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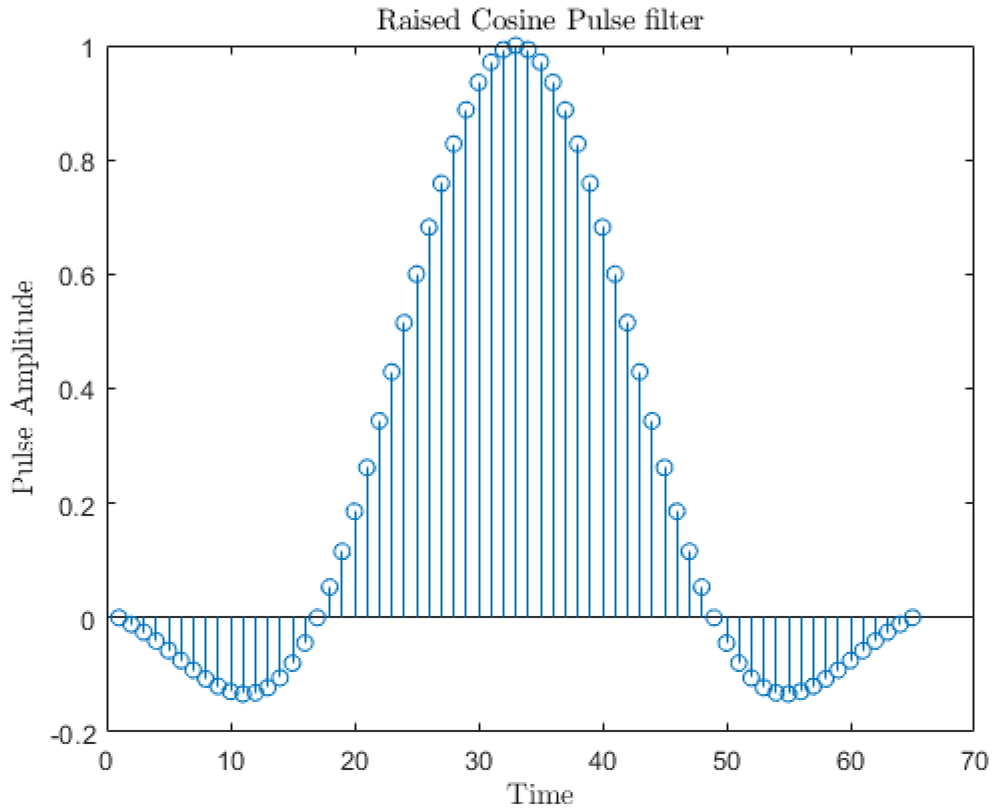
```
% David Dobbie : 300340161
% ECEN 310 / ENGR 440 Communications Engineering
% Lab 1 - Bit Error Rate

clear all; clc;
set(0, 'defaulttextInterpreter','latex')
%%Q3:
% how timing offset impacts the SER performance



N = 10;

s = zeros(N,1);
n = zeros(N,1);
r = zeros(N,1);
sest = zeros(N,1);
Es = 1;
```

a) generate raised cosine pulse

The raised cosine pulse lies from 0 to 64 since it is not possible to implement a non-causal filter. This will lead an offset in symbols that need to be accounted for.

```
b =0.5;
D = 2;
Rs = 16;
T = 1;




SNRdB_axis = 0:5:15;
M =2;
constel = exp((j * 2* pi * (0:M-1))/ (M));

rc = rcosfir(b,D,Rs,T);
rc_axis = -D*Rs:D*Rs;
figure(1)
```

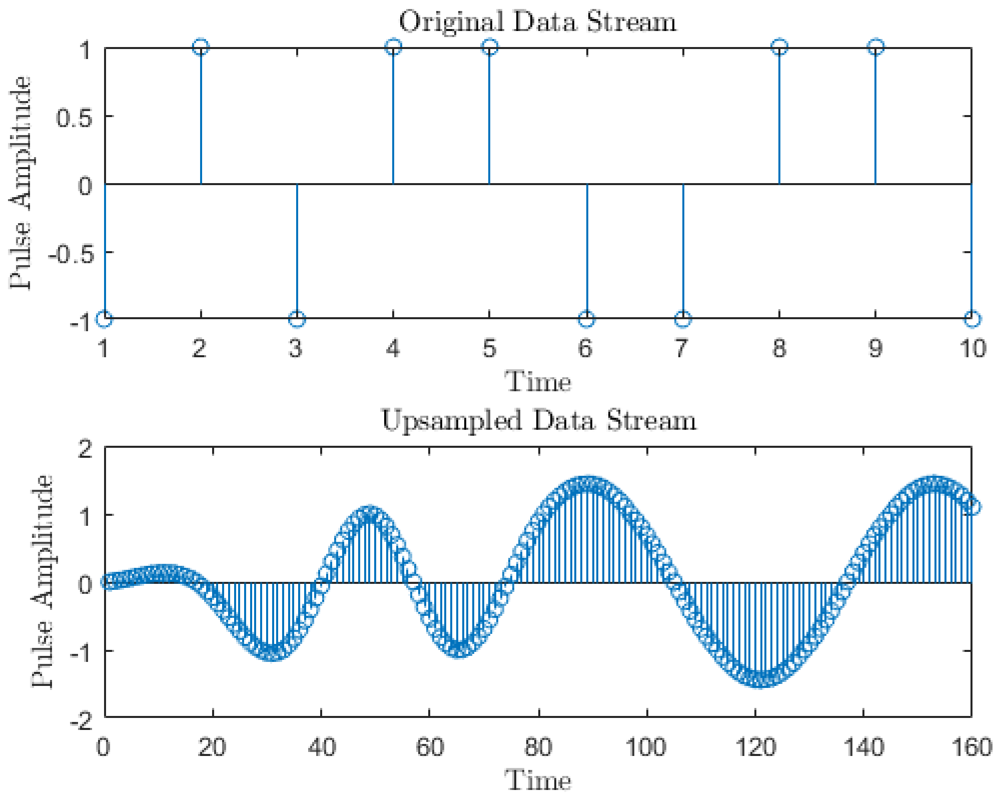
```
stem(rc);
title('Raised Cosine Pulse filter')
xlabel('Time')
ylabel('Pulse Amplitude')
```



b)

```
figure(2)

rng(6);
s = real(randsrc(N,1,constel)); % get rnd symbols, tx
n = 0;
r = s + n; % rx

x = upsample(s,Rs); % simulate filter sampled at Ts = T/Rs
y = filter(rc,1,x); %pass upsampled data through raised cosine filter

subplot(2,1,2)
stem(y);
title('Upsampled Data Stream')
xlabel('Time')
ylabel('Pulse Amplitude')

subplot(2,1,1)
stem(s);
title('Original Data Stream')
```

```
xlabel('Time')
ylabel('Pulse Amplitude')
```

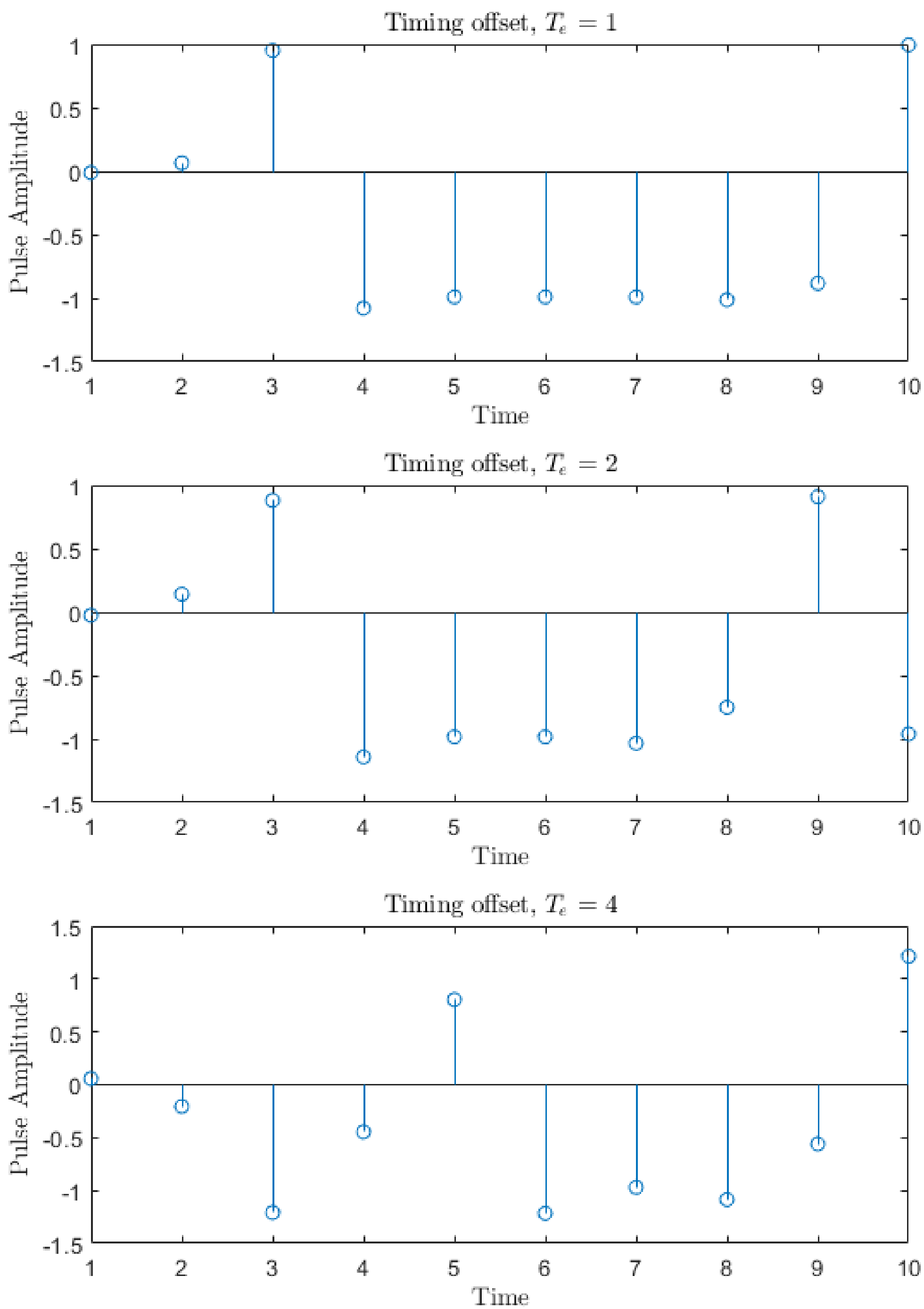


c) Sampling the filtered data

This demonstrates the sampling of filtered data through a raised cosine pulse. There is no noise in this initialisation.

```
Te_axis = [1 2 4]; %timing error
figure(3)
for indx = 1:length(Te_axis)
        Te = Te_axis(indx); % timing error

        s = real(randsrc(N,1,constel)); % get rnd symbols, tx
        n = 0;

        x = upsample(s,Rs); % simulate filter sampled at Ts = T/Rs
        y = filter(rc,1,x); %pass upsampled data through raised cosine
 filter
        z = downsample(y,Rs,Te_axis(indx)); % the receiver, no noise



        subplot(3,1,indx)
        stem(z);
        title(['Timing offset, $ T_e$ = ' num2str(Te)])
```

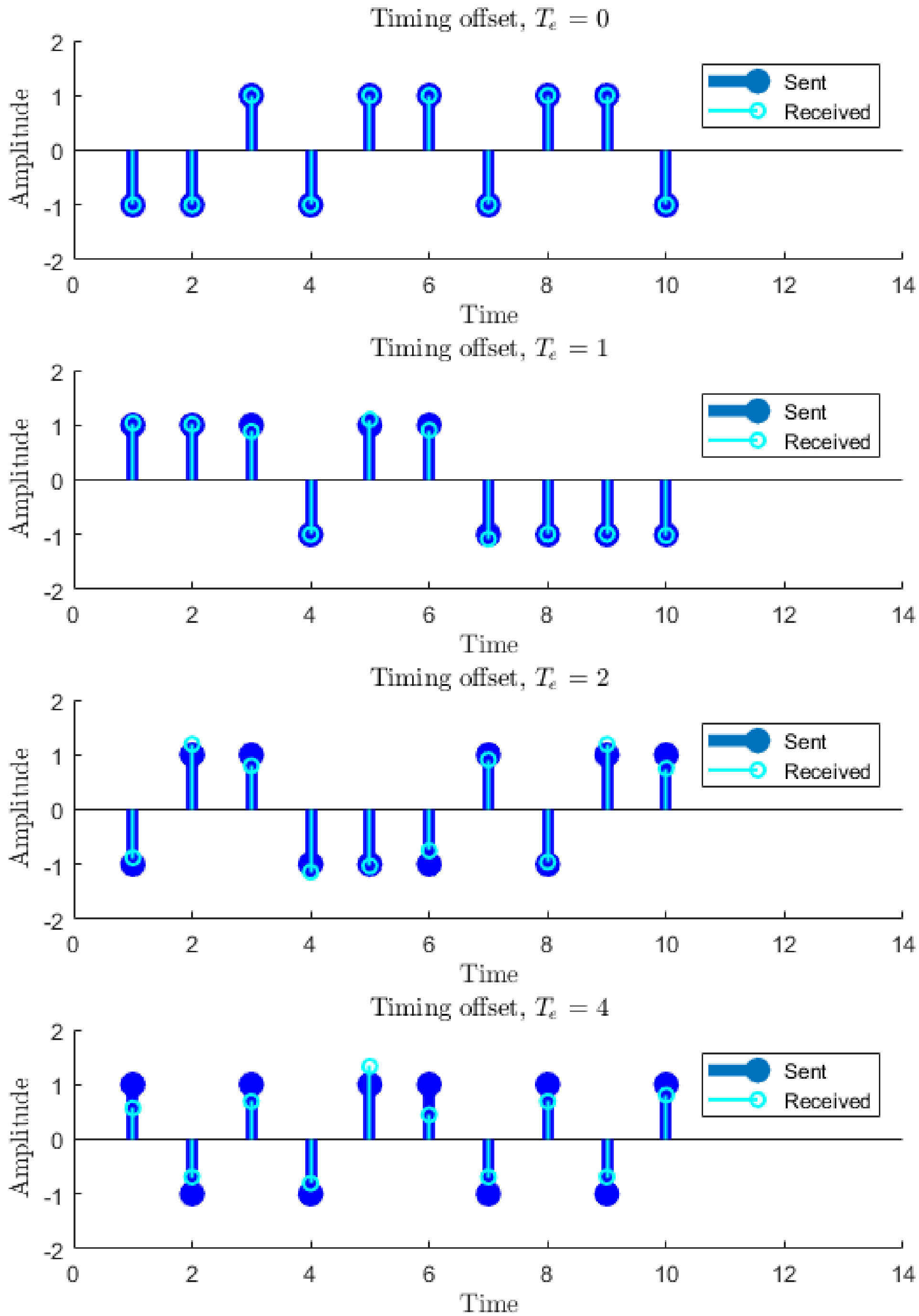
```
        xlabel('Time')
        ylabel('Pulse Amplitude')

end
```



d)e) add D extra symbols and remove D at end

This is done to align the sent bits with their corresponding mapped received bits. This allows for analysis of it.

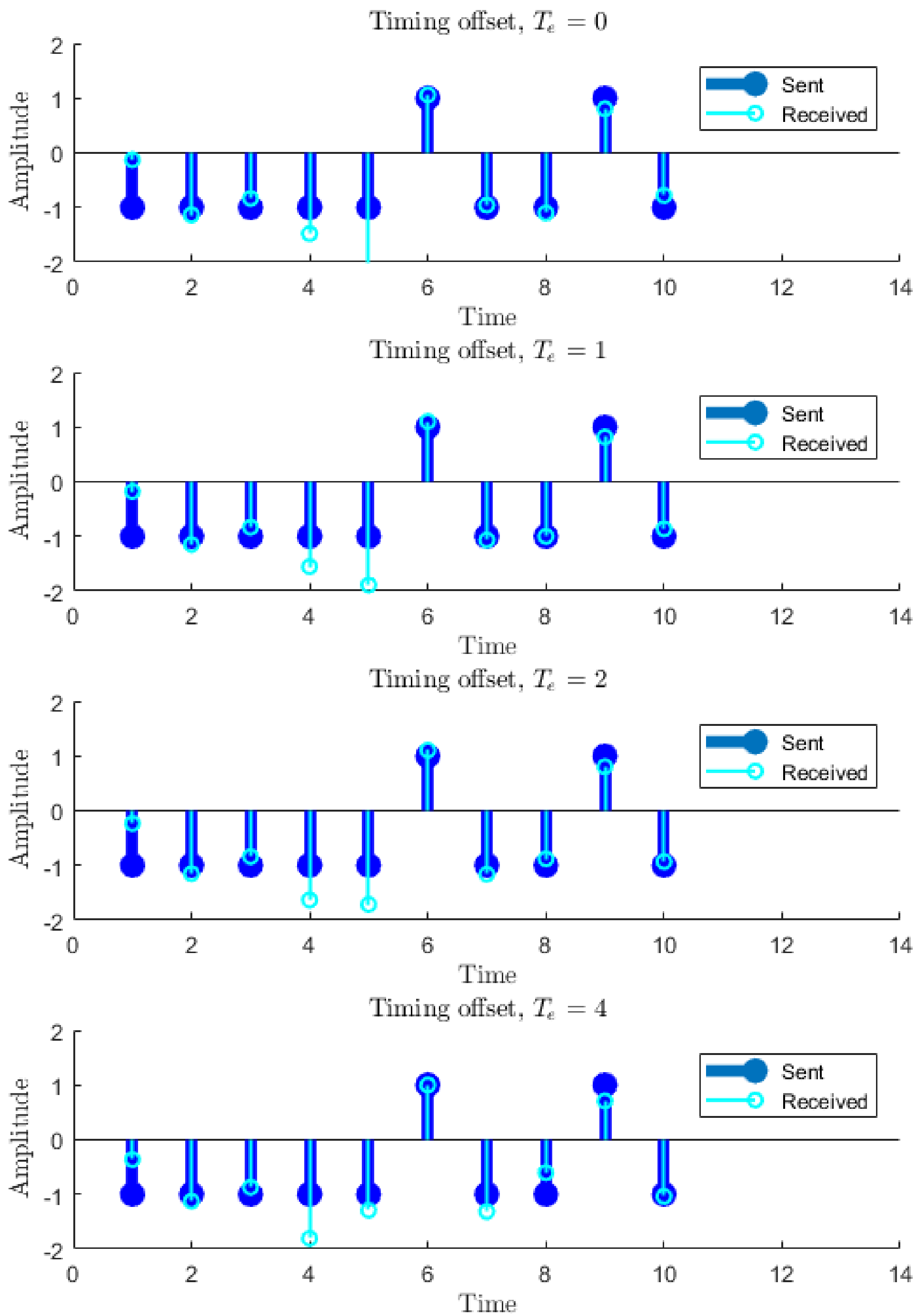
```
Ns = N + D;

Te_axis = [0 1 2 4]; %timing error
figure(4)
for indx = 1:length(Te_axis)
        Te = Te_axis(indx); % timing error

        s = real(randsrc(Ns,1,constel)); % get rnd symbols, tx
        n = 0;

        x = upsample(s,Rs); % simulate filter sampled at Ts = T/Rs
        s_ups = filter(rc,1,x); %pass upsampled data through raised
 cosine filter

        s_ups=s_ups;

        r = downsample(s_ups+n,Rs,Te); % received section


        r = r(1+D:end); % strip D bits at start
        s = s(1:end-D); % strip D bits at end


        subplot(4,1,indx)
        hold on
        stem(s,  'filled', 'linewidth', 5, 'Color', 'blue');
        stem(r, 'linewidth', 1.5, 'Color', 'cyan');
        hold off
        ylim([-2 2]);
        xlim([0 14]);
        title(['Timing offset, $ T_e$ = ' num2str(Te)])
        xlabel('Time')
        ylabel('Amplitude')
        leg = legend('Sent','Received');

end
```


Timing offset, $T_e = 0$
Timing offset, $T_e = 1$
Timing offset, $T_e = 2$
Timing offset, $T_e = 4$
Amplitude
Time
Sent
Received

f) add AWGN noise to the simulation

AWGN is added to the signal. It is not complex here as there is only one dimension to set the decision points. We see in comparison to the previous figure that noise has come into effect on the system.

```
Ns = N + D;
Es = 1;

SNRdB = 5;

Te_axis = [0 1 2 4]; %timing error
figure(5)
for indx = 1:length(Te_axis)

        No = Es/db2pow(SNRdB);

        rng(6);
        Te = Te_axis(indx); % timing error

        n = sqrt(No/2)*randn(Ns,1); % noise samples

        s = real(randsrc(Ns,1,constel)); % get rnd symbols, tx

        s_tx = s + n;

        x = upsample(s_tx,Rs); % simulate filter sampled at Ts = T/Rs
        s_ups = filter(rc,1,x); %pass upsampled data through raised
 cosine filter



        r = downsample(s_ups,Rs,Te); % received section


        r = r(1+D:end); % strip D bits at start
        s = s(1:end-D); % strip D bits at end


        subplot(4,1,indx)
        hold on
        stem(s,  'filled', 'linewidth', 5, 'Color', 'blue');
        stem(r, 'linewidth', 1.5, 'Color', 'cyan');
        hold off
        ylim([-2 2]);
        xlim([0 14]);
        title(['Timing offset, $ T_e$ = ' num2str(Te)])
        xlabel('Time')
        ylabel('Amplitude')
        leg = legend('Sent','Received');

end
```

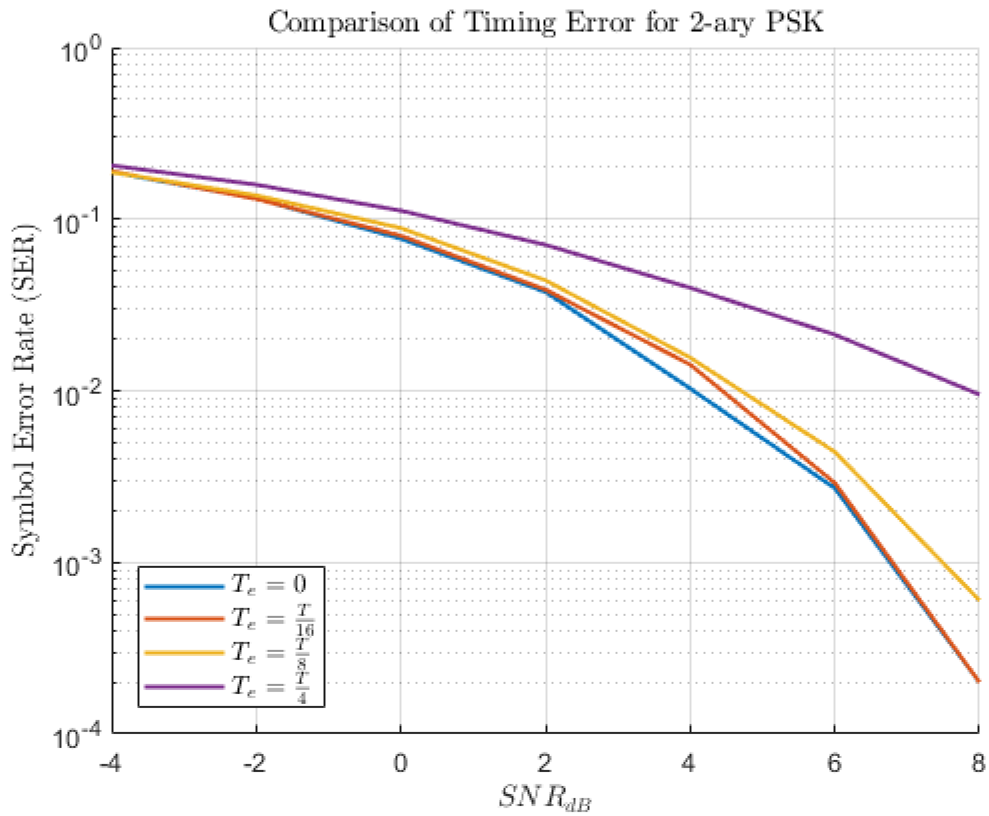

Timing offset, $T_e = 0$
Timing offset, $T_e = 1$
Timing offset, $T_e = 2$
Timing offset, $T_e = 4$
Amplitude
Time
Sent
Received
2
1
0
-1
-2
0
2
4
6
8
10
12
14

g,h)

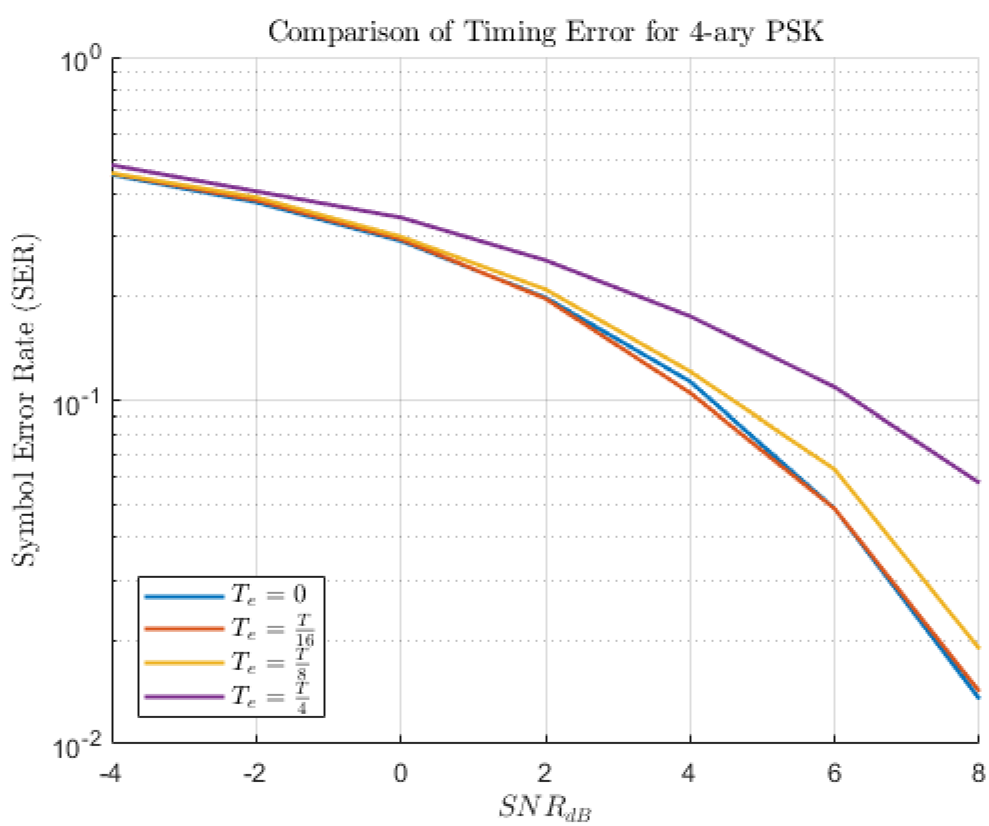
We see that larger timing errors lead to larger symbol error rates.

```
SNRdBAxis = -4:2:8;
TeAxis = [0 1 2 4];
SERresults = zeros(length(SNRdBAxis), length(TeAxis));
M_Axis = [2 4 8];

Ns = 1e4;

% loop through and test different M-ary schemes
for M_indx = 1:length(M_Axis)
    M = M_Axis(M_indx);
    for p = 1:length(SNRdBAxis)
        for q = 1:length(TeAxis)
            SNRdB_val = SNRdBAxis(p);
            Te = TeAxis(q);
            SERresults(p,q) = getSER(M, Ns, SNRdB_val, Te, Rs, D, rc);
        end
    end

    % plotting system
    figure(5 + M_indx);
    hold on
    grid on
    ax = gca;
    semilogy(SNRdBAxis ,SERresults,'linewidth', 1.5)
    ax.ColorOrderIndex = 1;

    set(ax,'yscale','log')

    hold off

    xlabel("$ SNR_{dB} $")
    ylabel("Symbol Error Rate (SER)")
    str = sprintf('Comparison of Timing Error for %c-ary PSK',
 (num2str(M)));
    title(str);
    lgnd = legend('$T_e = 0$','$T_e = \frac{T}{16}$','$T_e = \frac{T}
{8}$', ...
        '$T_e = \frac{T}{4}$');
    lgnd.Location = 'southwest';
    set(lgnd,'FontSize',10)
    set(lgnd,'Interpreter','latex')
end

% Functions:
% get SER function
% Inputs: M - number of decision points; Ns - number of data points
% simulated; SNRdB - SNRdB being tested; phaseError for phase error
% introduced
% Outputs: SER
```

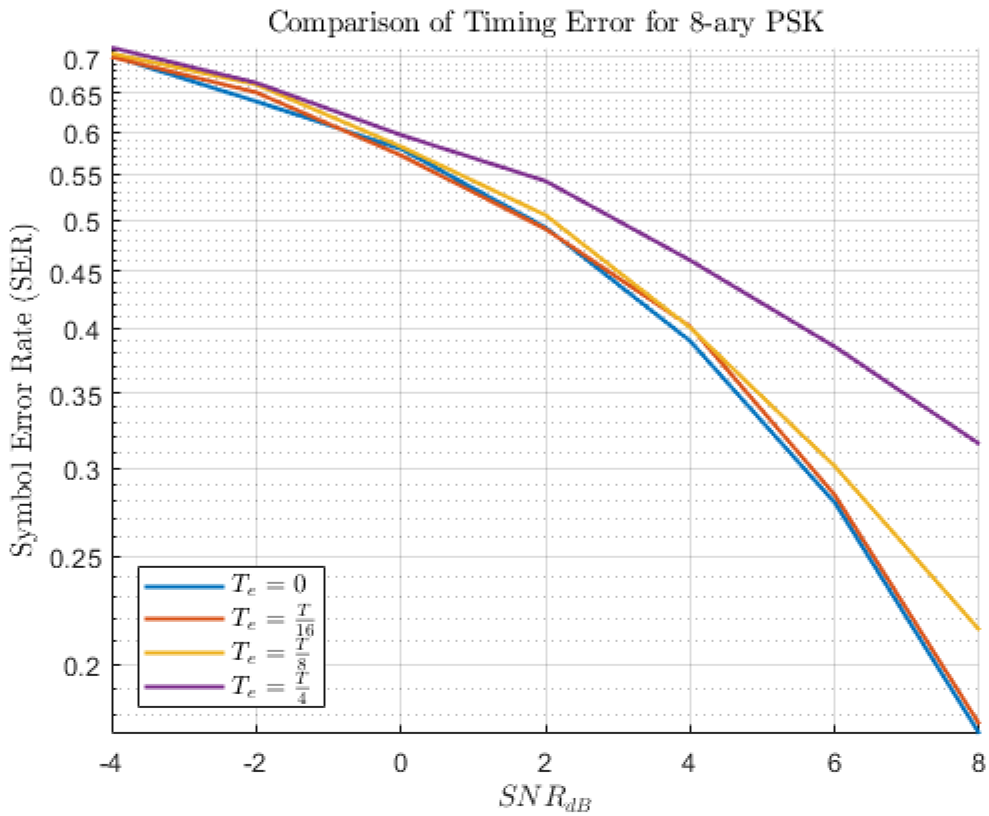
```
% get SER function
% Inputs: M - number of decision points; Ns - number of data points
% simulated; SNRdB - SNRdB being tested; Te - timing error causing
 ISI;
% Rs - symbol rate
% Outputs: SER

function SER = getSER(M, N, SNRdB, Te, Rs, D, rc);
    constel = exp((j * 2* pi * (0:M-1))/ (M));

    Ns = N + D;

    Es = 1;

    No = Es/db2pow(SNRdB);

    s = randsrc(Ns,1,constel); % get rnd symbols, tx
    n = sqrt(No/2)*complex(randn(Ns,1),randn(Ns,1)); % noise samples

    % simulating timing error
    s_tx = s + n;
    x = upsample(s_tx,Rs); % simulate filter sampled at Ts = T/Rs
    s_ups = filter(rc,1,x); %pass upsampled data through raised cosine
 filter
    r = downsample(s_ups,Rs,Te); % received section
    r = r(1+D:end); % strip D bits at start
    s = s(1:end-D); % strip D bits at end


    sest = zeros(N,1);

    for indx = 1:N
        %returns decision point closest to the received message
        [dmin, const_indx] = min(abs(r(indx) - constel));
        sest(indx) = constel(const_indx);
    end
    SER = (nnz(s-sest)/N);
end
```



Comparison of Timing Error for 2-ary PSK
Symbol Error Rate (SER)
SNR_{dB}
$T_e = 0$
$T_e = \frac{T}{16}$
$T_e = \frac{T}{8}$
$T_e = \frac{T}{4}$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
-4
-2
0
2
4
6
8



Comparison of Timing Error for 4-ary PSK
Symbol Error Rate (SER)
SNR_{dB}
$T_e = 0$
$T_e = \frac{T}{16}$
$T_e = \frac{T}{8}$
$T_e = \frac{T}{4}$
10^0
10^{-1}
10^{-2}
-4
-2
0
2
4
6
8



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