Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN 3053: Digital Communication I

LAB ASSIGNMENT

REPORT ON EYE DIAGRAMS OF PAM SIGNALLING

NAME	INDEX NO.
Abeywardena K.G	160005C
Adheesha K.G	160009R

This report was submitted in partial fulfillment of the requirements for the module EN 3053: Digital Communications I

Date of Submission: 03/05/2019

ABSTRACT

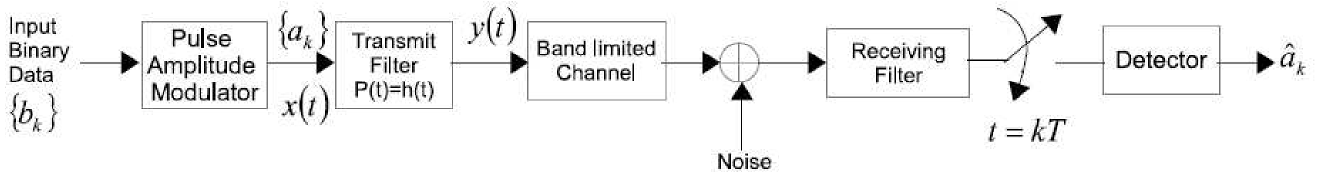
In any communication system, there are three major parts. They are the transmitter, medium and the receiver. Narrowing the scope of communication systems to the digital communication systems, a modulated baseband signal should be passed to through a 'Pulse Shaping Filter' before the transmission. When designing the pulse shapes, we need to consider the errors that the channel causes specially as the channel behaves as a low-pass filter. Communication engineers should make the communication systems as far as robust to the errors introduced by the mediums. For this we need to analyze the robustness of the channel to these various types of errors and fine tune the transmitter and receiver circuits to compensate these errors. To obtain such information we can use the engineering tool "Eye Diagrams". In this report we have obtained the eye diagrams for two modulation schemes using two types of pulse shapes and interpreted the information that we obtained from the diagrams.

Content

1. INTRODUCTION

A communication system is a system through which a message is generated, converted , transmitted and received by two or more parties. Narrowing down the scope of the communication systems, in this report we will consider a baseband digital communication system.

A baseband communication system model can be seen in the below diagram.



- Figure 1.1: Baseband Communication System Model -

The source generates the message that needs to be transmitted to another party. This message can be an analog or a digital message. For certain advantages, we use digital messages for transmission. Hence even the analog messages are converted to digital messages using Analog to Digital conversion circuitry,

Then we use a modulation technique to map the input binary data to a set if symbols before transmitting. In this, we consider the Pulse Amplitude Modulation (PAM) where the pulse amplitude is changed according to the bits input.

$$b_k \rightarrow a_k \;\; ; \text{ where } b_k \in \{0,1\} \text{ and } a_k \in \{\pm 1, \pm 2, \pm 3, \ldots\ldots, \pm(M-1)\}$$

This set of symbols cannot be sent through a channel as they are. To transmit the set of symbols through wired or wireless transmission mediums, first we need to embed the symbols to electrical or light pulses. For that we use the Pulse Shaping Filters with an impulse response of $p(t)$ which should be designed carefully such that the communication system is robust to the noise and interferences created by the channel.

$$y(t) = \sum_{k=-(M-1)}^{M-1} a_k \times p(t - kT_b) \qquad ; \text{where } T_b = {}^{1}/_{R_b} \text{ is the pulse duration}$$

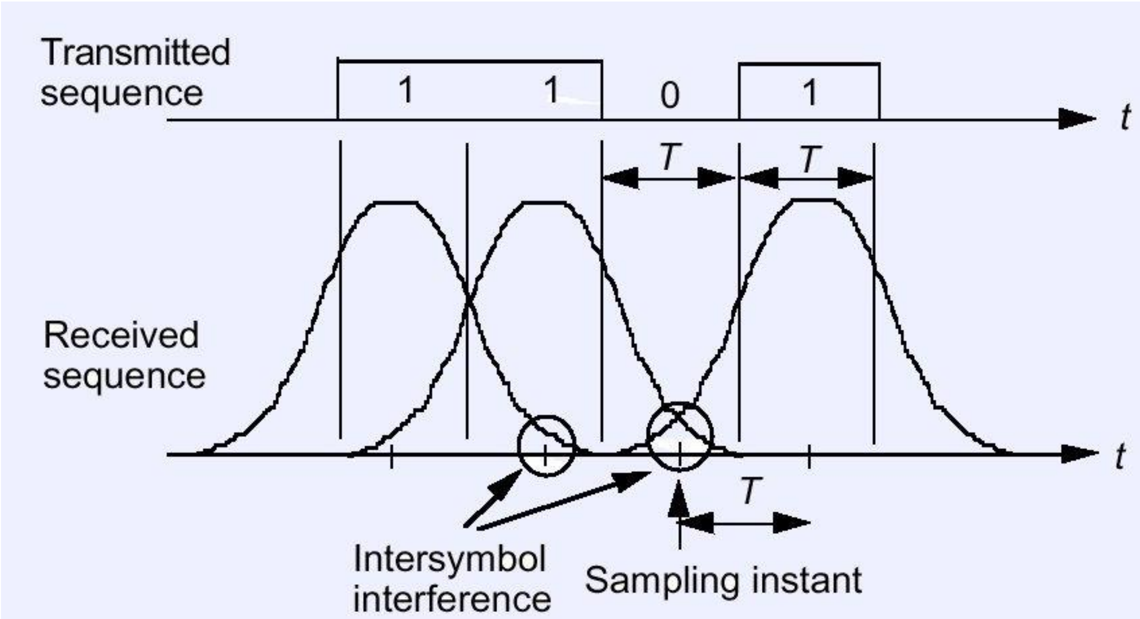
(R_b is bit rate or symbol rate)

After performing the line coding, we put this baseband signal into the channel through which the pulses are now being propagated. The channel introduces various types of errors to the pulses propagated. Few of them can be listed as follows;

1. Introduction of Additive White Gaussian Noise to the transmitted symbols
   - The Channel introduces the AWGN that will be super imposed on the pulses/ symbols transmitted. Due to this, the symbols are dispersed from there intended positions as the pulses transmitted are getting distorted due to the noise added to these pulses. Due to AWGN, at the receiver the sampled message will be erroneous which will lead to bit errors in the message.

2. Inter symbol Interferences (ISI)
   - Practically, the channels do not have unlimited bandwidth. They are characterized as 'Low-pass Filters' with a bandwidth of $W\ (Hz)$ and a transfer function (TF) of $C(f) = |C(f)| \times e^{j[\emptyset(f)]}$ where $|C(f)|$ and $\emptyset(f)$ respectively are the amplitude response and the phase response of the channel
   - Due to the bandwidth being limited to $W\ (Hz)$, any pulse having a bandwidth more than $W\ (Hz)$ will get some frequency components filtered-out.

- This distortion in spectrum of the pulse makes the pulse spread in the time domain. (Bandlimited signal will be not limited in time domain)
- Spreading the pulses more than their allotted pulse duration T_b, will cause interference with the neighboring pulses which is known as Inter Symbol Interferences (ISI).



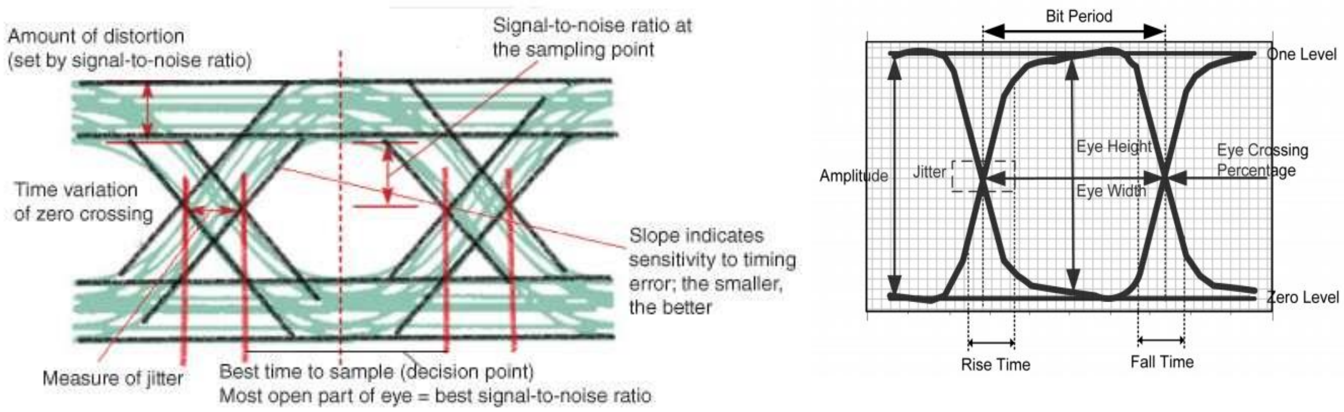
- Figure 1.2: How the ISI occurs at the sampling instances -

3. Synchronization errors : This is where the timing of the bits will be causing errors at the receiver as the timing of bits transmitted and received are not matched

A communication engineer should design a communication system in a way that reduces the effects of these types of errors. There should be an engineering tool to analyze how much a given system is robust to these errors. This technique is known as the 'Eye Diagram'.

Eye Diagram

An eye diagram is a common indicator of the quality of signals in high-speed digital transmissions. An oscilloscope generates an eye diagram by overlaying sweeps of different segments of a long data stream driven by a master clock.



- Figure 1.3: The Eye Diagram and the information we obtain -

Figure 1.3 shows some generic eye diagrams and the different information that we can extract from which we can analyze the robustness of the system to different types of errors mentioned above.

Below are some of the characteristics of an eye diagram and the information they convey.

i. The Slope of the eye :

- This shows the *sensitivity to the sampling time*. In other words, this shows the *level of immunity to the synchronization errors*.

$$Synchronization\ errors \propto Slope$$

- Higher the slope of the eye diagram, higher the synchronization errors that will occur where the timing information can be difficult to get.

ii. Optimum Sampling instant:

- This shows the optimum sampling point at which we should sample the pulses to extract the information.
- This is given at the maximum eye opening.

iii. Eye Height:

- This is an indication of the noise margin where $noise\ margin = {}^{1}/_{2} \times Eye\ height.$
- Higher the eye height, higher the noise margin.
- This will cause high robustness to the AWGN that is introduced by the channel.
- This can also be defined as the SNR at the optimum sampling point.

iv. Eye Width:

- This represents the region with the highest SNR.
- Further, this represents the bit/ symbol period (T_b) , the reciprocal of which gives the data rate.
- Higher the data transmission rates are, narrower the eye diagram is.
- Wider the eye, lower the probability of happening errors due to sampling.

v. Time variation of Level-Crossing (Zero-Crossing):

- This shows the time jitter (timing off-sets) of the pulses transmitted through the channel.
- Time jitter occurs when there is a mismatch between the rise time and the fall time of the pulses.
- Lower the width of the level-crossing ambiguity, better robustness will be there for the ISIs.
- This is more critical in high-speed data transmission systems.

vi. Peak Distortion:

- This shows by how much the peak amplitude of the pulse can change during the transmission due to the AWGN.
- Lower the value better robustness can be obtained for the AWGN.

Using the eye diagrams, we can evaluate the optimum pulse shapes to be used such that the ISI is minimized. These designing is done based on the Nyquist 1st and 2nd criteria for 0 ISI and Controlled ISI respectively.

In this assignment we consider two such pulse shapes obtained through the Nyquist 1st Criteria.

Nyquist 1st Criteria requires the pulse shape to have non-zero value at $t = 0$ where as it should have zero amplitudes at $\pm nT_b$.

$$p(t) = \begin{cases} 1 & t = 0 \\ 0 & t = \pm nT_b \end{cases}$$

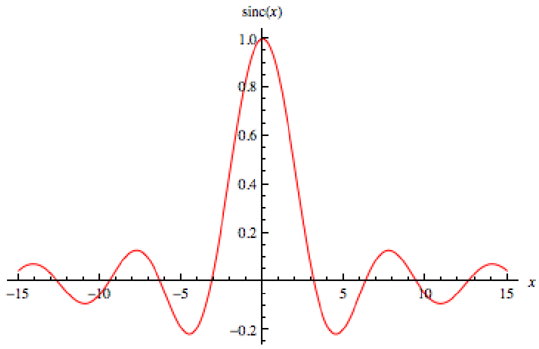
Two such pulse shapes are;

i. Sinc Pulse
ii. Raise Cosine Pulse with a roll-off defined

I. Sinc Pulse

$$p(t) = \begin{cases} 1 & t = 0 \\ \dfrac{\sin(\pi R_b t)}{\pi R_b t} & t \neq 0 \end{cases}$$

This is a pulse which extends from $-\infty \; to + \infty$. In other words, the pulse shape is not time limited. Since the decay is $1/_t$ the side lobes of the pulse are large. Due to these reasons there will be time jitters.

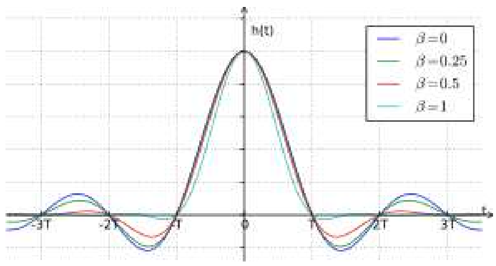


- Figure 1.4: Sinc Pulse -

II. Raised Cosine

$$p(t) = \begin{cases} R_b & t = 0 \\ R_b sinc(\pi R_b t)\dfrac{\cos(\pi\gamma R_b t)}{1-(2\gamma R_b t)^2} & otherwise \end{cases}$$

This has a decay of $1/_{t^3}$ which makes the side lobes small. Hence this is very robust to the synchronization errors.



- Figure 1.5: Raised Cosine for different γ values -

In the discussion part, the robustness of three systems based on these two types of pulse shapes are discussed using the eye diagrams obtained.

2. METHOD

This Lab Assignment comprises three tasks as follows.

Task 01

In this task we have created a Binary Phase Shift keying (BPSK) modulated signal from a random bit stream of 1000 bits that we crea2.ted using the MatLab built-in function.

The mapping between the bits and the symbols are as follows.

$0 \rightarrow -1\ (180°\ phase)$ $\qquad$ $1 \rightarrow +1\ (0°\ phase)$

We used a sampling frequency $f_s = 10Hz$, which is also equal to the bit rate (R_b), and created a BPSK impulse train.

Next, we created three pulse shapes; Sinc pulse, Raised Cosine with roll-off = 0.5 and Raised Cosine with roll-off = 1.0. The created BPSK impulse train was then convoluted with these pulse shapes separately and obtained the transmit signal into the channel. Before that we did an up-sampling to match the sampling frequency.

After the convolution we created the eye diagrams for these signals separately and plotted them on the graphs.

Task 02

In the second task we introduced AWGN to the signal to analyze how the communication system works for the noise which is being added by the channel. For that we created a 1D noise array with the noise power based on 10dB SNR. Since the BPSK modulated signal has an average bit (symbol) energy of 1, $N_0 = \left(\frac{1}{10^{0.1 \times 10dB}}\right) = 0.1$.

Then this noise array was added to the BPSK signal we created in the task 01 and obtained the eye diagrams and analyzed how robust the system is for the AWGN under different pulse shapes.

Task 03

In this part, we extended the analysis of eye diagrams to 4 level PAM modulated signal.

3. DISCUSSION

In this Lab Assignment we are analyzing the robustness of a digital communication system by using an engineering tool called 'Eye Diagram'. To analyze the robustness for the errors that could happen, first we need to create a baseband signal based on a message signal generated by the source.

The message we have created is an equi-probable bit array of 0s and 1s which is of 1000 bits long. We have used this much of samples such that we ensure there are enough samples to create a more accurate eye diagram.

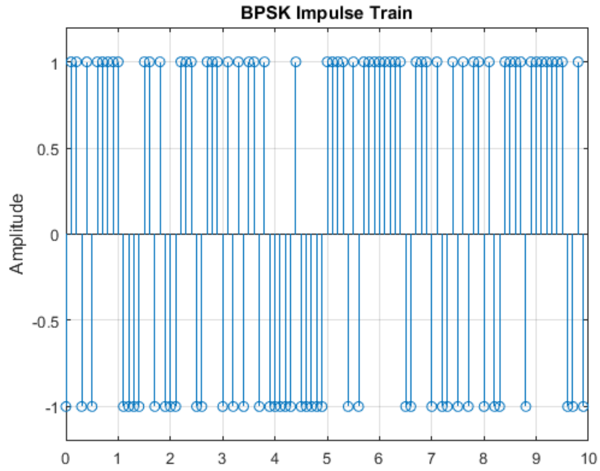
In the task 01, we have mapped these to a set of two symbols using BPSK modulation technique.

$$All\ 0s \rightarrow -1\ (180°\ Phase)$$
$$All\ 1s \rightarrow +1\ (0°\ Phase)$$

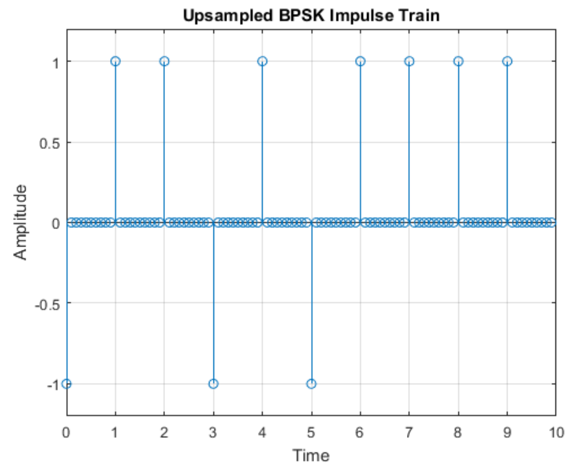
Before sending through the pulse shape filters, we do an up-sampling to match symbol rate to the sampling frequency that we are using.

This creates the baseband signal we need to be convolved with the pulse shape filters. As mentioned before here we use three pulses;

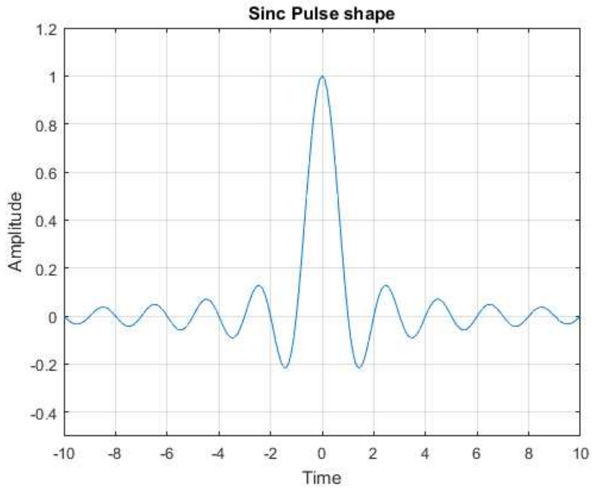
i. Sinc Pulse (Figure 3.3)
ii. Raised Cosine with roll-off = 0.5 (Figure 3.4)
iii. Raised Cosine with roll-off = 1 (Figure 3.5)



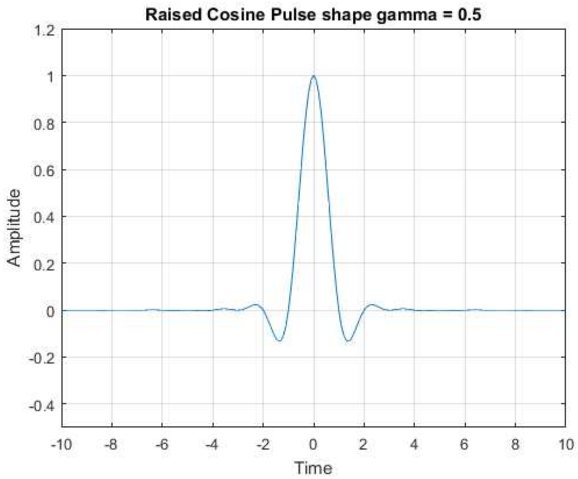
- Figure 3.1: BPSK Impulse train -



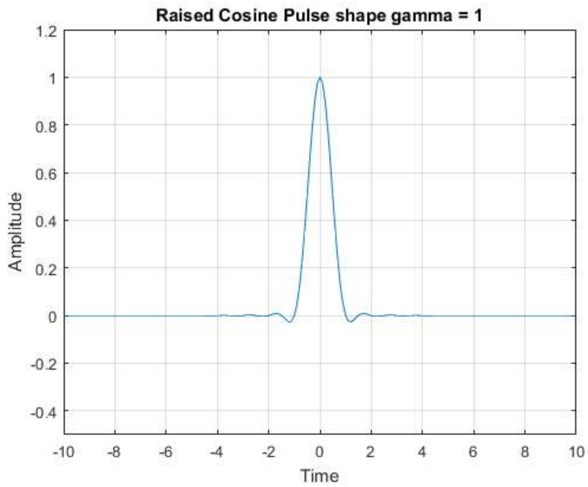
- Figure 3.2: Up-sampled BPSK Impulse train -



- Figure 3.3: Sinc Pulse Shape -



- Figure 3.4: Raised Cosine Pulse with roll-off = 0.5 -

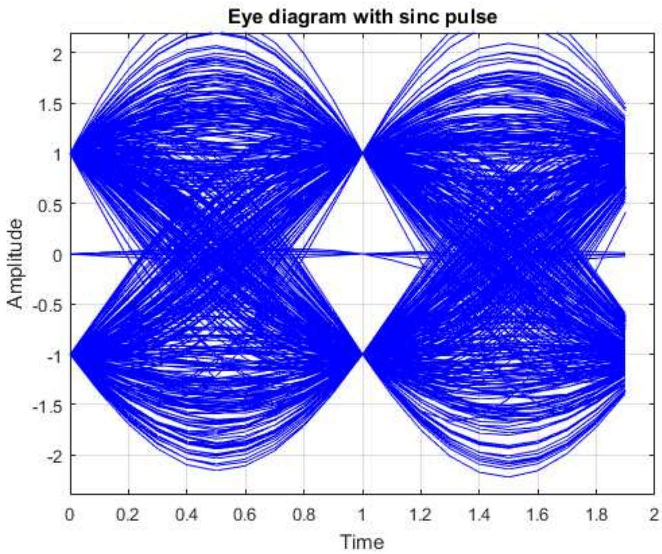


- Figure 3.5: Raised Cosine Pulse with roll-off = 1.0 -

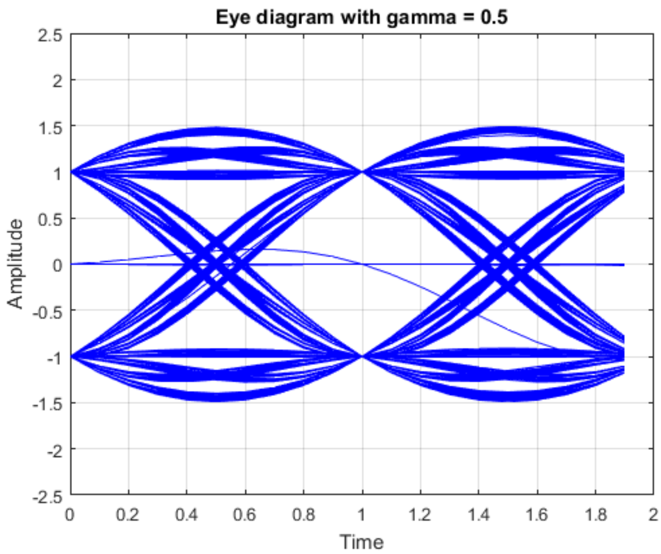
Comparing the pulse shapes that we are using for the analysis, considerable fluctuations can be seen in the sinc pulse from $-\infty\ to + \infty$ while the raised cosine pulses (both with $\gamma = 0.5\ and\ 1$) die down after ± 4. Further by considering the side lobes, we can see that the raised cosine pulses have smaller side lobes compared to the sinc and higher the roll-off smaller the side lobes they have.

Considering this we can conclude that the digital communication systems with raised cosine pulses are more robust to the errors than the sinc function. This can be verified using the eye diagrams we have obtained.

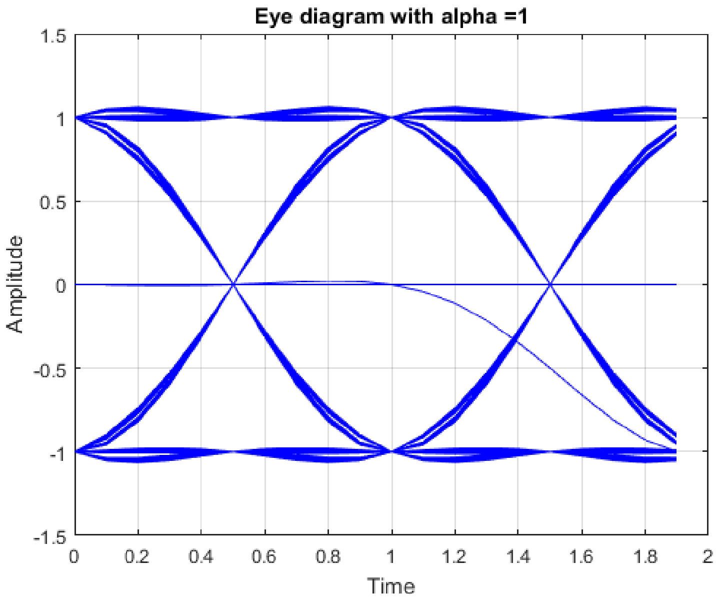
Here we check the robustness to the ISI and synchronization errors of the communication system. (As no noise is being introduced to the system)



- Figure 3.6: Eye Diagram for Sinc Pulse Shape -



- Figure 3.7: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 0.5) -

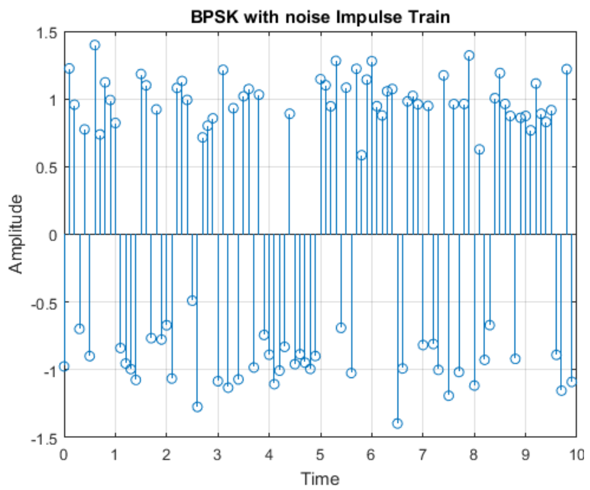


- Figure 3.8: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 1.0) -

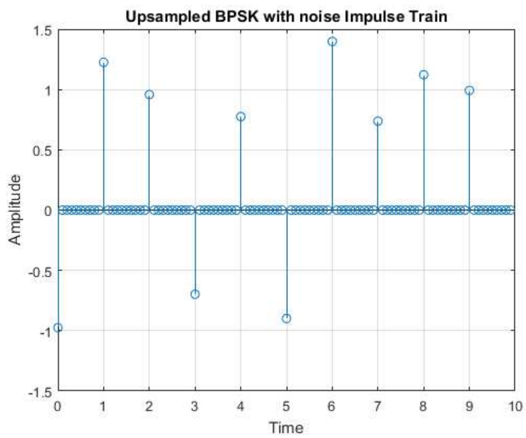
- Table 1: Comparison of Eye diagrams -

Characteristic of the Eye diagram	Information	Sinc Pulse	Raised Cosine Pulse (Roll-off = 0.5)	Raised Cosine Pulse (Roll-off =1)
Slope of the eye	Level of Synchronization Errors	Highest Slope of the three. High probability for timing errors	Slope Varies between a range. Compared to the other two, consists lowest slope as well. More robust to the timing errors.	Average Slope making this to be robust to the timing errors than sinc pulse but more errors than raised cosine with roll-off =0.5
Eye Height	Noise Immunity (0.5 * Height of Eye at optimum sampling point)	No noise is added in this instance hence better noise margin is present	No noise is added in this instance hence better noise margin is present	No noise is added in this instance hence better noise margin is present
Eye Width	Error free sampling region	Lowest of the three. Has less range to the error free sampling. Less robust to the sampling errors (ISI).	Wider than the Sinc Pulse but narrower than roll-off =1 raised cosine pulse. Medium range of sampling without any error.	Widest of the three. Has a larger region to sample the data with better SNR.
Time variation at zero-crossing	Time Jitter (Timing off-set)	Very higher jitter as the time variation at the zero crossing is high. High difference between rise and fall times.	It has some jitter due to some imbalance between rise and fall times of the pulse. Better than the Sinc pulse but not good as raised cosine with roll-off =1	No jitter. The rise and fall curves of the pulse converges at a point when crossing the zero-level. High robustness to the timing offsets hence robust to ISI errors
Thickness at the peak	Peak Deviation	No peak deviation.	Np peak deviation	No peak Deviation

Now we add AWGN to the pulses we transmit and analyze the eye diagrams we obtained.

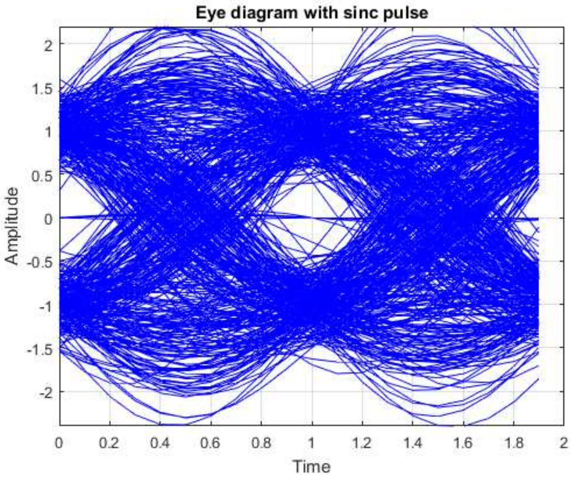


- Figure 3.9: BPSK with AWGN -

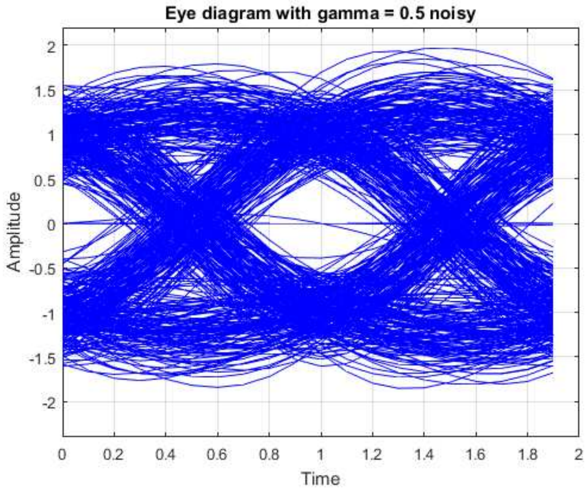


- Figure 3.10: Up-sampled BPSK with AWGN -

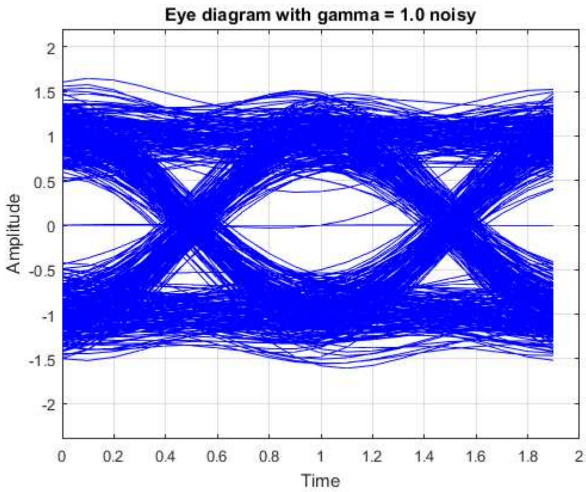
We can see that when the AWGN is added, our BPSK impulse train will have different amplitudes rather than ± 1 which in turns will change the amplitude of the pulses we transmit. This can lead to further errors which were not visible in the previous comparison.



- Figure 3.11: Eye Diagram for Sinc Pulse Shape -



- Figure 3.12: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 0.5) -



- Figure 3.13: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 1.0) -

- Table 2: Comparison of Eye diagrams with noise -

Characteristic of the Eye diagram	Information	Sinc Pulse	Raised Cosine Pulse (Roll-off = 0.5)	Raised Cosine Pulse (Roll-off =1)
Slope of the eye	Level of Synchronization Errors	Very High Slope. High possibility of synchronization error occurrence	Low Slope. Low possibility of synchronization error occurrence.	Average Slope (Between Sinc and Raised Cosine with roll-off = 0.5) Average chance of synchronization errors.

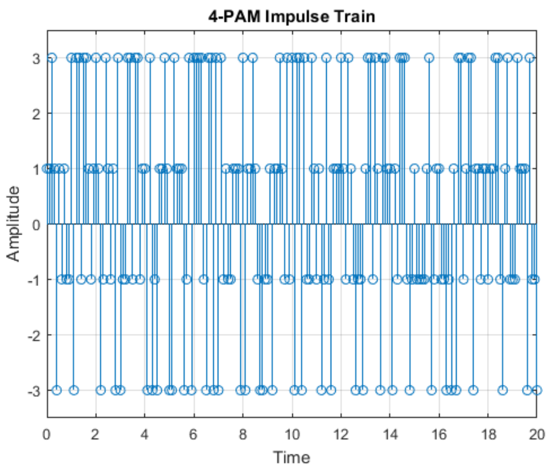
Eye Height	Noise Immunity (0.5 * Height of Eye at optimum sampling point)	Has diminished further than when there was no noise present. Low SNR at the sampling. High Bit error occurrence at sampling.	The height has diminished but opened more than the sinc with noise. Possibility of sampling errors has increased than before but better than sinc pulse	Height has reduced but the highest height out of the three eye diagrams with AWGN present. Better robustness to the sampling errors compared to other two in the presence of noise
Eye Width	Error free region (possible error free sampling region)	Width has further reduced. Almost all the region is not good for sampling with error free. Low robustness to the sampling errors.	Width has reduced due to the noise. Still a considerable region of error free sampling is present. Robust to sampling errors than the sinc pulse but worse than raised cosine with roll-off = 1.0	Width had reduced but still maintains adequate width for error free sampling. High robust to sampling errors compared to other two pulses.
Time variation at the zero-crossing	Time Jitter (timing Offset)	Jitter has further increased. Lowest robustness to the jitter or timing offsets,	Jitter has increased. Average robustness to the jitter.	Earlier there was no jitter present but now some jitter is visible. Still it is the lowest of three hence better robustness for jitter is shown.
Thickness at the peak	Peak Deviation	The peak deviation is preset due to the presence of the SNR value at the sampling region. This cause some distortions in the pulse amplitudes which in turns can cause sampling errors.	The peak deviation is preset due to the presence of the SNR value at the sampling region. This cause some distortions in the pulse amplitudes which in turns can cause sampling errors.	The peak deviation is preset due to the presence of the SNR value at the sampling region. This cause some distortions in the pulse amplitudes which in turns can cause sampling errors.

Next the results are extended to the 4-PAM baseband signal. In this the mapping of the bits is done as following.

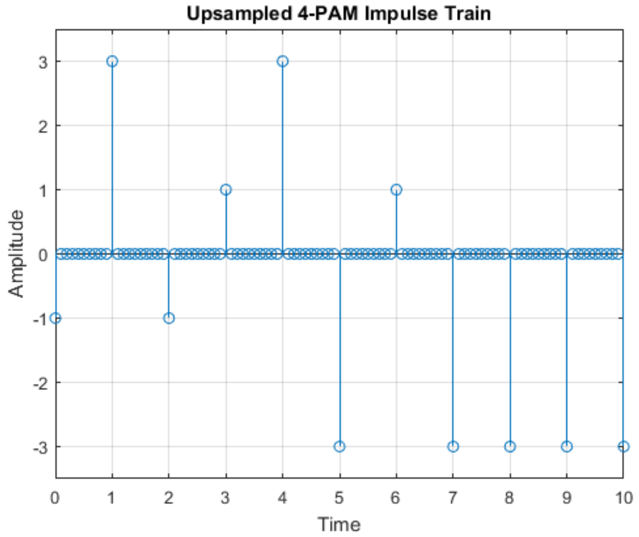
$$00 \rightarrow -3$$
$$01 \rightarrow -1$$
$$11 \rightarrow +1$$
$$10 \rightarrow +3$$

Then this is also up-sampled to match the symbol rate to the sampling frequency.

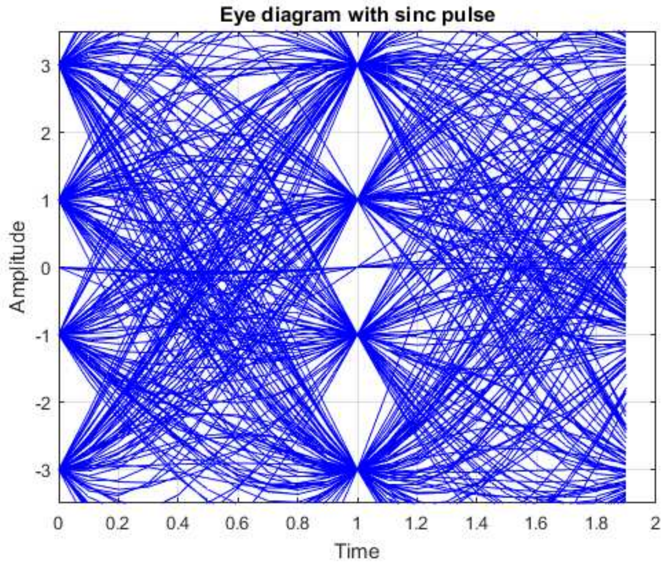
Then the up-sampled impulse train is convolved with the three pulse shape filters just like in the above discussion and obtain the eye diagrams as follows.



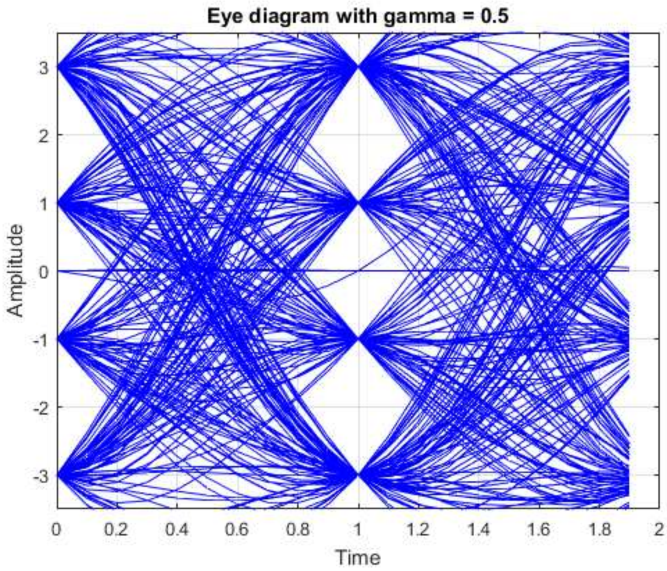
- Figure 3.14: 4-PAM signal -



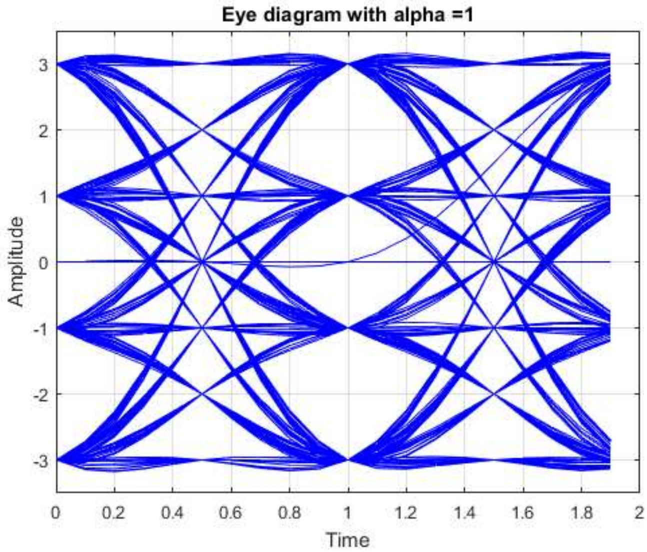
- Figure 3.15: Up-sampled 4-PAM Impulse train -



- Figure 3.16: Eye Diagram for Sinc Pulse Shape -



- Figure 3.17: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 0.5) -



- Figure 3.18: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 1.0) -

- Table 3: Comparison of Eye diagrams 4-PAM -

Characteristic of the Eye diagram	**Information**	**Sinc Pulse**	**Raised Cosine Pulse (Roll-off = 0.5)**	**Raised Cosine Pulse (Roll-off =1)**
Slope of the eye	Level of Synchronization Errors	Highest slope of the three diagrams. Least robust to the synchronization errors.	Average slope out of the three diagrams. Better robustness to the synchronization than sinc pulse system.	Lowest slope of the three diagrams. High robustness to the synch errors.
Eye Height	Noise Immunity (0.5 * Height of Eye at optimum sampling point)	Since no noise is being introduced, we have the opened eye and the heights are approx. similar of all three diagrams.	Since no noise is being introduced, we have the opened eye and the heights are approx. similar of all three diagrams.	Since no noise is being introduced, we have the opened eye and the heights are approx. similar of all three diagrams.

Eye Width	Error free region (possible error free sampling region)	Narrowest eye of the three. Least error free sampling region hence high chance it has sampling errors.	Wider than the sinc pulse system yet has a narrow eye. Has more error free sampling region than sinc pulse.	Widest of all. Highly robust to the sample errors as it has wider error free sample region.
Time variation at the zero-crossing	Time Jitter (timing Offset)	Wide time variation at the level crossings. High time jitter (timing offset) Least robust to sampling errors	Wider than the BPSK but narrower than the 4-PAM sinc system. Some robustness is there for sampling errors as comparatively the jitter is acceptable.	Some jitter is present compared to the BPSK, but it is tolerable. High robustness too the sampling errors due to that.
Thickness at the peak	Peak Deviation	No peak deviation as no noise is present	No peak deviation as no noise is present	No peak deviation as no noise is present

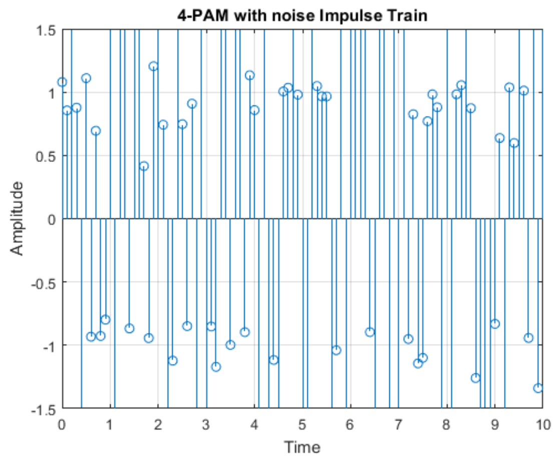
Now we add the noise to the 4-PAM signal. Now the average signal energy is calculated as follows.

$$e_b = \frac{9+1+1+9}{4} = 5$$

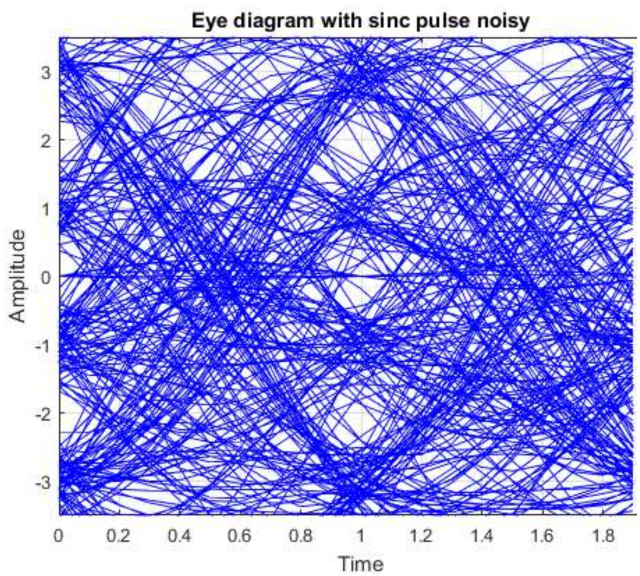
Hence the to maintain the same SNR ratio, the noise power need to rise to the below level.

$$N_0 = \frac{5}{10^{0.1\times 10dB}} = 0.5$$

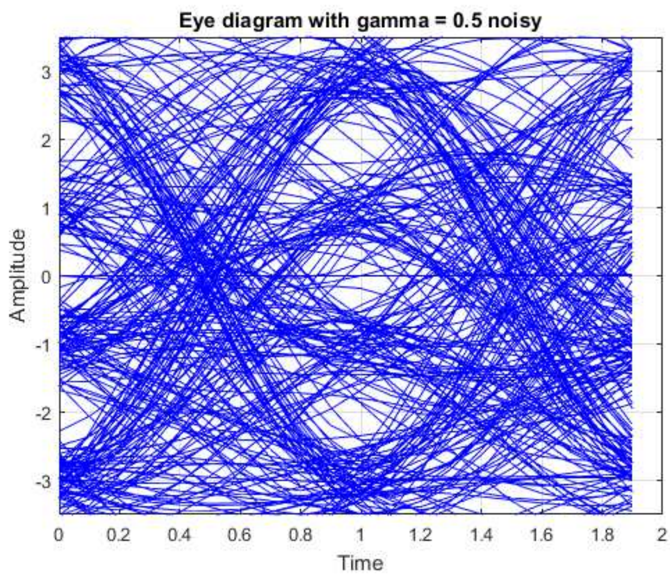
Now we obtain the eye diagrams and they are shown as follows.



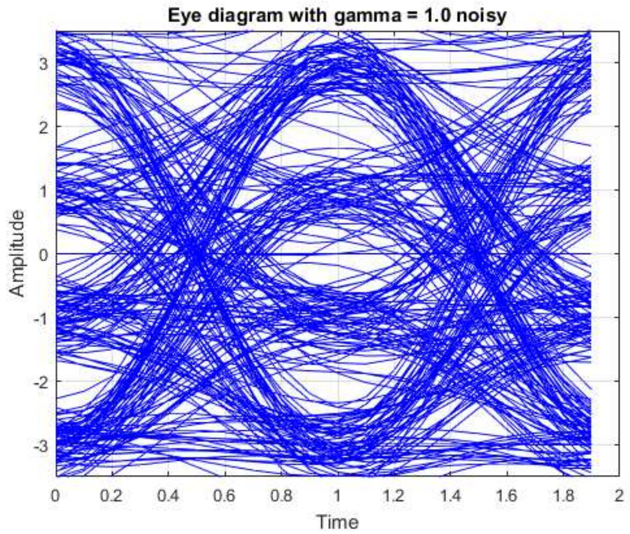
- Figure 3.19: 4-PAM signal with noise -



- Figure 3.20: Eye Diagram for Sinc Pulse Shape -



- Figure 3.21: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 0.5) -



- Figure 3.22: Eye Diagram for Raised Cosine Pulse Shape (roll-off = 1.0) -

- Table 4: Comparison of Eye diagrams 4-PAM with noise-

Characteristic of the Eye diagram	Information	Sinc Pulse	Raised Cosine Pulse (Roll-off = 0.5)	Raised Cosine Pulse (Roll-off =1)
Slope of the eye	Level of Synchronization Errors	Slope is slightly higher than the other two systems. Less Robust to the synch errors	Slope is slightly lower than the other two. Still this system is not robust to the synch errors.	Slope is slightly higher than raised cosine with roll-off = 0.5 but lower than the sinc system. Still this also is not that robust to the synch errors.
Eye Height	Noise Immunity (0.5 * Height of Eye at optimum sampling point)	Due to the noise the eyes are almost shut. i.e. lower noise margin present at the sampling point. Hence least robust to the sampling errors.	Even the opening of the eyes are better than sinc pulse shape, still it is not considerable. Hence this is not that robust as previous cases	Best eye opening out of three. Considerable noise margin is present which means less sampling errors than other two.
Eye Width	Error free region (possible error free sampling region)	Almost 0 eye width. Error free sampling region is hard to be found. Sampling errors are high based on the diagram.	Wider than the sinc pulse but still no considerable error free sampling region present. Hence low robustness to the sampling errors	Considerable error free sampling region is present. Comparatively, will have better robustness to the sampling errors
Time variations at zero-crossing	Time Jitter (timing Offset)	Highest time deviation at the level crossing. High time jitter is preset. Least robust to the sampling errors.	Lesser jitter when compared to sinc system.	Least jitter out of the three diagrams. More robust for the sampling errors than other two systems.
Thickness at the peak	Peak Deviation	Approx. similar peak deviation is present in all three diagrams.	Approx. similar peak deviation is present in all three diagrams.	Approx. similar peak deviation is present in all three diagrams.

4. CONCLUSION

From the above comparison of eye diagrams, we can conclude:

i. Raised cosine with roll-off = 1.0 robust to synch errors, sampling errors and noise in all the cases we considered
ii. Sinc pulse shaped system is the worst system which is having worst results for sampling and synch errors. Noise it has got acceptable level of robustness

Hence the best digital communication out of the three we compared is the system with a pulse shaping filter of raised cosine with a roll-off = 1.0.

5. BIBLIOGRAPHY

[1] Lecture notes of Digital Communication I - Dr. Kasun Hemachandra

[2] Understanding Data Eye Diagram Methodology for Analyzing High Speed Digital Signals

https://www.onsemi.cn/PowerSolutions/document/AND9075-D.PDF

[3] Eye Diagram Basics: Reading and applying eye diagrams by Behera D., Varshney S., Srivastava S., Tiwari S.

https://www.edn.com/design/test-and-measurement/4389368/Eye-Diagram-Basics-Reading-and-applying-eye-diagrams

6. APPENDICES

```
% Digital Communication I - Assignment I
% Authors : Abeywardena K.G. | Adhessha K.G.

clear all; close all; clc;

%Defining the system Parameters
BitLength  = 10^3;                    % No of Bits Transmitted
SampleFreq = 10;                      % sampling frequency in Hz
SNR_dB = 10;
NoisePower = 1./(10.^(0.1*SNR_dB));        % Noise Power (Eb = 1 in BPSK)

time = -SampleFreq:1/SampleFreq:SampleFreq; % Time Array

% Generating the BPSK Signal
% Mapping 0 -> -1  and 1 -> 1  (0 phase and 180 phase)
BPSKSignal = 2*(rand(1,BitLength)>0.5)-1;

t = 0:1/SampleFreq:99/SampleFreq;
stem(t, BPSKSignal(1:100)); xlabel('Time'); ylabel('Amplitude');
title('BPSK Impulse Train');
axis([0 10 -1.2 1.2]); grid on;

% Noise Array Generation based on SNR = 10dB
Noise1D = normrnd (0 , sqrt(NoisePower/2), [1, BitLength]);
AWGN_TX = BPSKSignal + Noise1D;

figure;
stem(t, AWGN_TX(1:100)); xlabel('Time'); ylabel('Amplitude');
title('BPSK with noise Impulse Train');
axis([0 10 -1.5 1.5]); grid on;



% Sinc Pulse Shape
Sinc_Num = sin(pi*time);                    % numerator of the sinc function
Sinc_Den = (pi*time);                       % denominator of the sinc function
Sinc_DenZero = find(abs(Sinc_Den) < 10^-10);    % Finding the t=0 position
Sinc_Filt = Sinc_Num./Sinc_Den;
Sinc_Filt(Sinc_DenZero) = 1;                % Defining the t=0 value

figure;
plot(time, Sinc_Filt);
title('Sinc Pulse shape');
xlabel('Time'); ylabel('Amplitude');
axis([-SampleFreq SampleFreq -0.5 1.2]); grid on

% Raised Cosine Pulse Shape
% roll-off = 0.5
roll_off = 0.5;
cos_Num = cos(roll_off*pi*time);
cos_Den = (1 - (2 * roll_off * time).^2);
cos_DenZero = abs(cos_Den)<10^-10;
RaisedCosine = cos_Num./cos_Den;
```

```
RaisedCosine(cos_DenZero) = pi/4;

RC_gamma5 = Sinc_Filt.*RaisedCosine;    % Getting the complete raised cosine pulse

figure;
plot(time, RC_gamma5);
title('Raised Cosine Pulse shape gamma = 0.5');
xlabel('Time'); ylabel('Amplitude');
axis([-SampleFreq SampleFreq -0.5 1.2]); grid on

% roll-off = 1
roll_off = 1;
cos_Num = cos(roll_off * pi * time);
cos_Den = (1-(2 * roll_off * time).^2);
cos_DenZero = find(abs(cos_Den)<10^-20);
RaisedCosine = cos_Num./cos_Den;
RaisedCosine(cos_DenZero) = pi/4;

RC_gamma1 = Sinc_Filt.*RaisedCosine;    % Getting the complete raised cosine pulse

figure;
plot(time, RC_gamma1);
title('Raised Cosine Pulse shape gamma = 1');
xlabel('Time'); ylabel('Amplitude');
axis([-SampleFreq SampleFreq -0.5 1.2]); grid on

% upsampling the transmit sequence
% Without Noise
BPSK_Upsample = [BPSKSignal;zeros(SampleFreq-1,length(BPSKSignal))]; %Upsampling the BPSK to match the sampling frequency
BPSK_U = BPSK_Upsample(:).';

figure;
stem(t, BPSK_U(1:100)); xlabel('Time'); ylabel('Amplitude');
title('Upsampled BPSK Impulse Train');
axis([0 10 -1.2 1.2]); grid on;

% With Noise
AWGNTx_Upsample = [AWGN_TX;zeros(SampleFreq-1,length(BPSKSignal))];
AWGNTx_U = AWGNTx_Upsample(:);

figure;
stem(t, AWGNTx_U(1:100)); xlabel('Time'); ylabel('Amplitude');
title('Upsampled BPSK with noise Impulse Train');
axis([0 10 -1.5 1.5]); grid on;

% Pulse Shaped sequences
% Without Noise
Conv_sincpulse = conv(BPSK_U, Sinc_Filt);
Conv_RCgamma5 = conv(BPSK_U,RC_gamma5);
Conv_RCgamma1 = conv(BPSK_U,RC_gamma1);

% With Noise
Conv_sincnoise = conv(AWGNTx_U,Sinc_Filt);
Conv_RC5noise = conv(AWGNTx_U,RC_gamma5);
```

```
Conv_R1noise = conv(AWGNTx_U,RC_gamma1);

% Taking only the first 10000 samples
%Without noise
Conv_sincpulse = Conv_sincpulse(1:10000);
Conv_RCgamma5 = Conv_RCgamma5(1:10000);
Conv_RCgamma1 = Conv_RCgamma1(1:10000);

%With noise
Conv_sincnoise = Conv_sincnoise(1:10000);
Conv_RC5noise = Conv_RC5noise(1:10000);
Conv_R1noise = Conv_R1noise(1:10000);

%Reshaping the sequences to build Eye Diagrams
%Without Noise
Conv_sincpulse_reshape = reshape(Conv_sincpulse, SampleFreq*2, BitLength*SampleFreq/20).';
Conv_RCgamma5_reshape = reshape(Conv_RCgamma5,SampleFreq*2,BitLength*SampleFreq/20).';
Conv_RCgamma1_reshape = reshape(Conv_RCgamma1,SampleFreq*2,BitLength*SampleFreq/20).';

%With Noise
Conv_sincnoise_reshape = reshape(Conv_sincnoise, SampleFreq*2, BitLength*SampleFreq/20).';
Conv_RC5noise_reshape = reshape(Conv_RC5noise,SampleFreq*2,BitLength*SampleFreq/20).';
Conv_R1noise_reshape = reshape(Conv_R1noise,SampleFreq*2,BitLength*SampleFreq/20).';

%Plotting the Eye Diagrams
%Without Noise
figure;
plot(0:1/SampleFreq:1.99, real(Conv_sincpulse_reshape).', 'b');
title('Eye diagram with sinc pulse');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -2.4 2.2]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_RCgamma5_reshape.','b');
title('Eye diagram with gamma = 0.5');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -2.5 2.5]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_RCgamma1_reshape.','b');
title('Eye diagram with alpha =1');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -1.5 1.5 ]);
grid on

%With Noise
figure;
plot(0:1/SampleFreq:1.99, Conv_sincnoise_reshape.', 'b');
title('Eye diagram with sinc pulse');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -2.4 2.2]);
grid on
```

```
figure;
plot(0:1/SampleFreq:1.99, Conv_RC5noise_reshape.', 'b');
title('Eye diagram with gamma = 0.5 noisy');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -2.4 2.2]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_R1noise_reshape.', 'b');
title('Eye diagram with gamma = 1.0 noisy');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -2.4 2.2]);
grid on
```

Published with MATLAB® R2016a

```
% Digital Communication I - Assignment I
% Authors : Abeywardena K.G. | Adhessha K.G.

clear all; close all; clc;

%Defining the system Parameters
BitLength  = 10^3;                    % No of Bits Transmitted
SampleFreq = 10;                      % sampling frequency in Hz
SNR_dB = 10;
NoisePower = 5./(10.^(0.1*SNR_dB));         % Noise Power (Eb = 5 in 4-PAM)

time = -SampleFreq:1/SampleFreq:SampleFreq; % Time Array
Bit_Array = round(rand(1,BitLength));

% 4-PAM modulation
M = 4;
pam4 = [];
for m = 1:M
    a(m) = 2*m-1-M;
end

for iter = 1:2:BitLength-1
    bit1 = Bit_Array(iter);
    bit2 = Bit_Array(iter+1);
    if bit1==0 && bit2==0        % 00 -> -3
        pam = a(1);
    elseif bit1==0 && bit2==1    % 01 -> -1
        pam = a(2);
    elseif bit1==1 && bit2==1    % 11 -> +1
        pam = a(3);
    else                         % 10 -> +3
        pam = a(4);
    end
    pam4 = [pam4 pam];
end

LenSymbols = length(pam4);      % Total Number of symbols sent

t = 0:1/SampleFreq:499/SampleFreq;

figure;
stem(t, pam4); xlabel('Time'); ylabel('Amplitude');
title('4-PAM Impulse Train');
axis([0 20 -3.5 3.5]); grid on;

%Noise Generation
Noise1D = normrnd (0 , sqrt(NoisePower/2), [1, LenSymbols]);
AWGN_TX = pam4 + Noise1D;

figure;
stem(t, AWGN_TX); xlabel('Time'); ylabel('Amplitude');
title('4-PAM with noise Impulse Train');
xlim([0 20]); grid on;
```

```
% Sinc Pulse Shape
Sinc_Num = sin(pi*time);                     % numerator of the sinc function
Sinc_Den = (pi*time);                        % denominator of the sinc function
Sinc_DenZero = find(abs(Sinc_Den) < 10^-10);    % Finding the t=0 position
Sinc_Filt = Sinc_Num./Sinc_Den;
Sinc_Filt(Sinc_DenZero) = 1;                  % Defining the t=0 value

% Raised Cosine Pulse Shape
% roll-off = 0.5
roll_off = 0.5;
cos_Num = cos(roll_off*pi*time);
cos_Den = (1 - (2 * roll_off * time).^2);
cos_DenZero = abs(cos_Den)<10^-10;
RaisedCosine = cos_Num./cos_Den;
RaisedCosine(cos_DenZero) = pi/4;

RC_gamma5 = Sinc_Filt.*RaisedCosine;    % Getting the complete raised cosine pulse

%roll-off = 1
roll_off = 1;
cos_Num = cos(roll_off * pi * time);
cos_Den = (1-(2 * roll_off * time).^2);
cos_DenZero = find(abs(cos_Den)<10^-20);
RaisedCosine = cos_Num./cos_Den;
RaisedCosine(cos_DenZero) = pi/4;

RC_gamma1 = Sinc_Filt.*RaisedCosine;    % Getting the complete raised cosine pulse

% upsampling the transmit sequence
% Without Noise
pam4_Upsample = [pam4;zeros(SampleFreq-1,length(pam4))]; %Upsampling the BPSK to match the sampling frequency
pam_U = pam4_Upsample(:).';

figure;
stem(time, pam_U(1:201)); xlabel('Time'); ylabel('Amplitude');
title('Upsampled 4-PAM Impulse Train');
axis([0 10 -3.5 3.5]); grid on;

% With Noise
AWGNTx_Upsample = [AWGN_TX;zeros(SampleFreq-1,length(AWGN_TX))];
AWGNTx_U = AWGNTx_Upsample(:);

figure;
stem(time, AWGNTx_U(1:201)); xlabel('Time'); ylabel('Amplitude');
title('Upsampled 4-PAM noise Impulse Train');
axis([0 10 -3.5 3.5]); grid on;

% Pulse Shaped sequences
% Without Noise
Conv_sincpulse = conv(pam_U, Sinc_Filt);
Conv_RCgamma5 = conv(pam_U,RC_gamma5);
Conv_RCgamma1 = conv(pam_U,RC_gamma1);
```

```
% With Noise
Conv_sincnoise = conv(AWGNTx_U,Sinc_Filt);
Conv_RC5noise = conv(AWGNTx_U,RC_gamma5);
Conv_R1noise = conv(AWGNTx_U,RC_gamma1);

% Taking only the first 5000 samples
%Without noise
Conv_sincpulse = Conv_sincpulse(1:5000);
Conv_RCgamma5 = Conv_RCgamma5(1:5000);
Conv_RCgamma1 = Conv_RCgamma1(1:5000);

%With noise
Conv_sincnoise = Conv_sincnoise(1:5000);
Conv_RC5noise = Conv_RC5noise(1:5000);

Conv_R1noise = Conv_R1noise(1:5000);

%Reshaping the sequences to build Eye Diagrams
%Without Noise
Conv_sincpulse_reshape = reshape(Conv_sincpulse, SampleFreq*2, LenSymbols*SampleFreq/20).';
Conv_RCgamma5_reshape = reshape(Conv_RCgamma5,SampleFreq*2,LenSymbols*SampleFreq/20).';
Conv_RCgamma1_reshape = reshape(Conv_RCgamma1,SampleFreq*2,LenSymbols*SampleFreq/20).';

%With Noise
Conv_sincnoise_reshape = reshape(Conv_sincnoise, SampleFreq*2, LenSymbols*SampleFreq/20).';
Conv_RC5noise_reshape = reshape(Conv_RC5noise,SampleFreq*2,LenSymbols*SampleFreq/20).';
Conv_R1noise_reshape = reshape(Conv_R1noise,SampleFreq*2,LenSymbols*SampleFreq/20).';

%Plotting the Eye Diagrams
%Without Noise
figure;
plot(0:1/SampleFreq:1.99, Conv_sincpulse_reshape.', 'b');
title('Eye diagram with sinc pulse');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_RCgamma5_reshape.','b');
title('Eye diagram with gamma = 0.5');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_RCgamma1_reshape.','b');
title('Eye diagram with alpha =1');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5 ]);
grid on
```

```
%With Noise
figure;
plot(0:1/SampleFreq:1.99, Conv_sincnoise_reshape.', 'b');
title('Eye diagram with sinc pulse noisy');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_RC5noise_reshape.', 'b');
title('Eye diagram with gamma = 0.5 noisy');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5]);
grid on

figure;
plot(0:1/SampleFreq:1.99, Conv_R1noise_reshape.', 'b');
title('Eye diagram with gamma = 1.0 noisy');
xlabel('Time'); ylabel('Amplitude');
axis([0 2 -3.5 3.5]);
grid on
```

Published with MATLAB® R2016a