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Table of Contents

1. Part 1 - EE 274: Tutorials for Discrete Fourier Transform
2. Part 2 - EE 274 / CoE 197E Lab Exercise: Properties of the DFT

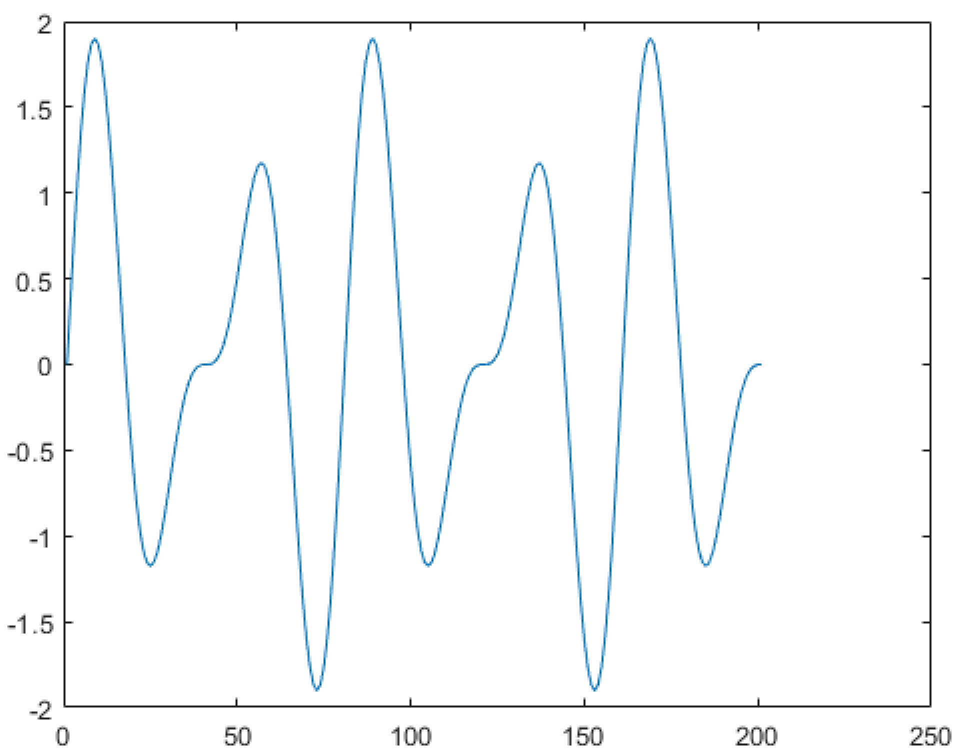
Part 1 - Tutorials for Discrete Fourier Transform

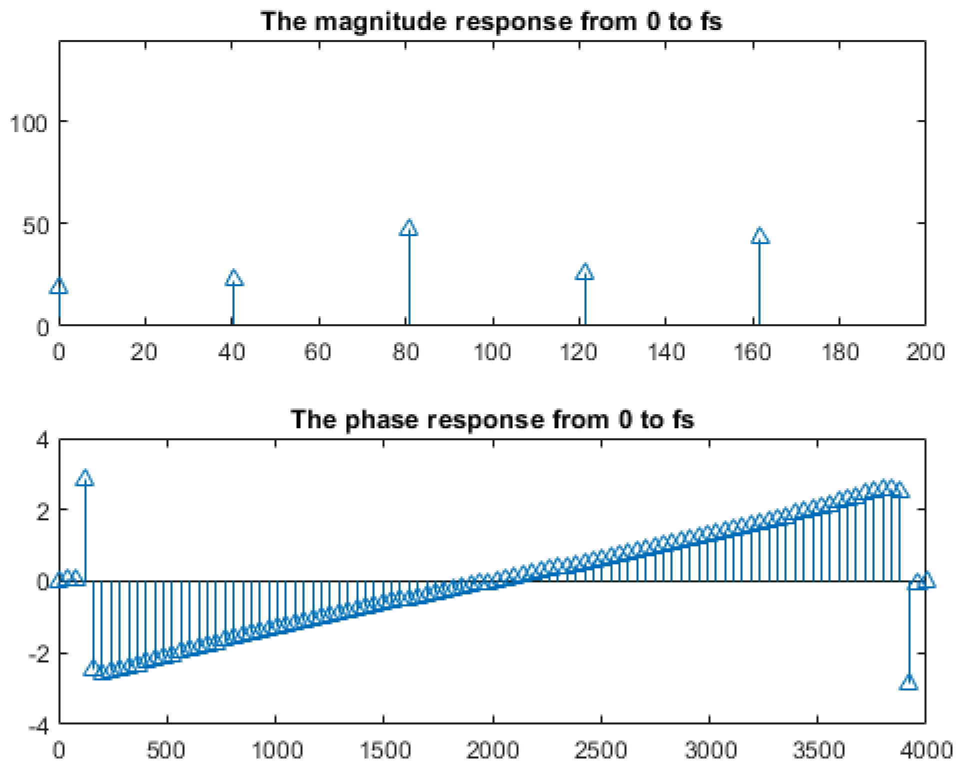
A. Resolving two signals of close frequency

A.1-2

```
fs = 4000;
```

```
freq = [100 150];
amp = [1.2 0.8];
ph = [0 0];
t = [0:1/fs:5/min(freq)];
% generate the sinusoid
y
 =((amp'*ones(1,length(t))).*sin((2*pi*freq'*t)+ph'*ones(1,length(t))))';
figure(6); plot(sum(y'));

ty_sum = sum(y');
y_sum = ty_sum(1:100);
Nfft = 100;
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0,fs,Nfft);
% Plot the magnitude and the phase response
mag = abs(y_fft);
ph1 = angle(y_fft);
figure(7); subplot(2,1,1), stem(w, mag, '^');
axis ([0, 200, 0, 140]);
% use axis to zoom into plot to determine frequencies of sinusoids
title('The magnitude response from 0 to fs');
axis; % turn autoscaling back on
subplot(2,1,2), stem(w,ph1, '^');
title('The phase response from 0 to fs');
```



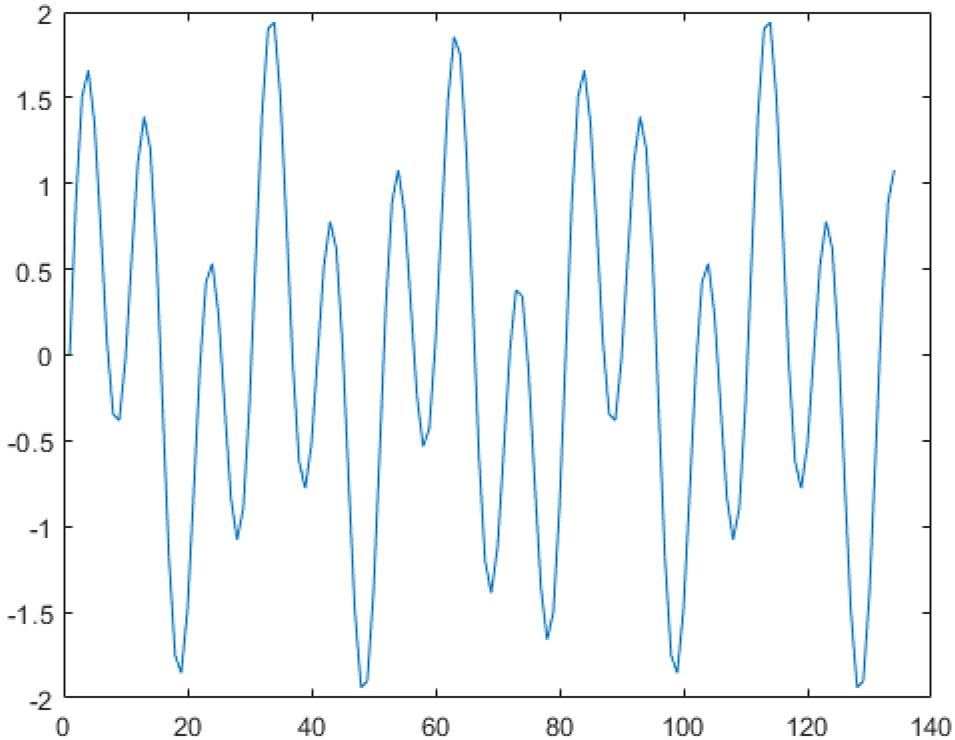


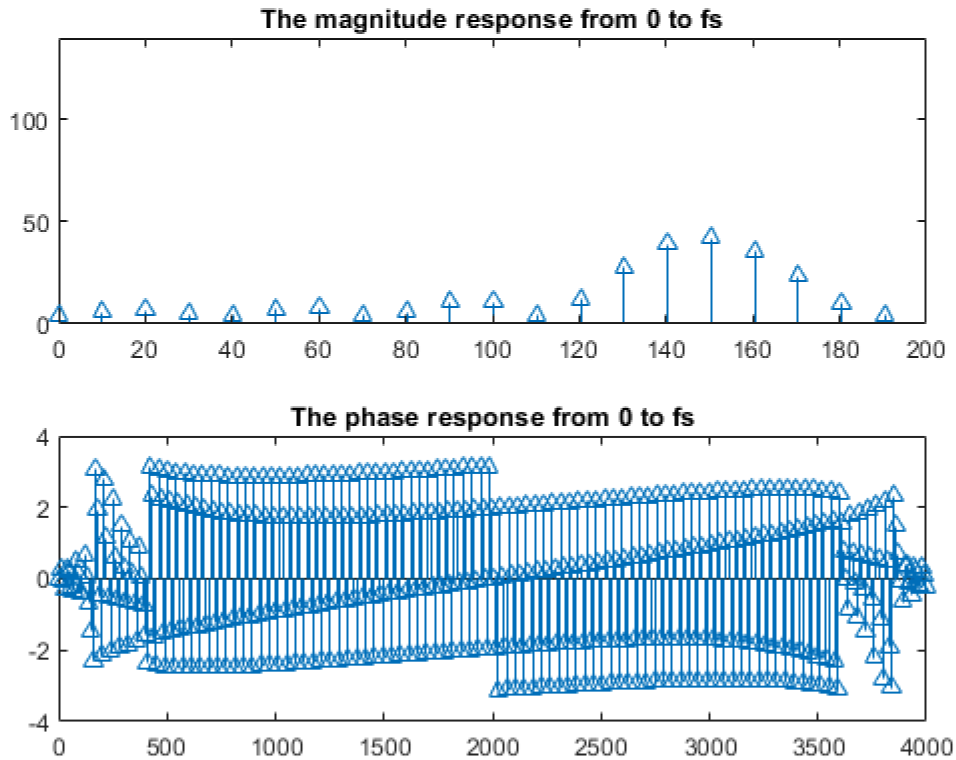
Question is pre-answered in the tutorial pdf file.

A.3.a-b.

```
fs = 4000;
freq = [400 150];
amp = [1.2 0.8];
ph = [0 0];
t = [0:1/fs:5/min(freq)];
% generate the sinusoid
y
 =((amp'*ones(1,length(t))).*sin((2*pi*freq'*t)+ph'*ones(1,length(t))))';
figure(); plot(sum(y'));

ty_sum = sum(y');
y_sum = ty_sum(1:100);
Nfft = 400;
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0,fs,Nfft);
% Plot the magnitude and the phase response
mag = abs(y_fft);
ph1 = angle(y_fft);
figure(); subplot(2,1,1), stem(w, mag, '^');
axis ([0, 200, 0, 140]);
% use axis to zoom into plot to determine frequencies of sinusoids
```

```
title('The magnitude response from 0 to fs');
axis; % turn autoscaling back on
subplot(2,1,2), stem(w,ph1, '^');
title('The phase response from 0 to fs');
```





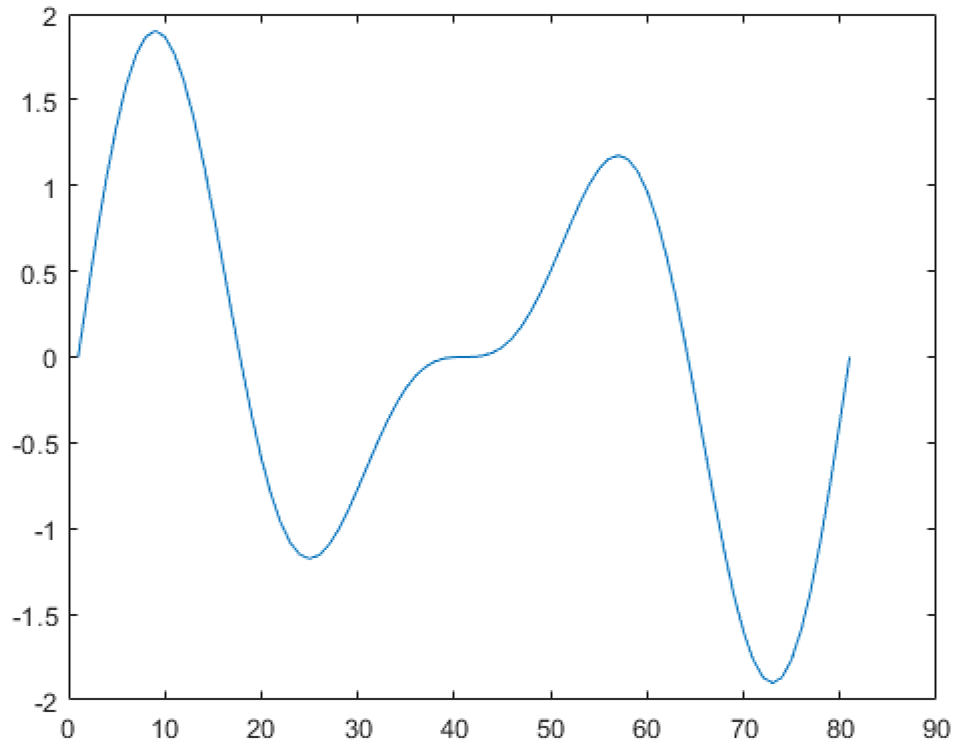
1. Can we now correctly determine the frequencies of the sinusoids?
2. What is the effect of increasing the number of frequency samples on the accuracy of the DFT?

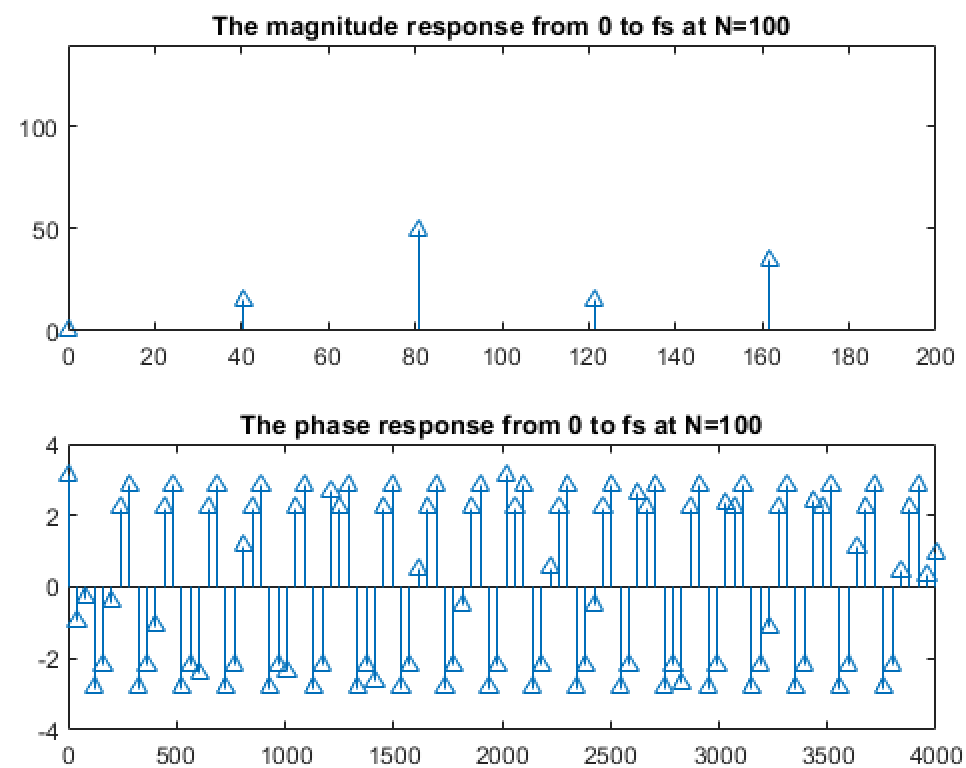
ANSWER Increasing the number of samples of the given sinusoids will allow us to correctly determine its frequencies with more certainty as it increases the number of phases and magnitudes of the DFT.

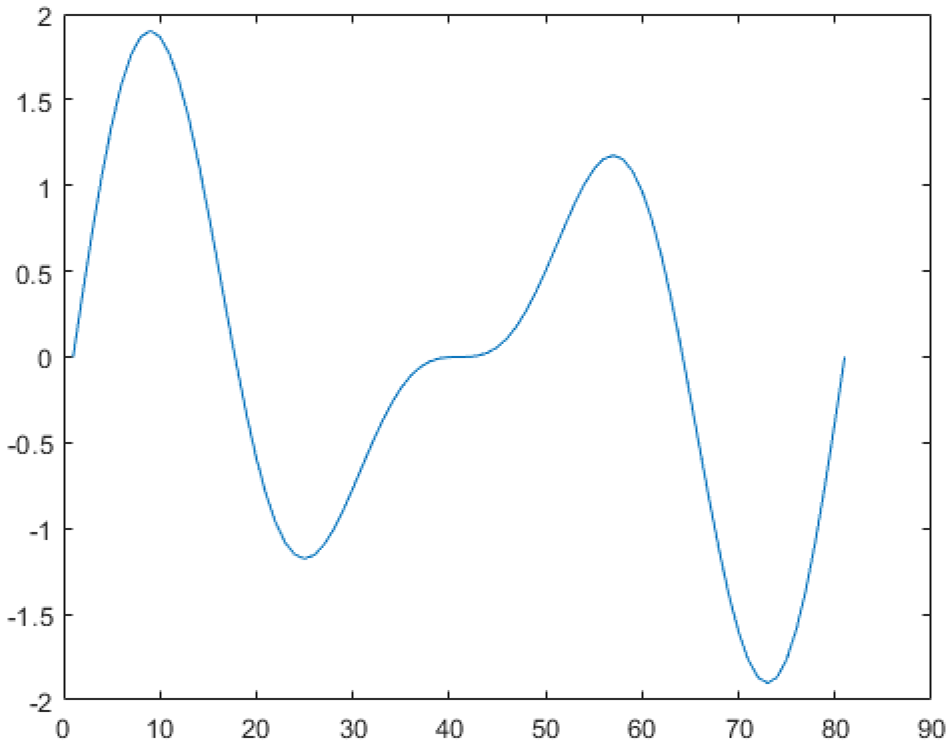
A.4.

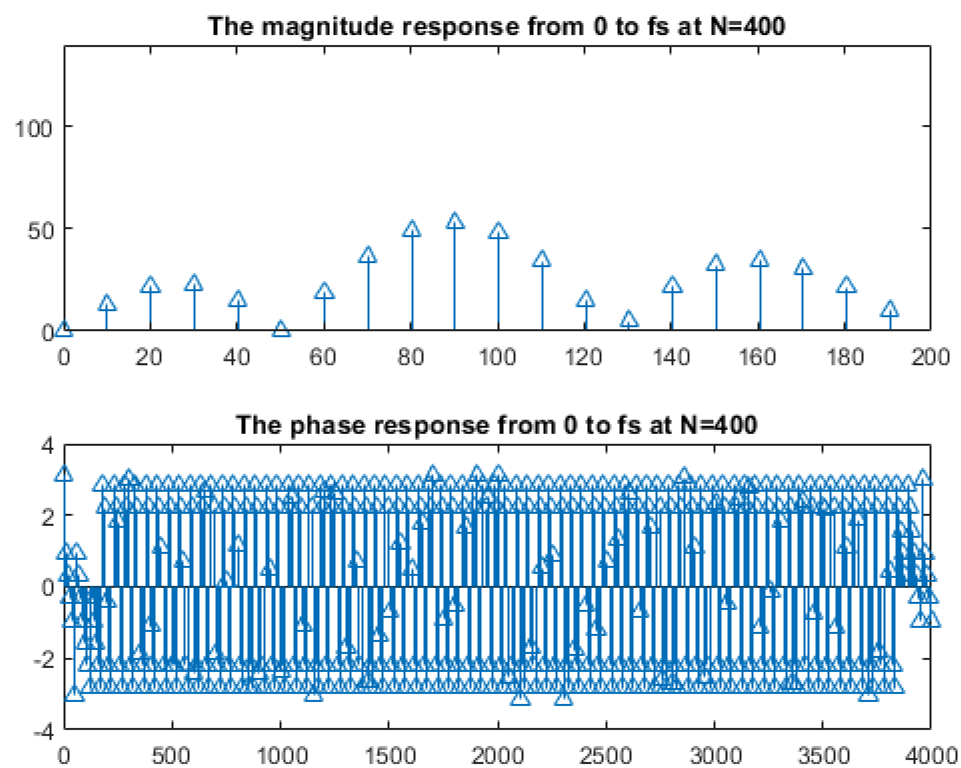
```
fs = 4000;
freq = [100 150];
amp = [1.2 0.8];
ph = [0 0];
t = [0:1/fs:2/min(freq)];
% generate the sinusoid
y
 =((amp'*ones(1,length(t))).*sin((2*pi*freq'*t)+ph'*ones(1,length(t))))';
figure(); plot(sum(y'));

ty_sum = sum(y');
y_sum = ty_sum();
Nfft = 100;
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0,fs,Nfft);
```

```
% Plot the magnitude and the phase response
mag = abs(y_fft);
ph1 = angle(y_fft);
figure(); subplot(2,1,1), stem(w, mag, '^');
axis ([0, 200, 0, 140]);
% use axis to zoom into plot to determine frequencies of sinusoids
title('The magnitude response from 0 to fs at N=100');
axis; % turn autoscaling back on
subplot(2,1,2), stem(w,ph1, '^');
title('The phase response from 0 to fs at N=100');

fs = 4000;
freq = [100 150];
amp = [1.2 0.8];
ph = [0 0];
t = [0:1/fs:2/min(freq)];
% generate the sinusoid
y
 =((amp'*ones(1,length(t))).*sin((2*pi*freq'*t)+ph'*ones(1,length(t))))';
figure(); plot(sum(y'));

ty_sum = sum(y');
y_sum = ty_sum();
Nfft = 400;
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0,fs,Nfft);

% Plot the magnitude and the phase response
mag = abs(y_fft);
ph1 = angle(y_fft);
figure(); subplot(2,1,1), stem(w, mag, '^');
axis ([0, 200, 0, 140]);
% use axis to zoom into plot to determine frequencies of sinusoids
title('The magnitude response from 0 to fs at N=400');
axis; % turn autoscaling back on
subplot(2,1,2), stem(w,ph1, '^');
title('The phase response from 0 to fs at N=400');
```




The magnitude response from 0 to fs at N=100
The phase response from 0 to fs at N=100


2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0 10 20 30 40 50 60 70 80 90


The magnitude response from 0 to fs at N=400
100
50
0
0 20 40 60 80 100 120 140 160 180 200
The phase response from 0 to fs at N=400
4
2
0
-2
-4
0 500 1000 1500 2000 2500 3000 3500 4000

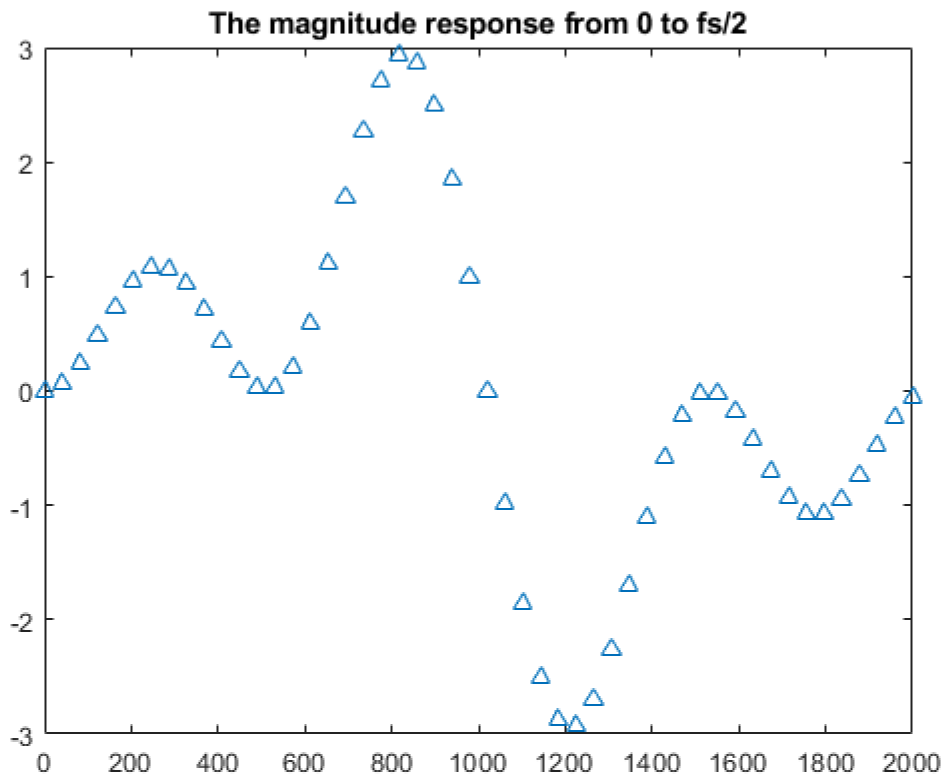
*As shown in the results above, the DFT can resolve the frequencies of the two signals. However with N=100, it cannot accurately resolve the frequencies due to the limited samples of magnitude and phase spectrum as compared to N=400, which contains more samples of phase and magnitude, thereby allowing us to resolve the frequency with better accuracy.

B. Effects of zero padding and signal length on the DFT

B.1.

```
fs = 4000;
freq = 1000;
amp = 1;
ph = 0;
t = [0:1/fs:2/freq];
% generate the sinusoid
y = amp*sin((2*pi*freq*t)+ph)';
y_sum = y;
Nfft = 100;
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0, fs/2, Nfft/2);
y_fft = y_fft(1:length(y_fft)/2);
% Plot the magnitude response,
mag = (y_fft);
figure(); plot(w, mag, '^');
title('The magnitude response from 0 to fs/2');
```

```
Warning: Imaginary parts of complex X and/or Y arguments ignored.
```

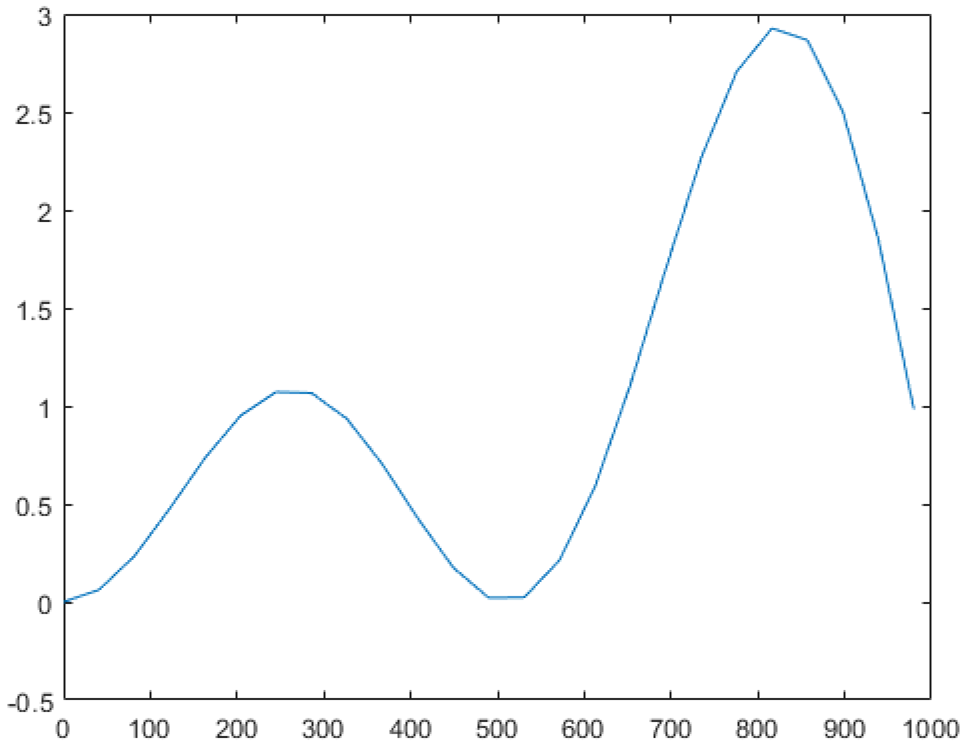


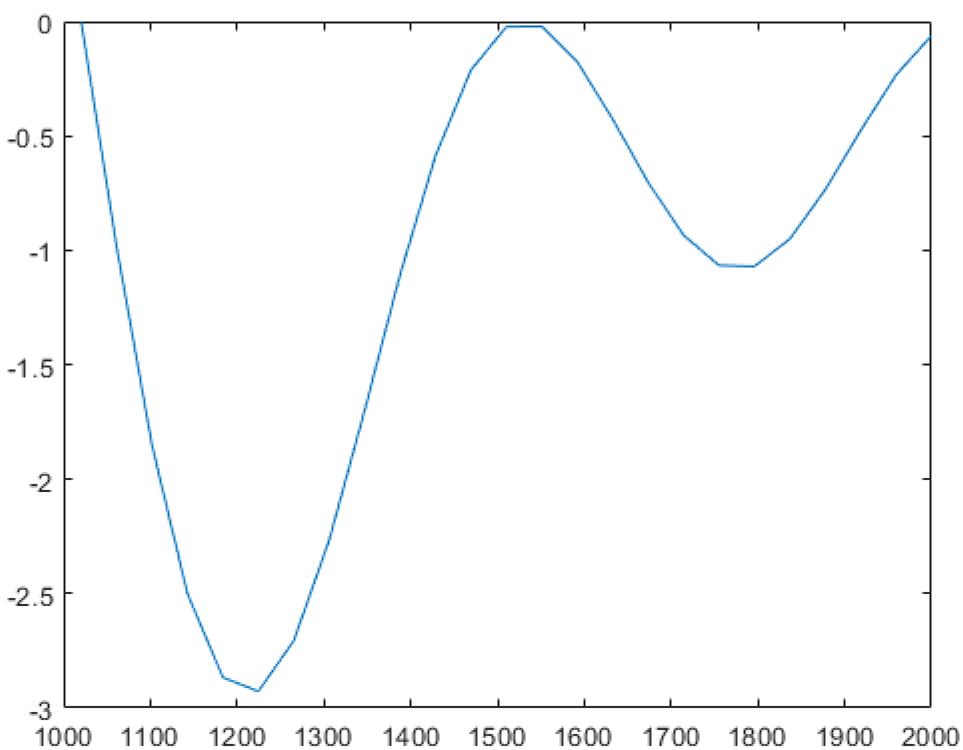
B.1.a.

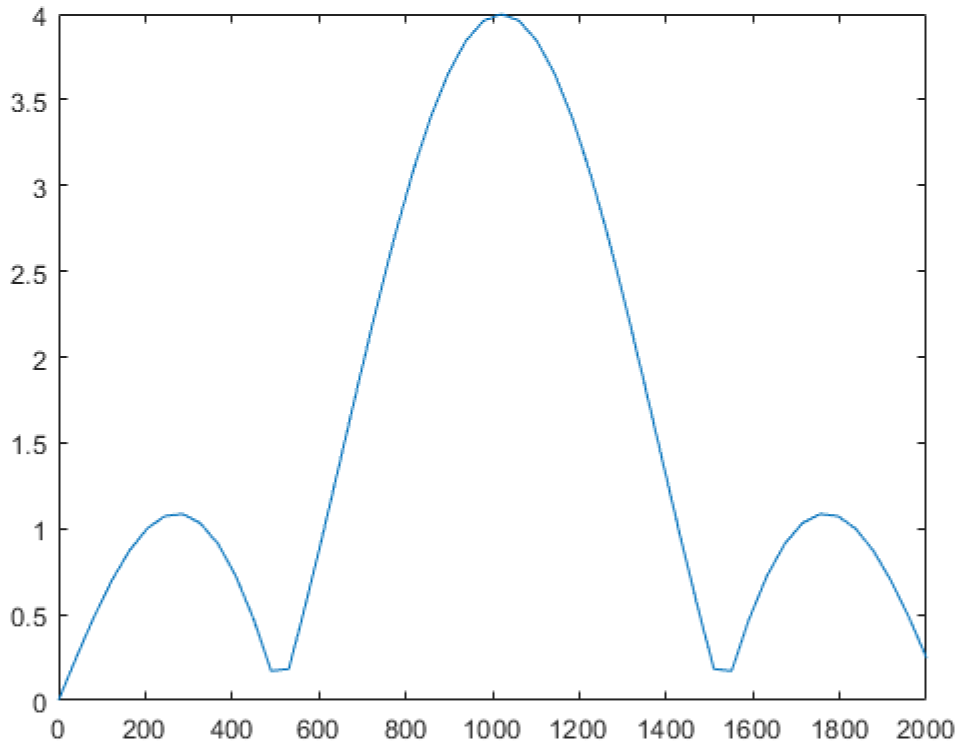
*The plot of the frequency response is similar to the sinc function because of the abs function applied to the sinusoid, thereby transporming its negative values into positive. As such, the sum values from 500:1500 samples yields to a wave with a max magnitude of 4 as shown below

```
figure(); plot(w(1:25), y_fft(1:25));
figure(); plot(w(26:50), y_fft(26:50));
figure(); plot(w,abs(y_fft));
```

```
Warning: Imaginary parts of complex X and/or Y arguments ignored.
Warning: Imaginary parts of complex X and/or Y arguments ignored.
```


3
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500
600
700
800
900
1000


0
-0.5
-1
-1.5
-2
-2.5
-3
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000



B.1.b.

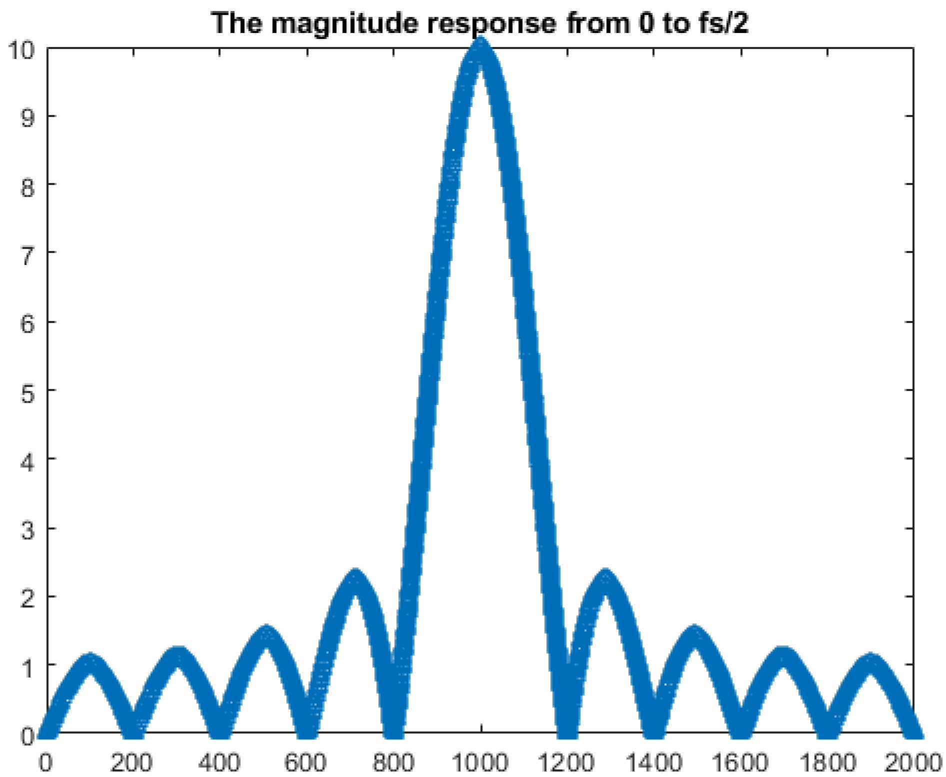
Increasing the number of frequency samples is equivalent to having a more accurate magnitude response and its plot.

B.1.c.

*The same result as with B.1.b for increasing the number of samples. Increasing the period means increasing the amplitude as show in the generated figure.

```
fs = 4000;
freq = 1000;
amp = 1;
ph = 0;
t = [0:1/fs:5/freq]; % period inc to 5 from 2.
% generate the sinusoid
y = amp*sin((2*pi*freq*t)+ph)';
y_sum = y;
Nfft = 10000; %Increase samples to 10K
y_fft = fft(y_sum, Nfft);
% generate the frequency axis
w = linspace(0, fs/2, Nfft/2);
y_fft = y_fft(1:length(y_fft)/2);
% Plot the magnitude response,
mag = abs(y_fft);
```

```
figure(); plot(w, mag, '^');
title('The magnitude response from 0 to fs/2');
```



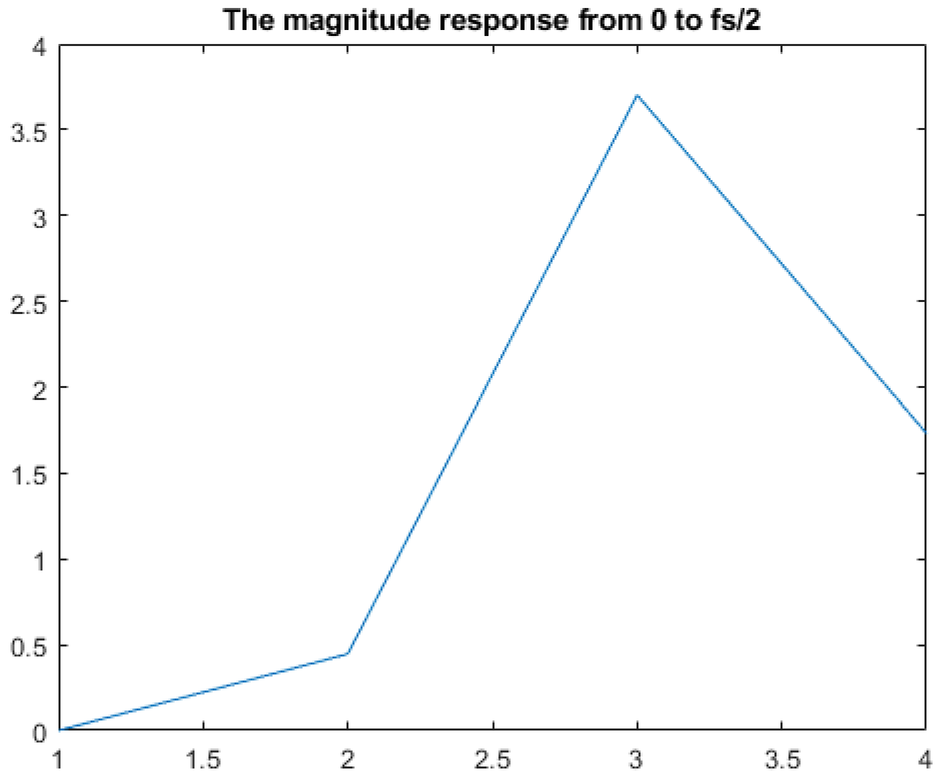
B.1.d.

Increasing the signal length means extending the range of lobes in the time domain. Therefore, if we will not modify the time range, the plot will not be seeon in the default range due to the increase in length.

B.2.

```
fs = 4000;
freq = 1000;
amp = 1;
ph = 0;
t = [0:1/fs:2/freq];
% generate the sinusoid
y = amp*sin((2*pi*freq*t)+ph)';
y_sum = y;
y_fft = fft(y_sum);
y_fft = y_fft(1:length(y_fft)/2);
% Plot the magnitude response,
mag = abs(y_fft);
figure(); plot(mag);
title('The magnitude response from 0 to fs/2');
```

Warning: Integer operands are required for colon operator when used as index.

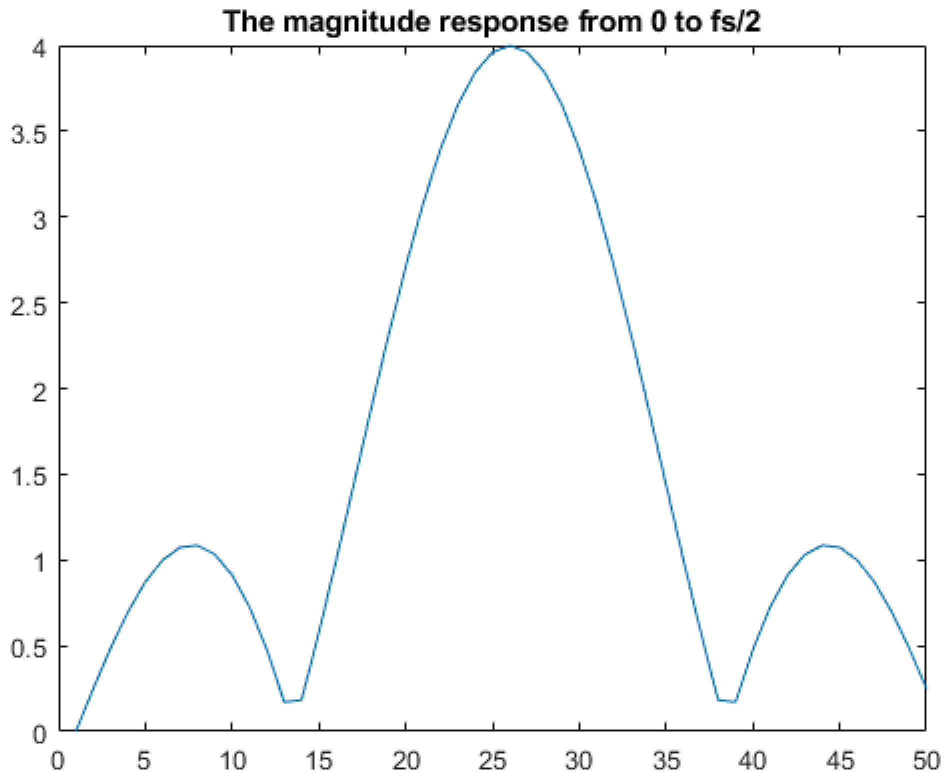


B.2.a.

As per the result of the code in this section and the fft() documatation, without specifying the sample number, function will return the fft as a vector of y_sum. As with the magnitude response, only the linear peak values of magnitude of the original plot.

B.2.b.

```
fs = 4000;
freq = 1000;
amp = 1;
ph = 0;
t = [0:1/fs:2/freq];
% generate the sinusoid
y = amp*sin((2*pi*freq*t)+ph)';
y(length(y)+1:100)=0; % 100 zero-padding
y_fft = fft(y);
y_fft = y_fft(1:length(y_fft)/2);
% Plot the magnitude response,
mag = abs(y_fft);
figure(); plot(mag);
title('The magnitude response from 0 to fs/2');
```

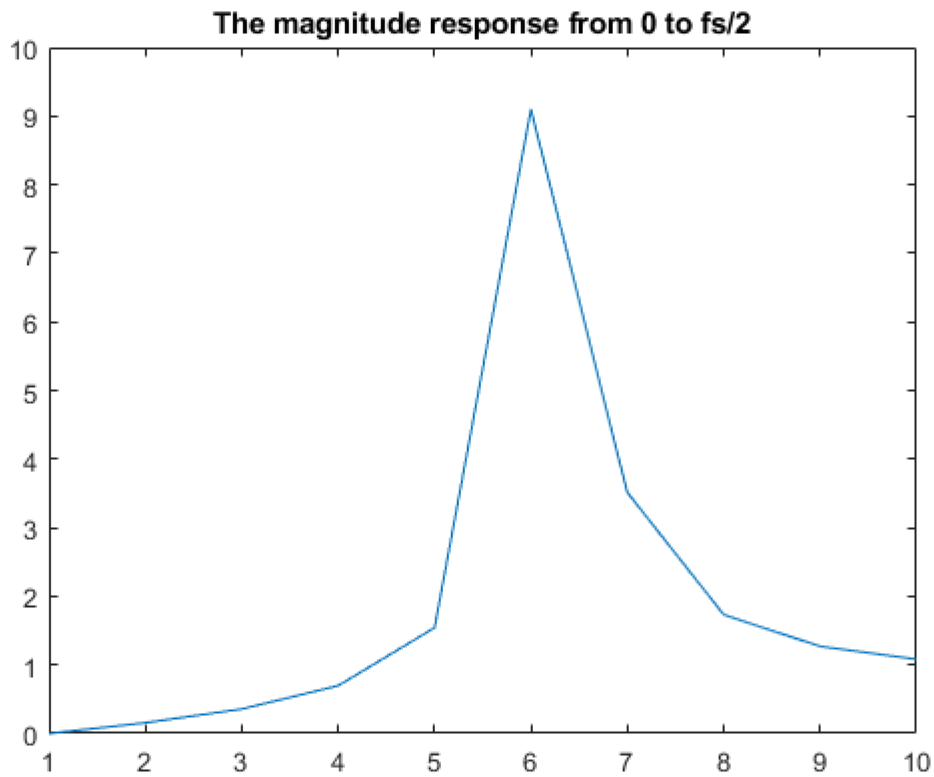



```
%Based on the results show in the figure, padded zeros in the DFT acts
%similar to the frequency sample in the DFT thus, making the signal
 revert
%to the sinc like plot.
```

B.2.c.

```
fs = 4000;
freq = 1000;
amp = 1;
ph = 0;
t = [0:1/fs:5/freq]; %change period to 5
% generate the sinusoid
y = amp*sin((2*pi*freq*t)+ph)';
% y(length(y)+1:100)=0; % 100 zero-padding
y_fft = fft(y);
y_fft = y_fft(1:length(y_fft)/2);
% Plot the magnitude response,
mag = abs(y_fft);
figure(); plot(mag);
title('The magnitude response from 0 to fs/2');
```

```
Warning: Integer operands are required for colon operator when used as
 index.
```

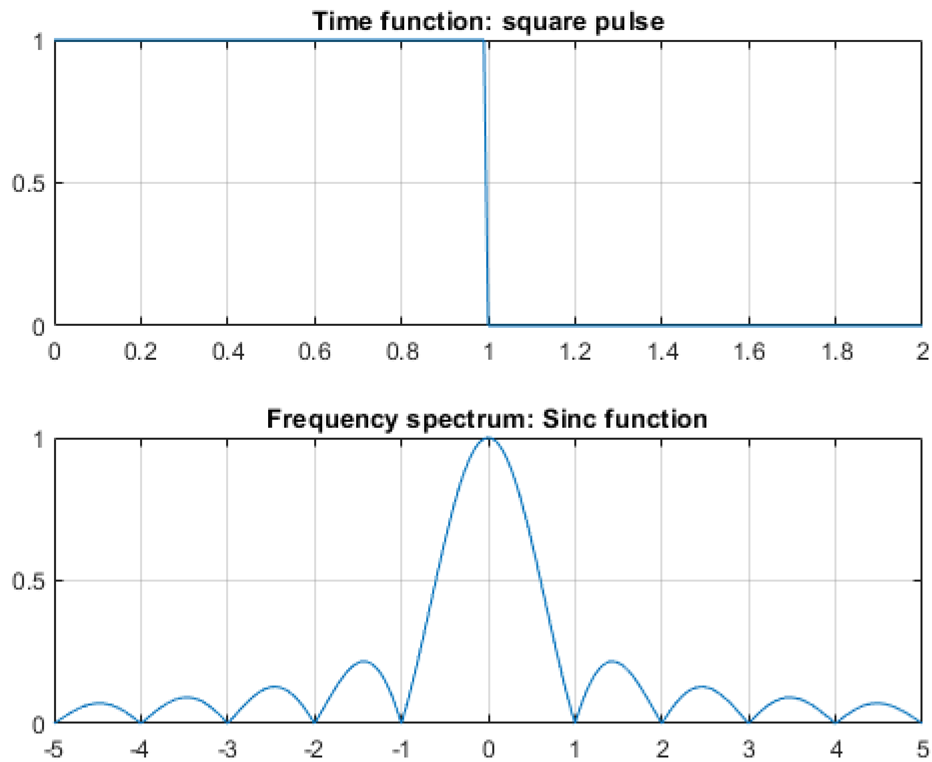


Increasing the signal period means increasing the magnitude of the peaks of the signal. Furthermore, the increase gradually eliminate the sidelobes in the magnitude spectrum.

C

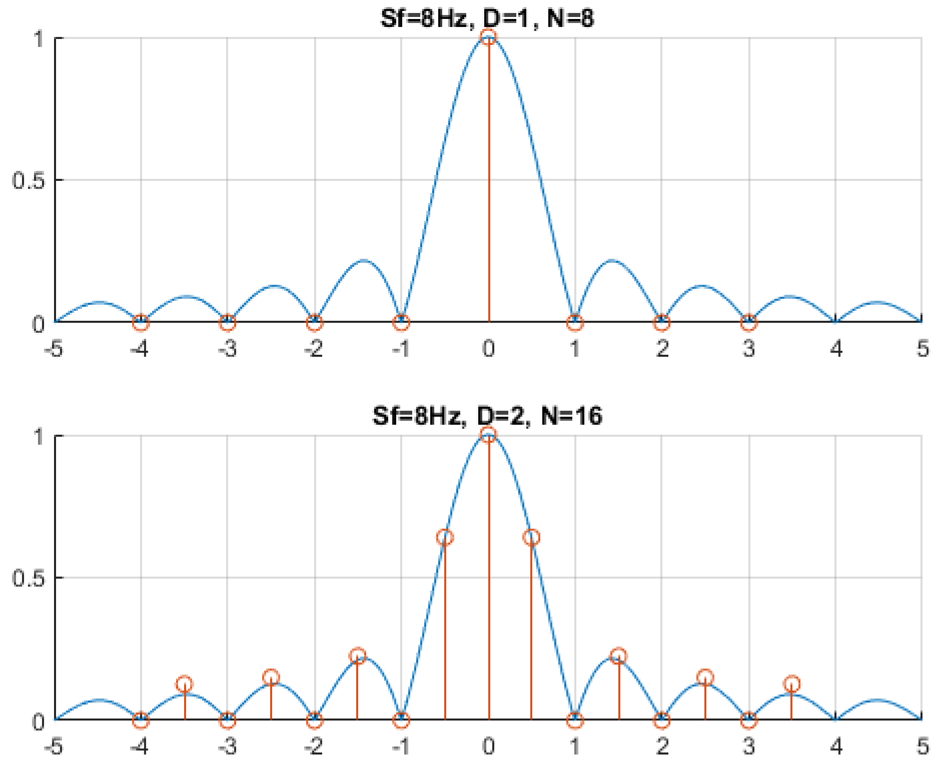
Write a Matlab code that will generate the presented figures Figure A and Figure B(see EE 274: Tutorials for Discrete Fourier Transform tutorial PDF file).

```
P=2;
W=2;
t=0:0.01:P;
R = rectpuls(t, W);
f=-5:0.01:5;
XR=exp(-j*pi*f).*sinc(f);
figure()
subplot 211
plot(t, R);
title("Time function: square pulse");
grid on;
subplot 212
plot(f,abs(XR));
title("Frequency spectrum: Sinc function");
grid on;
```



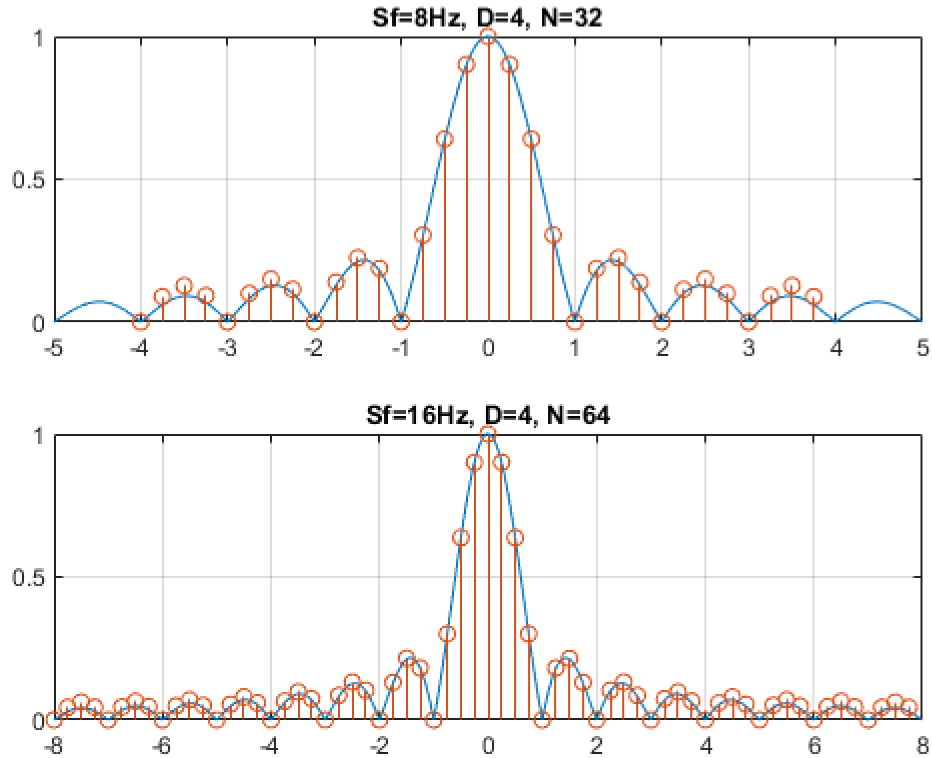

```
Sf=8;
D2=1;
N2=8;

tn2=0:1/Sf:(N2-1)*1/Sf;
C2_xn=rectpuls(tn2, W);
ya2=fft(C2_xn, N2);
ya2=fftshift(ya2);
fo2=1/D2;
fa2=-(N2/2)*fo2:fo2:(N2/2-1)*fo2;


D3=2;
N3=16;
tn3=0:1/Sf:(N3-1)*1/Sf;
xn3=rectpuls(tn3, W);
ya3=fft(xn3, N3);
ya3=fftshift(ya3);
fo3=1/D3;
fa3=-(N3/2)*fo3:fo3:(N3/2-1)*fo3;
figure();
subplot 211;
title('Sf=8Hz, D=1, N=8');
grid on;
hold on;
plot(f, abs(XR));
```

```
stem(fa2,1/Sf*(abs(ya2)));
hold off;

subplot 212;
title('Sf=8Hz, D=2, N=16');
grid on;
hold on;
plot(f, abs(XR));
stem(fa3,1/Sf*(abs(ya3)));
hold off;
```




```
Sf4=8;
D4=4;
N4=32;
tn4=0:1/Sf4:(N4-1)*1/Sf4;
xn4=rectpuls(tn4, W);
ya4=fft(xn4, N4);
ya4=fftshift(ya4);
fo4=1/D4;
fa4=-(N4/2)*fo4:fo4:(N4/2-1)*fo4;

f4=-8:0.01:8;
XR4=exp(-j*pi*f4).*sinc(f4);

Sf5=16;
D5=4;
```

```
N5=64;
tn5=0:1/Sf5:(N5-1)*1/Sf5;
xn5=rectpuls(tn5, W);
ya5=fft(xn5, N5);
ya5=fftshift(ya5);
fo5=1/D5;
fa5=-(N5/2)*fo5:fo5:(N5/2-1)*fo5;

figure();
subplot 211
plot(f, abs(XR));
title('Sf=8Hz, D=4, N=32');
grid on;
hold on;
stem(fa4,1/Sf4*(abs(ya4)));
hold off;

subplot 212
plot(f4, abs(XR4));
title('Sf=16Hz, D=4, N=64');
grid on;
hold on;
stem(fa5,1/Sf5*(abs(ya5)));
hold off;
```



Part 2 - Properties of DFT

A. Computation of DFT

```
clf;
w = -4*pi:8*pi/511:4*pi;
num = [2 1];den = [1 -0.6];
h = freqz(num, den, w);
x_axis = w/pi

subplot(4,1,1)
plot(x_axis,real(h));grid
title('Real part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,2)
plot(x_axis,imag(h));grid
title('Imaginary part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,3)
plot(x_axis,abs(h));grid
title('Magnitude Spectrum |H(e^{j\omega})|')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,4)
plot(x_axis,angle(h));grid
title('Phase Spectrum arg[H(e^{j\omega})]')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

```
x_axis =

  Columns 1 through 7

   -4.0000   -3.9843   -3.9687   -3.9530   -3.9374   -3.9217   -3.9061

  Columns 8 through 14

   -3.8904   -3.8748   -3.8591   -3.8434   -3.8278   -3.8121   -3.7965

  Columns 15 through 21

   -3.7808   -3.7652   -3.7495   -3.7339   -3.7182   -3.7025   -3.6869

  Columns 22 through 28

   -3.6712   -3.6556   -3.6399   -3.6243   -3.6086   -3.5930   -3.5773

  Columns 29 through 35
```

```
  -3.5616   -3.5460   -3.5303   -3.5147   -3.4990   -3.4834   -3.4677

Columns 36 through 42

  -3.4521   -3.4364   -3.4207   -3.4051   -3.3894   -3.3738   -3.3581

Columns 43 through 49

  -3.3425   -3.3268   -3.3112   -3.2955   -3.2798   -3.2642   -3.2485

Columns 50 through 56

  -3.2329   -3.2172   -3.2016   -3.1859   -3.1703   -3.1546   -3.1389

Columns 57 through 63

  -3.1233   -3.1076   -3.0920   -3.0763   -3.0607   -3.0450   -3.0294

Columns 64 through 70

  -3.0137   -2.9980   -2.9824   -2.9667   -2.9511   -2.9354   -2.9198

Columns 71 through 77

  -2.9041   -2.8885   -2.8728   -2.8571   -2.8415   -2.8258   -2.8102

Columns 78 through 84

  -2.7945   -2.7789   -2.7632   -2.7476   -2.7319   -2.7162   -2.7006

Columns 85 through 91

  -2.6849   -2.6693   -2.6536   -2.6380   -2.6223   -2.6067   -2.5910

Columns 92 through 98

  -2.5753   -2.5597   -2.5440   -2.5284   -2.5127   -2.4971   -2.4814

Columns 99 through 105

  -2.4658   -2.4501   -2.4344   -2.4188   -2.4031   -2.3875   -2.3718

Columns 106 through 112

  -2.3562   -2.3405   -2.3249   -2.3092   -2.2935   -2.2779   -2.2622

Columns 113 through 119

  -2.2466   -2.2309   -2.2153   -2.1996   -2.1840   -2.1683   -2.1526

Columns 120 through 126

  -2.1370   -2.1213   -2.1057   -2.0900   -2.0744   -2.0587   -2.0431
```

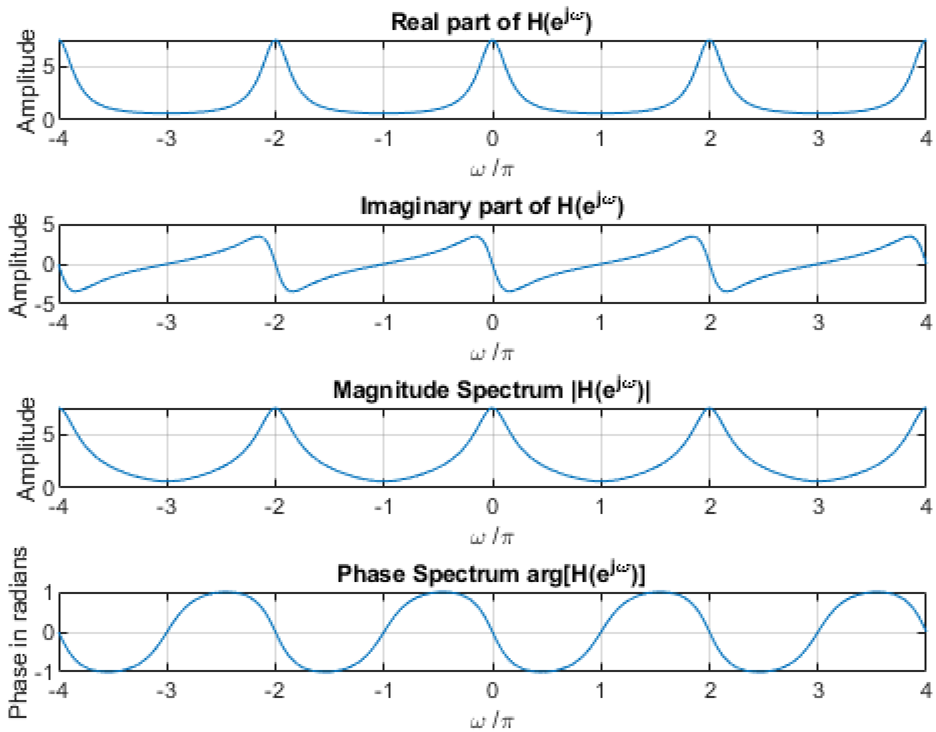
```
Columns 127 through 133

 -2.0274   -2.0117   -1.9961   -1.9804   -1.9648   -1.9491   -1.9335

Columns 134 through 140

 -1.9178   -1.9022   -1.8865   -1.8708   -1.8552   -1.8395   -1.8239

Columns 141 through 147

 -1.8082   -1.7926   -1.7769   -1.7613   -1.7456   -1.7299   -1.7143

Columns 148 through 154

 -1.6986   -1.6830   -1.6673   -1.6517   -1.6360   -1.6204   -1.6047

Columns 155 through 161

 -1.5890   -1.5734   -1.5577   -1.5421   -1.5264   -1.5108   -1.4951

Columns 162 through 168

 -1.4795   -1.4638   -1.4481   -1.4325   -1.4168   -1.4012   -1.3855

Columns 169 through 175

 -1.3699   -1.3542   -1.3386   -1.3229   -1.3072   -1.2916   -1.2759

Columns 176 through 182

 -1.2603   -1.2446   -1.2290   -1.2133   -1.1977   -1.1820   -1.1663

Columns 183 through 189

 -1.1507   -1.1350   -1.1194   -1.1037   -1.0881   -1.0724   -1.0568

Columns 190 through 196

 -1.0411   -1.0254   -1.0098   -0.9941   -0.9785   -0.9628   -0.9472

Columns 197 through 203

 -0.9315   -0.9159   -0.9002   -0.8845   -0.8689   -0.8532   -0.8376

Columns 204 through 210

 -0.8219   -0.8063   -0.7906   -0.7750   -0.7593   -0.7436   -0.7280

Columns 211 through 217

 -0.7123   -0.6967   -0.6810   -0.6654   -0.6497   -0.6341   -0.6184

Columns 218 through 224
```

```
  -0.6027   -0.5871   -0.5714   -0.5558   -0.5401   -0.5245   -0.5088

 Columns 225 through 231

  -0.4932   -0.4775   -0.4618   -0.4462   -0.4305   -0.4149   -0.3992

 Columns 232 through 238

  -0.3836   -0.3679   -0.3523   -0.3366   -0.3209   -0.3053   -0.2896

 Columns 239 through 245

  -0.2740   -0.2583   -0.2427   -0.2270   -0.2114   -0.1957   -0.1800

 Columns 246 through 252

  -0.1644   -0.1487   -0.1331   -0.1174   -0.1018   -0.0861   -0.0705

 Columns 253 through 259

  -0.0548   -0.0391   -0.0235   -0.0078    0.0078    0.0235    0.0391

 Columns 260 through 266

   0.0548    0.0705    0.0861    0.1018    0.1174    0.1331    0.1487

 Columns 267 through 273

   0.1644    0.1800    0.1957    0.2114    0.2270    0.2427    0.2583

 Columns 274 through 280

   0.2740    0.2896    0.3053    0.3209    0.3366    0.3523    0.3679

 Columns 281 through 287

   0.3836    0.3992    0.4149    0.4305    0.4462    0.4618    0.4775

 Columns 288 through 294

   0.4932    0.5088    0.5245    0.5401    0.5558    0.5714    0.5871

 Columns 295 through 301

   0.6027    0.6184    0.6341    0.6497    0.6654    0.6810    0.6967

 Columns 302 through 308

   0.7123    0.7280    0.7436    0.7593    0.7750    0.7906    0.8063

 Columns 309 through 315

   0.8219    0.8376    0.8532    0.8689    0.8845    0.9002    0.9159
```

```
Columns 316 through 322

  0.9315    0.9472    0.9628    0.9785    0.9941    1.0098    1.0254

Columns 323 through 329

  1.0411    1.0568    1.0724    1.0881    1.1037    1.1194    1.1350

Columns 330 through 336

  1.1507    1.1663    1.1820    1.1977    1.2133    1.2290    1.2446

Columns 337 through 343

  1.2603    1.2759    1.2916    1.3072    1.3229    1.3386    1.3542

Columns 344 through 350

  1.3699    1.3855    1.4012    1.4168    1.4325    1.4481    1.4638

Columns 351 through 357

  1.4795    1.4951    1.5108    1.5264    1.5421    1.5577    1.5734

Columns 358 through 364

  1.5890    1.6047    1.6204    1.6360    1.6517    1.6673    1.6830

Columns 365 through 371

  1.6986    1.7143    1.7299    1.7456    1.7613    1.7769    1.7926

Columns 372 through 378

  1.8082    1.8239    1.8395    1.8552    1.8708    1.8865    1.9022

Columns 379 through 385

  1.9178    1.9335    1.9491    1.9648    1.9804    1.9961    2.0117

Columns 386 through 392

  2.0274    2.0431    2.0587    2.0744    2.0900    2.1057    2.1213

Columns 393 through 399

  2.1370    2.1526    2.1683    2.1840    2.1996    2.2153    2.2309

Columns 400 through 406

  2.2466    2.2622    2.2779    2.2935    2.3092    2.3249    2.3405

Columns 407 through 413
```

```
    2.3562    2.3718    2.3875    2.4031    2.4188    2.4344    2.4501

  Columns 414 through 420

    2.4658    2.4814    2.4971    2.5127    2.5284    2.5440    2.5597

  Columns 421 through 427

    2.5753    2.5910    2.6067    2.6223    2.6380    2.6536    2.6693

  Columns 428 through 434

    2.6849    2.7006    2.7162    2.7319    2.7476    2.7632    2.7789

  Columns 435 through 441

    2.7945    2.8102    2.8258    2.8415    2.8571    2.8728    2.8885

  Columns 442 through 448

    2.9041    2.9198    2.9354    2.9511    2.9667    2.9824    2.9980

  Columns 449 through 455

    3.0137    3.0294    3.0450    3.0607    3.0763    3.0920    3.1076

  Columns 456 through 462

    3.1233    3.1389    3.1546    3.1703    3.1859    3.2016    3.2172

  Columns 463 through 469

    3.2329    3.2485    3.2642    3.2798    3.2955    3.3112    3.3268

  Columns 470 through 476

    3.3425    3.3581    3.3738    3.3894    3.4051    3.4207    3.4364

  Columns 477 through 483

    3.4521    3.4677    3.4834    3.4990    3.5147    3.5303    3.5460

  Columns 484 through 490

    3.5616    3.5773    3.5930    3.6086    3.6243    3.6399    3.6556

  Columns 491 through 497

    3.6712    3.6869    3.7025    3.7182    3.7339    3.7495    3.7652

  Columns 498 through 504

    3.7808    3.7965    3.8121    3.8278    3.8434    3.8591    3.8748
```

```
Columns 505 through 511

  3.8904    3.9061    3.9217    3.9374    3.9530    3.9687    3.9843

Column 512

  4.0000
```



A.1. Compare and differentiate above code output and freqz(num,den).

*The output waveform of freqz(num,den) with a w parameter plots every two interval in the x-space. While when we remove the w parameter in the freqz function, it maximize the signa plot on the entire -4:4 w/π space.

A.2. Symmetries in real and imag parts of DFT.

The two graphs are symmetric as they follow the same function, only that the real parts plot every 8*pi/511 in -4:4 w/π space while the latter plots in the entire plane. DFT is a periodic function of omega with a period of 2*pi. All of the plots presented above are in the period of 2*pi, with the real part and magnitude are even symmetric while the imaginary part of phase are odd symmetric.

A.3. Modify the above code and to satisfy the given function below.

$$U(e^{j\omega}) = \frac{0.7-0.5e^{j\omega}+0.3e^{-j2\omega}+e^{-j3\omega}}{1+0.3e^{-j\omega}-0.5^{-j2\omega}+0.7e^{-j3\omega}}$$

```
N_A3 = 512;
g_n3 = [0.7 -0.5 0.3 1];
den_A3 = [1 0.3 -0.5 0.7];
[h_A_3, w_A3] = freqz(g_n3, den_A3, N_A3);
x_axis = w_A3/pi

figure()
subplot(4,1,1)
plot(x_axis,real(h_A_3));
grid on;
title('Real part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,2)
plot(x_axis,imag(h_A_3));
grid on;
title('Imaginary part of H(e^{j\omega})')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,3)
plot(x_axis,abs(h_A_3));
grid on;
title('Magnitude Spectrum |H(e^{j\omega})|')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,4)
plot(x_axis,angle(h_A_3));
grid on
title('Phase Spectrum arg[H(e^{j\omega})]')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

```
x_axis =

         0
    0.0020
    0.0039
    0.0059
    0.0078
    0.0098
    0.0117
    0.0137
    0.0156
    0.0176
    0.0195
    0.0215
```

```
0.0234
0.0254
0.0273
0.0293
0.0313
0.0332
0.0352
0.0371
0.0391
0.0410
0.0430
0.0449
0.0469
0.0488
0.0508
0.0527
0.0547
0.0566
0.0586
0.0605
0.0625
0.0645
0.0664
0.0684
0.0703
0.0723
0.0742
0.0762
0.0781
0.0801
0.0820
0.0840
0.0859
0.0879
0.0898
0.0918
0.0938
0.0957
0.0977
0.0996
0.1016
0.1035
0.1055
0.1074
0.1094
0.1113
0.1133
0.1152
0.1172
0.1191
0.1211
0.1230
0.1250
0.1270
```

```
0.1289
0.1309
0.1328
0.1348
0.1367
0.1387
0.1406
0.1426
0.1445
0.1465
0.1484
0.1504
0.1523
0.1543
0.1562
0.1582
0.1602
0.1621
0.1641
0.1660
0.1680
0.1699
0.1719
0.1738
0.1758
0.1777
0.1797
0.1816
0.1836
0.1855
0.1875
0.1895
0.1914
0.1934
0.1953
0.1973
0.1992
0.2012
0.2031
0.2051
0.2070
0.2090
0.2109
0.2129
0.2148
0.2168
0.2188
0.2207
0.2227
0.2246
0.2266
0.2285
0.2305
0.2324
```

```
0.2344
0.2363
0.2383
0.2402
0.2422
0.2441
0.2461
0.2480
0.2500
0.2520
0.2539
0.2559
0.2578
0.2598
0.2617
0.2637
0.2656
0.2676
0.2695
0.2715
0.2734
0.2754
0.2773
0.2793
0.2812
0.2832
0.2852
0.2871
0.2891
0.2910
0.2930
0.2949
0.2969
0.2988
0.3008
0.3027
0.3047
0.3066
0.3086
0.3105
0.3125
0.3145
0.3164
0.3184
0.3203
0.3223
0.3242
0.3262
0.3281
0.3301
0.3320
0.3340
0.3359
0.3379
```

```
0.3398
0.3418
0.3438
0.3457
0.3477
0.3496
0.3516
0.3535
0.3555
0.3574
0.3594
0.3613
0.3633
0.3652
0.3672
0.3691
0.3711
0.3730
0.3750
0.3770
0.3789
0.3809
0.3828
0.3848
0.3867
0.3887
0.3906
0.3926
0.3945
0.3965
0.3984
0.4004
0.4023
0.4043
0.4062
0.4082
0.4102
0.4121
0.4141
0.4160
0.4180
0.4199
0.4219
0.4238
0.4258
0.4277
0.4297
0.4316
0.4336
0.4355
0.4375
0.4395
0.4414
0.4434
```

```
0.4453
0.4473
0.4492
0.4512
0.4531
0.4551
0.4570
0.4590
0.4609
0.4629
0.4648
0.4668
0.4687
0.4707
0.4727
0.4746
0.4766
0.4785
0.4805
0.4824
0.4844
0.4863
0.4883
0.4902
0.4922
0.4941
0.4961
0.4980
0.5000
0.5020
0.5039
0.5059
0.5078
0.5098
0.5117
0.5137
0.5156
0.5176
0.5195
0.5215
0.5234
0.5254
0.5273
0.5293
0.5313
0.5332
0.5352
0.5371
0.5391
0.5410
0.5430
0.5449
0.5469
0.5488
```

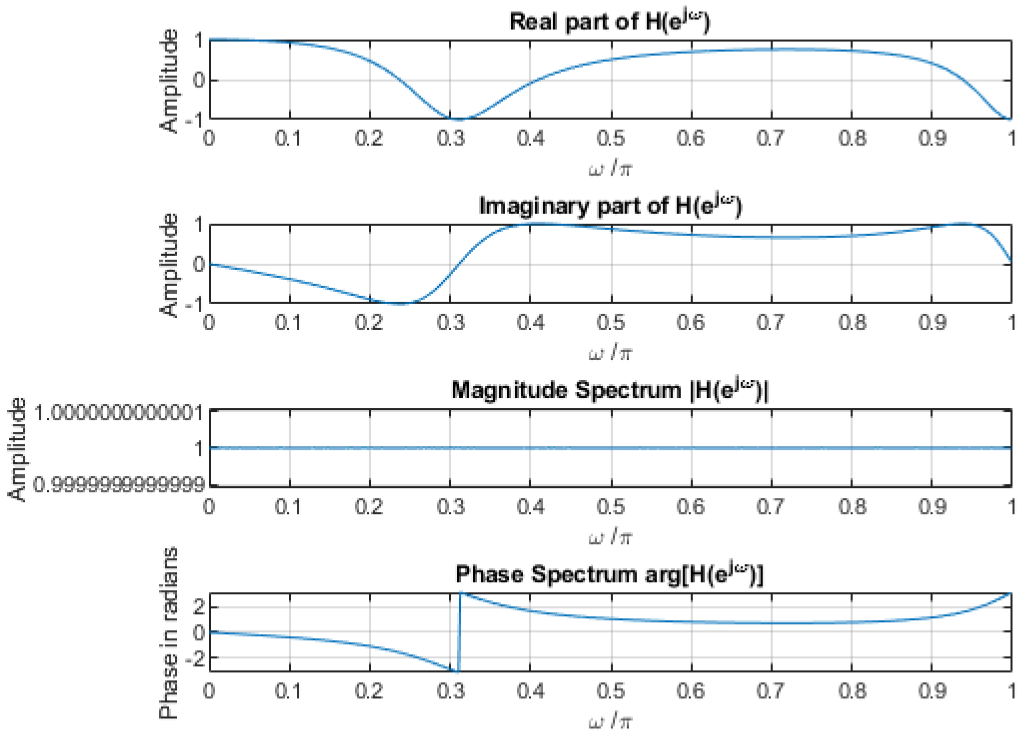
```
0.5508
0.5527
0.5547
0.5566
0.5586
0.5605
0.5625
0.5645
0.5664
0.5684
0.5703
0.5723
0.5742
0.5762
0.5781
0.5801
0.5820
0.5840
0.5859
0.5879
0.5898
0.5918
0.5938
0.5957
0.5977
0.5996
0.6016
0.6035
0.6055
0.6074
0.6094
0.6113
0.6133
0.6152
0.6172
0.6191
0.6211
0.6230
0.6250
0.6270
0.6289
0.6309
0.6328
0.6348
0.6367
0.6387
0.6406
0.6426
0.6445
0.6465
0.6484
0.6504
0.6523
0.6543
```

```
0.6563
0.6582
0.6602
0.6621
0.6641
0.6660
0.6680
0.6699
0.6719
0.6738
0.6758
0.6777
0.6797
0.6816
0.6836
0.6855
0.6875
0.6895
0.6914
0.6934
0.6953
0.6973
0.6992
0.7012
0.7031
0.7051
0.7070
0.7090
0.7109
0.7129
0.7148
0.7168
0.7188
0.7207
0.7227
0.7246
0.7266
0.7285
0.7305
0.7324
0.7344
0.7363
0.7383
0.7402
0.7422
0.7441
0.7461
0.7480
0.7500
0.7520
0.7539
0.7559
0.7578
0.7598
```

```
0.7617
0.7637
0.7656
0.7676
0.7695
0.7715
0.7734
0.7754
0.7773
0.7793
0.7813
0.7832
0.7852
0.7871
0.7891
0.7910
0.7930
0.7949
0.7969
0.7988
0.8008
0.8027
0.8047
0.8066
0.8086
0.8105
0.8125
0.8145
0.8164
0.8184
0.8203
0.8223
0.8242
0.8262
0.8281
0.8301
0.8320
0.8340
0.8359
0.8379
0.8398
0.8418
0.8438
0.8457
0.8477
0.8496
0.8516
0.8535
0.8555
0.8574
0.8594
0.8613
0.8633
0.8652
```

```
0.8672
0.8691
0.8711
0.8730
0.8750
0.8770
0.8789
0.8809
0.8828
0.8848
0.8867
0.8887
0.8906
0.8926
0.8945
0.8965
0.8984
0.9004
0.9023
0.9043
0.9062
0.9082
0.9102
0.9121
0.9141
0.9160
0.9180
0.9199
0.9219
0.9238
0.9258
0.9277
0.9297
0.9316
0.9336
0.9355
0.9375
0.9395
0.9414
0.9434
0.9453
0.9473
0.9492
0.9512
0.9531
0.9551
0.9570
0.9590
0.9609
0.9629
0.9648
0.9668
0.9688
0.9707
```

```
0.9727
0.9746
0.9766
0.9785
0.9805
0.9824
0.9844
0.9863
0.9883
0.9902
0.9922
0.9941
0.9961
0.9980
```



A.4. Modify the code and evaluate the sequence. Use freqz and fft. Compare.

```
N_A4 = 512
w_A4 = -4*pi:8*pi/511:4*pi;
g_n = [1 3 5 7 9 11 13 15 17]; A4_den = 1;
h_freqz_A4 = freqz(g_n, A4_den, w_A4); % freqz function
hf_fft_A4 = fft(g_n, N_A4); % fft function
x_axis =w_A4/pi
```

```
%freqz
figure()
subplot(4,1,1)
plot(x_axis,real(h_freqz_A4));grid
title('Real part of H(e^{j\omega}) using freqz()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,2)
plot(x_axis,imag(h_freqz_A4));grid
title('Imaginary part of H(e^{j\omega}) using freqz()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,3)
plot(x_axis,abs(h_freqz_A4));grid
title('Magnitude Spectrum |H(e^{j\omega})| using freqz()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,4)
plot(x_axis,angle(h_freqz_A4));grid
title('Phase Spectrum arg[H(e^{j\omega})] using freqz()')
xlabel('\omega /\pi');
ylabel('Phase in radians');

% fft
figure()
subplot(4,1,1)
plot(x_axis,real(hf_fft_A4));grid
title('Real part of H(e^{j\omega}) using fft()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,2)
plot(x_axis,imag(hf_fft_A4));grid
title('Imaginary part of H(e^{j\omega}) using fft()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,3)
plot(x_axis,abs(hf_fft_A4));grid
title('Magnitude Spectrum |H(e^{j\omega})| using fft()')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(4,1,4)
plot(x_axis,angle(hf_fft_A4));grid
title('Phase Spectrum arg[H(e^{j\omega})] using fft()')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

```
N_A4 =

   512


x_axis =
```

```
Columns 1 through 7

 -4.0000   -3.9843   -3.9687   -3.9530   -3.9374   -3.9217   -3.9061

Columns 8 through 14

 -3.8904   -3.8748   -3.8591   -3.8434   -3.8278   -3.8121   -3.7965

Columns 15 through 21

 -3.7808   -3.7652   -3.7495   -3.7339   -3.7182   -3.7025   -3.6869

Columns 22 through 28

 -3.6712   -3.6556   -3.6399   -3.6243   -3.6086   -3.5930   -3.5773

Columns 29 through 35

 -3.5616   -3.5460   -3.5303   -3.5147   -3.4990   -3.4834   -3.4677

Columns 36 through 42

 -3.4521   -3.4364   -3.4207   -3.4051   -3.3894   -3.3738   -3.3581

Columns 43 through 49

 -3.3425   -3.3268   -3.3112   -3.2955   -3.2798   -3.2642   -3.2485

Columns 50 through 56

 -3.2329   -3.2172   -3.2016   -3.1859   -3.1703   -3.1546   -3.1389

Columns 57 through 63

 -3.1233   -3.1076   -3.0920   -3.0763   -3.0607   -3.0450   -3.0294

Columns 64 through 70

 -3.0137   -2.9980   -2.9824   -2.9667   -2.9511   -2.9354   -2.9198

Columns 71 through 77

 -2.9041   -2.8885   -2.8728   -2.8571   -2.8415   -2.8258   -2.8102

Columns 78 through 84

 -2.7945   -2.7789   -2.7632   -2.7476   -2.7319   -2.7162   -2.7006

Columns 85 through 91

 -2.6849   -2.6693   -2.6536   -2.6380   -2.6223   -2.6067   -2.5910

Columns 92 through 98
```

-2.5753   -2.5597   -2.5440   -2.5284   -2.5127   -2.4971   -2.4814

Columns 99 through 105

-2.4658   -2.4501   -2.4344   -2.4188   -2.4031   -2.3875   -2.3718

Columns 106 through 112

-2.3562   -2.3405   -2.3249   -2.3092   -2.2935   -2.2779   -2.2622

Columns 113 through 119

-2.2466   -2.2309   -2.2153   -2.1996   -2.1840   -2.1683   -2.1526

Columns 120 through 126

-2.1370   -2.1213   -2.1057   -2.0900   -2.0744   -2.0587   -2.0431

Columns 127 through 133

-2.0274   -2.0117   -1.9961   -1.9804   -1.9648   -1.9491   -1.9335

Columns 134 through 140

-1.9178   -1.9022   -1.8865   -1.8708   -1.8552   -1.8395   -1.8239

Columns 141 through 147

-1.8082   -1.7926   -1.7769   -1.7613   -1.7456   -1.7299   -1.7143

Columns 148 through 154

-1.6986   -1.6830   -1.6673   -1.6517   -1.6360   -1.6204   -1.6047

Columns 155 through 161

-1.5890   -1.5734   -1.5577   -1.5421   -1.5264   -1.5108   -1.4951

Columns 162 through 168

-1.4795   -1.4638   -1.4481   -1.4325   -1.4168   -1.4012   -1.3855

Columns 169 through 175

-1.3699   -1.3542   -1.3386   -1.3229   -1.3072   -1.2916   -1.2759

Columns 176 through 182

-1.2603   -1.2446   -1.2290   -1.2133   -1.1977   -1.1820   -1.1663

Columns 183 through 189

-1.1507   -1.1350   -1.1194   -1.1037   -1.0881   -1.0724   -1.0568

```
Columns 190 through 196

 -1.0411   -1.0254   -1.0098   -0.9941   -0.9785   -0.9628   -0.9472

Columns 197 through 203

 -0.9315   -0.9159   -0.9002   -0.8845   -0.8689   -0.8532   -0.8376

Columns 204 through 210

 -0.8219   -0.8063   -0.7906   -0.7750   -0.7593   -0.7436   -0.7280

Columns 211 through 217

 -0.7123   -0.6967   -0.6810   -0.6654   -0.6497   -0.6341   -0.6184

Columns 218 through 224

 -0.6027   -0.5871   -0.5714   -0.5558   -0.5401   -0.5245   -0.5088

Columns 225 through 231

 -0.4932   -0.4775   -0.4618   -0.4462   -0.4305   -0.4149   -0.3992

Columns 232 through 238

 -0.3836   -0.3679   -0.3523   -0.3366   -0.3209   -0.3053   -0.2896

Columns 239 through 245

 -0.2740   -0.2583   -0.2427   -0.2270   -0.2114   -0.1957   -0.1800

Columns 246 through 252

 -0.1644   -0.1487   -0.1331   -0.1174   -0.1018   -0.0861   -0.0705

Columns 253 through 259

 -0.0548   -0.0391   -0.0235   -0.0078    0.0078    0.0235    0.0391

Columns 260 through 266

  0.0548    0.0705    0.0861    0.1018    0.1174    0.1331    0.1487

Columns 267 through 273

  0.1644    0.1800    0.1957    0.2114    0.2270    0.2427    0.2583

Columns 274 through 280

  0.2740    0.2896    0.3053    0.3209    0.3366    0.3523    0.3679

Columns 281 through 287
```

0.3836 0.3992 0.4149 0.4305 0.4462 0.4618 0.4775

Columns 288 through 294

0.4932 0.5088 0.5245 0.5401 0.5558 0.5714 0.5871

Columns 295 through 301

0.6027 0.6184 0.6341 0.6497 0.6654 0.6810 0.6967

Columns 302 through 308

0.7123 0.7280 0.7436 0.7593 0.7750 0.7906 0.8063

Columns 309 through 315

0.8219 0.8376 0.8532 0.8689 0.8845 0.9002 0.9159

Columns 316 through 322

0.9315 0.9472 0.9628 0.9785 0.9941 1.0098 1.0254

Columns 323 through 329

1.0411 1.0568 1.0724 1.0881 1.1037 1.1194 1.1350

Columns 330 through 336

1.1507 1.1663 1.1820 1.1977 1.2133 1.2290 1.2446

Columns 337 through 343

1.2603 1.2759 1.2916 1.3072 1.3229 1.3386 1.3542

Columns 344 through 350

1.3699 1.3855 1.4012 1.4168 1.4325 1.4481 1.4638

Columns 351 through 357

1.4795 1.4951 1.5108 1.5264 1.5421 1.5577 1.5734

Columns 358 through 364

1.5890 1.6047 1.6204 1.6360 1.6517 1.6673 1.6830

Columns 365 through 371

1.6986 1.7143 1.7299 1.7456 1.7613 1.7769 1.7926

Columns 372 through 378

1.8082 1.8239 1.8395 1.8552 1.8708 1.8865 1.9022

Columns 379 through 385

1.9178 1.9335 1.9491 1.9648 1.9804 1.9961 2.0117

Columns 386 through 392

2.0274 2.0431 2.0587 2.0744 2.0900 2.1057 2.1213

Columns 393 through 399

2.1370 2.1526 2.1683 2.1840 2.1996 2.2153 2.2309

Columns 400 through 406

2.2466 2.2622 2.2779 2.2935 2.3092 2.3249 2.3405

Columns 407 through 413

2.3562 2.3718 2.3875 2.4031 2.4188 2.4344 2.4501

Columns 414 through 420

2.4658 2.4814 2.4971 2.5127 2.5284 2.5440 2.5597

Columns 421 through 427

2.5753 2.5910 2.6067 2.6223 2.6380 2.6536 2.6693

Columns 428 through 434

2.6849 2.7006 2.7162 2.7319 2.7476 2.7632 2.7789

Columns 435 through 441

2.7945 2.8102 2.8258 2.8415 2.8571 2.8728 2.8885

Columns 442 through 448

2.9041 2.9198 2.9354 2.9511 2.9667 2.9824 2.9980

Columns 449 through 455

3.0137 3.0294 3.0450 3.0607 3.0763 3.0920 3.1076

Columns 456 through 462

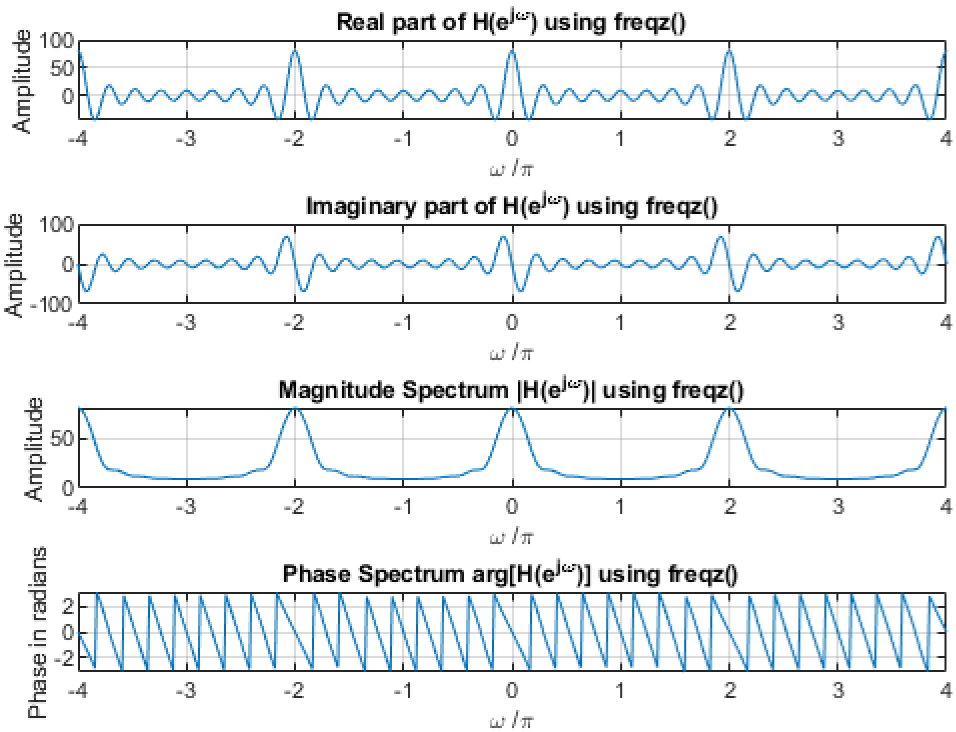
3.1233 3.1389 3.1546 3.1703 3.1859 3.2016 3.2172

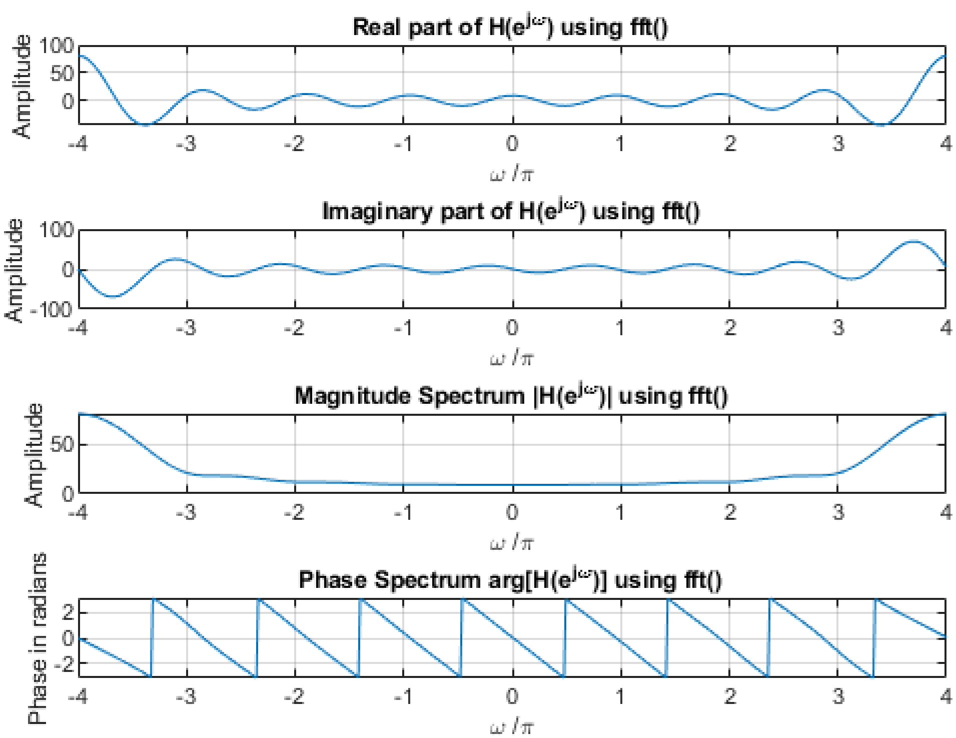
Columns 463 through 469

3.2329 3.2485 3.2642 3.2798 3.2955 3.3112 3.3268

Columns 470 through 476

```
  3.3425    3.3581    3.3738    3.3894    3.4051    3.4207    3.4364

Columns 477 through 483

  3.4521    3.4677    3.4834    3.4990    3.5147    3.5303    3.5460

Columns 484 through 490

  3.5616    3.5773    3.5930    3.6086    3.6243    3.6399    3.6556

Columns 491 through 497

  3.6712    3.6869    3.7025    3.7182    3.7339    3.7495    3.7652

Columns 498 through 504

  3.7808    3.7965    3.8121    3.8278    3.8434    3.8591    3.8748

Columns 505 through 511

  3.8904    3.9061    3.9217    3.9374    3.9530    3.9687    3.9843

Column 512

  4.0000
```

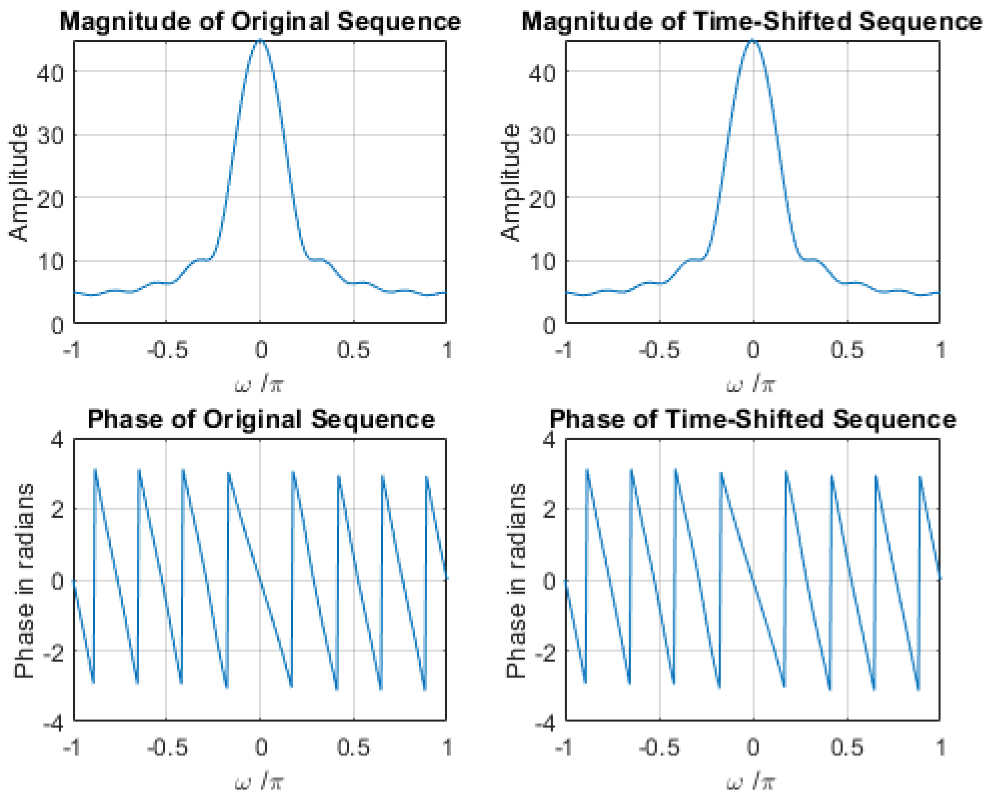

Real part of H(e^jω) using freqz()
Amplitude
ω /π
Imaginary part of H(e^jω) using freqz()
Amplitude
ω /π
Magnitude Spectrum |H(e^jω)| using freqz()
Amplitude
ω /π
Phase Spectrum arg[H(e^jω)] using freqz()
Phase in radians
ω /π


Real part of H(e^jω) using fft()
Amplitude
ω /π
Imaginary part of H(e^jω) using fft()
Amplitude
ω /π
Magnitude Spectrum |H(e^jω)| using fft()
Amplitude
ω /π
Phase Spectrum arg[H(e^jω)] using fft()
Phase in radians
ω /π

*freqz() and fft() function performs the same operation for DFT. However, freqz() compute the phase and magnitude periodically while fft() performs the same operation on one period.

B. Time shift property of the DFT

```
clf;
w_B = -pi:2*pi/255:pi;
D_B = -10; %time shift
B_num = [1 2 3 4 5 6 7 8 9];
h1_B = freqz(B_num, 1, w_B);
h2_B = freqz([zeros(1,D_B) B_num], 1, w_B);

subplot(2,2,1)
plot(w_B/pi,abs(h1_B));grid
title('Magnitude of Original Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w_B/pi,abs(h2_B));grid
title('Magnitude of Time-Shifted Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w_B/pi,angle(h1_B));grid
title('Phase of Original Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w_B/pi,angle(h2_B));grid
title('Phase of Time-Shifted Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

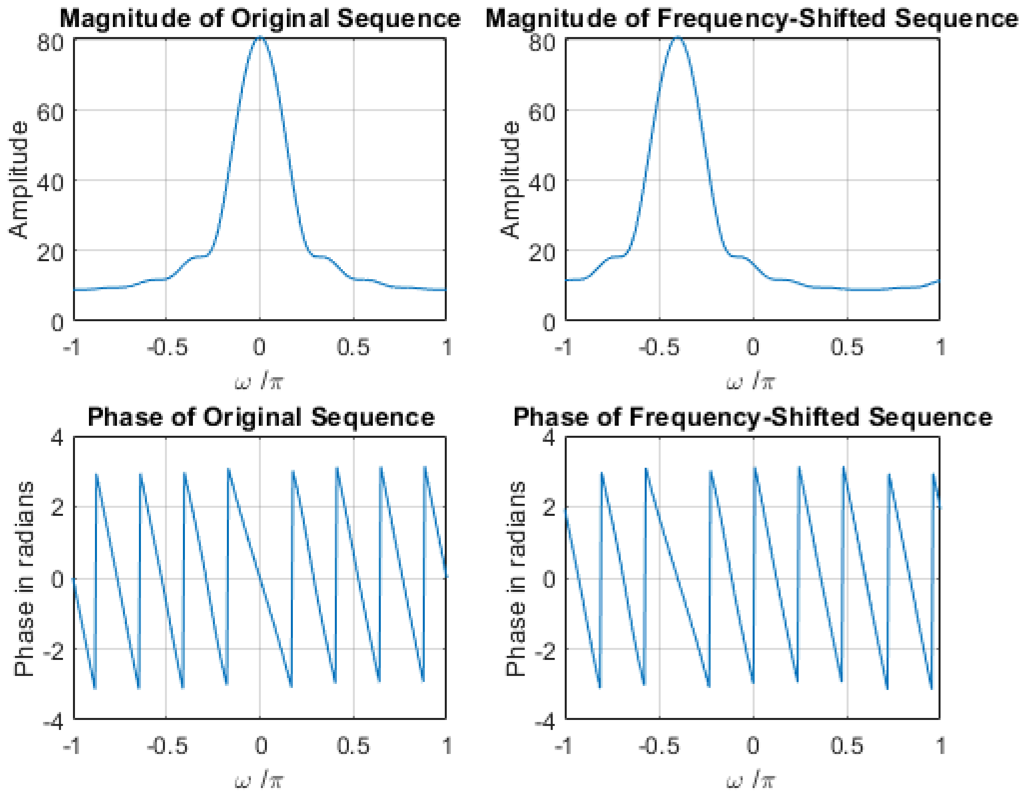


- As shown on the generated plots, the magnitude spectrum is not affected by the time shift, instead the time shift is applied to the phase spectrum. The variable that handles the time shift is D_B. Increasing the time shift makes the phase angle oscilllates faster in the the %w/pi% domain.

C. Frequency-shift property of DFT

```
clf;
w = -pi:2*pi/255:pi;
wo = -0.4*pi; %frequency shifted to the left
num1 = [1 3 5 7 9 11 13 15 17];
L = length(num1);
h1 = freqz(num1, 1, w);
n = 0:L-1;
num2 = exp(wo*i*n).*num1;
h2 = freqz(num2, 1, w);
subplot(2,2,1)
plot(w/pi,abs(h1));grid
title('Magnitude of Original Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h2));grid
title('Magnitude of Frequency-Shifted Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
```

```
plot(w/pi,angle(h1));grid
title('Phase of Original Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h2));grid
title('Phase of Frequency-Shifted Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

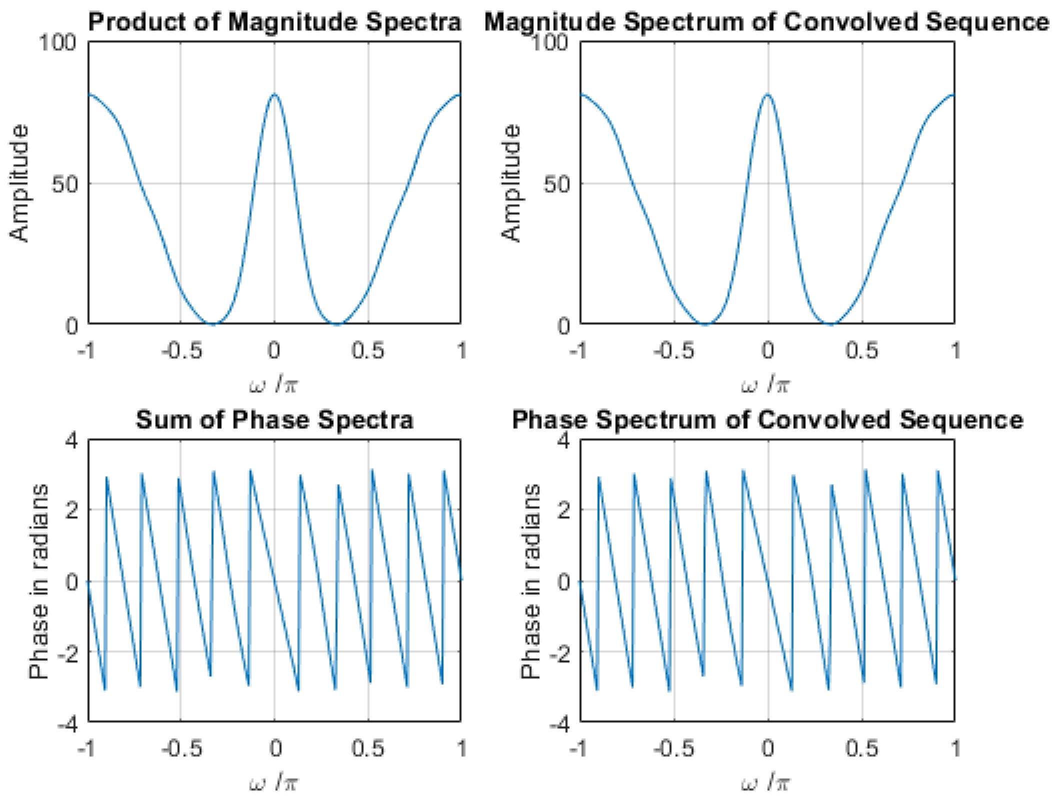


*The generated plot shows that both the phase and magnitude are shifted according to the magnitude of the parameter wo (negative shifts to the left, while positive shifts to the right).

D. Convolution property of DFT

```
clf;
w = -pi:2*pi/255:pi;
x1 = [1 3 5 7 9 11 13 15 17];
x2 = [1 -2 3 -2 1];
y = conv(x1,x2); %time domain convolution
h3 = freqz(y,1,w);

h1 = freqz(x1, 1, w);
h2 = freqz(x2, 1, w);
hp = h1.*h2; %DFT multiplication
```

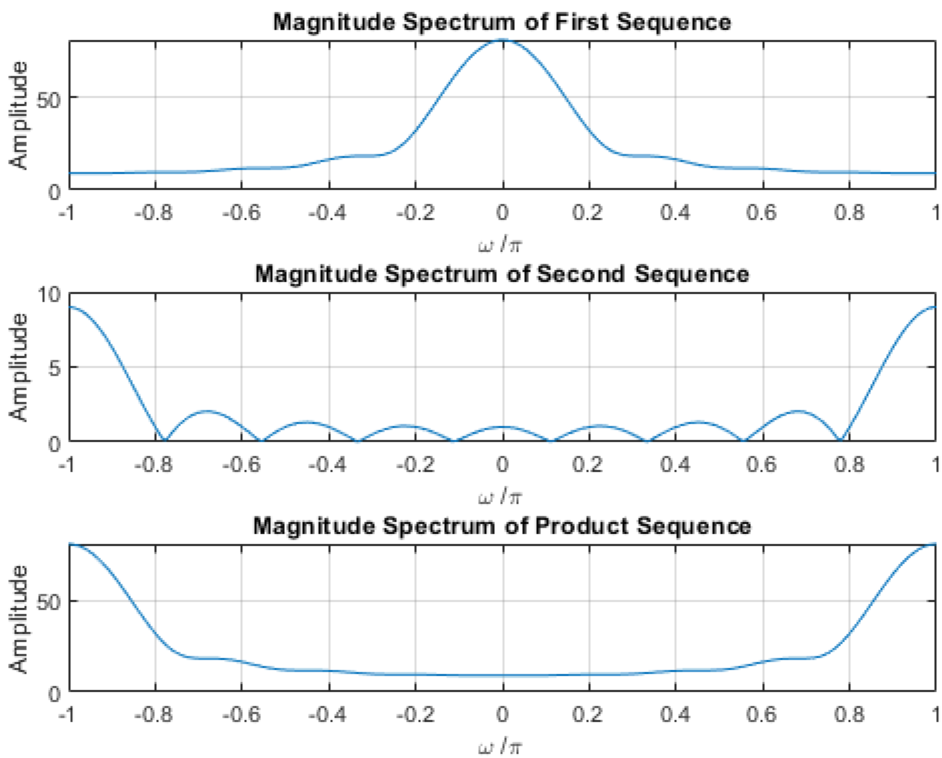
```
subplot(2,2,1)
plot(w/pi,abs(hp));grid
title('Product of Magnitude Spectra')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Convolved Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(hp));grid
title('Sum of Phase Spectra')
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h3));grid
title('Phase Spectrum of Convolved Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```



- As shown in the generated plots, the magnitude and phase from the multiplication of two DFT from the original sequences are the same to those obtained from the time-domain convolution of the said sequence. Hence, the convolution operation in time-domain is the same as the multiplication in DFT as presented in comparing the results obtained in the DFT version of y and the product of DFT multiplication hp.

E. Modulation property

```
clf;
w = -pi:2*pi/255:pi;
x1 = [1 3 5 7 9 11 13 15 17];
x2 = [1 -1 1 -1 1 -1 1 -1 1];
y = x1.*x2;

h1 = freqz(x1, 1, w);
h2 = freqz(x2, 1, w);
h3 = freqz(y,1,w);

subplot(3,1,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of First Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(3,1,2)
plot(w/pi,abs(h2));grid
title('Magnitude Spectrum of Second Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(3,1,3)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Product Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
```

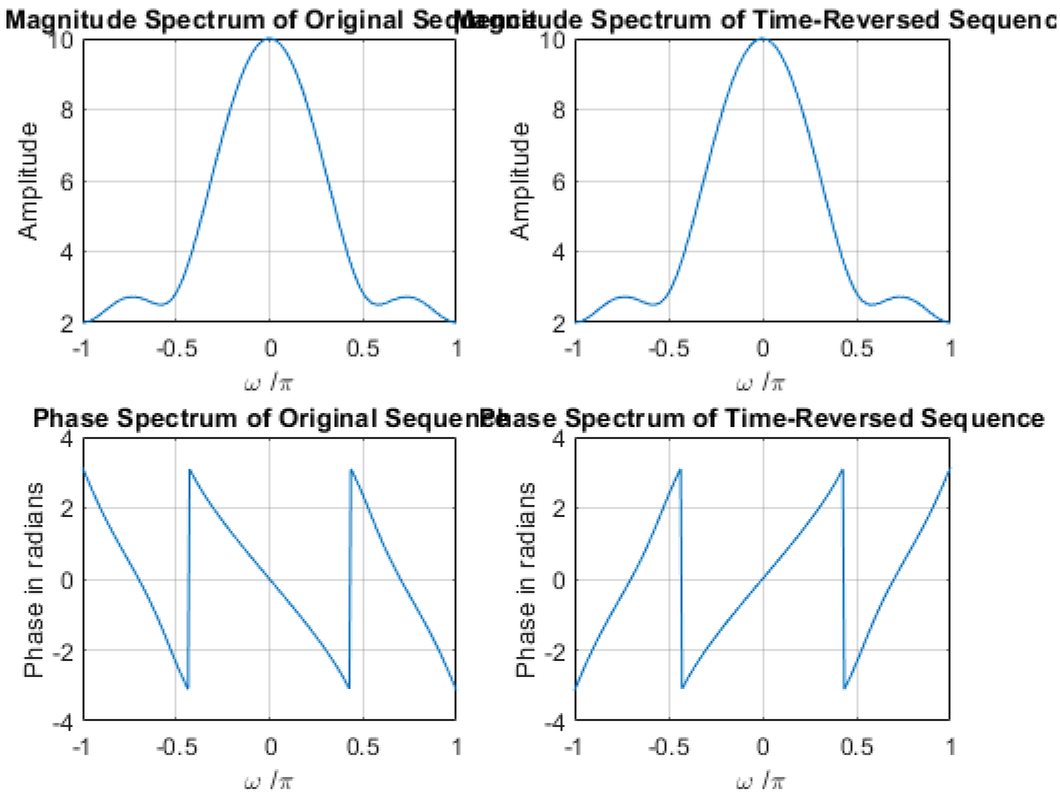


Based on the graph presented above, the DFT is modulated when you multiply the two sequence in the time domain as performed on the code above, where y is the product of x1 and x2 in the time domain. Hence, the modulation property of the DFT says that the function is modulated by another function if they are multiplied in the time domain.

F. Time-reversal property

```
clf;
w = -pi:2*pi/255:pi;
num = [1 2 3 4];
L = length(num)-1;
h1 = freqz(num, 1, w);
h2 = freqz(fliplr(num), 1, w);
h3 = exp(w*L*i).*h2;
subplot(2,2,1)
plot(w/pi,abs(h1));grid
title('Magnitude Spectrum of Original Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,2)
plot(w/pi,abs(h3));grid
title('Magnitude Spectrum of Time-Reversed Sequence')
xlabel('\omega /\pi');
ylabel('Amplitude');
subplot(2,2,3)
plot(w/pi,angle(h1));grid
```

```
title('Phase Spectrum of Original Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
subplot(2,2,4)
plot(w/pi,angle(h3));grid
title('Phase Spectrum of Time-Reversed Sequence')
xlabel('\omega /\pi');
ylabel('Phase in radians');
```

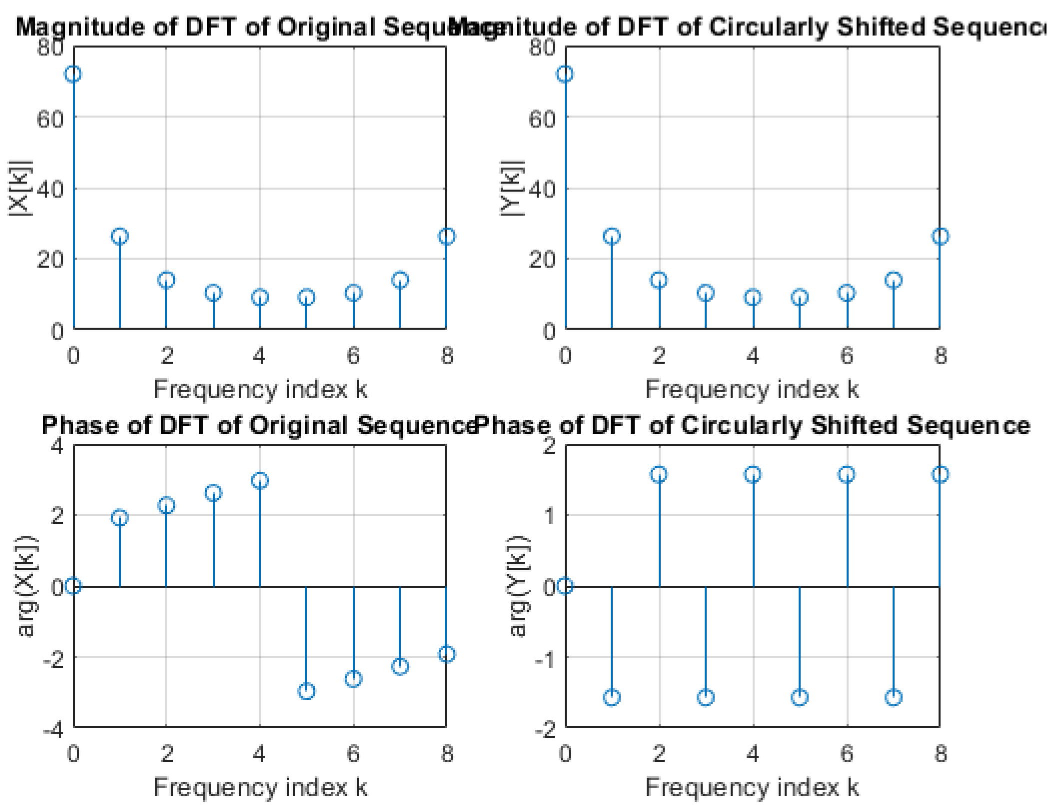


As presented on the generated plot, the direction of phase spectrum is reversed as compared to the original DFT sequence. This time reversal is done by forming a new sequence using the function fliplr which reverse the samples contained on the original ramp sequence. The time reversal operation are as follows. First we call the freqz() function to set the h2 equal to DFT of the new sequence obtained from using fliplr() on the original ramp seuqnce. Then, h3 is set equal to the DFT of the time reversed ramp by multiplying h2 with a linear phase term to implement the shifting in the time domain.

G.1 Circular-shifting property

```
clf;
x = [0 2 4 6 8 10 12 14 16];
N = length(x)-1;
n = 0:N;
y = circshift(x,5); %circshift is defined by the matlab function
 circshift in matlab2020a.
XF = fft(x);
YF = fft(y);
```

```
subplot(2,2,1);
stem(n,abs(XF));
grid;
title('Magnitude of DFT of Original Sequence');
xlabel('Frequency index k');
ylabel('|X[k]|');
subplot(2,2,2);
stem(n,abs(YF));
grid;
title('Magnitude of DFT of Circularly Shifted Sequence');
xlabel('Frequency index k');
ylabel('|Y[k]|');
subplot(2,2,3);
stem(n,angle(XF));grid;
title('Phase of DFT of Original Sequence');
xlabel('Frequency index k');
ylabel('arg(X[k])');
subplot(2,2,4);
stem(n,angle(YF));grid;
title('Phase of DFT of Circularly Shifted Sequence');
xlabel('Frequency index k');
ylabel('arg(Y[k])');
```



The above code demonstrate the circshift function in matlab for DFT. Circshift function operates as follows: the input sequence **x** is circularly shifted by **M** position. If **M > 0**, then circshift remove the leftmost

M elements from the input function x and appends them on the right side of the remaining input sequence to obtain the circularly shifted sequence. In case when **M <0**, circshift first complements **M** by the length of input sequence **x**.

On the given example, we can see on its generated plots that the length of sequence **x** is **n=8** and the time shift is shifted to the left by five samples as shown in the phase term expression below. $W[N][kn0] = W[N][-k5] = exp(jk10pi/8) = exp(jk5pi/4)$ which increases the slope of phase.

G.2 Circular-convolution property

```
g1 = [1 2 3 4 5];
g2 = [2 2 0 1 1];
g1e = [g1 zeros(1,length(g2)-1)];
g2e = [g2 zeros(1,length(g1)-1)];
ylin = cconv(g1e,g2e);
disp('Linear convolution via circular convolution = ');
disp(ylin(1:9));
y = conv(g1, g2);
disp('Direct linear convolution = ');
disp(y);
```

```
Linear convolution via circular convolution =
  Columns 1 through 7

    2.0000    6.0000   10.0000   15.0000   21.0000   15.0000    7.0000

  Columns 8 through 9

    9.0000    5.0000

Direct linear convolution =
     2     6    10    15    21    15     7     9     5
```

The above code demonstrate the circular convolution property of DFT. circonv or cconv is a function that requires two inputs **g1e and g2e** of equal length. Then, we let **g2e** be the infinite length periodic extension of **g2e**. Next, the elements from **1 to L** of the output vector **ylin** are obtained by taking the inner product between **g1e** and a length vector **L** which is obtained by circularly shifting to the right the time reversed vector **g2etr**. The output sample **y[n]** with **n** greater than or equal to **1** and less than or equal to **L**, the amounth of circular shift is **n-1** position. Based from the generated results, zero padding onto the match length is made possible for the implementation of linear convolution using circular convolution.

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