Signals Systems and Transforms
EEET-332
Lab 7

For each section using MATLAB:

1) Create a new *.m or *.mlx file and call init() in the first line. Save it. Remember, no spaces in the file name!
2) Copy last lab's init.m and make_plot.m (or *.mlx) functions to the same directory.

A quiz is available at https://grader.mathworks.com. An invite to enroll was sent to each student; check your spam folder if you did not receive it.

Prelab:

1. Processing and plotting Fourier series coefficients involves accessing certain frequency ranges and frequencies. The code below generates the Fourier series coefficients for a rectified sine wave. Enter this code in a MATLAB script. Copy init.m and make_plot.m to your working directory.

```
init();
M = 8; % number of positive harmonics
m = -M:M;
% Fourier series coefficients for y(t) = A|sin(wo*t)|
A = 10;
cm = 2*A./(pi*(1-4*m.^2));
make_plot(m,cm,'coef of rect sine wave','harmonics','cm');
```

2. Add the new lines to the script. The first two lines plot the center 7 points of the spectrum. The remaining code finds the power spectrum by squaring the magnitude of cm.

```
ind3 = find(m>=-3 & m<=3);
make_plot(m(ind3),cm(ind3),'sin coef, center 7 points','m','cm_part');

cm_power = abs(cm).*abs(cm);
make_plot(m,cm_power,'full wave sine power spectrum','harmonics','power');
```

In the example above, the center 7 points of m and cm were plotted. Working with subsets of arrays in MATLAB is made easier with the find command.

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m is stored in columns 1 through 17.

```
m =
  Columns 1 through 13
   -8     -7     -6     -5     -4     -3     -2     -1      0      1      2      3      4
  Columns 14 through 17
    5      6      7      8
```

The find command returns the columns (indexes) where m is greater than or equal to -3 and less than or equal to 3. The 6th column, the 7th column, and so on to the 12th column. When m(ind) is used, it refers to m values with the desired columns. Since m was used to create cm, cm(ind) refers to the same desired columns.

```
>> ind3=find(m>=-3 & m<=3)

ind3 =

     6     7     8     9    10    11    12

>> m(ind3)

ans =

    -3    -2    -1     0     1     2     3
```

Watch the video on “find” at youtube: https://www.youtube.com/watch?v=a-V3a5O9Dm8

3. Complete the code below, so the zeroth element is found (zero_ind) and all positive values (pos_ind) of the m vector. Power vector is created by concatenating cm_power(0) and 2*cm_power (all positive values).

```
zero_ind=find(______________);

pos_ind=find(____________ & ____<=M);

cm_pos_pwr=[cm_power(zero_ind) 2*cm_power(pos_ind)];
make_plot([0:M],cm_pos_pwr,'one sided power spectrum','m','power');
```

4. Use what you have learned to plot cm(0) through cm(5).

```
%Find values of m between 0 and 5
first6_ind=find(__________________ & __________________);
make_plot(m(_________________),cm(first6_ind),'one sided power spectrum,
first 6 points','harmonics','power');
```

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In preparation for the prelab quiz, practice the find command. First, create n and A.

```
n=-5:5;
A=2*n
```

The commands above produce.

```
A =
  -10  -8  -6  -4  -2   0   2   4   6   8  10
```

The code below creates A1, which is comprised of the highlighted values of A = A(-4), A(-2), A(-1), A(-0). The vector n is used to find the A values. Notice | is used for OR and & for AND.

```
ind1=find(n==-4 | (n>=-2 & n<=0))
A1 = A(ind1)
```

```
A1 =
   -8  -4  -2   0
```

4. Write the code for a vector, A2, that produces the following:

```
A2 =
  -10  -8  -6  -4  -2   0   2   4   8
```

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Section 1: Euler Phasors

A sawtooth waveform with period T = 2π/ω_o can be described using the following Euler Phasors and Fourier series.

$$c_m = \frac{jA}{2\pi m}\ for\ all\ m\ except\ m = 0\ where\ c_m = 0$$

1) Complete the entries in table 1 by hand using A = 10. Then use the MATLAB script, the function below, and the workspace to find the other values. You can double-click on cm and m in the workspace to find cm and the column number. The logical operation cm(m == x) where x any value will return cm(x) when typed in the command window. For example cm(m==-1) displays cm = -1.5915j.

m	c_m	MATLAB column for cm and m	Logical operator
1			
-1	-1.5915j	15	cm(m == -1)
2			
3			
15	0.1061j	31	cm(m == 15)

Table 1

Script

```
init();
M = 15; % number of harmonics
T = 2; % waveform period 2s
[m,cm] = create_cm_series(M,T); % create fourier coefficients
```

Function (save as create_cm_series.m)

```
function [m,cm] = create_cm_series(M,T)
  m = -M:M;
  A = 10;
  cm = 1j*A./(2*pi*m);
  zero_ind = find(m==0);
  cm(zero_ind) = 0; % set DC value, avoid infinite cm @ m = 0;
end
```

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2) Now let's use the Euler phasors and the Fourier series coefficients to create y (a sawtooth signal). Add the commands given below to the script and complete the function (wo and y) to generate y.

$$y = \sum_{m=-\infty}^{\infty} c_m \, e^{jm\omega_o t}$$

Add to the script.

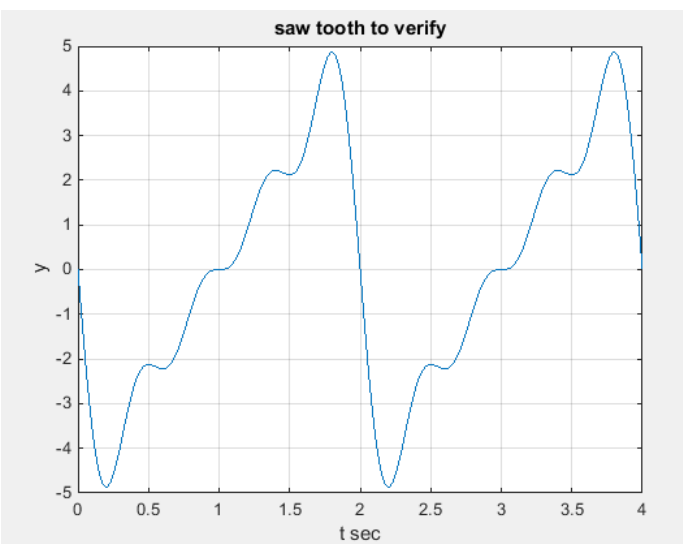
```
t = 0:4/1000:4; % 1001 points from 0 sec to 4 sec
[y] = cm2yt(t,T,m,cm,M);

make_plot(t,y,'sawtooth to verify','t sec','y');
```

Complete function (save as cm2yt.m)

```
function [y] = cm2yt(t,T,m,cm,M)
  wo = 2*pi/                             ; % angular velocity (omega)
  y = zeros(size(t)); % create y, all zero, same size as t
  num_harmonics = M; % set equal to M to use all harmonics
  for i = -num_harmonics:num_harmonics
    ind=find(m==i);
    y = y+cm(ind)*exp(1j * i *                           );
  end
end
```

3) Change the number of harmonics to 4 and compare the plot with the result below.



How is this applied today? The *sawtooth* can represent an audio or video signal. Instead of transmitting 1001 data points to be played or displayed, the cm values are sent, and the receiver reconstructs *y* in real-time. Significantly less data is sent.

Prepare table 1 (it can be handwritten) and the plot of the sawtooth using 9 terms (4 harmonics) and get a sign-off.

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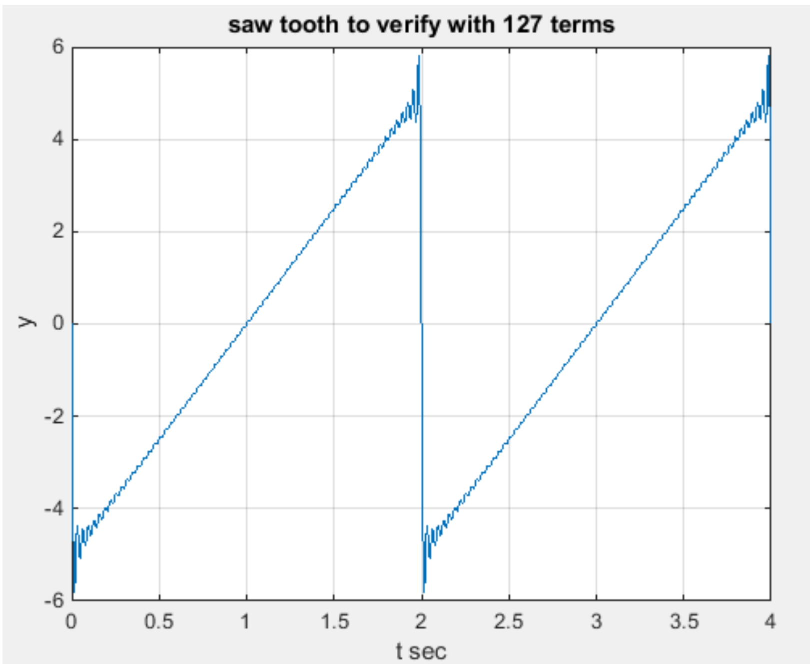
Section 2: Fourier series

The sawtooth in section 1 left a little to the imagination. More "cm" terms (Fourier coefficients) create a more accurate wave. Using the script and functions from section 1.

1) Change M, the number of harmonics, to 63 in the main script.
2) Compare the plot to the figure below.



Plot the sawtooth wave using 127 terms (63 harmonics) and get a sign-off.

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Section 3: The Spectrum and Cumulative Power

The spectrum and power are generally plotted using a stem plot. We will now have two functions for creating figures. Since make_plot.m and stem_plot.m will be assigning figure numbers, fig_num needs to become a global variable. This way, multiple plotting functions can use fig_num.

1) Create a new function for creating stem plots (save as make_stem.m)

```
function make_stem(m,cm,graph_title,x_label,y_label)
  global fig_num;
  figure(fig_num);
  fig_num = fig_num + 1;

  stem(m,abs(cm),'b');
  grid on;
  xlabel(x_label);
  ylabel(y_label);
  title(graph_title);
end
```

2) Add the following code to the script used in sections 1 and 2. Complete the Pcm_harmonic function so Pcm(1) through Pcm(M) are doubled. (This is similar to step 3 in the prelab section)

```
make_stem(m,cm,'Spectrum','harmonic','Fourier coefficient');
% Find power
Pcm = (abs(cm).*abs(cm));
make_stem(m,Pcm,'Power Spectrum','harmonic','power');
%Find cumulative power in spectrum lines
% Find zero element in m
zero_ind=find(____________________________________);
% Find all positive values in m (1 through M)
pos_ind=find(____________________________________);
Pcm_harmonic = [Pcm(zero_ind) 2*Pcm(____________________________)];
make_stem([0:M],cumsum(Pcm_harmonic),'Cumulative Power
Spectrum','harmonic','cumulative power');
```

“cm” values become smaller and smaller at the tails of the stem plot as M increases and the saw tooth improves. Parseval’s Theorem allows us to calculate the power of each harmonic term. We can then see how much power each additional harmonic adds to our time function.

3) Use the “Data Cursor” to determine the value of X where the Cumulative Power Spectrum is at or just over 8.2.

The power in a sawtooth wave is

$$P = \frac{1}{T}\int_0^2 (5t-5)^2 dt = \frac{1}{2}\int_0^2 (25t^2 - 50t + 25)dt = 8.333\overline{3}$$

So 8.2 represents over 98% of the energy.

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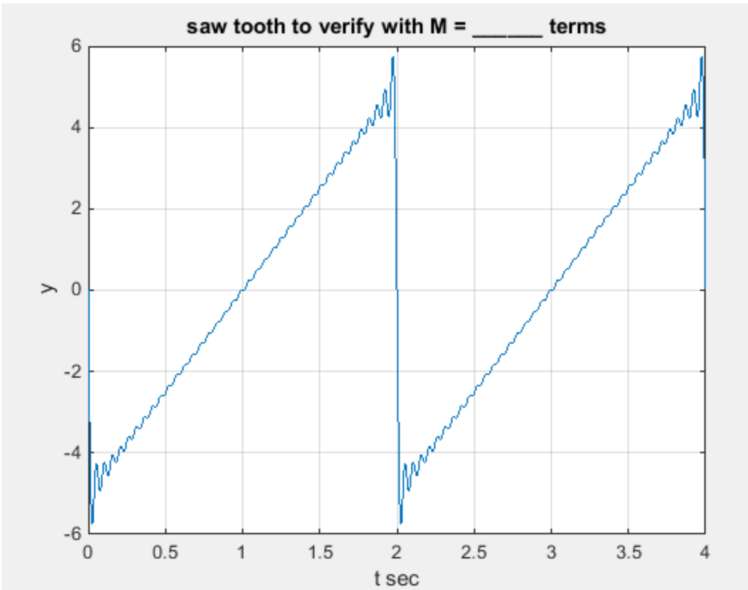
Change M, so the Cumulative Power Spectrum has just one value above 8.2. **Take a screenshot of the resulting sawtooth wave with the value of M in the title and the MATLAB code and submit it in your report.**



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Section 4: Windowing.

As has been seen, the number of terms (size of M) can be increased to improve the sawtooth accuracy. However, even with a large number of terms, there will be imperfections in the abrupt changes in the wave. Windowing will allow us to keep the number of terms down while improving the representation at the corners. There are numerous window functions, including rectangular, hanning and hamming to mention a few.

Complete the code below that will use the windowed cm values (cwin) to display the windowed sawtooth wave when M=31 (less than the number found in section 3).

```
init();
M = 31;
T = 2; % waveform period 2s
[m,cm] = create_cm_series(M,T); % create Fourier coefficients


t = 0:4/1000:4; % 1001 points from 0 sec to 4 sec

% original sawtooth
[y] = cm2yt(t,T,m,cm,M);
make_plot(t,y,'Sawtooth (original version)','t sec','y');

% windowed sawtooth
win = hamming(2*M+1)'; %Hamming window
cwin = cm.*win;    %Windowed Fourier coefficients
[ywin] = cm2yt(t,T,m,________);  % <---- Complete this line
make_plot(t,ywin,'Windowed sawtooth','t sec','y');
```

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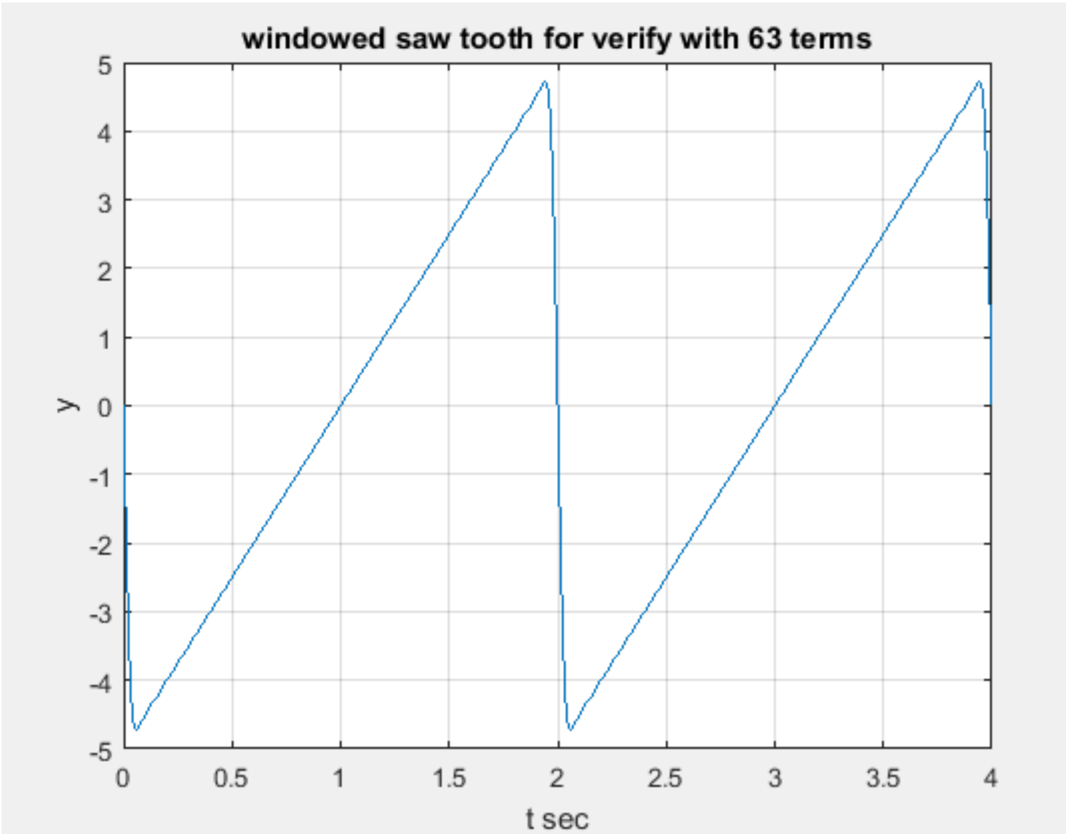

Take a screenshot of the original and windowed sawtooth waves along with the MATLAB code and submit it in your report.

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Report:

Create your own cover page.

Submit your cover page, the requested screenshots (sections 3 and 4), and this sign-off sheet.

Sign-offs

Name ______________________

Section 1: Table 1and plot of the sawtooth using 9 terms

______________________	/ /
Signature	Date

Section 2: Sawtooth wave using 127 terms

______________________	/ /
Signature	Date