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Lab 10 – DFT & Windowing

EEET-332.01 – Signals, Systems, and Transformers Lab

Due Date: 12/01/2024

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Note: You may change variable names and comments to make them make more sense to you. Section 1 will be used with several homework problems.

Section 1: FFT and IFFT – Create a new script named section1.m for the code below.

```
init();
N=16; %number of samples in time and freq domain
n=0:N-1; %index for freq domain.
T=9; %signal period
Ts=T/N; %sample period
t=0:Ts:T-Ts;
```

1) Calculate Ts and ws (sample angular frequency = 2*pi/Ts)

Ts = 0.5625 sec   ws = 11.1701 rad/sec

2) Complete the table for the t array

0.0000	0.5625	1.125	1.6875	2.25	2.8125	3.3750	3.9375	4.5000	5.0625
5.6250	6.1875	6.75	7.3215	7.8750	8.4375				

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5) Using figure #2 generated by the script (spectrum amplitude) and the "data cursor", click on the plot to help you complete the list below of c_m values (some are given, rounded to the nearest thousandth).

   a) DC: m = 0 and $|c_m|$ = 1.301
   b) 1^{st} harmonic: m = 1 and $|c_m|$ = 1.449
   c) -1^{st} harmonic: m = 15 and $|c_m|$ = 1.449
   d) 2^{nd} harmonic: m = 2 and $|c_m|$ = 1.339
   e) -2^{nd} harmonic: m = 14 and $|c_m|$ = 1.339

6) (True/False) The DC value is the average value of the waveform True

MATLAB's arrangement of the FFT is confusing and inconvenient. Change the fft_ifft.m function (or *.mlx) so it shifts the spectrum, putting the DC value in the center. Changes are highlighted.

```
function [m_ctr,cm_ctr,yy] = fft_ifft(t,n,y,N)
  % Calculate, display F(m).
  % NOTE: Matlab fft() returns N times spectrum so N is divided out
  %       Matlab ifft() used later will scale it back up by N
  m_ctr=-N/2:N/2-1;
  cm_ctr = fftshift(fft(y,N)/N);
  make_stem(m_ctr,abs(cm_ctr),'shifted spectrum','m(center)','abs(cm)');

  % Reconstruct y (called yy) using inverse FFT (IFFT).
  % NOTE: Matlab fft() returns N times spectrum so N is was divided out
  %       Matlab ifft() now expects fft() scale up by N
  yy = real(ifft(N*fftshift(cm_ctr))); % scrub imaginary vestiges
  make_plot(t,yy,'Reconstructed Waveforms','seconds','reconstructed y');
end
```

Do not forget to modify section1.m to call the new fft_ifft function.

7) Repeat the exercise using the Shifted Spectrum Amplitude and the "data cursor" to click on the plot. Use these results to complete the list below of c_m values.

   f) DC: m_ctr = 0 and $|c_m|$ = 1.301
   g) 1^{st} harmonic: m_ctr = 1 and $|c_m|$ = 1.449
   h) -1^{st} harmonic: m_ctr = -1 and $|c_m|$ = 1.449
   i) 2^{nd} harmonic: m_ctr = 2 and $|c_m|$ = 1.339
   j) -2^{nd} harmonic: m_ctr = -2 and $|c_m|$ = 1.339

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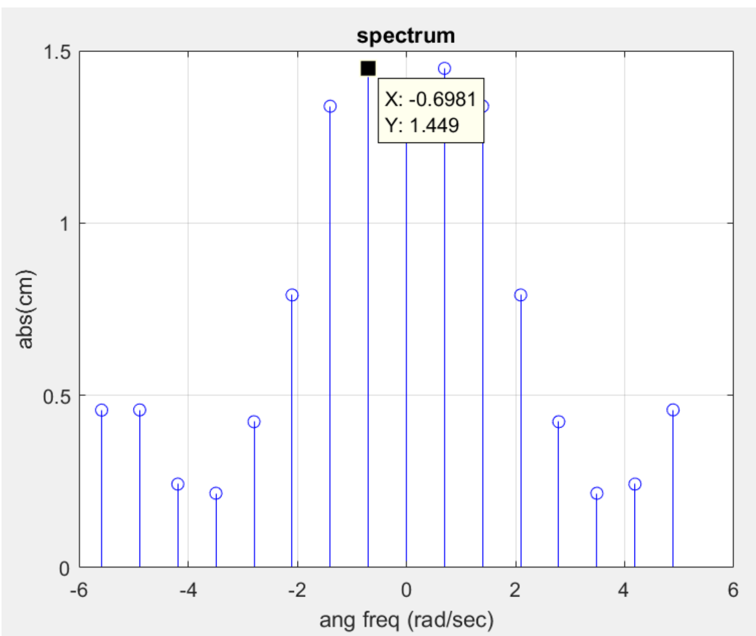
The spectrum can be further enhanced by displaying the actual frequency and not just the harmonic number. The frequency of any coefficient can be calculated by multiplying the harmonic number by the fundamental frequency. Add a make_stem in your script after the call to fft_ifft to plot cm_ctr using the angular frequency for the x-axis variable.

$$angular\ frequency = m\_ctr * 2 * pi/T$$

8) From Figure 4 complete the list below of c_m values (plot given below)

   a) DC: ω = ____0____ and $|c_m(0)|$ = 1.301
   b) 1^{st} harmonic: ω = __0.698132__ rad/sec and $|c_m(1)|$ = ____1.449____
   c) -1^{st} harmonic: ω = = - 0.698132 rad/sec and $|c_m(-1)|$ = 1.449 (shown on plot)
   d) 2^{nd} harmonic: ω = __1.39626__ rad/sec and $|c_m(2)|$ = ____1.339____
   e) -2^{nd} harmonic: ω = -1.39626 rad/sec and $|c_m(-2)|$ = 1.339



Submit:

Section 1 blanks completed (handwritten is acceptable) in your report.

b. Define win as a zero vector the same size as cm. To do this, refer to previous sections to see how the zeros() and size() functions were used. Complete the table and verify that you get the same plot.

win

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0				

The window will now be placed in the center of the win vector.

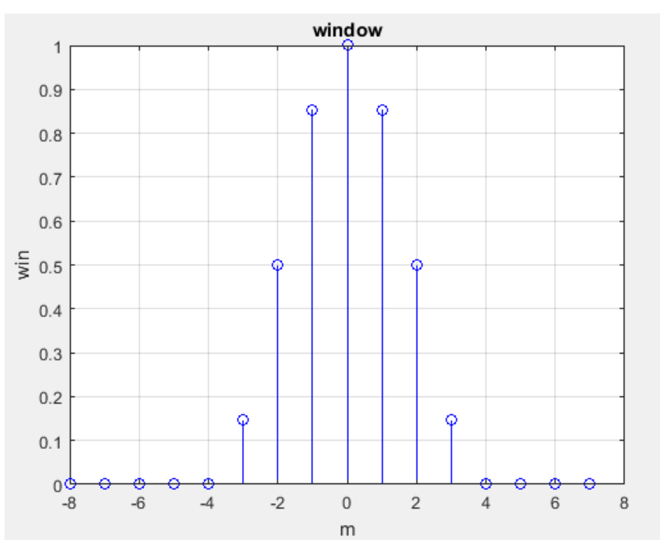
c. Use the find() command to locate the m values between –M and M.
d. Load the Hanning window values in the center of the win vector, from -M to M.

The most common error in this step is “Unable to perform assignment because the left and right sides have a different number of elements.” Make sure the size of “m_between_negM_and_posM” is equal to 2*M+1. If not, fix the find command making sure you include the end points, –M and M.

Complete the table and verify that you get the same plot.

win

0	0	0	0	0	0	0.25	0.75	1	0.75
0.25	0	0	0	0	0				



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Answer the following questions.

2) What is the sample period? $\frac{T}{N} = Ts =$ 0.0029 second
3) What is the sample frequency? $f_s = \frac{1}{Ts} =$ 341.333 Hz or Samples/second
4) What is the fundamental frequency? $fo = \frac{1}{T} =$ 0.333 Hz
5) The frequency of the input sine waves: 8 Hz and 15 Hz.
6) (True/False) This system's Nyquist frequency is much greater than the frequency of either of the input sine waves. True
The maximum frequency the system can sample without aliasing is the Nyquist frequency. The system Nyquist frequency is: $\frac{f_s}{2}$.

7) Examine the spectrum.
   a. What is the frequency of the 24th harmonic? $24fo =$ 8 Hz
   b. What is m equal to at each of the spikes in the spectrum? Execute section5.m, observe the shifted spectrum plot (Figure 2) created by section5.m and fill in the table.

-45	-24	0	24	-45

   c. Convert these sample numbers to frequency. Fill in the table.

-15 Hz	-8 Hz	0 Hz	8 Hz	15 Hz

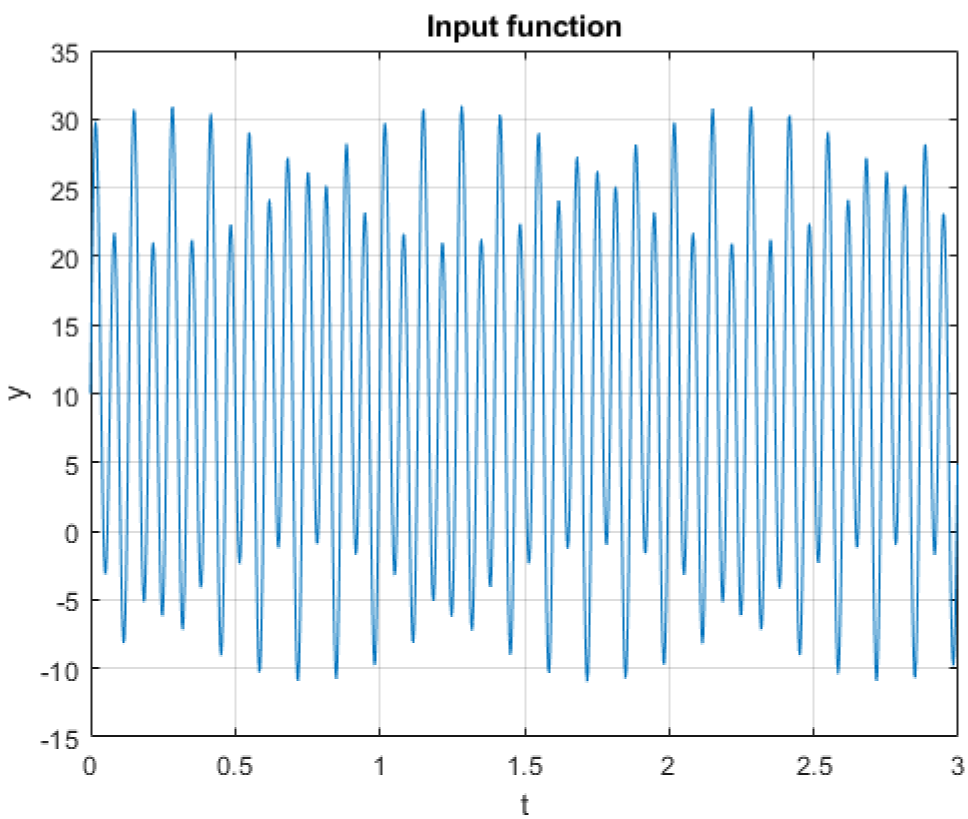
Submit the following in your report:

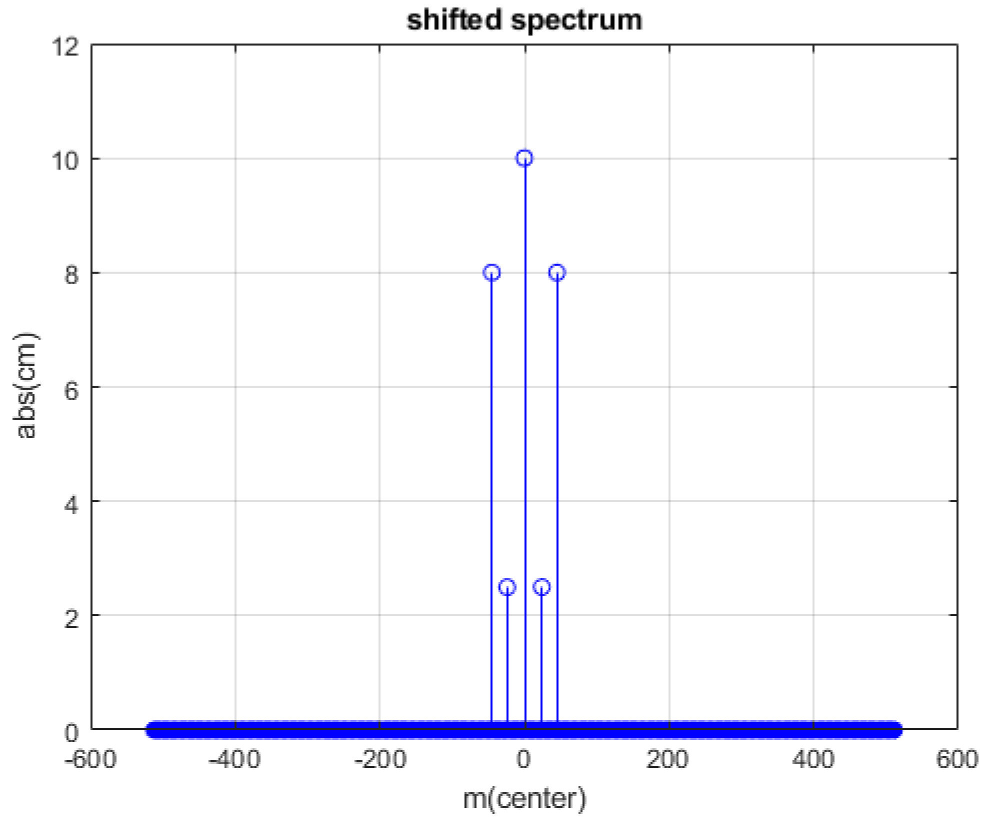
a) **Screenshots of the Section5.m code and plots.**
b) **Answers to questions 2-7 (handwritten is acceptable).**

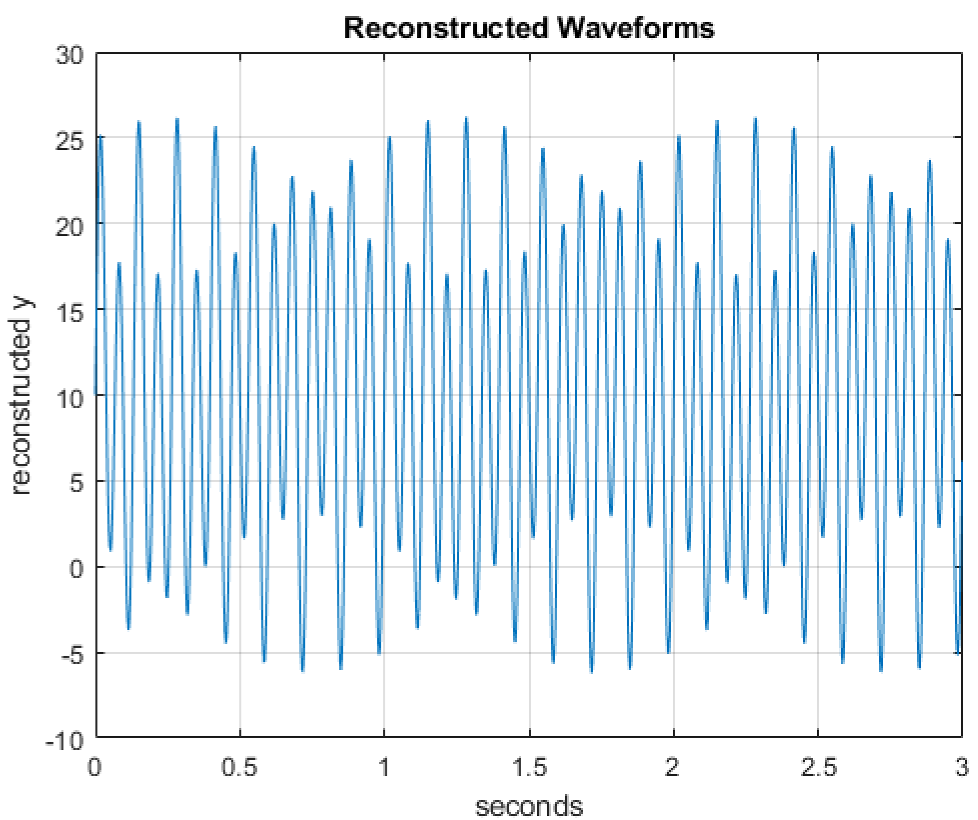
Editor - C:\Users\impos\OneDrive - rit.edu\School\Year 5\Semester 1\EEET 332\Lab 10\section5.m

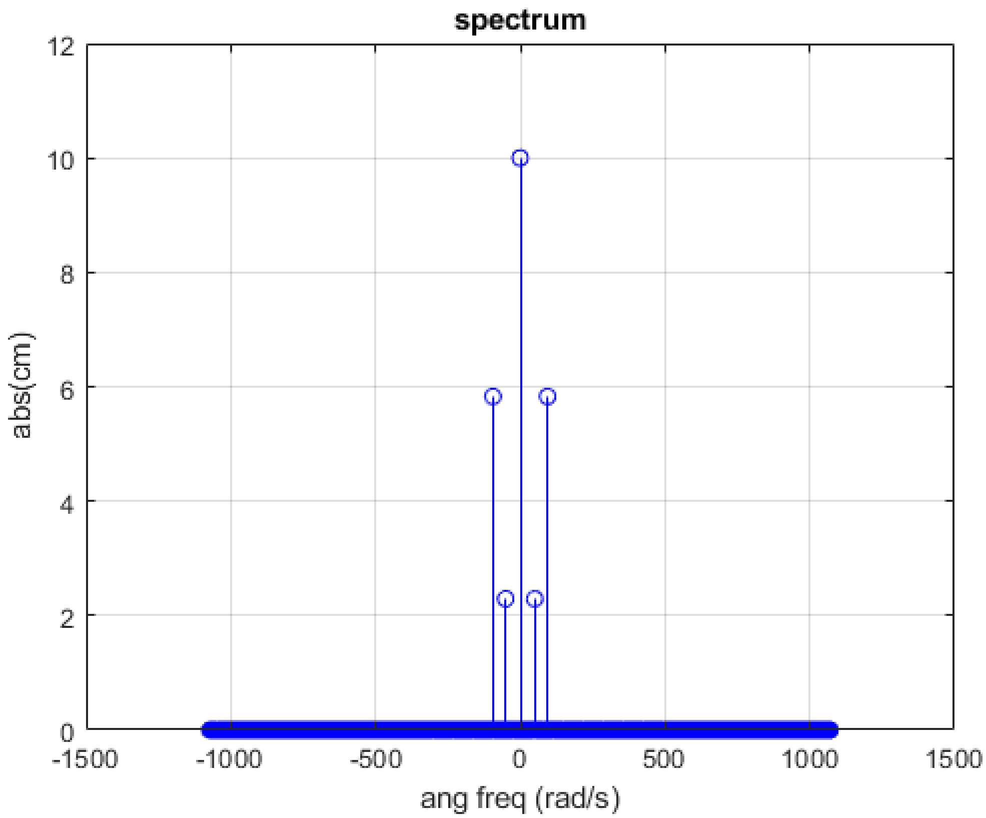
section1.m | section2.m | section3.m | section4.m | section5.m | fft_hanning_ifft.m | +

```
init();
N=1024; %number of samples in time and freq domain
n=0:N-1; %index for freq domain
T= 3; %signal period
Ts=T/N; %sample period
t=0:Ts:T-Ts;
y=zeros(size(t));

w1 = 8*2*pi;
w2 = 15*2*pi;

y = 10 + 5*sin(w1*t) + 16*sin(w2*t);

make_plot(t,y,'Input function','t','y');
Mwin=128;
[m_ctr,cm_ctr,yy] = fft_hanning_ifft(t,y,N,Mwin); %Shifted spectrum
omega = m_ctr *2 * pi/T;
make_stem(omega,cm_ctr,'spectrum','ang freq (rad/s)','abs(cm)');
```




shifted spectrum
abs(cm)
m(center)
12
10
8
6
4
2
0
-600
-400
-200
0
200
400
600


Reconstructed Waveforms
reconstructed y
seconds
30
25
20
15
10
5
0
-5
-10
0
0.5
1
1.5
2
2.5
3


spectrum
12
10
8
6
4
2
0
-1500
-1000
-500
0
500
1000
1500
abs(cm)
ang freq (rad/s)

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Report:

Create your own cover page.

Submit your cover page, the requested screenshots (sections 1 and 5), and this sign-off sheet on the second page.

Sign-offs

Name Jonathan Sumner

Section 2: Other waveforms

Signature	Date 11/18/24

Section 3: Windowed spectrum

Signature	Date 11/18/24

Section 4: Reconstructed waveform from the windowed spectrum

Signature	Date 11/18/24