Fall 2021 EE 313 Linear Systems and Signals Prof. Evans

Homework #2 Fourier Series

Assigned on Sunday, September 5, 2021
Due on Friday, September 10, 2021, by 11:59 pm via Canvas submission

Late homework is subject to a penalty of two points per minute late.

Reading: McClellan, Schafer and Yoder, *Signal Processing First*, 2003, Ch. 3. Errata.
Companion Web site with demos and other supplemental information: http://dspfirst.gatech.edu/
Web site contains solutions to selected homework problems from *DSP First*.

E-mail address for Mr. Faris Tabbara (TA) is firas.tabbara@utexas.edu. Lecture hours and office hours for Mr. Tabbara and Prof. Evans on Zoom (see links on the Canvas calendar) follow:

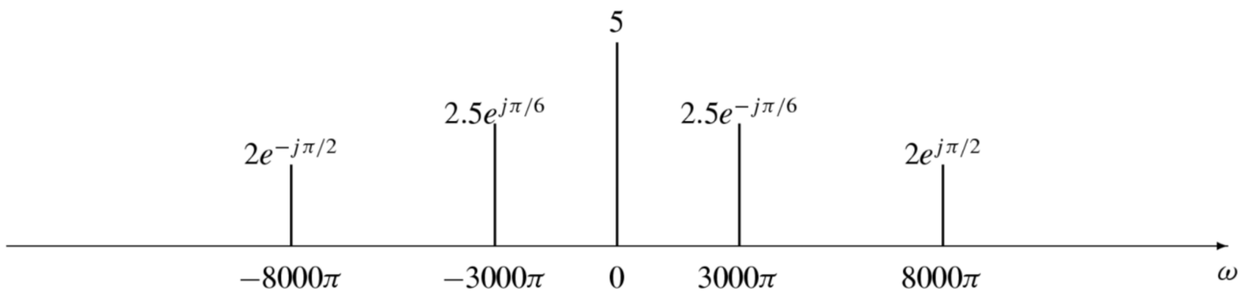
Time Slot	***Monday***	***Tuesday***	***Wednesday***	***Thursday***	***Friday***
9:30 am				Evans (Zoom)	
10:00 am				Evans (Zoom)	
10:30 am					
11:00 am		Evans (EER 1.516)		Evans (EER 1.516)	
11:30 am		Evans (EER 1.516)		Evans (EER 1.516)	
12:00 pm		Evans (EER 1.516)		Evans (EER 1.516)	
12:30 pm		Evans (Zoom)			
1:00 pm		Evans (Zoom)			
1:30 pm					
2:00 pm					Evans (Zoom)
2:30 pm					Evans (Zoom)
3:00 pm					Tabbara (Zoom)
3:30 pm			Tabbara (Zoom)		Tabbara (Zoom)
4:00 pm			Tabbara (Zoom)		Tabbara (Zoom)
4:30 pm			Tabbara (Zoom)		

As stated on the course descriptor, "Discussion of homework questions is encouraged. Please be sure to submit your own independent homework solution."

In your solutions, please put all work for problem 1 together, then all work for problem 2 together, etc. Please see the guidelines for writing your solutions on the homework page.

1. Fourier Synthesis. 25 points.

Signal Processing First, problem P-3.2, page 65, but use the following spectrum:



2. Amplitude Modulation. 24 points.

In AM radio, the transmitted signal (voice or music) is modulated by a sinusoid at the assigned broadcast frequency of the AM station. For example, the Zone Austin Sports Talk in Austin has a carrier frequency f_c of 1300 kHz. For example, if $x(t)$ is the voice/music signal, then the transmitted signal would be:

$$y(t) = (x(t) + A)\cos(2\,\pi\, f_c\, t)$$

where A is a constant. (A is introduced to make the AM receiver design easier, in which case A must be chosen to be larger than the maximum value of $v(t)$.) Suppose that the signal that is to be transmitted is

$$x(t) = 3\cos(2000\pi t + \pi/4) + \cos(4000\pi t + \pi/2)$$

Draw the spectrum for $y(t)$ assuming a carrier frequency of 1300 kHz with $A = 2$. Hint: Substitute for $x(t)$ and expand $y(t)$ into a sum of cosine terms of three different frequencies.

3. Chirp Signal. 27 points.

This problem analyzes the chirp signal, which is used in sonar and radar systems, indoor positioning, test and measurement, and 4G cellular communications. The chirp signal is a sinusoid whose principal frequency content increases (or decreases) over time. A chirp signal has the form

$$c(t) = \cos(\,\theta(t)\,) \quad \text{where } \theta(t) = 2\,\pi\,(\,f_0 + \tfrac{1}{2} f_{step}\, t\,)\, t = 2\,\pi\, f_0\, t + \pi\, f_{step}\, t^2$$

The principal frequency is f_0 when $t = 0$ and then changes over time at a rate of f_{step} in units of Hz/s. The principal frequency of a sinusoid at a given point in time is called the *instantaneous frequency*, and it is defined as $d\theta(t)\,/\,dt$ in units of rad/s. Here, $d\theta(t)\,/\,dt = 2\,\pi\, f_0 + 2\,\pi\, f_{step}\, t = 2\,\pi\,(f_0 + f_{step}\, t)$.

(a) Generate a chirp signal that lasts 10s with $f_0 = 20$ Hz and $f_{step} = 420$ Hz/s. Use sampling rate f_s of 44100 Hz. The chirp will sweep through the frequencies of the keys on an 88-key piano: https://en.wikipedia.org/wiki/Piano_key_frequencies. Here is Matlab code to help get started:

```
%%% Generate a chirp signal with frequency increasing
%%% from f0 to (f0 + fstep time) over time seconds
time = 10;
f0 = 20;
fstep = 420;
```

```
fs = 44100;
Ts = 1 / fs;
t = 0 : Ts : time;
%%% Add code here to define the chirp signal y = cos( angle(t) )
```

(b) Play the chirp signal as an audio signal. Describe what you hear. The Matlab command is

```
sound(y, fs);
```

(c) Plot the spectrogram of the chirp signal using the `spectrogram` function in Matlab and describe the visual representation. Here's Matlab code to get started:

```
figure;
spectrogram(y, hamming(256), 128, 256, fs, 'yaxis');
```

Provide all the Matlab code that you used in solving this problem.

4. Audio Effects. 24 points.

Consider the signal $x(t) = \cos(2\,\pi\, f_0\, t)$ where $f_0 = 440$ Hz which an 'A' note on the Western scale.

Write MATLAB code to implement the following audio effects. Play each audio signal over $0 \le t \le 5$ and use a sampling rate of 8000 Hz:

(a) $y(t) = |\, x(t)\, |$

(b) $y(t) = x^2(t)$

(c) $y(t) = x^4(t)$

(d) $y(t) = \cos(\pi\, x(t))$

For each part, give a mathematical analysis to determine what frequencies are present in $y(t)$ and play $y(t)$ as an audio signal and describe what you hear vs. $x(t)$.

Note that in parts (a), (b) and (c), $y(t)$ will have a DC value. You can either remove the DC value from $y(t)$ and play the resulting signal with the `sound` command, or simply play $y(t)$ using the `soundsc` command. To remove the DC (average) value from vector `sig` in MATLAB, use `sig - mean(sig)`.

Please submit the MATLAB code that you have written.