EE451 LAB REPORT

LAB 4 – Inter-Symbol Interference (ISI)

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Procedure

4.1 Creating the message signal

4-ary PAM signal is processed during the laboratory experiment. In order to create the symbol representation of the signal without using any built-in functions, such as pammod(.), with the given parameters, the code is provided below:

```
%% Creating message signal
%% step 1
Fs = 27*10^3;
Rb = 18*10^3;
Ts = 1/Fs;
Tb = 1/Rb;
N = 1000;
M = 4;
W = 6000;
A = 1;
randoms = randi(4,1,N);
k = log2(M);
%% step 2
for j=1:N
    if(randoms(j)==1)
        pamd(j)=-3*A;
    elseif(randoms(j)==2)
        pamd(j)=-1*A;
    elseif(randoms(j)==3)
        pamd(j)=1*A;
    elseif(randoms(j)==4)
        pamd(j)=3*A;
    end
end
```

From the given parameters, the symbol rate Rs and symbol per second value (sps) is calculated as below:

```
%% step 3
Rs = Rb/k;
sps = Fs/Rs;
```

4.2 Pulse shaping the data

By using built-in function rcosdesign(.) with the specified roll-off factor values 0, 0.5 and 1 transmitting filter (Tx) responses $h_0(t)$, $h_1(t)$, $h_2(t)$ is designed as below:

```
%% Pulse shaping the data
%% step 4
rolloff_1 = 0;
rolloff_2 = 0.5;
rolloff_3 = 1;
span = 10;

ht0 = rcosdesign(rolloff_1,span,sps,"sqrt");
ht1 = rcosdesign(rolloff_2,span,sps,"sqrt");
ht2 = rcosdesign(rolloff_3,span,sps,"sqrt");

L = length(ht0);

t = linspace(-N/Rs,N/Rs,L);

hf0 = abs(fftshift((fft(ht0,L))/L));
hf1 = abs(fftshift((fft(ht1,L))/L));
hf2 = abs(fftshift((fft(ht2,L))/L));

f=linspace(-Fs/2,Fs/2,L);
```

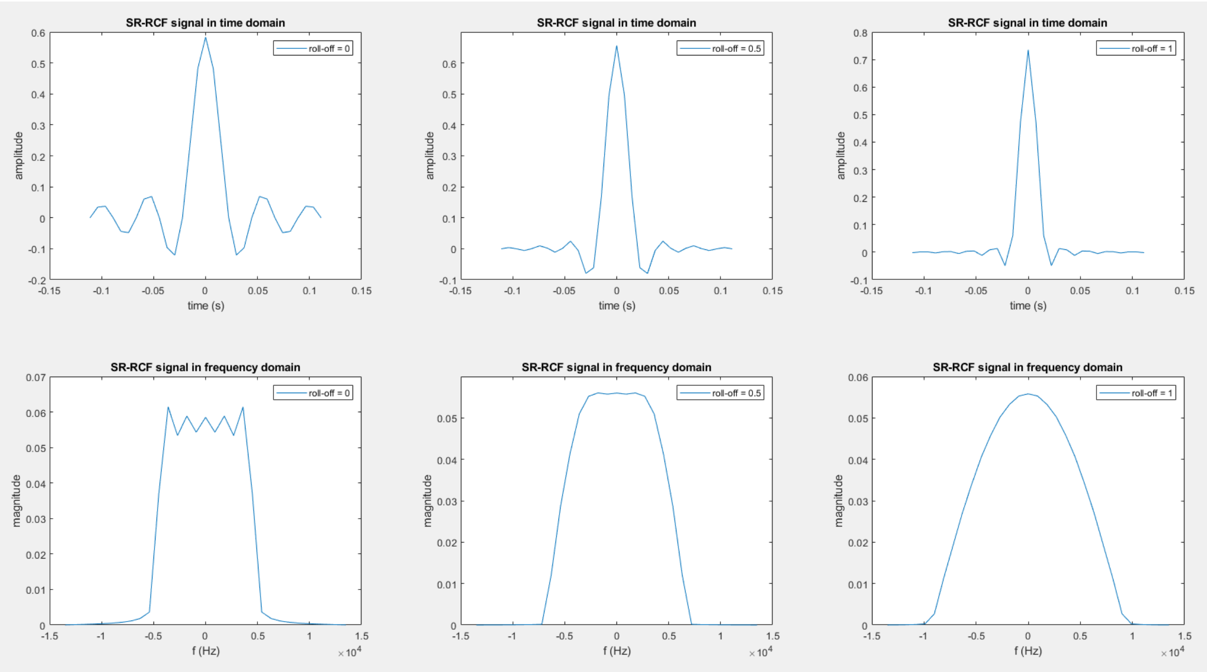

Figure 1: Tx filter responses with different roll-off factors ($h_0(t)$, $h_1(t)$, $h_2(t)$)

From the frequency responses of the filters, it is predicted that with the roll-off factors 0.5 and 1, inter-symbol interference would be cancelled better in further processes. Wider bandwidth provides lower ISI.

4.3 The transmitted/received signal

Since the channel response hc(t) is designed with low-pass frequency response. The multiplication in frequency domain is 1 with the transmitted signal.

```
%% The transmitted/received signal
%%
cf = 1; % no need to filter channel
%% step 6
t1=upfirdn(pamd,ht0,sps,1);
t2=upfirdn(pamd,ht1,sps,1);
t3=upfirdn(pamd,ht2,sps,1);
%% step 7
r1 = awgn(t1,20,'measured');
r2 = awgn(t2,20,'measured');
r3 = awgn(t3,20,'measured');
%% step 8
yout1 = upfirdn(r1,ht0,1,sps);
yout2 = upfirdn(r2,ht1,1,sps);
yout3 = upfirdn(r3,ht2,1,sps);
%% step 9
yout1 = yout1(10+1:end-10);
yout2 = yout2(10+1:end-10);
yout3 = yout3(10+1:end-10);
```

The digital communication system process is applied above. Tx filter, AWGN Channel, Rx Filter and finally extraction of the delayed symbols from the output signal is applied with an order.

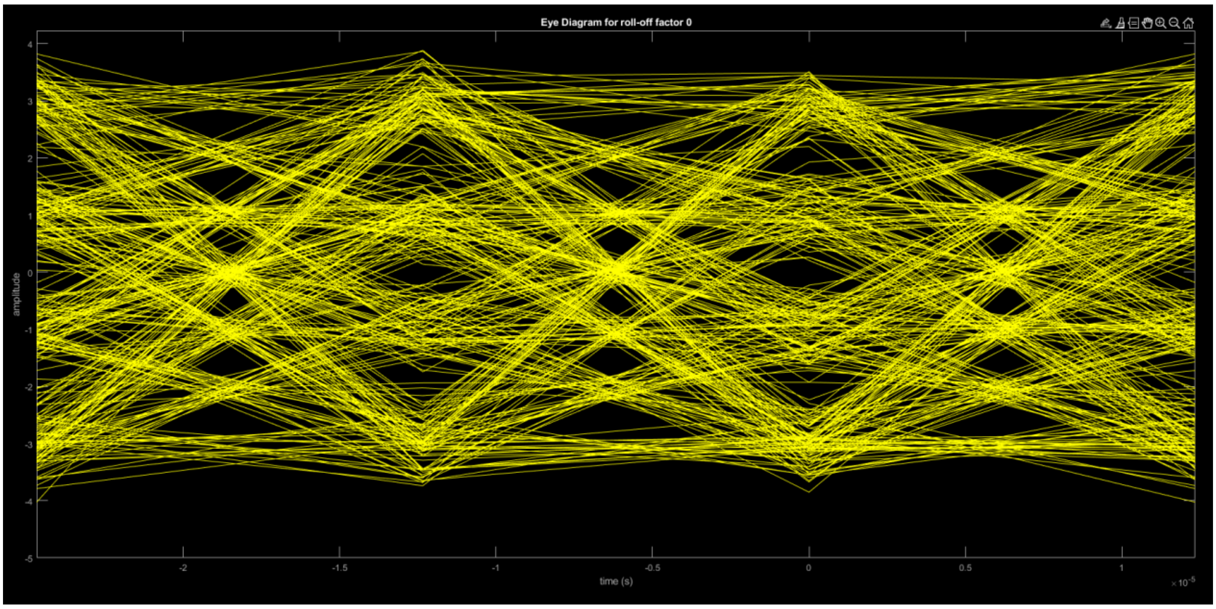

Figure 2: Eye diagram for roll-off factor 0

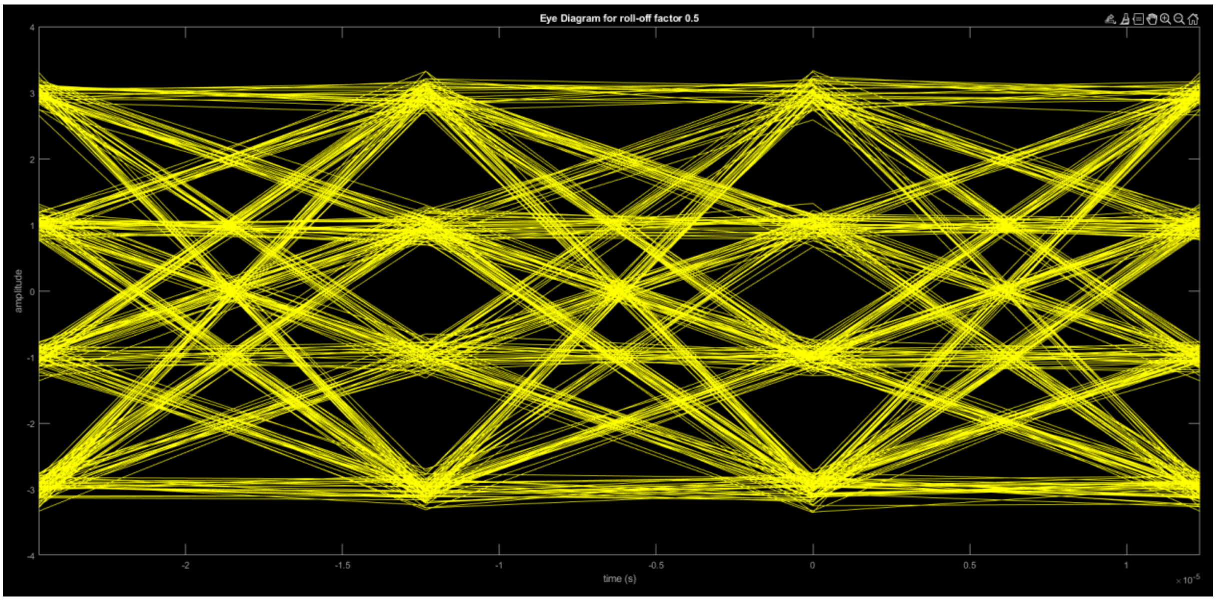

Figure 3: Eye diagram for roll-off factor 0.5

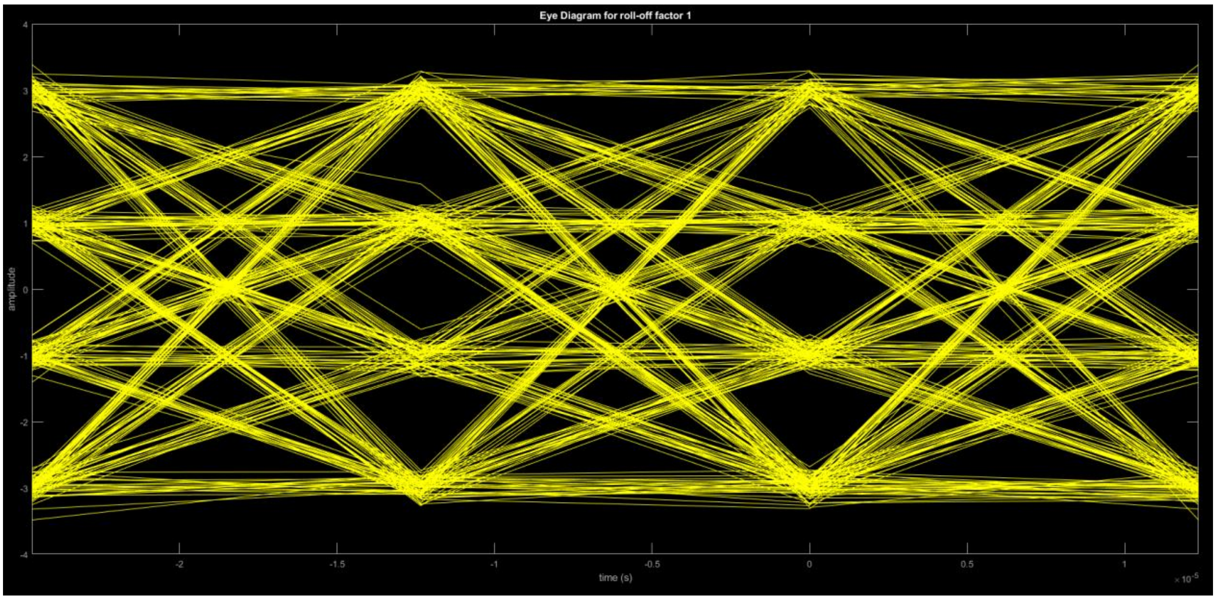

Figure 4: Eye diagram for roll-off factor 1

By analyzing the eye diagrams, the estimation that is made in step 4.2 is confirmed that with the roll-off factor 0.5 and 1 better inter-symbol interference cancellation is obtained. More open eyes in second and third eyediagrams compared to the first indicates minimal ISI.

In the last step, the symbol rate (Rs) vs. excess bandwith rate is created by different roll-off factor values (0.25, 0.33, 0.5, 0.67, 0.75, 1).

```
%% step 11
rolloff = [0.25 0.33 0.5 0.67 0.75 1];
Rs_v(1) = (2*W)/(1+rolloff(1));
Rs_v(2) = (2*W)/(1+rolloff(2));
Rs_v(3) = (2*W)/(1+rolloff(3));
Rs_v(4) = (2*W)/(1+rolloff(4));
Rs_v(5) = (2*W)/(1+rolloff(5));
Rs_v(6) = (2*W)/(1+rolloff(6));
```

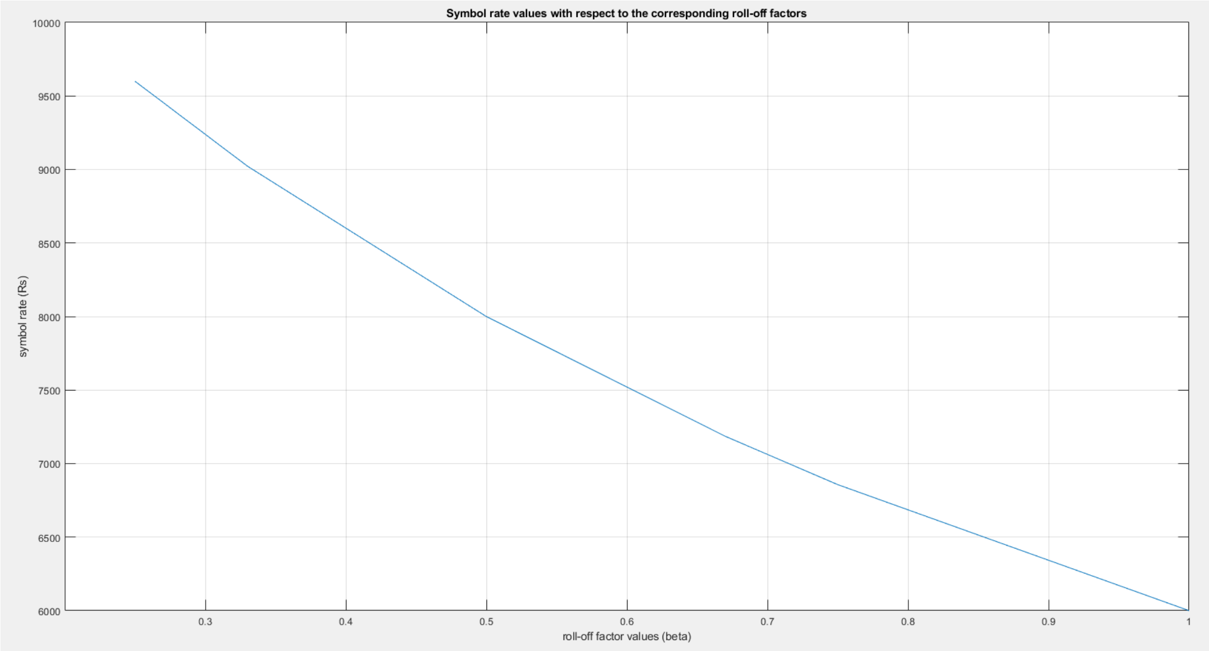

Figure 5: Symbol rate values with respect to the corresponding roll-off factors

Questions & Answers

Q1. What are the major approaches to deal with ISI?

A1. There are several approaches to deal with Inter-Symbol Interference (ISI):

- **Equalization:** This involves adjusting the received signal to compensate for the distortion caused by ISI. Different types of equalizers, such as linear and decision feedback equalizers, can be used.
- **Raised Cosine Filtering:** By using pulse shaping techniques like raised cosine filtering, the transmission pulse is shaped to reduce ISI. This is evident in this code where it has applied raised cosine filters with different roll-off factors.
- **Nyquist Filtering:** It ensures that the pulses used for transmission satisfy the Nyquist criterion, preventing ISI. This is related to the pulse shaping techniques mentioned earlier.
- **Maximum Likelihood Sequence Estimation (MLSE):** MLSE is a powerful technique that jointly estimates the transmitted symbols and compensates for ISI.
- **Adaptive Filtering:** Techniques such as decision-directed adaptation can be employed to adaptively adjust the equalizer parameters based on the received signal.

Q2. What is the effect of small and large roll-off factor considering figure which is obtained in step 5.

A2. The roll-off factor in pulse shaping affects the bandwidth of the transmitted signal. In figure 1, there are three different roll-off factors: 0, 0.5, and 1.

- **Roll-off factor = 0 (Rectangular Pulse):** This corresponds to a square pulse in the time domain and results in the widest frequency spectrum. It has a faster roll-off, leading to larger bandwidth.

- **Roll-off factor = 0.5:** This represents a compromise between bandwidth efficiency and spectral containment. The frequency spectrum is narrower compared to the roll-off factor of 0.
- **Roll-off factor = 1 (Nyquist Pulse):** This results in a narrow frequency spectrum but requires more bandwidth. It has a slower roll-off compared to the other two.

So, the choice of roll-off factor balances the trade-off between bandwidth efficiency and spectral containment.

Q3. How can we observe the effect of the excess bandwidth in the eye-diagram?

A3. The eye diagram provides a visual representation of the received signal's quality and helps in observing ISI effects. A wider eye opening indicates less ISI.

The excess bandwidth affects the eye diagram by influencing the width of the eye opening. A larger roll-off factor (closer to 1) results in a narrower eye opening, indicating increased ISI. Conversely, a smaller roll-off factor (closer to 0) results in a wider eye opening, suggesting less ISI.

Q4. Determine and calculate the channel bandwidth to achieve a zero-ISI condition considering Rs?

A4. To achieve zero-ISI condition, the channel bandwidth (B) should be related to the symbol rate (Rs) by the Nyquist criterion:

- $B = Rs*(1+\beta)$

, where $B = 2W$ and β is the roll-off factor. The symbol rates (Rs) for different roll-off factors are calculated. To achieve zero-ISI, B needs to be equal to or greater than Rs.

Q5. Considering the symbol rate values versus the corresponding roll-off factors figure which is obtained in step 11, comment on the relationship between roll-off factor and the symbol rate and also explain the effect on ISI.

A5. In the figure obtained in step 11, an inverse relationship between the symbol rate (Rs) and the roll-off factor (β) is observed as the latter increases. The decrease in symbol rate is attributed to the spreading of the signal's energy over a broader bandwidth with a higher roll-off factor, maintaining the same bandwidth efficiency.

The effect on ISI is as follows:

With a higher roll-off factor (β), a slower roll-off of the spectrum is observed, resulting in increased susceptibility to ISI. This is due to a larger portion of the signal's energy being distributed over a wider frequency range, thereby escalating the likelihood of interference between symbols.

Conversely, a lower roll-off factor (β) leads to a faster roll-off and a narrower frequency spectrum, mitigating ISI. However, this choice necessitates more bandwidth to uphold the same symbol rate.

Hence, the selection of the roll-off factor entails a trade-off among symbol rate, bandwidth efficiency, and susceptibility to ISI.

Conclusion

In conclusion, this report detailed the laboratory experiment involving the creation and processing of a 4-ary PAM signal. The steps included generating the message signal, pulse shaping the data with different roll-off factors, and examining the transmitted/received signals. The analysis of Tx filter responses and eye diagrams confirmed the effectiveness of roll-off factors in mitigating inter-symbol interference (ISI). The report also addressed key questions, highlighting approaches to deal with ISI, the impact of roll-off factors on signal bandwidth, the observation of excess bandwidth in eye diagrams, and the relationship between roll-off factor and symbol rate in the context of ISI. The findings underscore the importance of selecting an appropriate roll-off factor to balance bandwidth efficiency and susceptibility to ISI in digital communication systems.