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FACULTY OF ENGINEERING

ELECTRONICS AND COMMUNICATIONS DEPT.

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Digital Communications

Project # 1

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I. Problem description

It is required to generate an ensemble that consists of 500 waveforms, each containing 100 bits,
for the line codes (Unipolar, NRZ, RZ). It is required to compute:

1- The statistical mean.
2- Is the random process stationary?
3- Determine the ensemble autocorrelation function $Rx(\tau)$.
4- The time mean and autocorrelation function for one waveform.
5- Is the random process Ergodic?
6- What is the bandwidth of the transmitted signal

II. Introduction

In the following pages each part of the code that is attached will be explained in details accompanied with the resulting figures and graphs and comments on the results

III. Control flags

These are values that control the most important aspects of the code and can be changed easily through the whole code by changing their values

```
%% Control flags
%value of the desired amplitude
A=4;
%number of waveforms
w=500;
%number of bits
b=100;
%sampling frequency is 100 hz
fs=100;
```

IV. Generation of data

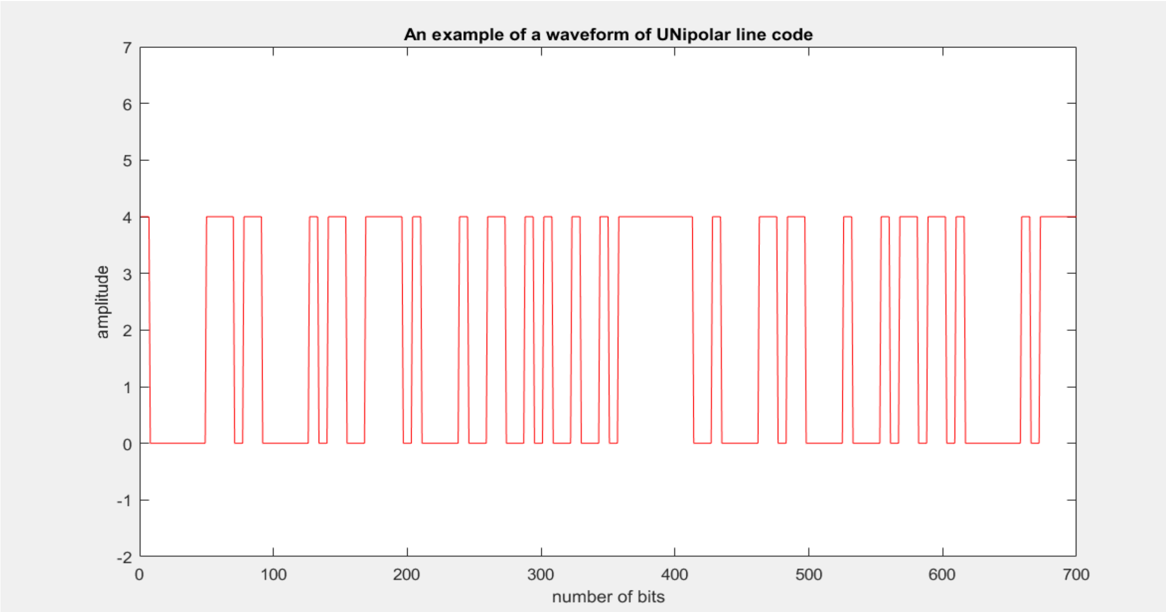
500 random waveforms of binary digits are required to be generated each having 100 bits, we used the binomial distribution to have equal probabilities for ones and zeros ,random function was used to generate random bits following the given distribution ,cell matrices are used for easier dealing with each waveforms when doing loops

```
%% Creating 500 waveforms each with 100 random bits
distr=makedist('Binomial');
Data = cell(1,w);
for K = 1 : w
  Data{K} = random(distr, 1,b);
end
```

V. Creation of unipolar ensemble

Using the cell array we represented the data in the unipolar form then the matrix was repeated to make the pulse width 70ms as described after that the cell array was reshaped such that it has size of 1x500 representing the number of waveforms and each cell is an array of 700x1 representing the bits of each waveform .

```
for K1 = 1 : w
 UNI{K1} = Data{K1}*A;
  UNI_repeated{K1}=repmat( UNI{K1},7,1);
  UNI_ready{K1}=reshape( UNI_repeated{K1},size(
UNI_repeated{K1},1)* size( UNI_repeated{K1},2),1);
end
figure ;
plot(UNI_ready{1},'r');
ylim([-2 7]);
title('An example of a waveform of UNipolar line code');
xlabel('number of bits') ;
ylabel('amplitude') ;
```

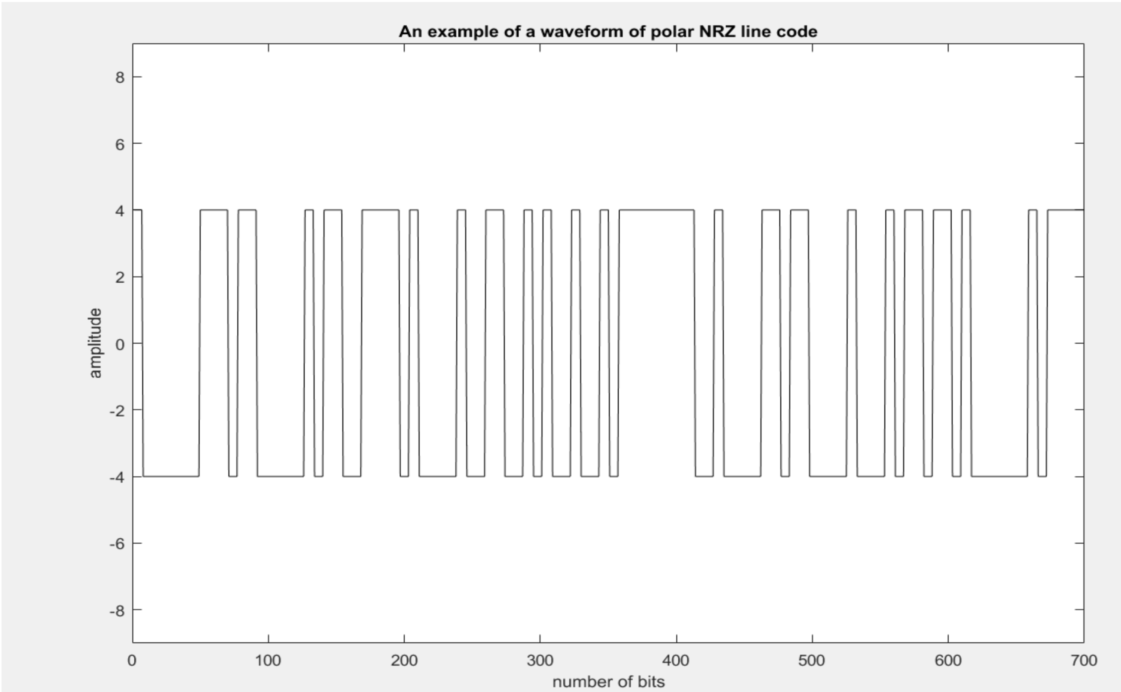


VI. Creation of polar NRZ ensemble

Using the cell array we represented the data in the polar NRZ form then the matrix was repeated to make the pulse width 70ms as described after that the cell array was reshaped such that it has size of 1x500 representing the number of waveforms and each cell is an array of 700x1 representing the bits of each waveform .

```
for K1 = 1 : w
 NRZ{K1} = ((2*Data{K1})-1)*A;
 NRZ_repeated{K1}=repmat(NRZ{K1},7,1);

NRZ_ready{K1}=reshape(NRZ_repeated{K1},size(NRZ_repeated{K1
},1)* size(NRZ_repeated{K1},2),1);
end
figure ;
plot(NRZ_ready{1},'k');
ylim([-9 9]);
title('An example of a waveform of polar NRZ line code');
xlabel('number of bits') ;
ylabel('amplitude') ;
```

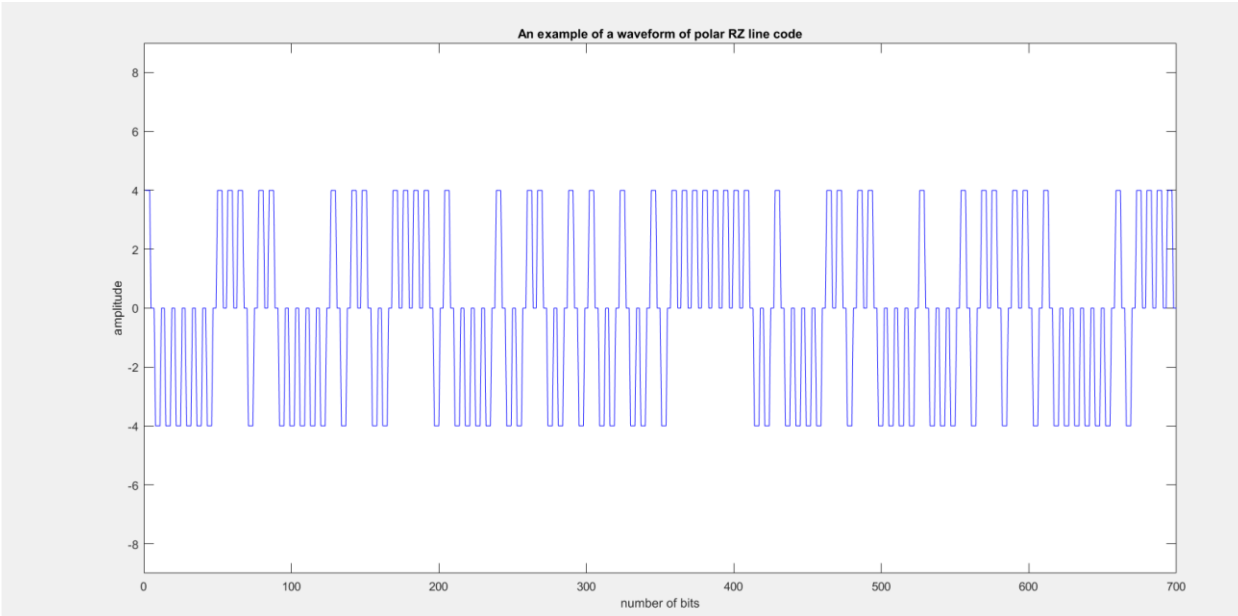


VII. Creation of polar RZ ensemble

Using the cell array we represented the data in the polar RZ form then the matrix was repeated to make the pulse width 70ms as described after that the cell array was reshaped such that it has size of 1x500 representing the number of waveforms and each cell is an array of 700x1 representing the bits of each waveform .

```
for K1 = 1 : w
 RZ{K1}=((2*Data{K1})-1)*A ;
 RZ_repeated{K1}=repmat (RZ{K1},4,1);
RZ_repeated{K1}=cat(1,RZ_repeated{K1},zeros(3,100));

RZ_ready{K1}=reshape(RZ_repeated{K1},size(RZ_repeated{K1},1
)* size(RZ_repeated{K1},2),1);
end
figure ;
plot(RZ_ready{1},'b');
ylim([-9 9]);
title('An example of a waveform of polar RZ line code');
xlabel('number of bits') ;
ylabel('amplitude') ;
```



VIII. Applying random initial time shifts for each waveform

To get waveforms having random initial shifts the function circshift was used with a random number as a shift parameter ,this has made the initial starting points of each waveform random

```
for K1 = 1:w
    random_shift = randi([19 30], 1, 1);
  UNI_ready{1,K1} = circshift(
UNI_ready{1,K1},random_shift);
   NRZ_ready{K1}=circshift( NRZ_ready{K1},random_shift);
  RZ_ready{K1}=circshift( RZ_ready{K1},random_shift);
end
```

IX. Getting the cell arrays ready to calculate the statistical mean and autocorrelation

The matrix has been transposed such that each cell now represents an array with the time instances of each of the 500 waves

```
UNI=num2cell(transpose(cell2mat(UNI_ready)),1);
NRZ=num2cell(transpose(cell2mat(NRZ_ready)),1);
RZ=num2cell(transpose(cell2mat(RZ_ready)),1);
```

X. Q1:Calculating the statistical mean

After the cell array was transposed the function mean was used to do the basic operation of (sum/num of elements) in an easy manner

```
for i=1:700
      meanUNI{i}=mean(UNI{i});
end
%mean for RZ
for i=1:700
      meanRZ{i}=mean(RZ{i});
end
%mean for NRZ

for i=1:700
    meanNRZ{i}=mean(NRZ{i});

end
```

XI. Plotting the statistical mean

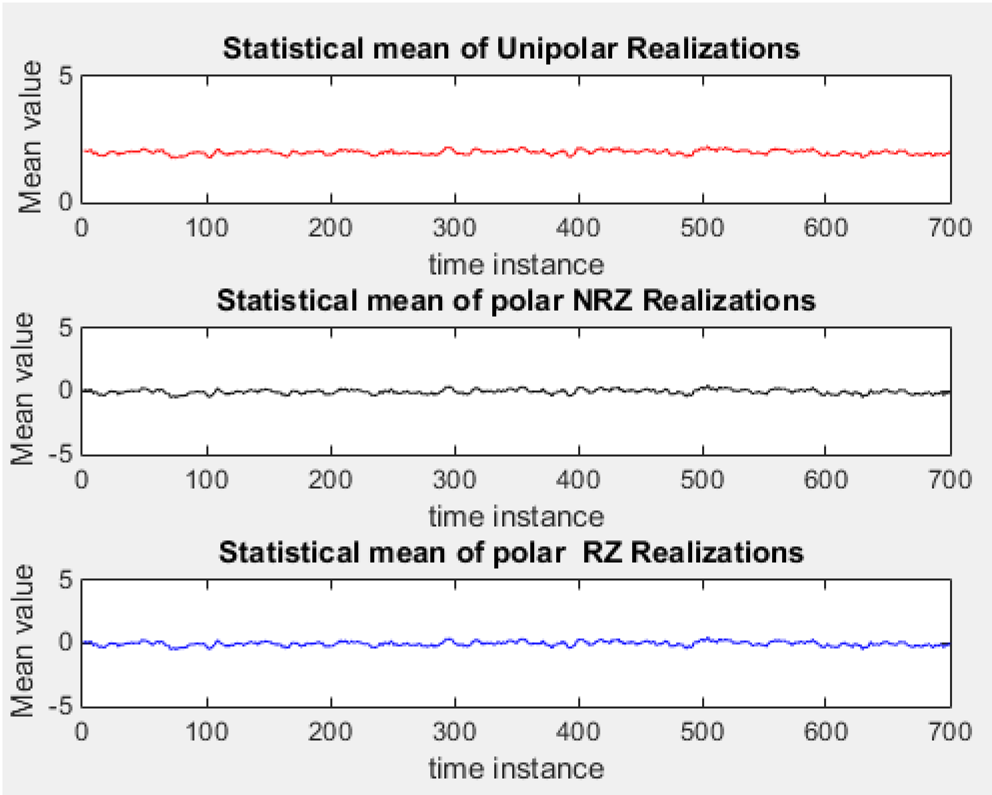
By observing the figure below, we can note that the statistical means for each line code is as follows:

- **Unipolar**: around 2 which is logical as the ratio of ones and zeros is half and A=4 so the average is **around 2** (It will be 2 exactly if we have infinite number of wave forms)
- **Polar NRZ**: around 0 which is logical as the ratio of ones and zeros is half and A=4 or -4 so the average is **around zero** (It will be 0 exactly if we have infinite number of wave forms)
- **Polar RZ**: around 0 which is logical as the ratio of ones and zeros is half and A=4 or -4 so the average is **around zero** (It will be 0 exactly if we have infinite number of wave forms)

```
figure;
subplot(3,1,1);
plot(cell2mat(meanUNI),'r');
ylim([0 5]);
title('Statistical mean of Unipolar Realizations ');
xlabel('time instance') ;
ylabel('Mean value') ;

subplot(3,1,2);
plot(cell2mat(meanNRZ),'k');
ylim([-5 5]);
title('Statistical mean of polar NRZ Realizations');
xlabel('time instance') ;
ylabel('Mean value') ;

subplot(3,1,3);
plot(cell2mat(meanNRZ),'b');
ylim([-5 5]);
title('Statistical mean of polar  RZ Realizations ');
xlabel('time instance') ;
ylabel('Mean value') ;
```



Fig(X.1): Statistical Mean

XII. Q3: Calculating the statistical autocorrelation

Since the auto correlation function is the expected value of (x(t)*x(t+tao)) and the mean is the expected value ,So using the following code we can obtain the statistical autocorrelation for each realization , the auto correlation is independent of the time instance yet dependent on the time difference ,applying the commented line will give the same result

```
%autocorrelation of UNIpolar
for tao=0:1:699

autoUNI{(tao)+1}=mean(UNI{1}.*UNI{1+tao});
%autoUNI(tao+1)=mean(UNI{700}.*UNI{700-tao});
end
%autocorrelation of polarNRZ
for tao=0:1:699
  autoNRZ{tao+1}=mean(NRZ{1}.*NRZ{1+tao});
  %autoNRZ(tao+1)=mean(NRZ{700}.*NRZ{700-tao});
end
%autocorrelation of polarRZ
for tao=0:1:699
    autoRZ{tao+1}=mean(RZ{1}.*RZ{1+tao});
    %autoRZ(tao+1)=mean(RZ{700}.*RZ{700-tao});
end
```

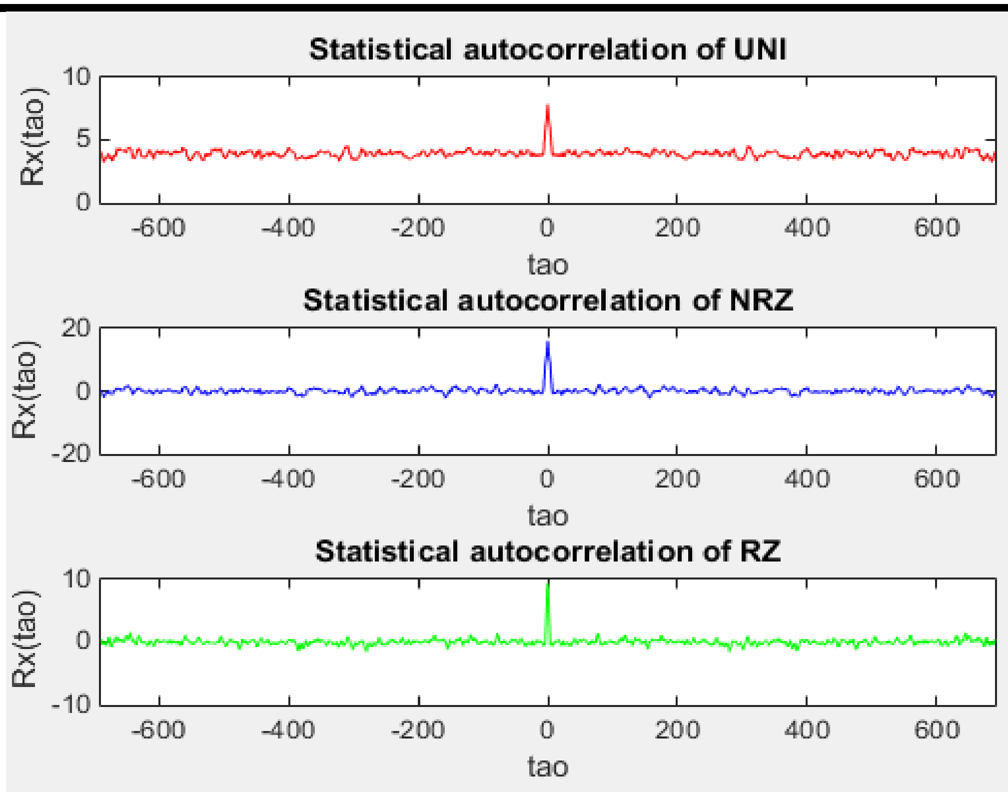
XIII. Plotting the statistical autocorrelation

After plotting the statistical autocorrelation using the following code we can note that its is as expected as the autocorrelation is maximum when the time difference is zero then it decrease gradually till tao is equal to tp then it fluctuates about a certain point

```
figure;
subplot(3,1,1);
t=0:699 ;
plot(-t,cell2mat(autoUNI),'r',t,cell2mat(autoUNI),'r');
xlim([-700 700]);
title('Statistical autocorrelation of UNI');
xlabel('tao') ;
ylabel('Rx(tao)') ;

subplot(3,1,2);
t=0:699 ;
plot(-t,cell2mat(autoNRZ),'b',t,cell2mat(autoNRZ),'b');
xlim([-700 700]);
title('Statistical autocorrelation of NRZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;
```

```
subplot(3,1,3);
t=0:699 ;
plot(-t,cell2mat(autoRZ),'g',t,cell2mat(autoRZ),'g');
xlim([-700 700]);
title('Statistical autocorrelation of RZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;
```



Fig(XII.1):ensemble autocorrelation function Rx(tao)

XIV. Q2:Is the process stationary?

Since:

The mean is constant across ensemble (1) from Q1

The autocorrelation is a function of Tao only not time (2) from Q3

Therefore: from 1,2

The process is stationary

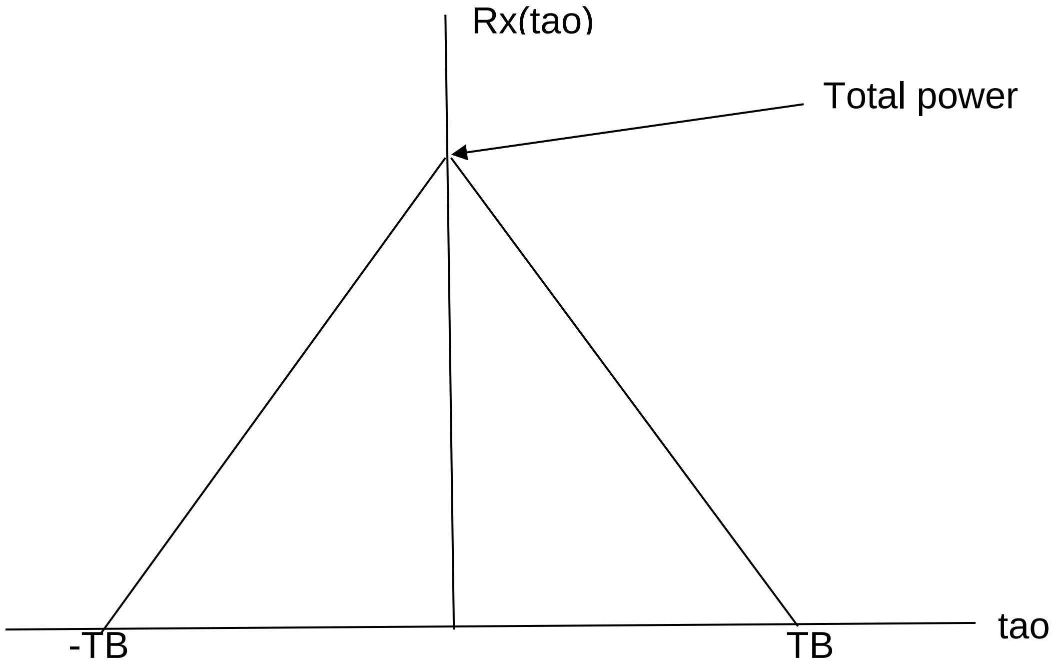
XV. Q4: Computing the time mean and auto correlation of one wave form

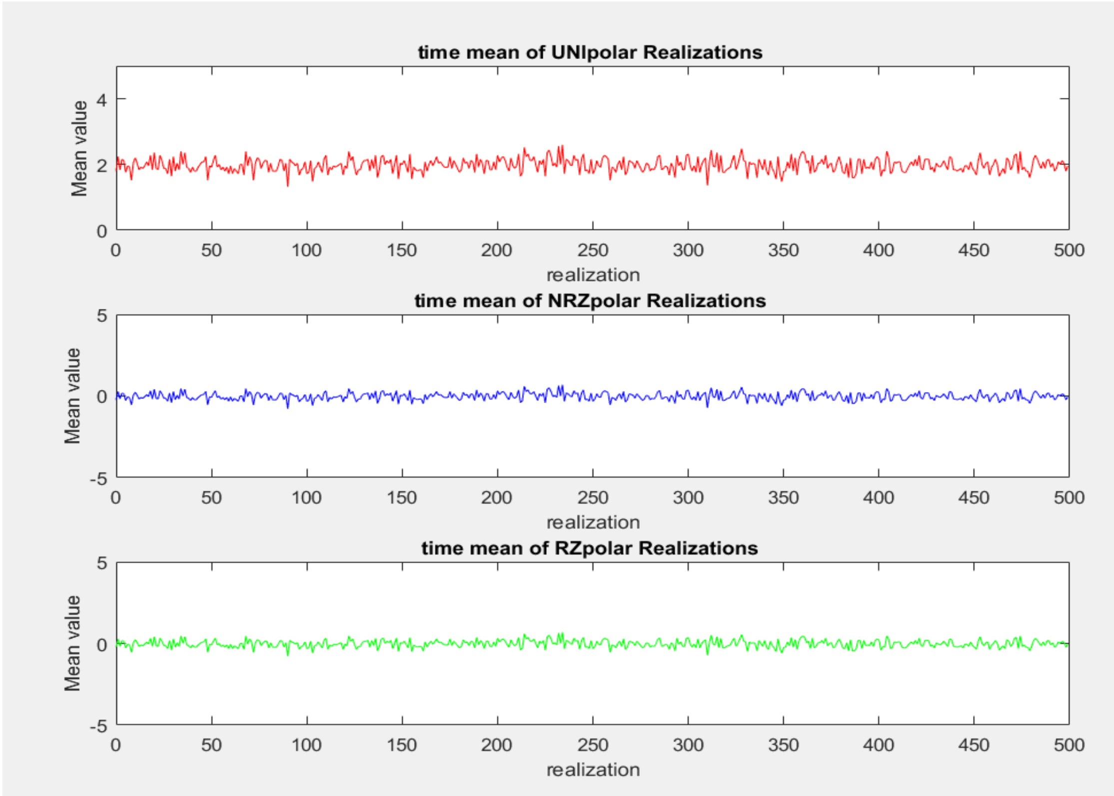
To calculate the time mean we need to get the average of one wave form,but we calculated time mean for all wave forms and plotted it in Fig (4.1)
So a variable that has a random number from 1 to 500 representing a random wave form is created to prove our point in Q5

and to calculate time auto correlation We used this relation

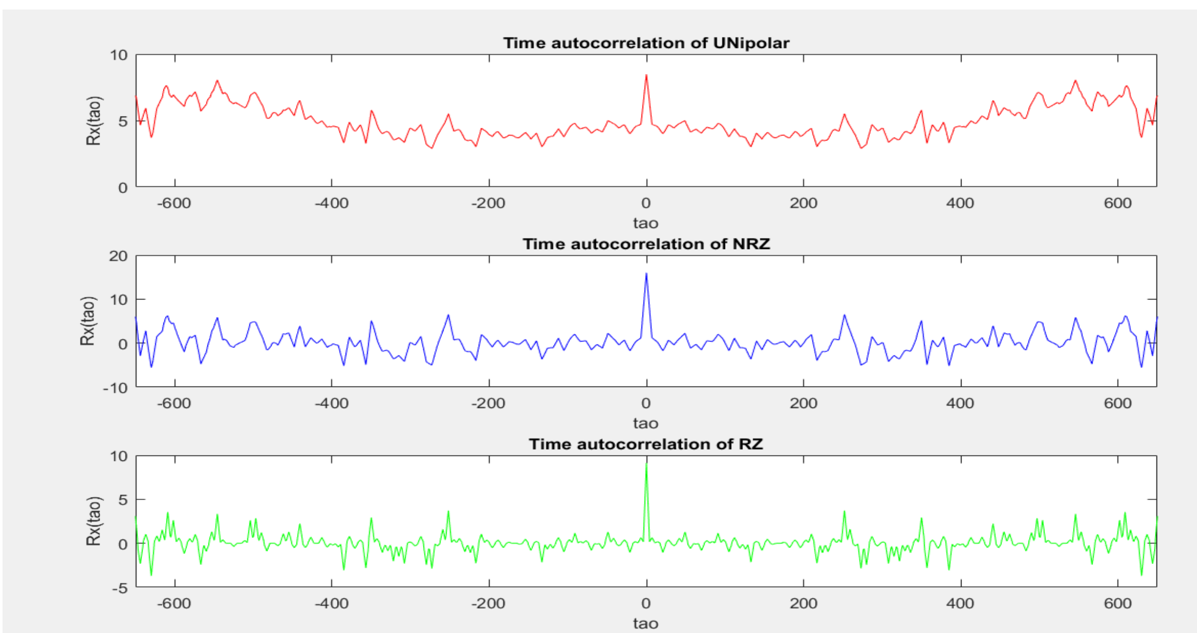
$$r_{uu}(\tau) = \lim_{N \to \infty} \frac{1}{N} \sum_{i=1}^{N-\tau} u(i)u(i+\tau)$$

where we get the results we know from analytical analysis as in shape below





Fig(4.1):Time Mean for Random Processes



Fig(4.2):Time Autocorrelation for Random Processes

```
%getting the time mean of a random wave form from any of
the 500 wavefroms
sum=0;
for tao=0:699
for x=1:700
```

```
    if((tao+x)<=700)
    y=onewaveformUNI(x,1)*onewaveformUNI(x+tao,1);
    sum=sum+y;
    end

    end
 sum=sum/(700-tao);
tauni(tao+1,1)=sum;
end

 t=0:699 ;
 figure;
 subplot(3,1,1);
plot(-t,tauni,'r',t,tauni,'r');
title('Time autocorrelation of UNipolar');
xlabel('tao') ;
ylabel('Rx(tao)') ;

sum=0;
for tao=0:699
for x=1:700
    if((tao+x)<=700)
    y=onewaveformNRZ(x,1)*onewaveformNRZ(x+tao,1);
    sum=sum+y;
    end

    end
 sum=sum/(700-tao);
tanrz(tao+1,1)=sum;
end

 t=0:699 ;
 subplot(3,1,2);
plot(-t,tanrz,'b',t,tanrz,'b');
title('Time autocorrelation of NRZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;

sum=0;
for tao=0:699
for x=1:700
    if((tao+x)<=700)
    y=onewaveformRZ(x,1)*onewaveformRZ(x+tao,1);
    sum=sum+y;
```

```
    end

    end
 sum=sum/(700-tao);
tarz(tao+1,1)=sum;
end



 t=0:699 ;
 subplot(3,1,3);
plot(-t,tarz,'g',t,tarz,'g');
title('Time autocorrelation of RZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;
```

XVI. Q5: IS the random process ergodic?

since:

The time means and statistical means are equal (1)

The time autocorrelation of one wave is equivalent to the

the statistical autocorrelation of the ensemble(2)

Therefore:

The process is ergodic

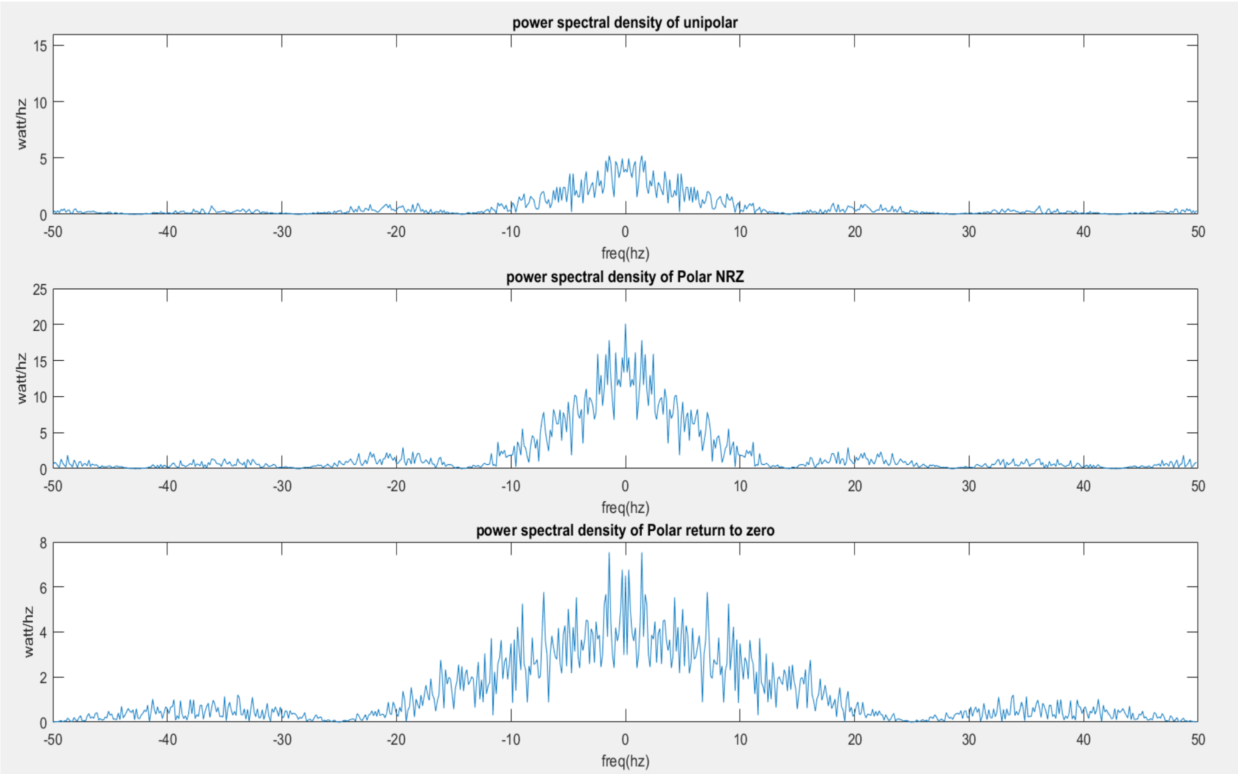
XVII. Plotting the PSD of the ensemble:

We know that the PSD of a signal can be got from the Fourier transform of the statistical autocorrelation this what we have done here for each line code ensemble

```
tao=700;
    %represents the size of statsical autocorrelation
arrays
     figure;
  subplot(3,1,1);
 DC=mean(cell2mat(autoUNI));
 autoUNI=cell2mat(autoUNI)-DC;
 PSDUNI=fft((autoUNI));
 k=-tao/2:tao/2-1;
 hold on;
 stem(0,DC);
plot(k*fs/tao,fftshift(abs( PSDUNI)/10));
hold off;
title('power spectral density of unipolar');
  xlabel('freq(hz)') ;
  ylabel('watt/hz') ;
  axis([-50 50 0 16]);


 subplot(3,1,2);
 PSDNRZ=fft((cell2mat((autoNRZ))));
 k=-tao/2:tao/2-1;
plot(k*fs/tao,fftshift(abs( PSDNRZ)));
title('power spectral density of Polar NRZ');
xlabel('freq(hz)') ;
ylabel('watt/hz') ;

subplot(3,1,3);
PSDRZ=fft((cell2mat((autoRZ))));
k=-tao/2:tao/2-1;
plot(k*fs/tao,fftshift(abs( PSDRZ)));
title('power spectral density of Polar return to zero');
xlabel('freq(hz)') ;
ylabel('watt/hz') ;
```



Fig(6):Power Spectral Density For Unipolar,Polar RZ, Polar NRZ

XVIII. Q6 : What is the bandwidth of the transmitted signal ?

(1)**unipolar**:~14.2857Hz

(2)**polarNRZ**:~14.2857Hz

(3)**polarRZ**:~25Hz

Note: in order to calculate bandwidth for unipolar we removed DC before FFT as FFT converts DC into unit impulse in Frequency domain which is practically impossible so after removing DC and doing FFT we added the DC value.

Bandwidth

Unipolar and polar NRZ signals have same bandwidth ,where polar RZ has approximately double the bandwidth of polar NRZ and unipolar and this because its bit duration is approximately half of Tb duration of unipolar and polar RZ (we made it for (4/7 of Tb))

DC power

Unipolar has less DC power compared to Polar NRZ as Polar consume more power on sending logic ‘0’ where Polar RZ is in between as it sends signal on a proportion of Tb (we made it 4/7 Tb)

XIX.FULL MATLAB code:

```
clear;
clc;

%% Control flags
%value of the desired amplitide
A=4;
%number of waveforms
w=500;
%number of bits
b=100;
%sampling frequency is 100 hz
fs=100;



%% Creating 500 waveforms each with 100 random bits
```

```
distr=makedist('Binomial');
Data = cell(1,w);
for K = 1 : w
  Data{K} = random(distr, 1,b);
end


%% Unipolar Realizations


for K1 = 1 : w
 UNI{K1} = Data{K1}*A;
  UNI_repeated{K1}=repmat( UNI{K1},7,1);
  UNI_ready{K1}=reshape( UNI_repeated{K1},size(
UNI_repeated{K1},1)* size( UNI_repeated{K1},2),1);
end

figure ;
plot(UNI_ready{1},'r');
ylim([-2 7]);
title('An example of a waveform of UNipolar line code');
xlabel('number of bits') ;
ylabel('amplitude') ;

%% Polar non return to zero Realizations

for K1 = 1 : w
 NRZ{K1} = ((2*Data{K1})-1)*A;
 NRZ_repeated{K1}=repmat(NRZ{K1},7,1);

NRZ_ready{K1}=reshape(NRZ_repeated{K1},size(NRZ_repeated{K1
},1)* size(NRZ_repeated{K1},2),1);
end

figure ;
plot(NRZ_ready{1},'k');
ylim([-9 9]);
title('An example of a waveform of polar NRZ line code');
xlabel('number of bits') ;
ylabel('amplitude') ;


%% Polar Return to zero Realizations
for K1 = 1 : w
```

```
 RZ{K1}=((2*Data{K1})-1)*A ;
 RZ_repeated{K1}=repmat (RZ{K1},4,1);
RZ_repeated{K1}=cat(1,RZ_repeated{K1},zeros(3,100));

RZ_ready{K1}=reshape(RZ_repeated{K1},size(RZ_repeated{K1},1
)* size(RZ_repeated{K1},2),1);
end
figure ;
plot(RZ_ready{1},'b');
ylim([-9 9]);
title('An example of a waveform of polar RZ line code');
xlabel('number of bits') ;
ylabel('amplitude') ;

%% Applying time shifts to create different initial time
shifts
for K1 = 1:w
    random_shift = randi([19 30], 1, 1);
  UNI_ready{1,K1} = circshift(
UNI_ready{1,K1},random_shift);
   NRZ_ready{K1}=circshift( NRZ_ready{K1},random_shift);
  RZ_ready{K1}=circshift( RZ_ready{K1},random_shift);
end

%% Creating cell matrices where each coloumn represents a
time instance of each realization
UNI=num2cell(transpose(cell2mat(UNI_ready)),1);
NRZ=num2cell(transpose(cell2mat(NRZ_ready)),1);
RZ=num2cell(transpose(cell2mat(RZ_ready)),1);



%% Q1 :compute the statistical mean

%% calculating the Statistical mean of realizations

for i=1:700
      meanUNI{i}=mean(UNI{i});
end
%mean for RZ
for i=1:700
      meanRZ{i}=mean(RZ{i});
end
%mean for NRZ
```

```
for i=1:700
    meanNRZ{i}=mean(NRZ{i});

end

%% ploting the statistical mean of each line code
figure;
subplot(3,1,1);
plot(cell2mat(meanUNI),'r');
ylim([0 5]);
title('Statistical mean of Unipolar Realizations ');
xlabel('time instance') ;
ylabel('Mean value') ;

subplot(3,1,2);
plot(cell2mat(meanNRZ),'k');
ylim([-5 5]);
title('Statistical mean of polar NRZ Realizations');
xlabel('time instance') ;
ylabel('Mean value') ;

subplot(3,1,3);
plot(cell2mat(meanNRZ),'b');
ylim([-5 5]);
title('Statistical mean of polar  RZ Realizations ');
xlabel('time instance') ;
ylabel('Mean value') ;

%% Q3 : Determine the ensemble autocorrelation function
Rx(?)

%% calculating the autocorelation for the line code
ensemble

%autocorrelation of UNIpolar
for tao=0:1:699

autoUNI{(tao)+1}=mean(UNI{1}.*UNI{1+tao});
%autoUNI(tao+1)=mean(UNI{700}.*UNI{700-tao});
end
%autocorrelation of polarNRZ
for tao=0:1:699
  autoNRZ{tao+1}=mean(NRZ{1}.*NRZ{1+tao});
```

```
  %autoNRZ(tao+1)=mean(NRZ{700}.*NRZ{700-tao});
end
%autocorrelation of polarRZ
for tao=0:1:699
    autoRZ{tao+1}=mean(RZ{1}.*RZ{1+tao});
    %autoRZ(tao+1)=mean(RZ{700}.*RZ{700-tao});
end
%% Ploting the statistical autocorrelation of each line
code
figure;
subplot(3,1,1);
t=0:699 ;
plot(-t,cell2mat(autoUNI),'r',t,cell2mat(autoUNI),'r');
xlim([-690 690]);
title('Statistical autocorrelation of UNI');
xlabel('tao') ;
ylabel('Rx(tao)') ;

subplot(3,1,2);
t=0:699 ;
plot(-t,cell2mat(autoNRZ),'b',t,cell2mat(autoNRZ),'b');
xlim([-690 690]);
title('Statistical autocorrelation of NRZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;

subplot(3,1,3);
t=0:699 ;
plot(-t,cell2mat(autoRZ),'g',t,cell2mat(autoRZ),'g');
xlim([-690 690]);
title('Statistical autocorrelation of RZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;
%% Q2 : Is the process stationary ?
%since :
%The mean is constant across ensemble (1)
%The autocorelation is a function of tao only not time (2)
%therefore:
%The procees is stationary

%% Q4 :Compute the time mean and auto correlation of one
wave form
```

```
%getting the time mean of a random wave form from any of
the 500 wavefroms
RandomWaveNum=randi([1 500]);

onewaveformUNI=circshift(UNI_ready{RandomWaveNum},[1 90]);
onewaveformNRZ=circshift(NRZ_ready{RandomWaveNum},[1 90]);
onewaveformRZ=circshift(RZ_ready{RandomWaveNum},[1 90]);

tmeanuni=zeros(500,1);
tmeannrz=zeros(500,1);
tmeanrz=zeros(500,1);

for i=1:500
tmeanuni(i,1)=tmeanuni(i,1)+mean(UNI_ready{i});
tmeannrz(i,1)=tmeannrz(i,1)+mean(NRZ_ready{i});
tmeanrz(i,1)=tmeanrz(i,1)+mean(RZ_ready{i});
end


 figure;
 r=0:499 ;
 subplot(3,1,1);
plot(r,tmeanuni,'r');
ylim([0 5]);
title('time mean of UNIpolar Realizations ');
xlabel('realization') ;
ylabel('Mean value') ;
 r=0:499 ;
 subplot(3,1,2);
plot(r,tmeanrz,'b');
ylim([-5 5]);
title('time mean of NRZpolar Realizations ');
xlabel('realization') ;
ylabel('Mean value') ;
  r=0:499 ;
subplot(3,1,3);
plot(r,tmeanrz,'g');
ylim([-5 5]);
title('time mean of RZpolar Realizations ');
xlabel('realization') ;
ylabel('Mean value') ;


tauni=zeros(700,1);
```

```
tanrz=zeros(700,1);
tarz=zeros(700,1);
sum=0;
for tao=0:699
for x=1:700
    if((tao+x)<=700)
    y=onewaveformUNI(x,1)*onewaveformUNI(x+tao,1);
    sum=sum+y;
    end

    end
 sum=sum/(700-tao);
tauni(tao+1,1)=sum;
end

 t=0:699 ;
 figure;
 subplot(3,1,1);
plot(-t,tauni,'r',t,tauni,'r');
title('Time autocorrelation of UNipolar');
xlim([-650 650]);
xlabel('tao') ;
ylabel('Rx(tao)') ;

sum=0;
for tao=0:699
for x=1:700
    if((tao+x)<=700)
    y=onewaveformNRZ(x,1)*onewaveformNRZ(x+tao,1);
    sum=sum+y;
    end

    end
 sum=sum/(700-tao);
tanrz(tao+1,1)=sum;
end

 t=0:699 ;
 subplot(3,1,2);
plot(-t,tanrz,'b',t,tanrz,'b');
title('Time autocorrelation of NRZ');
xlim([-650 650]);
xlabel('tao') ;
ylabel('Rx(tao)') ;
```

```
sum=0;
for tao=0:699
for x=1:700
    if((tao+x)<=700)
    y=onewaveformRZ(x,1)*onewaveformRZ(x+tao,1);
    sum=sum+y;
    end

    end
 sum=sum/(700-tao);
tarz(tao+1,1)=sum;
end



 t=0:699 ;
 subplot(3,1,3);
plot(-t,tarz,'g',t,tarz,'g');
xlim([-650 650]);
title('Time autocorrelation of RZ');
xlabel('tao') ;
ylabel('Rx(tao)') ;

%% Q5: IS the random process ergodic ??
 % since:
 %The time means and stastistical means are equal (1)
 %The time autocorrelation of one wave is equivalent to the
 %the statistical autocorrelation (as it is the same
waveform )(2)
 % Therefore :
 % The process is ergodic


 %% PLoting the PSD of the ensemble
    tao=700;
    %represents the size of statsical autocorrelation
arrays
     figure;
 subplot(3,1,1);
 DC=mean(cell2mat(autoUNI));
 autoUNI=cell2mat(autoUNI)-DC;
 PSDUNI=fft((autoUNI));
 k=-tao/2:tao/2-1;
```

```
 hold on;
 stem(0,DC);
plot(k*fs/tao,fftshift(abs( PSDUNI)/10));
hold off;
title('power spectral density of unipolar');
  xlabel('freq(hz)') ;
  ylabel('watt/hz') ;
  axis([-50 50 0 16]);

 subplot(3,1,2);
 PSDNRZ=fft((cell2mat((autoNRZ))));
 k=-tao/2:tao/2-1;
plot(k*fs/tao,fftshift(abs( PSDNRZ))/10);
title('power spectral density of Polar NRZ');
xlabel('freq(hz)') ;
ylabel('watt/hz') ;

subplot(3,1,3);
PSDRZ=fft((cell2mat((autoRZ))));
k=-tao/2:tao/2-1;
plot(k*fs/tao,fftshift(abs( PSDRZ))/10);
title('power spectral density of Polar return to zero');
xlabel('freq(hz)') ;
ylabel('watt/hz') ;

 %% Q6 : What is the bandwidth of the transmitted signal ?
 %(1)unipolar:14.2857hz
 %(2)polarNRZ:14.2857hz
 %(3)polarRZ:25hz
```