# EE5141 Wireless Communication

# Computer Assignment 1

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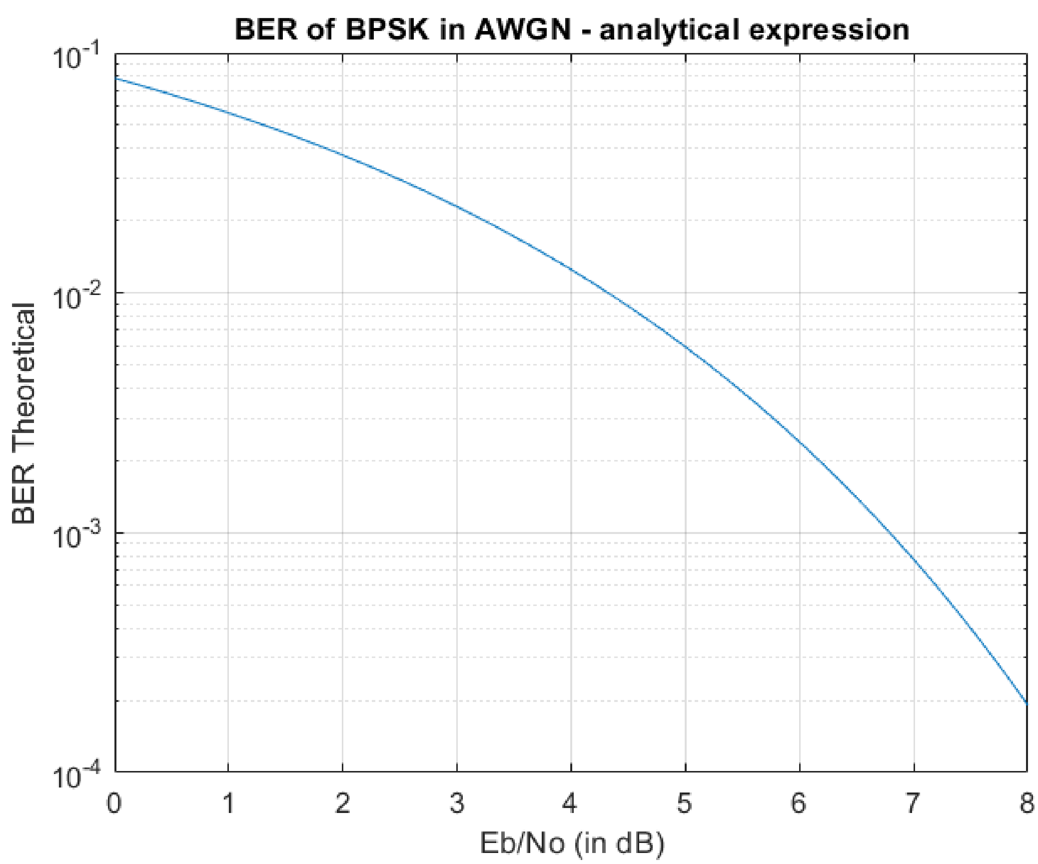
Q1. BER performance of BPSK in AWGN using a theoretical technique.

$$BER = Q\left(\sqrt{\frac{2Eb}{No}}\right)$$




For SNR (Eb/No) chosen in the range 0-8 dB (in steps of 0.2 dB) we have plotted the theoretical estimate of the bit error rate in a semilogy plot.

Q2. Visualizing **Square Root Raised Cosine** (SRRC) Pulse waveform and its Normalized Frequency Response for different roll-off factors(α).

Pulse Truncation Length : 10 symbol interval

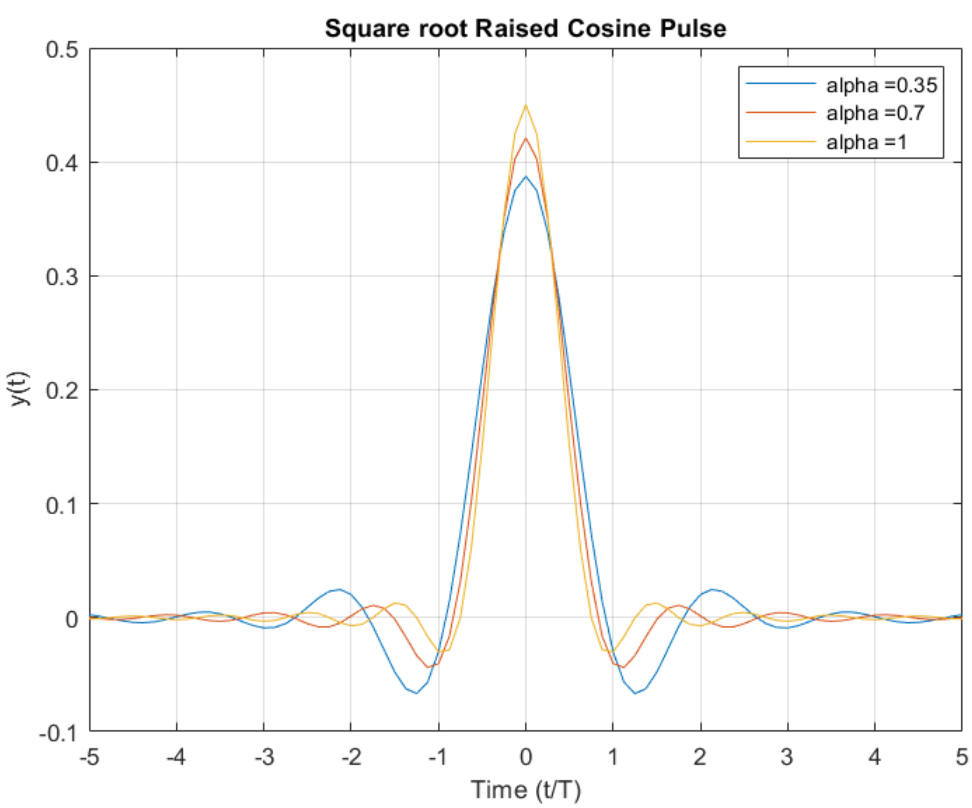
Oversampling per Symbol : 8

Symbol Rate (1/T) : 25K symbols/sec

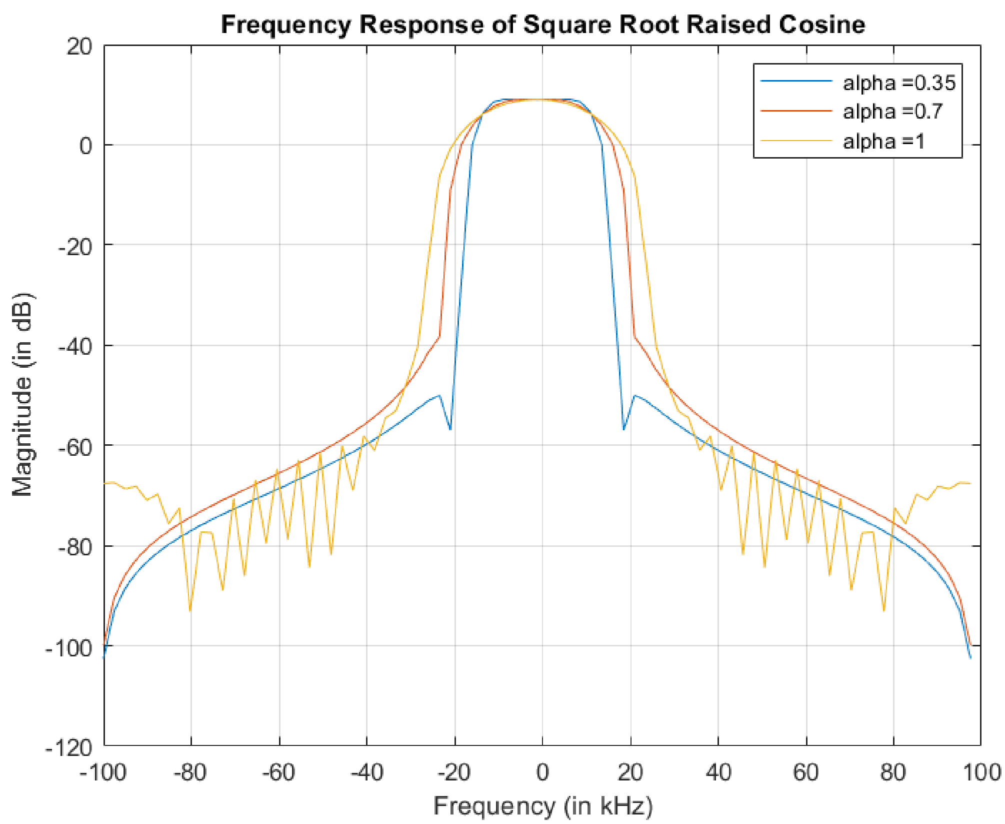
Roll-off factor (α) = 0.35, 0.70, 1.00

$$h(t) = \begin{cases} 1-\alpha+4\dfrac{\alpha}{\pi}, & t=0 \\ \dfrac{\alpha}{\sqrt{2}}\left[\left(1+\dfrac{2}{\pi}\right)\sin\left(\dfrac{\pi}{4\alpha}\right)+\left(1-\dfrac{2}{\pi}\right)\cos\left(\dfrac{\pi}{4\alpha}\right)\right], & t=\pm\dfrac{T}{4\alpha} \\ \dfrac{\sin\left[\pi(1-\alpha)\dfrac{t}{T}\right]+4\alpha\dfrac{t}{T}\cos\left[\pi(1+\alpha)\dfrac{t}{T}\right]}{\pi\dfrac{t}{T}\left[1-\left(4\alpha\dfrac{t}{T}\right)^2\right]}, & \text{for all other } t \end{cases}$$

**SRRC Pulse Waveform :**



**SRRC Normalized Frequency Response (20 log10(H(jw)) ) :**




**Observation :** As the roll-off factor increases, the bandwidth occupancy of the pulse increases. Hence alpha =1 occupies the largest bandwidth and alpha = 0.35 .

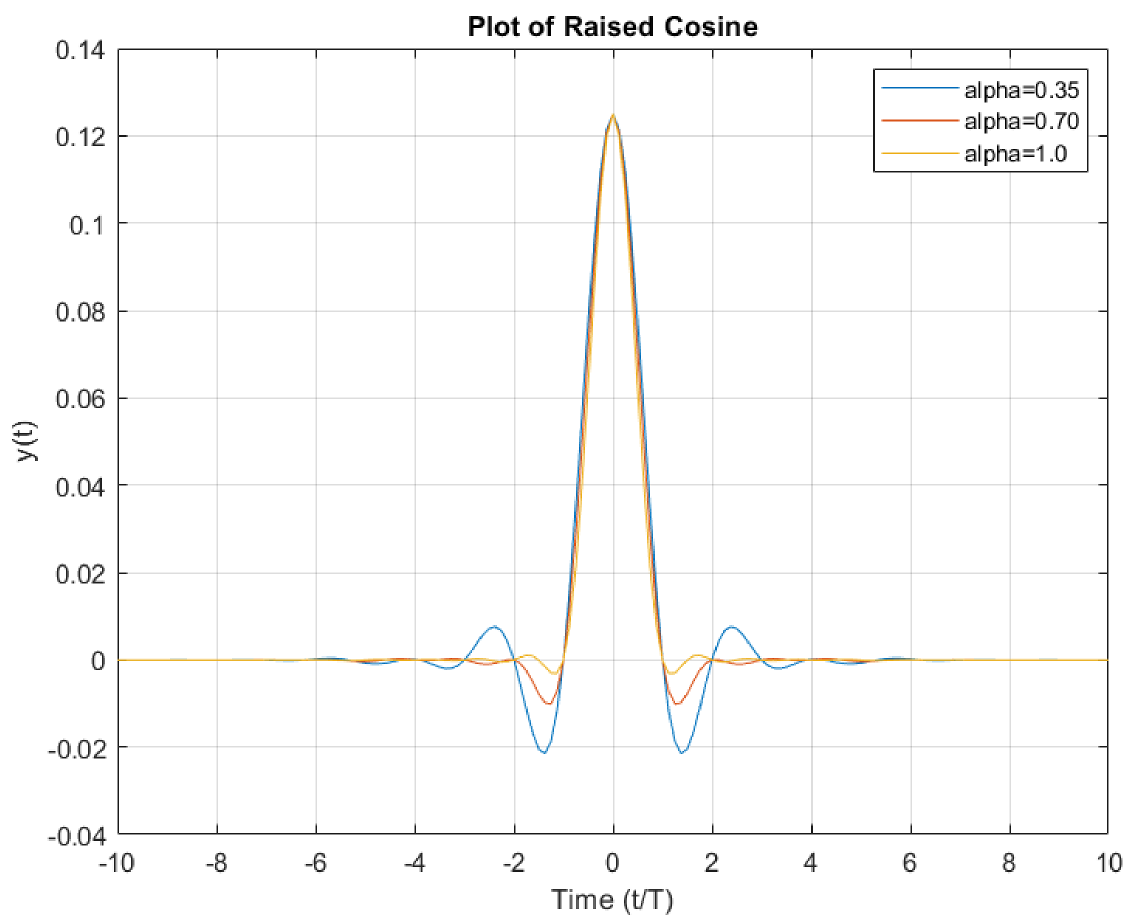
The roll-off factor is a measure of excess bandwidth of the filter (the bandwidth beyond Nquist bandwidth ). The time domain ripple decreases as alpha increases, i.e, the excess bandwidth can be reduced at the expense of elongated impulse response.

Q3.  B)  Convolve SRRC Pulse with itself to get **Raised Cosine** (RC) Pulse

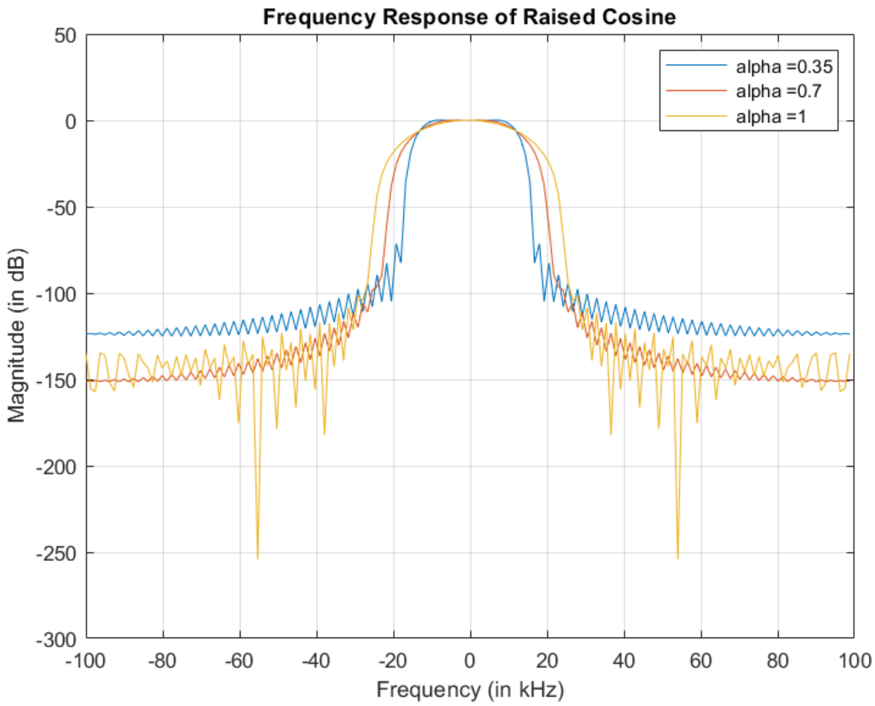
**RC (t) = (SRRC ∗ SRRC)(t)** in continuous-time domain. The sampled version or the vectorized version of the RC pulse waveform is given by

**RC[n] = (SRRC ∗ SRRC)(n) * (Ts * Symbol Rate)**

**RC Pulse Waveform** :

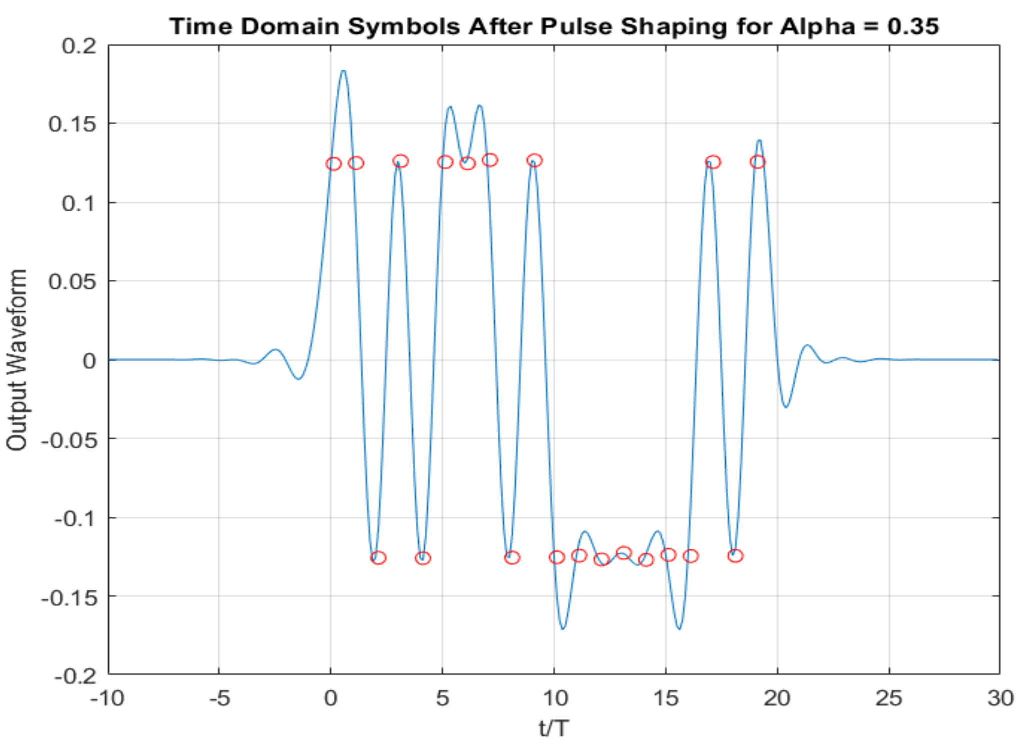


**RC Normalized Frequency Response :**




Q3 C,D,E  RC Pulse shaping of Random BPSK Modulated data sequence and sampling at sample spaced sampling points.

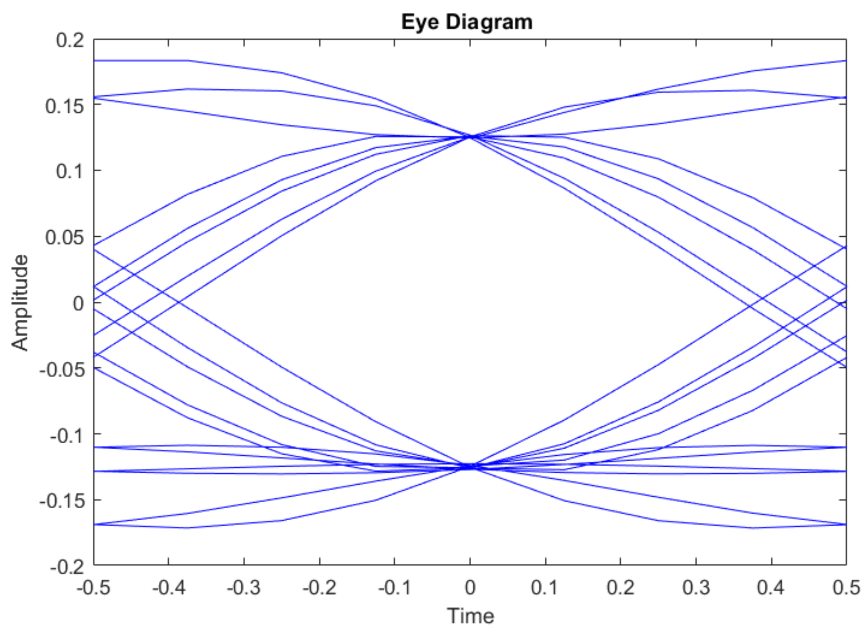
**Input Data Sequence** : [1 1 -1 1 -1 1 1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1]



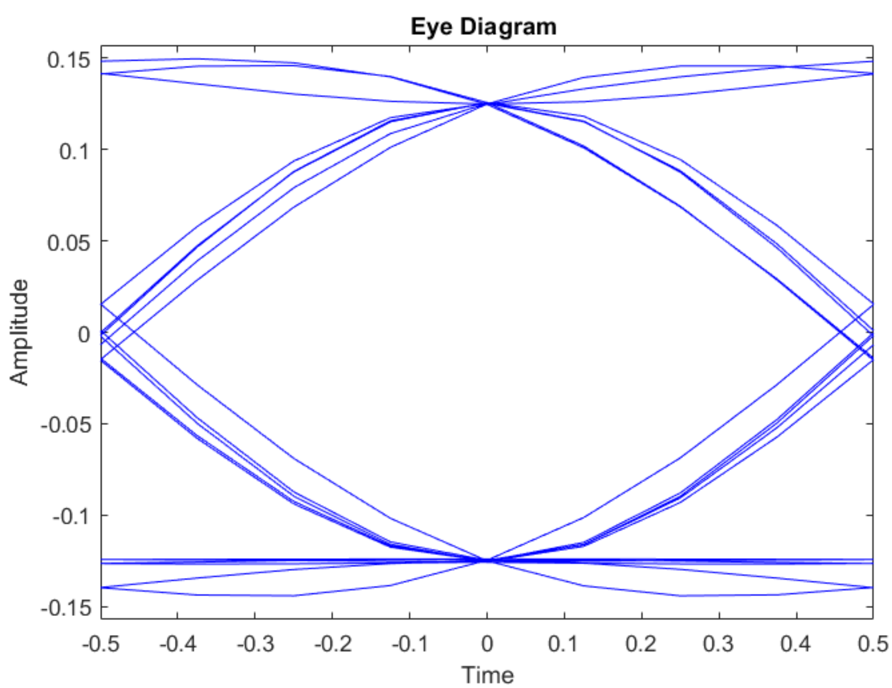
The sample values and decoded values from the resultant waveform at symbol-spaced sampling points which correspond to the peak of the RC pulse for all three values of roll-off factor are attached at the end of the assignment.

The original input and the received bit values are shown and minimum distance rule (which in this case reduces to simple sign check) is used for decoding the output bits .

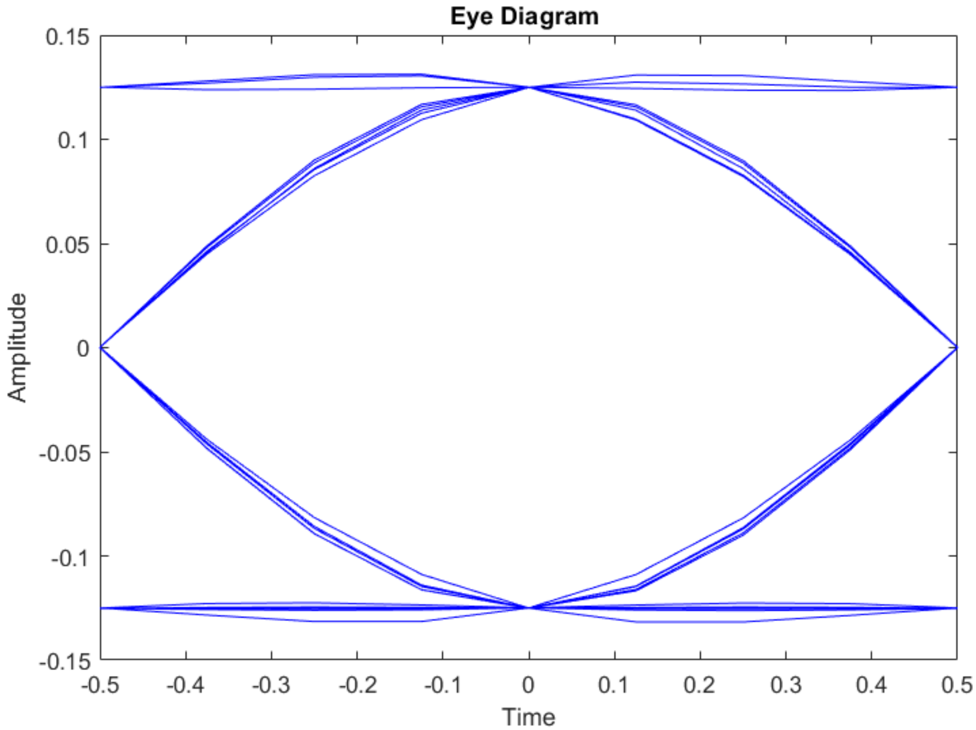
Q3 F,G **Eye Diagram** - To show the Optimum Sampling Point .(rolling-factor : 0.35)




**Eye Diagram** - To show the Optimum Sampling Point .(rolling-factor : 0.70)



**Eye Diagram** - To show the Optimum Sampling Point .(rolling-factor : 1.00)




- We observe that the eye (from the eye diagram) opens at integral multiples of T= 8 samples.
- An open eye corresponds to zero ISI at these sampling points.
- Also, as we increase the roll-off factor we observe the ISI reduces (eye becomes more open).

## ***Samples of the resultant waveform at symbol-spaced sampling points***

***Alpha = 0.35***

Sampled Value: 0.12424; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12475; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12582; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12598; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12606; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12537; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12449; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12669; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12574; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.1264; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12543; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12446; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12686; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12271; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12711; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12392; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12468; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12538; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12453; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12546; Decoded Value: 1; Actual Value:1

***Alpha = 0.70***

Sampled Value: 0.12467; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12471; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12535; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12549; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12541; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12499; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12491; Decoded Value: 1; Actual Value:1

Sampled Value: 0.1257; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12521; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.1257; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12509; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12494; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12578; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12408; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12585; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12462; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12473; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12524; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12479; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12523; Decoded Value: 1; Actual Value:1

***Alpha = 1.00***

Sampled Value: 0.12502; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12498; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12509; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12502; Decoded Value: 1; Actual Value:1

Sampled Value: -0.1251; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12492; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12501; Decoded Value: 1; Actual Value:1

Sampled Value: 0.12506; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12504; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12505; Decoded Value: 1; Actual Value:1

Sampled Value: -0.12505; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12492; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.125; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12486; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12503; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12492; Decoded Value: -1; Actual Value:-1

Sampled Value: -0.12497; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.12502; Decoded Value: 1; Actual Value:1

Sampled Value: -0.125; Decoded Value: -1; Actual Value:-1

Sampled Value: 0.125; Decoded Value: 1; Actual Value:1

# 1 Code Listing

```
%% EE5141 Wireless Communication : Computer Assignment 1
%  Name : K.R.Srinivas
%  Roll No : EE18B136

close all ;
clear all ;

%% Question 1

ebno_db = (0:0.2:8) ;
ebno = 10.^(ebno_db./10) ;
ber_theory = qfunc(sqrt(2.*ebno)) ;

semilogy(ebno_db,ber_theory) ;
xlabel("Eb/No (in dB)") ;
ylabel("BER Theoretical") ;
title("BER of BPSK in AWGN - analytical expression");
grid on ;

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%% Question 2

alpha = [0.35 0.70 1] ;
sym_rate = 25e3 ;
oversampling = 8 ;
trunc_length = 5 ;
t_bnd = trunc_length/sym_rate ;
t_res = 1/(sym_rate*oversampling) ;

t_srrc = (-t_bnd:t_res:t_bnd) ;
srrc_arr = zeros(length(alpha),length(t_srrc)) ;

for i = 1:length(alpha)
    srrc_arr(i,:) = srrc_gen(oversampling,alpha(i)) ;
end

srrc_fft = zeros(length(alpha),length(t_srrc)) ;
srrc_f = (0:length(t_srrc)-1)/(t_res*length(t_srrc))-1/(2*t_res);

for i=1:length(alpha)
    srrc_fft(i,:) = abs(fftshift(fft(srrc_arr(i,:)))) ;
end
```

```
figure;
plot(t_srrc*sym_rate, srrc_arr(1,:)) ;
hold on ;
plot(t_srrc*sym_rate, srrc_arr(2,:)) ;
plot(t_srrc*sym_rate, srrc_arr(3,:)) ;
title (" Square root Raised Cosine Pulse ") ;
xlabel (" Time (t/T) ") ;
ylabel (" y(t) ") ;
legend (" alpha =0.35" , " alpha =0.7" , " alpha =1") ;
grid on ;

figure ;
plot( srrc_f/1000 , 20*log10(abs(srrc_fft(1,:)))) ;
hold on ;
plot( srrc_f/1000 , 20*log10(abs(srrc_fft(2,:)))) ;
plot( srrc_f/1000 , 20*log10(abs(srrc_fft(3,:)))) ;
title(" Frequency Response of Square Root Raised Cosine ") ;
xlabel(" Frequency (in kHz) ") ;
ylabel(" Magnitude (in dB) ") ;
legend(" alpha =0.35" , " alpha =0.7" , " alpha =1") ;
grid on ;

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%% Question 3

rc_arr = zeros(length(alpha),2*length(t_srrc)-1) ;
t_rc= -2*t_bnd:t_res:2*t_bnd ;

for i=1:length(alpha)
    rc_arr(i,:) = conv(srrc_arr(i,:),srrc_arr(i,:))*(t_res*sym_rate);
end

rc_fft = zeros(length(alpha),length(t_rc)) ;
rc_f = (0:length(t_rc)-1)/(t_res*length(t_rc))-1/(2*t_res);

for i=1:length(alpha)
    rc_fft(i,:) = abs(fftshift(fft(rc_arr(i,:)))) ;
end


figure;
plot(t_rc*sym_rate, rc_arr(1,:));
hold on ;
plot(t_rc*sym_rate, rc_arr(2,:));
```

```
plot(t_rc*sym_rate, rc_arr(3,:));
hold off ;
title("Plot of Raised Cosine");
xlabel('Time (t/T)')
ylabel('y(t)')
legend('alpha=0.35','alpha=0.70','alpha=1.0')
grid on ;

figure ;
plot( rc_f/1000 , 20*log10(abs(rc_fft(1,:)))) ;
hold on ;
plot( rc_f/1000 , 20*log10(abs(rc_fft(2,:)))) ;
plot( rc_f/1000 , 20*log10(abs(rc_fft(3,:)))) ;
title(" Frequency Response of Raised Cosine ") ;
xlabel(" Frequency (in kHz) ") ;
ylabel(" Magnitude (in dB) ") ;
legend(" alpha =0.35" , " alpha =0.7" , " alpha =1") ;
grid on ;

n_symbols = 20 ;
input_symbols = [1 1 -1 1 -1 1 1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1] ;
% 2.* randi([0 1] , 1 , n_symbols) - 1 ;

ind = 1;
output = zeros(1 , oversampling*(n_symbols + 4*trunc_length));

for j=1:n_symbols
    output(ind : ind + length(t_rc)-1) = output(ind : ind + length(t_rc)-1) + ...
    input_symbols(j)*rc_arr(3,:);
    ind = ind + 1*oversampling;
end

sample_time = -2*trunc_length:1/oversampling:(n_symbols+2*trunc_length);

op_samples = zeros(1,n_symbols) ;
sym_sample = zeros(1,n_symbols) ;
for i = 1:n_symbols
    disp("Sampled Value: " + output(2*oversampling*trunc_length+1 + (i-1)*8)...
    + "; Decoded Value: " + sign(output(2*oversampling*trunc_length+1 + (i-1)*8))...
    + "; Actual Value:" + input_symbols(i))
    op_samples(i) = output(2*oversampling*trunc_length+1 + (i-1)*8) ;
    sym_sample(i) = 2*oversampling*trunc_length+1 + (i-1)*8 ;
end

figure;
plot(sample_time(1:end-1),output);
```

```
hold on ;
plot(sym_sample/oversampling -2*trunc_length ,op_samples,'ro') ;
grid on;
ylabel("Output Waveform");
xlabel("t/T");
title('Time Domain Symbols After Pulse Shaping for Alpha = 0.35');

% slice the output to remove the unnecessary zero parts
op = output(2*oversampling*trunc_length+1 : 2*oversampling*trunc_length + ...
1 + (4*trunc_length-1)*oversampling);
eyediagram(op,oversampling) ;

function [srrc] = srrc_gen(os_factor,a)
    t = -5:1/os_factor:5 ;
    p = zeros(1,length(t)) ;

    for i=1:1:length(t)

        if t(i)==0
            p(i) = 1 - a + (4*a/pi) ;
        elseif ( t(i)==1/(4*a) || t(i)==-1/(4*a) )
            p(i) = a/sqrt(2)*((1+2/pi)*sin(pi/(4*a) + (1-2/pi)*cos(pi/(4*a))));
        else
            p(i) = (sin(pi*t(i)*(1-a))+4*a*t(i).*cos(pi*t(i)*(1+a)))./...
            (pi*t(i).*(1-(4*a*t(i)).^2));
        end
    end
    srrc = p./sqrt(sum(p.^2)) ;
end
```