8 Bandlimited channels and intersymbol interference

Intersymbol interference - baseband channels

1. We will study and visualize the effect of intersymbol interference (ISI) using the baseband channel models developed in Labsheet 6 (Chapter 4 in the lab manual).
2. Consider the baseband channel modelled as a low pass filter. We will investigate what happens to a baseband waveform as it passes through a low pass or baseband channel.
3. We will use a sampling frequency of 100 Hz for this task.
4. Use a low pass filter with a passband edge of 10 Hz with a passband gain of 1 to model the channel. Obtain and plot the magnitude spectrum of the channel.
5. Generate a baseband BPSK signal $b(t)$ corresponding to a random sequence of 100 bits for $T_b = 0.1s$.
6. Plot the eye diagram of this baseband BPSK signal. You should observe that this is the eye diagram of a signal without ISI.
7. Pass the baseband BPSK signal through the channel model and plot the eye diagram of the channel output. Comment on what you have observed.
8. Plot the eye diagrams for $T_b = 0.05$ and $T_b = 0.2$. Comment on your observations.
9. Suppose the channel output is passed through a matched filter for the case of $T_b = 0.1$. Plot the eye diagram of the matched-filtered received signal. What differences do you observe?

Intersymbol interference - passband channels

1. Consider the passband channel modelled as a band-pass filter. We will investigate what happens to a baseband waveform as it is modulated, passed through the passband channel, and demodulated.
2. We will use a sampling frequency of $1kHz$ for this task.
3. Use a bandpass filter with a center frequency of $100Hz$, with a one-sided bandwidth of $20Hz$ to model the passband channel. Obtain and plot the magnitude response of the channel.
4. Generate a baseband BPSK signal as in the section above and modulate it and pass through the channel. Demodulate the channel output and plot the eye diagram of the demodulated channel output.
5. Comment on whether there are any fundamental differences between nature of ISI for passband and baseband communication.

Pulse shaping

1. Since we consider ISI at baseband, we will only look at baseband channels for the rest of this labsheet.
2. We will use a sampling frequency of 100 Hz for this task.

3. Generate a baseband BPSK signal $b_r(t)$ corresponding to a random sequence of 1000 bits for $T_b = 0.1s$. Note that this baseband BPSK signal should be generated using the rectangular pulse shape.

4. Generate a baseband BPSK signal $b_s(t)$ corresponding to the same random sequence of bits used above, but using the sinc pulse shape.

$$AT_b \frac{sin\left(\pi \frac{t}{T_b}\right)}{t}$$

Note that the sinc pulse shape needs to be truncated to duration of $5T_b$ so that the truncated pulse shape is symmetric.

5. Generate a baseband BPSK signal $b_c(t)$ corresponding to the same random sequence of bits used above, but using the raised cosine pulse shape.

$$AT_b \frac{sin\left(\pi \frac{t}{T_b}\right)}{t} \frac{cos\left(\pi\alpha \frac{t}{T_b}\right)}{\left(1 - \left(2\alpha \frac{t}{Tb}\right)^2\right)}.$$

Note that the raised cosine pulse shape needs to be truncated to duration of $5T_b$ so that the truncated pulse shape is symmetric.

6. Plot the power spectral densities of the signals $b_r(t), b_s(t)$, and $b_c(t)$. Comment on the differences in the three spectra.

7. Plot the eye diagrams of $b_r(t), b_s(t)$, and $b_c(t)$. Comment on the differences and main features of each eye diagram.

8. Plot the spectra and eye diagrams of $b_c(t)$ for different values of α. What do you observe?

9. Generate a baseband BPSK signal $b_{rc}(t)$ using the square root raised cosine pulse shape. Obtain the power spectral density and eye diagram for this pulse shape.

10. For each of the signals $b_r(t), b_s(t), b_c(t)$, and $b_{rc}(t)$ obtain the channel output when the respective baseband signals are sent through a baseband channel. Use a low pass filter with a passband edge of 10 Hz with a passband gain of 1 to model the channel.

11. Obtain the PSD and eye diagram of the channel output in each of the cases. Compare the bandwidth and eye width properties for each of the pulse shapes for $T_b = 0.1, 0.05$ and 0.2.

Channel inversion

1. In this task, you will consider a baseband channel which has a non-flat response in the passband.

2. First, you have to modify the channel model that you have written in a previous lab to model a baseband channel which has the frequency response shown in Figure 2.

3. We will use a sampling frequency of 100 Hz for this task.

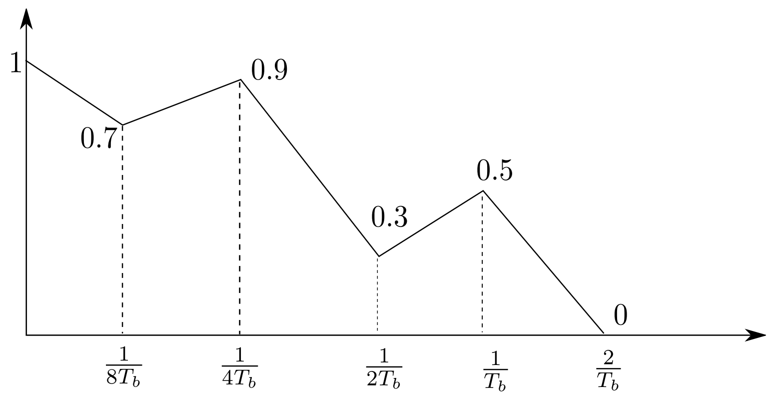
4. Generate a baseband BPSK signal using rectangular pulse corresponding to a random sequence of 100 bits with $T_b = 0.1$.

5. Obtain the eye diagram of the channel output when the above baseband signal is passed through the channel.

6. In order to undo the effect of the channel, whose response $H(f)$ is known to us, we can use a equalizer which undoes the effect of the channel by channel inversion, i.e., the equalizer is a receive/transmit filter which has a response $G(f)$ such that $H(f)G(f) = 1$ over the effective bandwidth of the signal. Design a equalizer using channel inversion.

7. Modify your receiver to process the received signal out of the channel using the equalizer.

8. Visualize the output from the equalizer using an eye diagram. What do you observe?



Duobinary signalling

1. Read/review duobinary signalling from the textbook - Communication Systems by Simon Haykin.
2. In the above task, we had designed an equalizer with response $G(f)$ such that $H(f)G(f) = 1$ over the effective bandwidth of the signal. Designing such a response might be difficult (with the sharp rolloffs or transitions that are required). In duobinary signalling, we design an equalizer with response $G(f)$ such that $G(f)H(f) = H_d(f)$ where

$$H_d(f) = \begin{cases} 2cos(\pi f T_b)e^{-j\pi f T_b}, \text{ for } |f| \leq \frac{1}{2T_b}, \\ 0, \text{ otherwise.} \end{cases}$$

   Design an equalizer which satisfies the above condition. Visualize the frequency response of the combination.
3. Generate a baseband PAM signal corresponding to a random sequence of 1000 bits for any choice of T_b and transmit it through the channel $H(f)$ and the receiver filter $G(f)$.
4. Assuming that symbol synchronization is achieved, sample the received signal at the middle of each bit time and use the decision feedback rule in order to obtain the transmitted bits - under the assumption that the first bit is known at the receiver (use the first bit from the random sequence at the receiver in order to simulate this).
5. Check how many bits are received in error - note that error here is not due to noise, and would be caused due to any deterministic imperfections in the filter design.
6. Read about the precoding method for duobinary signalling from the textbook. Implement the precoding method and the modified decoding method.

Linear equalizer - Tapped delay line

1. Assume that the baseband communication channel has a response $H(f)$ as in the above tasks. Let $h(t)$ be the corresponding time domain impulse response.
2. We note that the effect of ISI just needs to reduced at the sampling instants.
3. We assume that the output of this communication channel is fed into an equalizer with impulse response $q(t)$, so that the effective pulse shape from the input to the channel to the output is $p(t) = h(t) \star q(t)$ (here $\star$ denotes convolution).
4. Assume that in order to reduce the effect of ISI at sampling instants we require that

$$\begin{aligned} p(0) &= 1, \\ p(nT_b) &= 0, \text{ for } n = \pm 1, \pm 2, \pm N; \end{aligned}$$

   where T_b is the sampling period (or bit duration).

5. Design the equalizer impulse response $q(t)$ assuming that $q(t)$ is a tapped delay line filter (with delays of magnitude T_b). Note that the design should therefore specify the values of the tap weights of the filter. Do this design for $N = 2, 5, 10, 50$.
6. Visualize the output of the equalizer using an eye diagram for different values of N.