Indian Institute of Space science and Technology

AV343 Communication Systems Lab: 2

BANDLIMITED CHANNELS AND INTER-SYMBOL INTERFERENCE

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B-Tech Electronics & Communication Engineering (SEMESTER VI)

Baseband channel modelling

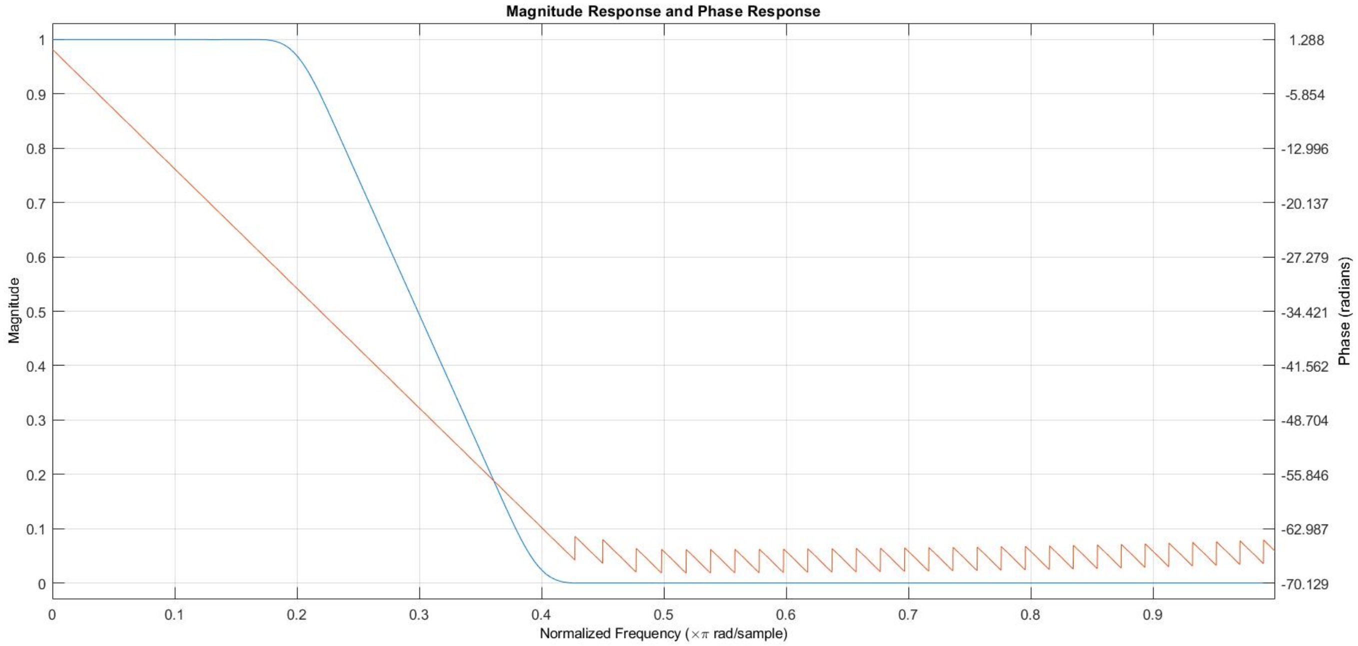
Write a Matlab *channel* function that takes as input a sampled signal $x[n]$ and produces an output $y[n]$.

Modify your channel function to low-pass filter the input $x[n]$; the low pass filter should have a gain g in the passband as input, and a passband cutoff frequency of f_c.

Plot the frequency and phase response of the channel that you have modelled for your choice of channel parameters.

```
% Low pass filter implementation of ideal baseband channel
function [channelOutput, tchOut] = channel(inputSignal, fs)
order = 100;
fpass = 10; % passband cutoff fc
fstop = 20; % stopband cutoff
frequencySamples = [0, fpass, fstop, fs/2]/(fs/2);
g = 1; % passband gain
amplitudes = [g, g, 0, 0];
channel = fir2(order, frequencySamples, amplitudes); % filter impulse response
fvtool(channel, 1);
title('Frequency response of baseband channel')
channelOutput = conv(inputSignal, channel);
ts = 1/fs;
tchOut = 0: ts: (length(channelOutput) - 1)* ts;
end
```

CODE

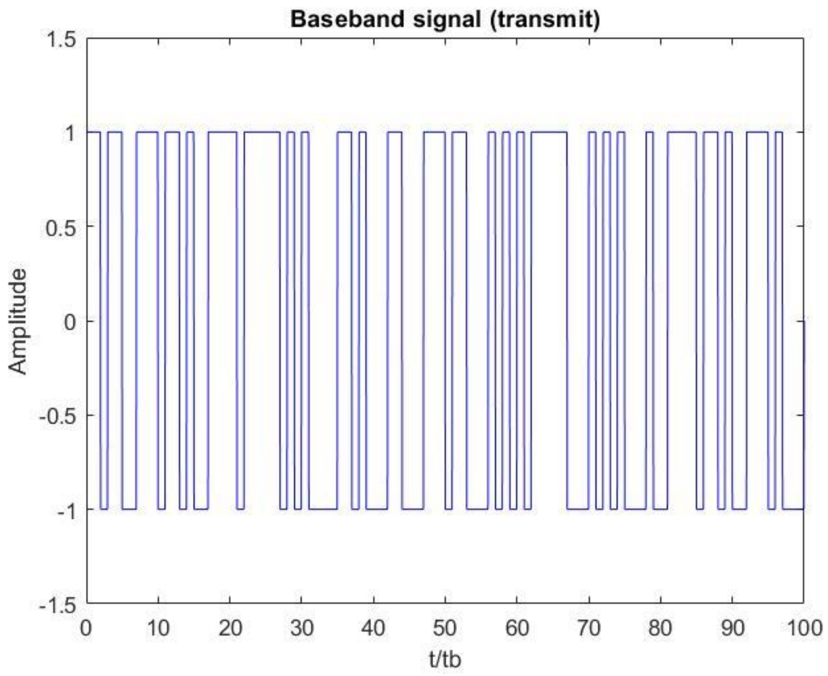


OUTPUT

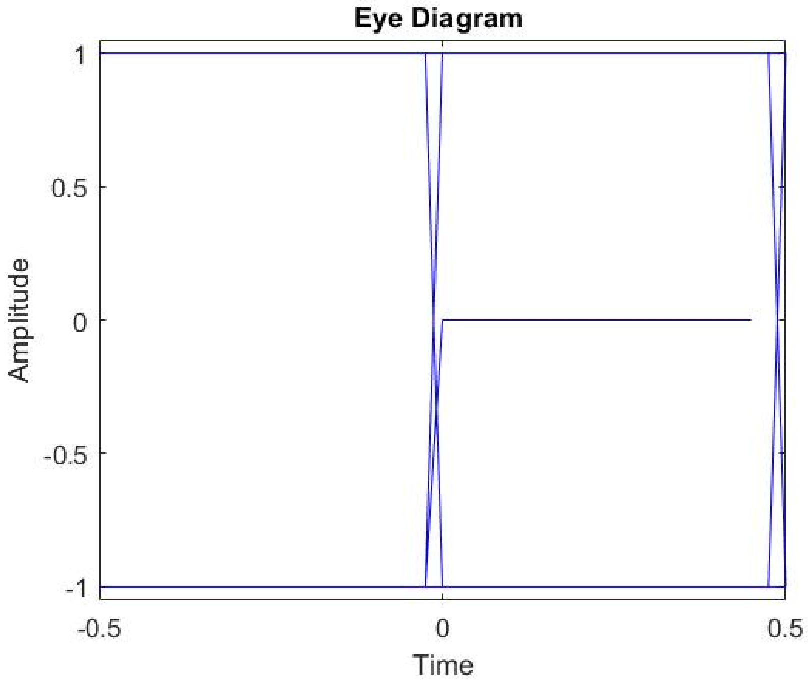
Inter-symbol interference baseband channels

Generate a baseband BPSK signal $b(t)$ corresponding to a random sequence of 100 bits for $T_b = 0.1s$.

Plot the eye diagram of this baseband BPSK signal. You should observe that this is the eye diagram of a signal without ISI.

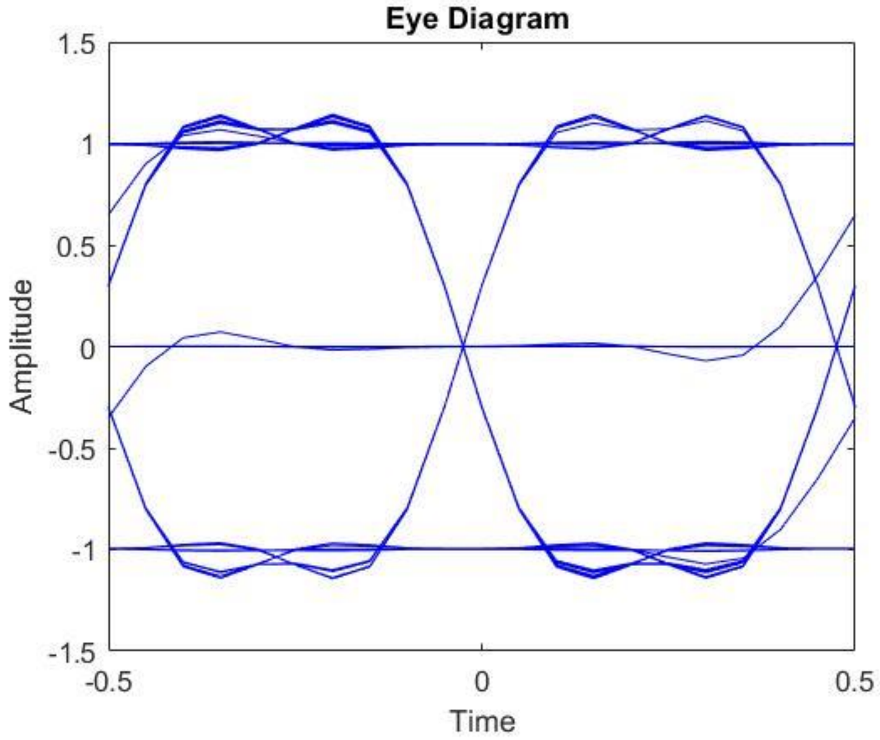


Baseband BPSK signal b(t)



As there is neither amplitude distortion nor jitter in the eye diagram, it is inferred that there is no ISI in the system.

Pass the baseband BPSK signal through the channel model and plot the eye diagram of the channel output. Comment on what you have observed.

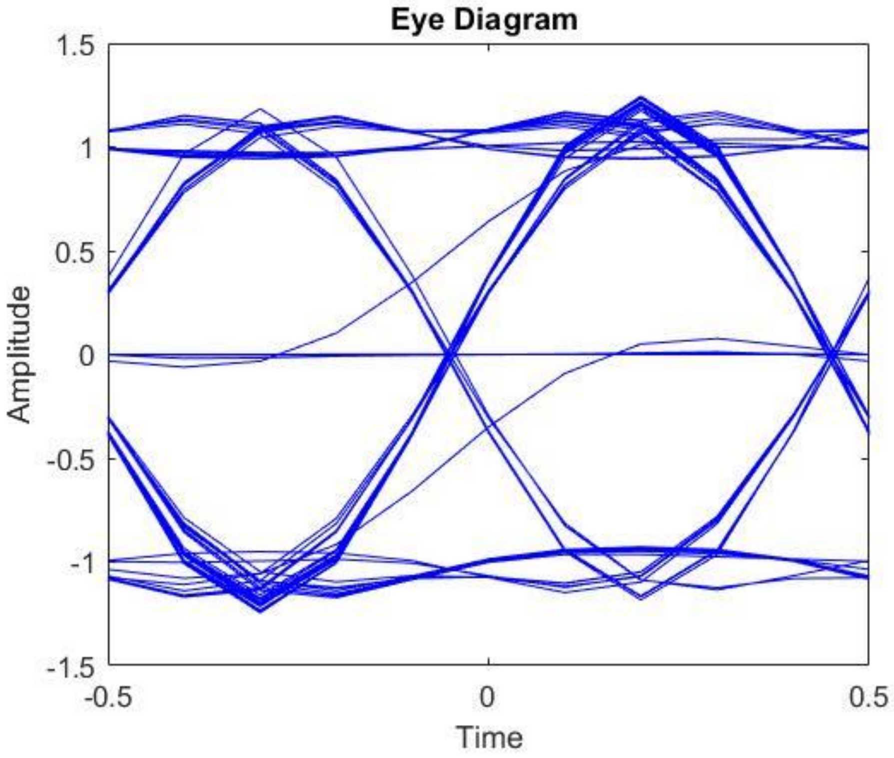


Eye diagram of channel output

Observations

- ISI effects clearly visible due to amplitude distortion at all points of a pulse.
- Lower noise margin.
- Finite jitter at the middle of a pulse.
- High timing sensitivity near the end of a pulse.
- Insignificant jitter effects at the end of a pulse.
- Reduced effective eye-opening.

Plot the eye diagrams for $T_b = 0.05$ and $T_b = 0.2$. Comment on your observations.



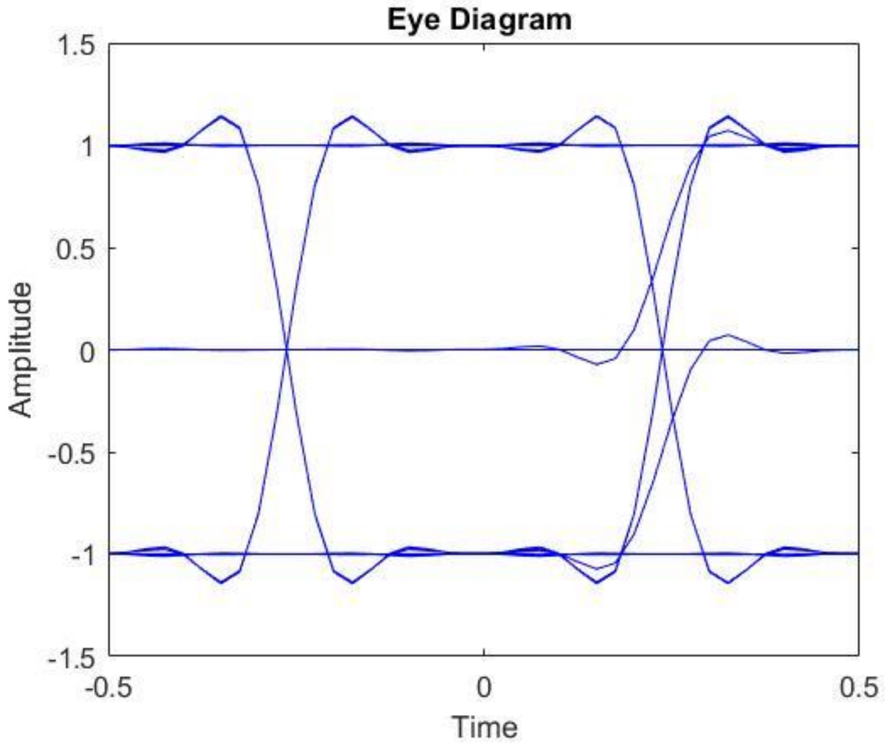
Eye diagram for Tb = 0.05

Observations

- Increased peak distortion.
- Reduced noise margin.
- Timing/synchronization jitter at the end of a pulse.
- Similar timing sensitivity at the end of a pulse.
- Reduced effective eye-opening.

Tb = 0.05 corresponds to <u>double the signal frequency</u>. As channel has cut-off still at 10 Hz, higher frequency components of the signal are cut-off resulting in spreading of the signal and hence greater ISI.

Plot the eye diagrams for $T_b = 0.05$ and $T_b = 0.2$. Comment on your observations.



Eye diagram for Tb = 0.05

Observations

- Lower peak distortion.
- Greater noise margin.
- Negligible jitter at the end of a pulse.
- Larger timing sensitivity at the end of a pulse.
- Larger effective eye-opening.

Tb = 0.2 corresponds to half the signal frequency. As channel has cut-off still at 10 Hz, higher frequency components of the signal are not cut-off resulting in lesser spreading of the signal and hence lower ISI.

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?

Can’t comment. We haven’t studied it yet.

Pulse shaping

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

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.

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

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

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

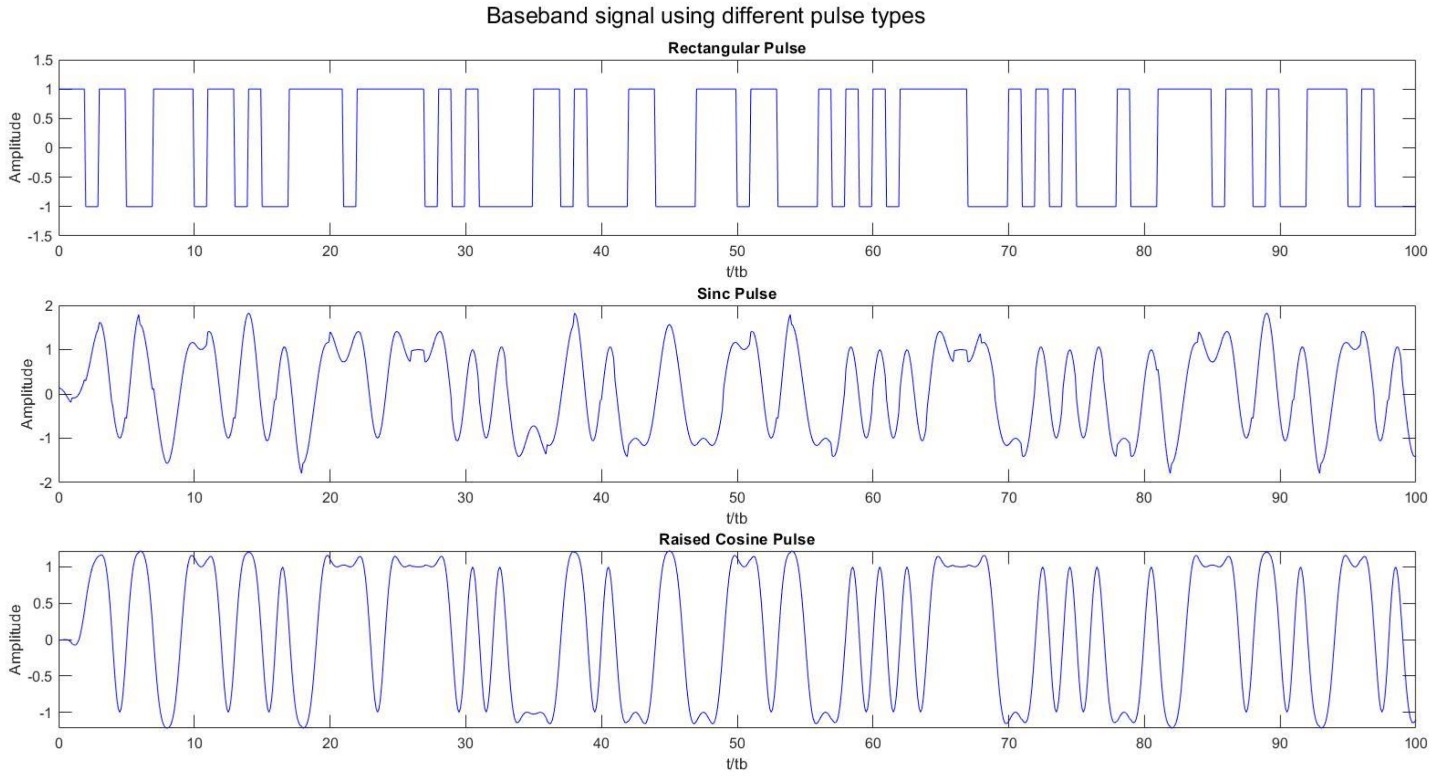
Generate a baseband BPSK signal $b_c(t)$ corresponding to the same random sequence of bits used above, but using the raised cosine pulse shape.

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

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

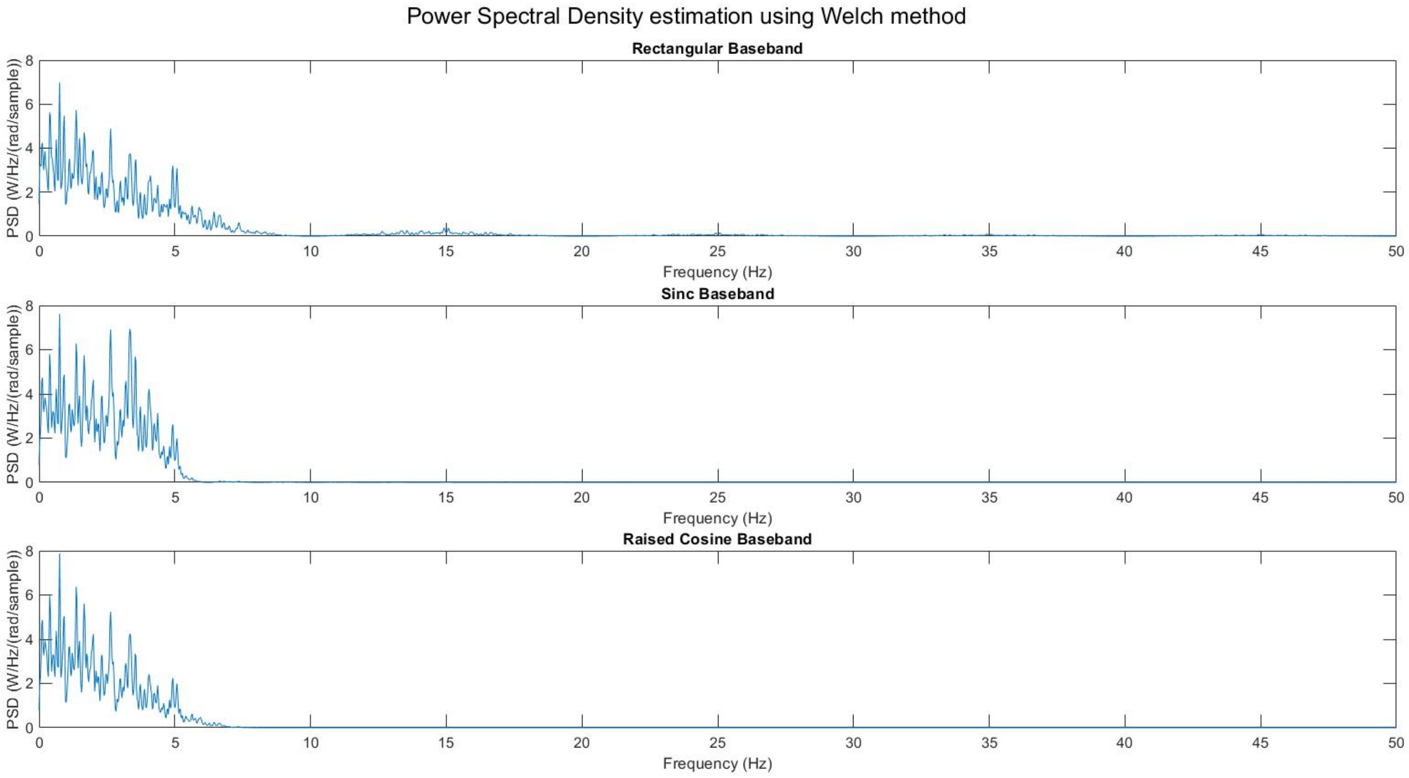
Graphs in the next slide…

Baseband signals



Baseband signals made from different pulse shapes are shown.
Only first 100 pulses are shown for clarity.

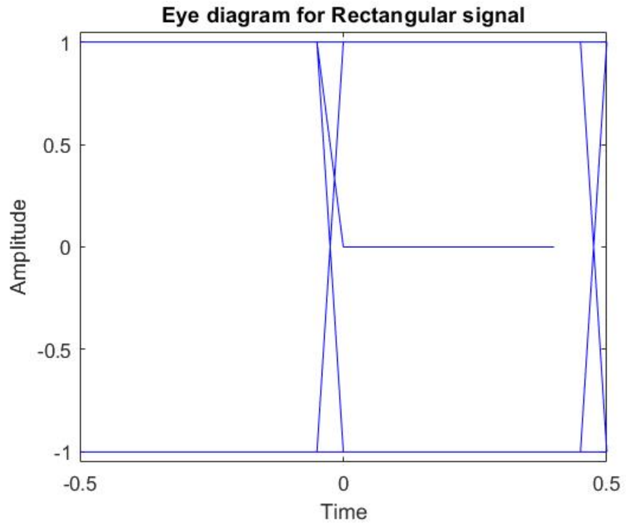
Plot the power spectral densities of the signals $b_r(t), b_s(t)$, and $b_c(t)$. Comment on the differences in the three spectra.

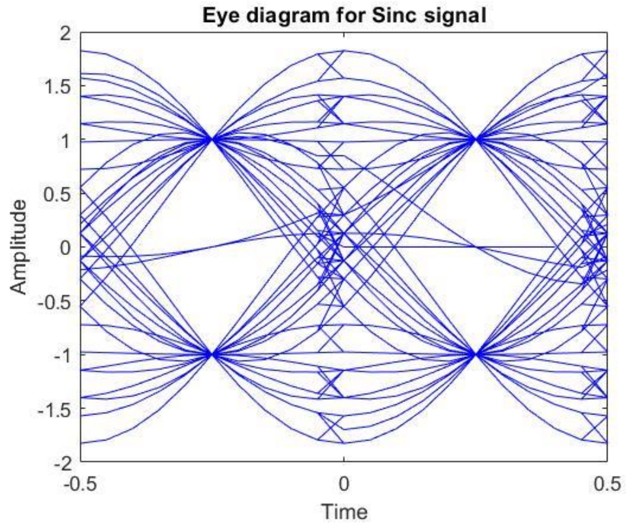


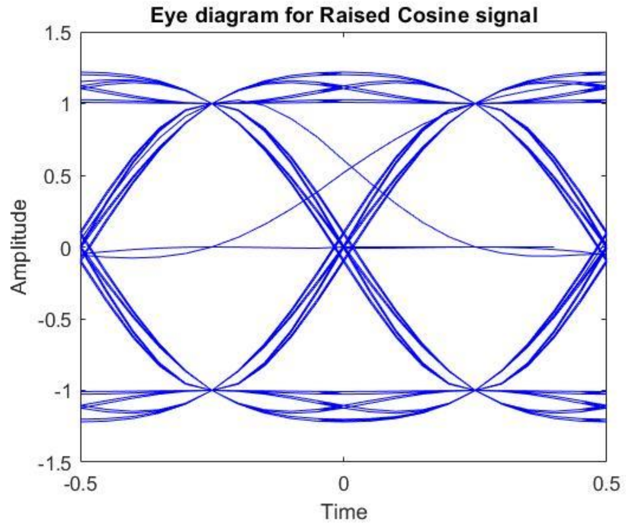
Observations

- Rectangular signal occupies greater bandwidth as the graph has non zero points near 15 Hz, which is absent in the other 2 cases.
- Sinc signal has greater power at many frequencies as compared to other 2 cases. Also, it occupies the least bandwidth.
- Raised cosine signal has lesser bandwidth than that of rectangular but more than that of sinc signal.

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.



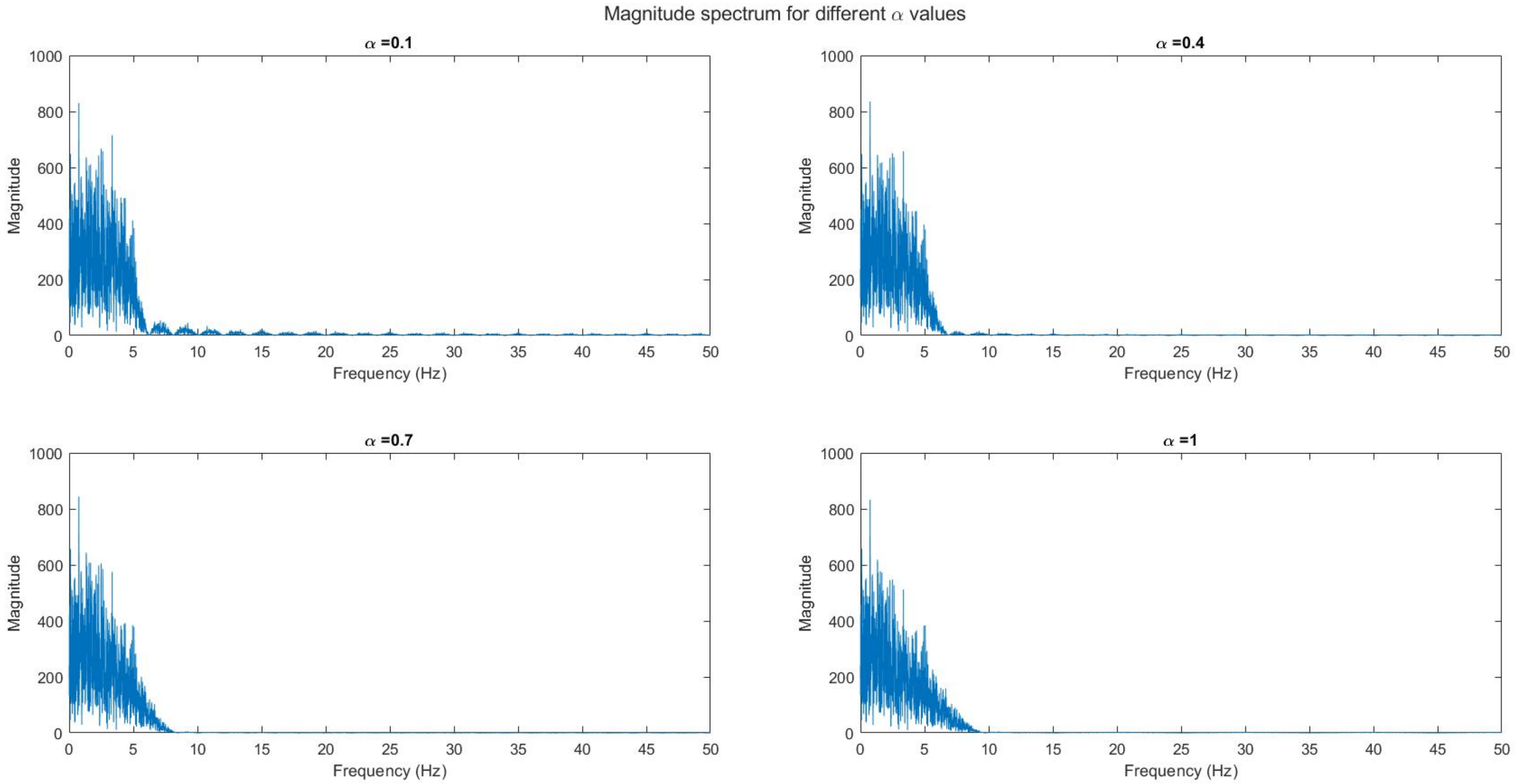




Feature	Rectangular	Sinc	Raised Cosine
Zero-crossing jitter (for extracting clock)	Negligible	Very High	Significant
Amplitude Distortion	Negligible	High	Medium

Common feature: All of them have negligible amplitude distortion at the middle of a pulse, and hence a larger noise margin there. Also, rectangular has the largest eye opening, followed by raised cosine and sinc.

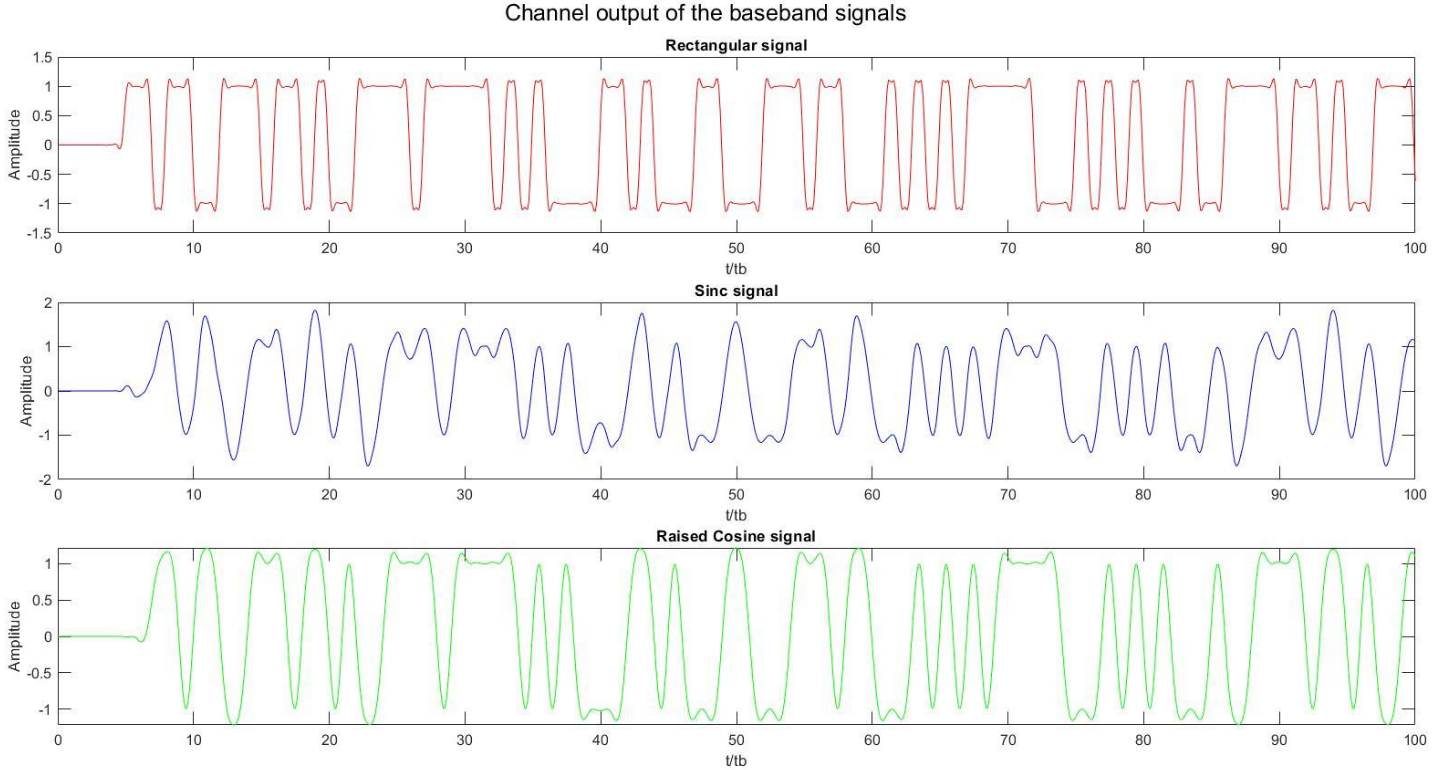
Plot the spectra and eye diagrams of $b_c(t)$ for different values of α. What do you observe?



It is observed that as α increases,

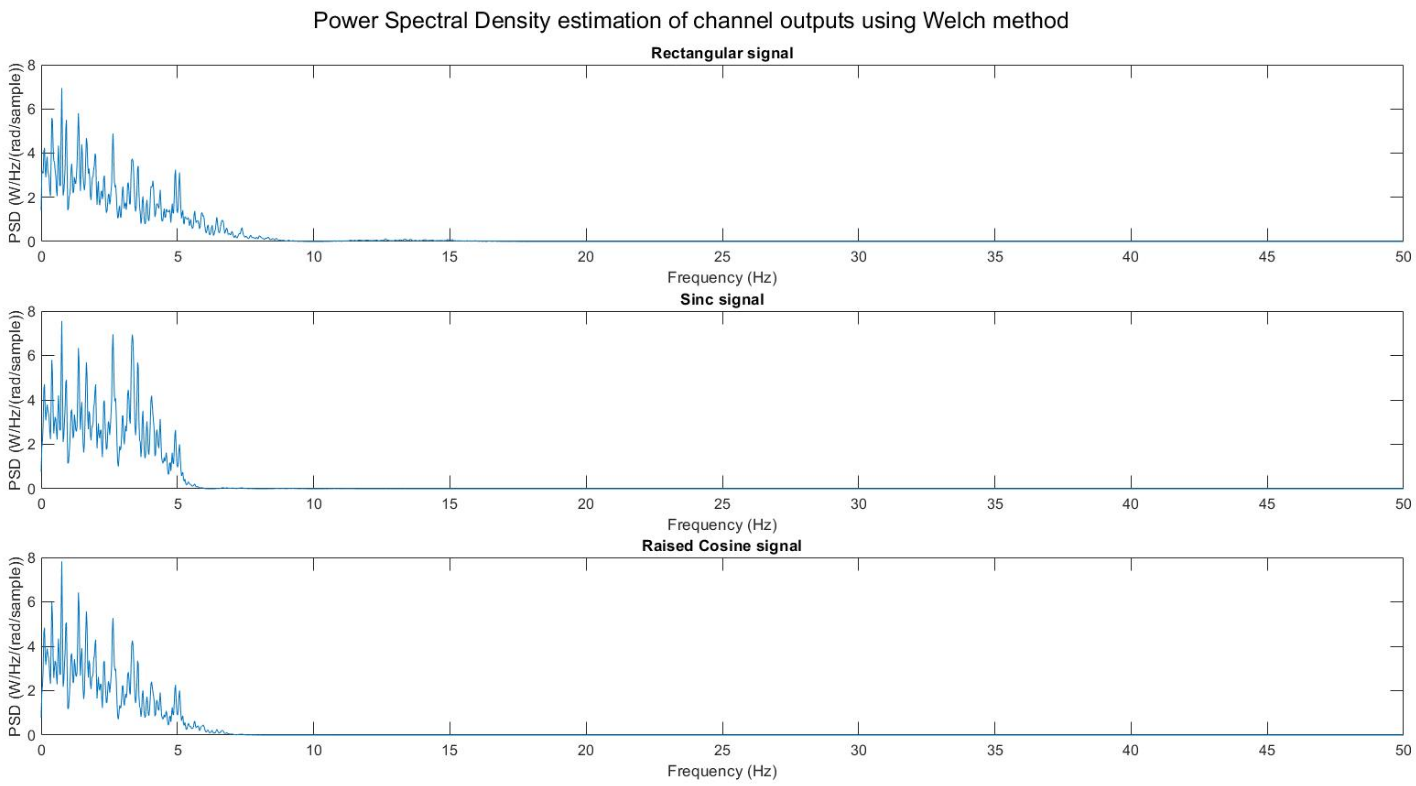
- The ripples go away
- Main lobe width increases e.g., from around 5 Hz in α = 0.1 to around 10 Hz in α = 1.

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.



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.

Case 1:
Tb = 0.1

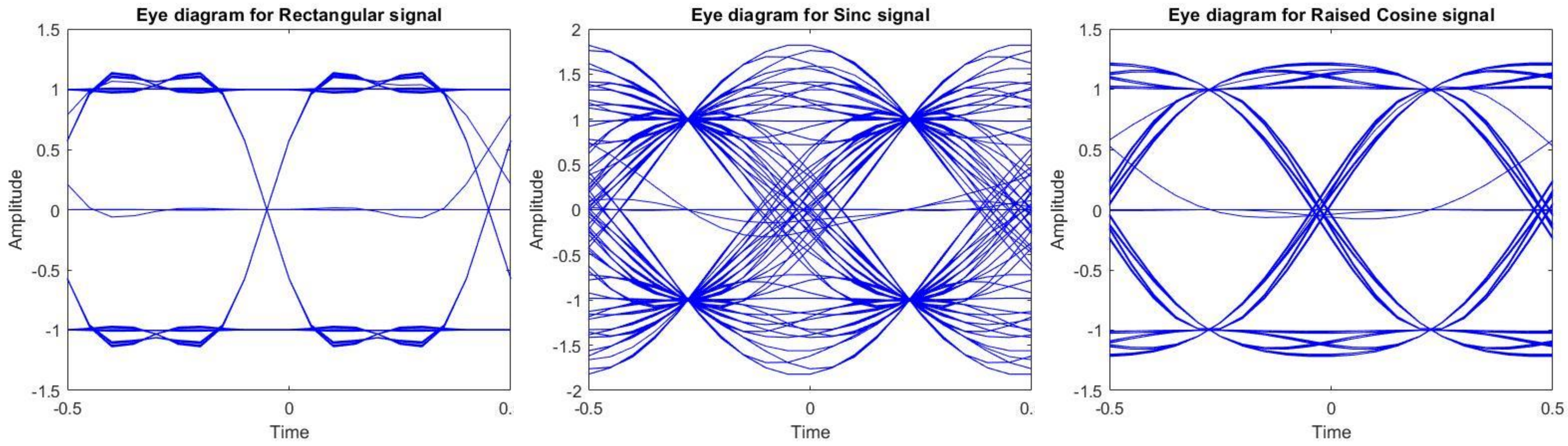


Observations

- Rectangular signal has the largest bandwidth followed by raised cosine and sinc finally.
- Sinc signal has greater power at many frequencies as compared to other 2 cases.
- The bandlimited channel has cut-off the power around 15 Hz which was present in the transmitted rectangular signal.

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.

Case 1:
Tb = 0.1



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.

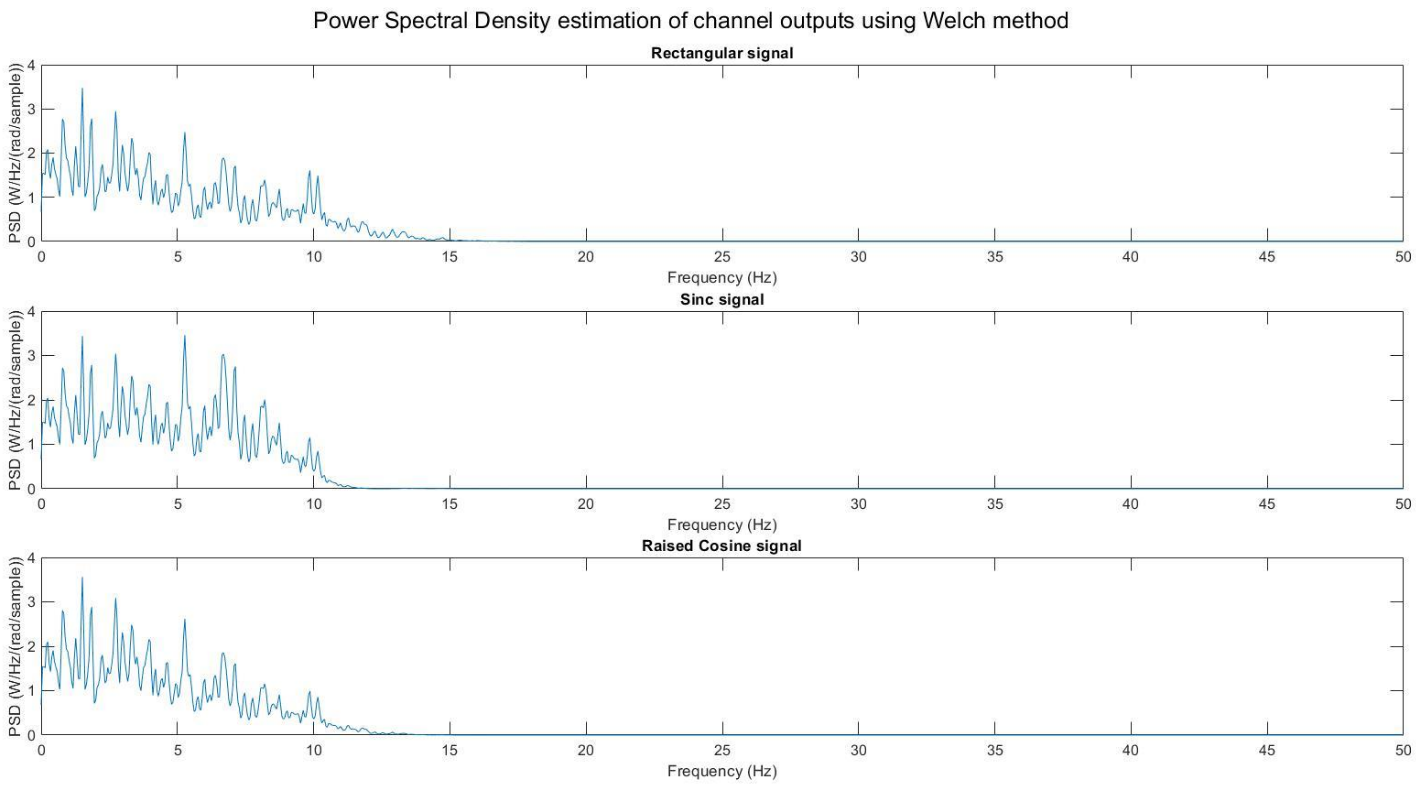
Case 1:
Tb = 0.1

Observations

- Bandlimited channel has introduced amplitude distortion in all the baseband signals.
- Sinc and Raised cosine signals have negligible ISI at middle of a pulse. Rectangular baseband signal has non-zero ISI.
- Timing synchronisation at sampling point (middle of pulse, since eye-opening is maximum there) has huge penalty if not done correctly for all the three signals, with rectangular having the least of it.
- Sinc has the least eye-width. Rectangular has the largest eye-width.
- Very difficult to do perform zero-crossing synchronization for sinc signal. The situation is much better for raised cosine and ideal for rectangular.

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.

Case 2:
Tb = 0.05

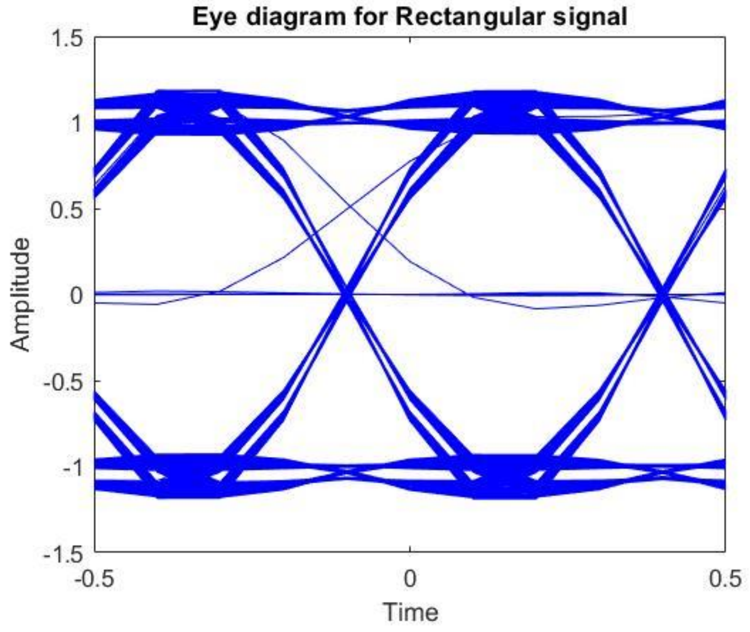


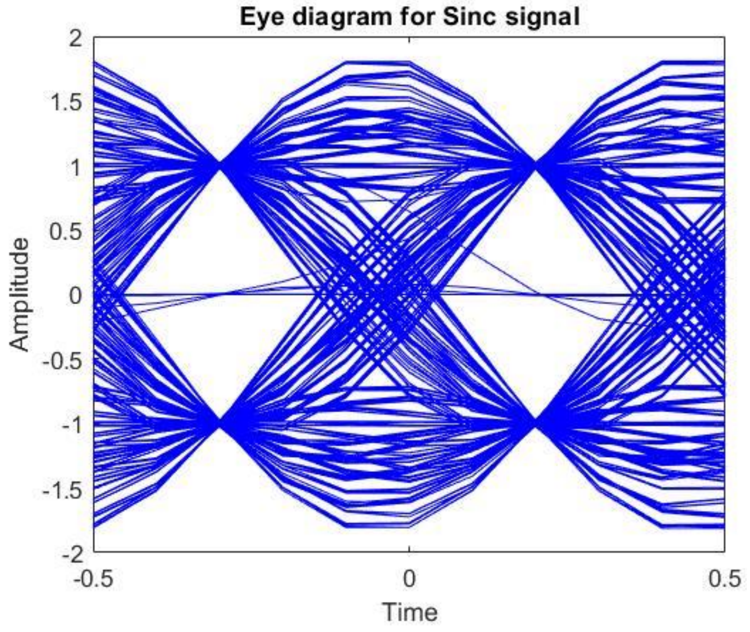
Observations

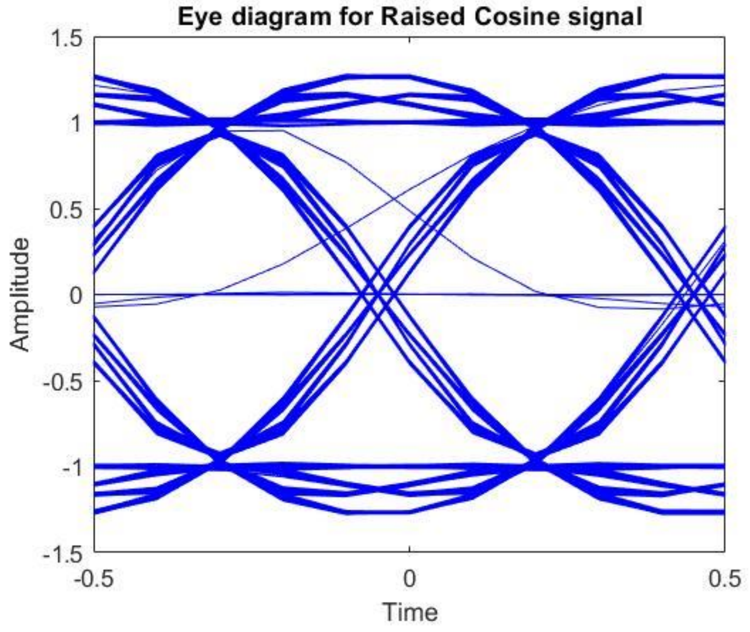
- Rectangular signal has the largest bandwidth followed by raised cosine and sinc finally.
- Sinc signal has greater power at many frequencies as compared to other 2 cases.

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.

Case 2:
Tb = 0.05







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.

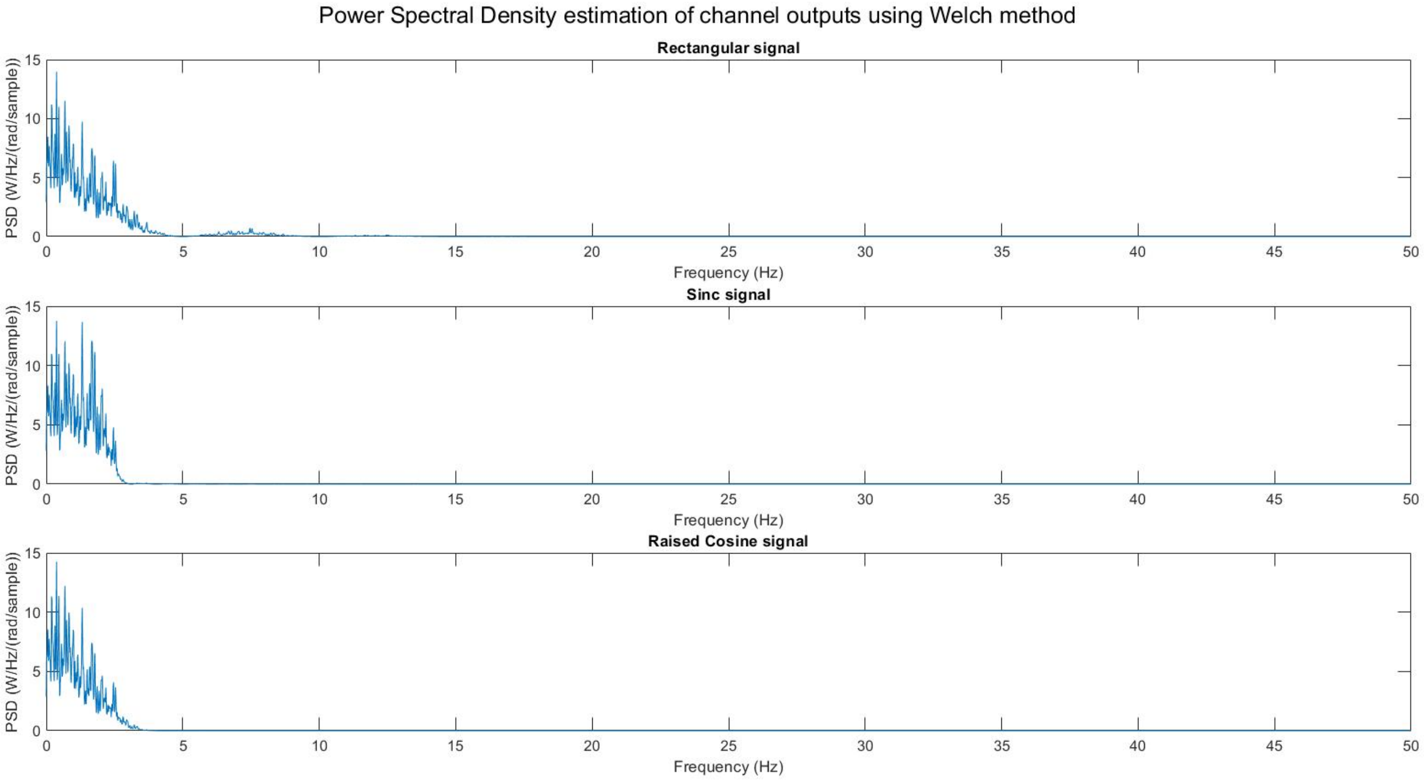
Case 2:
Tb = 0.05

Observations

- Increased amplitude distortion.
- Sinc and Raised cosine now have non-zero significant ISI at the middle of a pulse.
- Timing synchronisation at sampling point (middle of pulse, since eye-opening is maximum there) has huge penalty if not done correctly for all the three signals, with rectangular having the least of it.
- Sinc has the least eye-width. Rectangular has the largest eye-width.
- Zero-crossing synchronization has become much more difficult for sinc signal. Raised cosine and rectangular, though better, now face this synchronization issue.
- The above happened due to higher frequencies in the transmitted signal and hence cut-off from the bandlimited channel having cut-off frequency same as earlier.

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.

Case 3:
Tb = 0.2

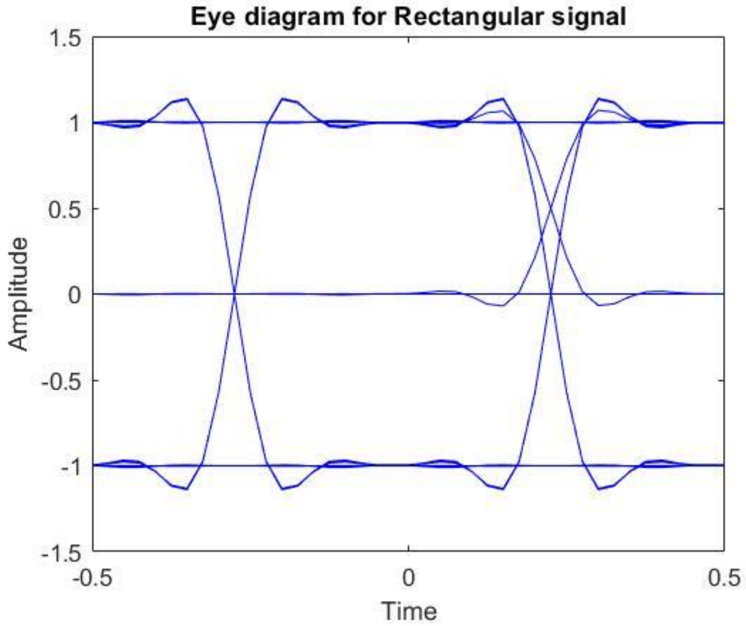


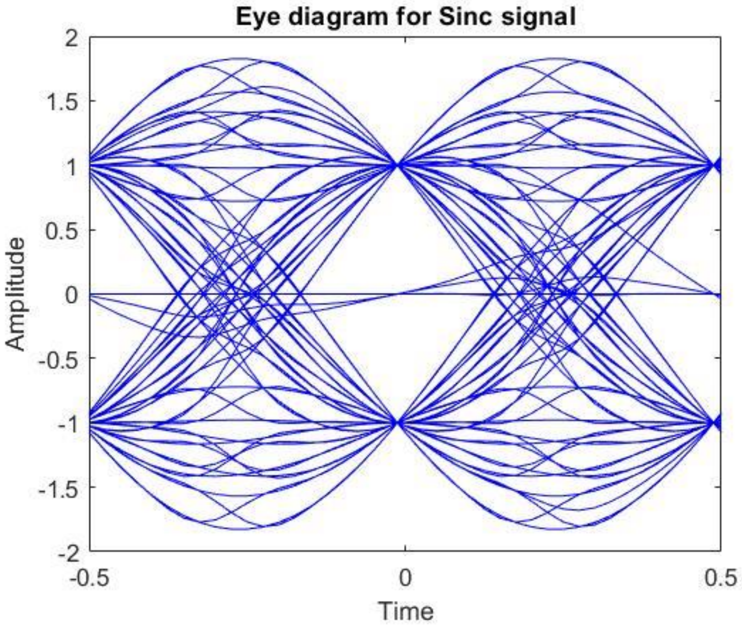
Observations

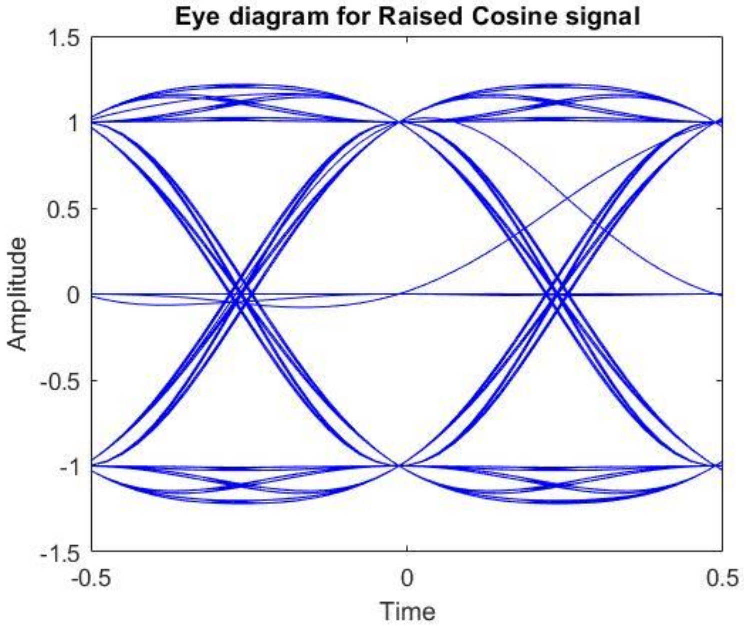
- Rectangular signal has the largest bandwidth followed by raised cosine and sinc finally.
- Rectangular signal also has non-zero power at frequencies around 7 Hz, which is not present in the other two cases.
- Sinc signal has greater power at many frequencies as compared to other 2 cases.

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.

Case 3:
Tb = 0.2







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.

Case 3:
Tb = 0.2

Observations

- Decreased amplitude distortion.
- All three signals have non-zero significant ISI at the middle of a pulse.
- Timing synchronisation at sampling point (middle of pulse, since eye-opening is maximum there) has huge penalty if not done correctly for sinc signal. Raised cosine has lesser penality, with rectangular having the least of it.
- Sinc has the least eye-width. Rectangular has the largest eye-width.
- Zero-crossing synchronization has become comparatively easier (though still difficult) for sinc signal. The situation is much better for raised cosine and ideal for rectangular.
- The above happened due to lower frequencies in the transmitted signal and hence lesser cut-off from the bandlimited channel having cut-off frequency same as earlier.

Result and MATLAB Codes

The effects of bandlimitedness of a baseband channel and resulting ISI were simulated in MATLAB assuming perfect frame and symbol synchronization.

MATLAB codes written for this lab work can be found here.