides the fastest decay? Don't forget to label axes and to include `legend`.

   PS: You have to be careful about the pulse when $t \to \{0, \mp T_s/4\beta\}$.

2. Plot the frequency domain of pulse $g(t)$ for $\beta \in \{0, 0.25, 0.5, 0.75, 1\}$ on a single plot. What can you say about the bandwidth of these signals? How does bandwidth vary with β? Which β gives the narrowest bandwidth? What is the trade-off in choosing a value for β? Don't forget to label axes and to include `legend`.

   PS: You can use `fftshift` *command for better Fourier domain visualization.*

3. Now plot the frequency domain representation of a rectangular pulse on the graph in question 2, and compare the spectra of rectangular and root raised cosine pulses. Discuss the differences.

4. Why do you think this pulse shaping filter is more widely used than, say, the rectangular pulse? Discuss this with the results obtained in questions 1, 2 and 3.

Problem 2 (*Digital PAM and Eye Diagram*)

IN THIS PROBLEM, YOU ARE NOT ALLOWED TO USE MATLAB FUNCTIONS `rcosdesign` AND `eyediagram` AS WELL AS `comm` AND `commscope`. Also, you have to normalize the pulse such that energy of it should be unity.

1. Generate a digital PAM signal and its eye diagram by following the steps:

   (a) Generate a double-polarity random sequence with length 300 for 3 bits/symbol transmission. How many different pulse amplitude values can there be? What are those values? Explain.

   (b) PAM-modulate the sequence via root raised cosine pulses with $T_s = 1$ s, $\beta = 1$, and the pulse span with 6 symbols (since the signal is infinitely long, we have to truncate it). Write your first 10 elements of your sequence and plot the first 10.5 seconds of PAM-modulated signal. Assume that the sampling rate f_s for PAM-modulated signal is 500 Hz. Don't forget to label the axes.

   (c) Root raised cosine filter should be used in both the transmitter and the receiver side. Since we have the signal modulated with root raised cosine, we have to filter the modulated signal again with the same pulse. Filter the received signal, and plot the eye diagram for that signal. For this, you should be careful about the following aspects which you should apply in your code:

   - In an eye diagram plot, horizontal axis (time) starts from $-T_s$ and finishes at T_s.
   - The diagram is superposition of plots of each $2T_s$ interval from the signal.
   - The n^{th} interval should start from $(n-1)T_s$ and finish at $(n+1)T_s$, where n is integer.

2. Repeat question 1 with $\beta = 0.5$ and $\beta = 0.25$. You can use the same message sequence in part 1(a). What do you see in the eye diagrams? Why are they different that much? What can you conclude about these different pulses? Explain by using and referring the eye diagrams.

3. Repeat question 1 by adding 15 dB SNR white-Gaussian noise to the received signal. You can use the same message sequence in part 1(a). Explain what happens to and what you see in the eye diagram. Comment on the received signal by comparing noisy-channel and noiseless-channel eye diagrams.

Problem 3 (QAM)

A QAM signal $s(t)$ can be mathematically expressed as

$$
\begin{aligned}
s(t) &= \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \cos\left(\Omega_c t + \phi[n]\right) \\
&= \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \left[\cos\left(\Omega_c t\right) \cos\left(\phi[n]\right) - \sin\left(\Omega_c t\right) \sin\left(\phi[n]\right)\right] \\
&= \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \cos\left(\phi[n]\right) \cos\left(\Omega_c t\right) - \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \sin\left(\phi[n]\right) \sin\left(\Omega_c t\right) \\
&= I(t) \cos\left(\Omega_c t\right) - Q(t) \sin\left(\Omega_c t\right)
\end{aligned}
$$

where

$$
I(t) = \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \cos\left(\phi[n]\right) \quad \text{and} \quad Q(t) = \sum_{n=-\infty}^{\infty} a[n]\, p(t-nT) \sin\left(\phi[n]\right)
$$

The values that $a[n]$ can take depend on the constellation size M of PAM, and should contain positive and negative values.

For the following questions, assume that $p(t-nT)$'s are rectangular pulses.

1. Apply 64-QAM modulation and demodulation by following the steps:
   (a) Create a uniformly distributed random bit sequence with length 180.
   (b) Draw the constellation diagram for 64-QAM. What are the amplitude values that in-phase component $I(t)$ and quadrature component $Q(t)$ can take? How did you choose those values? Don't forget to name the axes.
   PS: You don't have to consider Gray coding.
   (c) Take baud rate $f_b = 50$ Hz, carrier frequency $f_c = 1$ kHz, and sampling rate for QAM-modulated signal $f_s = 5$ kHz. Modulate the signal with 64-QAM. What is the duration of a single symbol? How many symbols do you expect to see in the modulated signal? What is the duration of the total modulated signal? Explain the details of how you modulated the signal. Plot the modulated signal.
   (d) Demodulate the signal applying the steps below:
      - Multiply the modulated signal with in-phase and quadrature components separately. Should there be any constant in front of them?
      - Take the integral of branches over each symbol interval $[nT,\ (n+1)T]$, where n is an integer and T is symbol duration (*you calculated it in part c*). Remember that the result of integration should be a single number since it is a definite integral.
      - Find the closest symbols to the resultant amplitudes.
      - Convert them to the bit sequence.

   Did you get the original sequence?
2. Repeat question 1 for 10 dB SNR white-Gaussian noise added onto the modulated signal. You can use the same message sequence in part 1(a), and you don't have to re-draw the constellation diagram asked in part 1(b).