

HW 2 — Due: September 3, 12:59 PM (in class)

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Instructions

- (a) ONE part of a question will be graded (5 pt). Of course, you do not know which part will be selected; so you should work on all of them.
- (b) It is important that you try to solve all problems. (5 pt)
- (c) Late submission will be heavily penalized.
- (d) Write down all the steps that you have done to obtain your answers. You may not get full credit even when your answer is correct without showing how you get your answer.
- (e) For questions that require the use of MATLAB,
 - (i) the codes used should be printed,
 - (ii) if the code is based on some provided code, all modified lines should be highlighted or underlined,
 - (iii) the results displayed in the command window should be captured and printed out as well.

Problem 1.

- (a) Plot (by hand) the *amplitude spectrum* of the signal $x(t) = \begin{cases} 1, & -4 < t < 4, \\ 0, & \text{otherwise.} \end{cases}$
- (b) Plot (by hand) the *amplitude spectrum* of the signal $x(t) = \begin{cases} 2, & -2 < t < 2, \\ 0, & \text{otherwise.} \end{cases}$
- (c) Plot (by hand) the *amplitude spectrum* of the signal $x(t) = \begin{cases} 2, & -3 < t < 1, \\ 0, & \text{otherwise.} \end{cases}$

Problem 2. ¹ Using MATLAB to find the (amplitude) spectrum² of a signal:

A signal $g(t)$ can often be expressed in analytical form as a function of time t , and the Fourier transform is defined as the integral of $g(t) \exp(-j2\pi ft)$. Often however, there is no analytical expression for a signal, that is, there is no (known) equation that represents the value of the signal over time. Instead, the signal is defined by measurements of some physical process. For instance, the signal might be the waveform at the input to the receiver, the output of a linear filter, or a sound waveform encoded as an mp3 file.

In all these cases, it is not possible to find the spectrum by analytically performing a Fourier transform. Rather, the discrete Fourier transform (or DFT, and its cousin, the more rapidly computable fast Fourier transform, or FFT) can be used to find the spectrum or frequency content of a measured signal. The MATLAB function `plotspect.m`, which plots the spectrum of a signal can be downloaded from our course website. Its help portion³ notes

```
% plotspect(x,t) plots the spectrum of the signal x
% whose values are sampled at time (in seconds) specified in t
```

- (a) The function `plotspect.m` is easy to use. For instance, the spectrum of a rectangular pulse⁴ $g(t) = 1[0 \leq t \leq 2]$ can be found using:

```
% spectrect.m plot the spectrum of a square wave
close all
Ts=1/100;           % time interval between adjacent samples
t=0:Ts:20;         % create a time vector
x=[t <= 2];        % rectangular pulse 1[0 ≤ t ≤ 2]
plotspect(x,t)     % call plotspect to draw spectrum
xlim([-5,5])       % look only from f = -5 to f = 5 Hz
```

The output of `spectrect.m` is shown in Figure 2.1. The top plot shows the first 20 seconds of $g(t)$. The bottom plot shows $|G(f)|$.

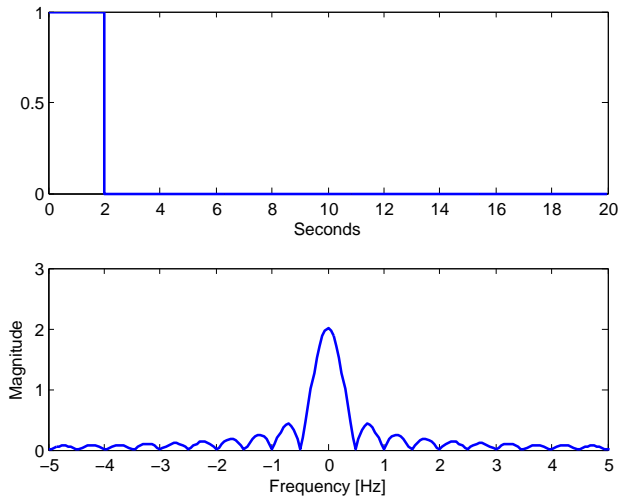
¹Based on [Johnson, Sethares, and Klein, 2011, Sec 3.1 and Q3.3].

²also referred to by “amplitude spectrum” or simply “spectrum”

³You can view the “help” portion for a MATLAB function `xxx` by typing `help xxx` at the MATLAB prompt. If you get an error such as `xxx not found`, then this means either that the function does not exist, or that it needs to be moved into MATLAB’s search path.

⁴Here, we define a rectangular pulse using the indicator function $1[\cdot]$. This function outputs a 1 when the statement inside the square brackets is true; otherwise, it outputs a 0. For example,

$$1[0 \leq t \leq 2] = \begin{cases} 1, & 0 \leq t \leq 2, \\ 0, & \text{otherwise.} \end{cases}$$

Figure 2.1: Plots from `specrect.m`

- (i) Use what we studied in class about the Fourier transform of a rectangular pulse (and the time-shift property) to find a simplified expression for $|G(f)|$.
 - (ii) Plot your analytical expression derived in ~~the previous~~ part. Did your plot agree with the bottom plot in Figure 2.1? (i)
- (b) Now consider an exponential pulse

$$s(t) = e^{-t}u(t).$$

- (i) Modify the code in `specrect.m` to show the (magnitude) spectrum $|S(f)|$.
- (ii) Find $S(f)$ and $|S(f)|$ analytically. (Hopefully, you still remember how to integrate exponential function.)
- (iii) Compare the plot of your analytical expression in part (ii) with the plot in part (i).
- (iv) MATLAB can also perform symbolic manipulation when symbolic toolbox is installed. It can find the Fourier transform of a symbolic expression via the command `fourier`. Unfortunately, the `fourier` command uses the ω -version of the definition. So, to convert the answer to the f -version, we also need to substitute $\omega = 2\pi f$. This is done automatically in our provided function `fourierf`. Run the file `SymbFourier.m`. Check whether you have the same result as part (ii).

Problem 3.

(a) Suppose the Fourier transform of a signal $x(t)$ is given by

$$X(f) = \text{sinc}(5\pi f) = \frac{\sin(5\pi f)}{(5\pi f)}.$$

(i) Plot (by hand) $x(t)$.

(ii) Find $\int_{-\infty}^{\infty} X(f)df$. (Hint: This integration is exactly the inverse Fourier transform formula with $t = 0$.)

(b) Suppose the Fourier transform of a signal $y(t)$ is given by

$$Y(f) = \text{sinc}^2(5\pi f) = \left(\frac{\sin(5\pi f)}{(5\pi f)} \right)^2.$$

(i) Plot (by hand) $y(t)$.

(ii) Find $\int_{-\infty}^{\infty} Y(f)df$.

Problem 4. The Fourier transform of the triangular pulse $g(t)$ in Figure 2.2a is given as

$$G(f) = \frac{1}{(2\pi f)^2} (e^{j2\pi f} - j2\pi f e^{j2\pi f} - 1)$$

Using this information, and the time-shifting and time-scaling properties, find the Fourier transforms of the signals shown in Figure 2.2b, c, d, e, and f.

Remark: Don't forget to simplify your answers. For example, the answer in part (d) should be of the form $\text{sinc}^2(\cdot)$ and the answer in part (e) should be of the form $\text{sinc}(\cdot)$

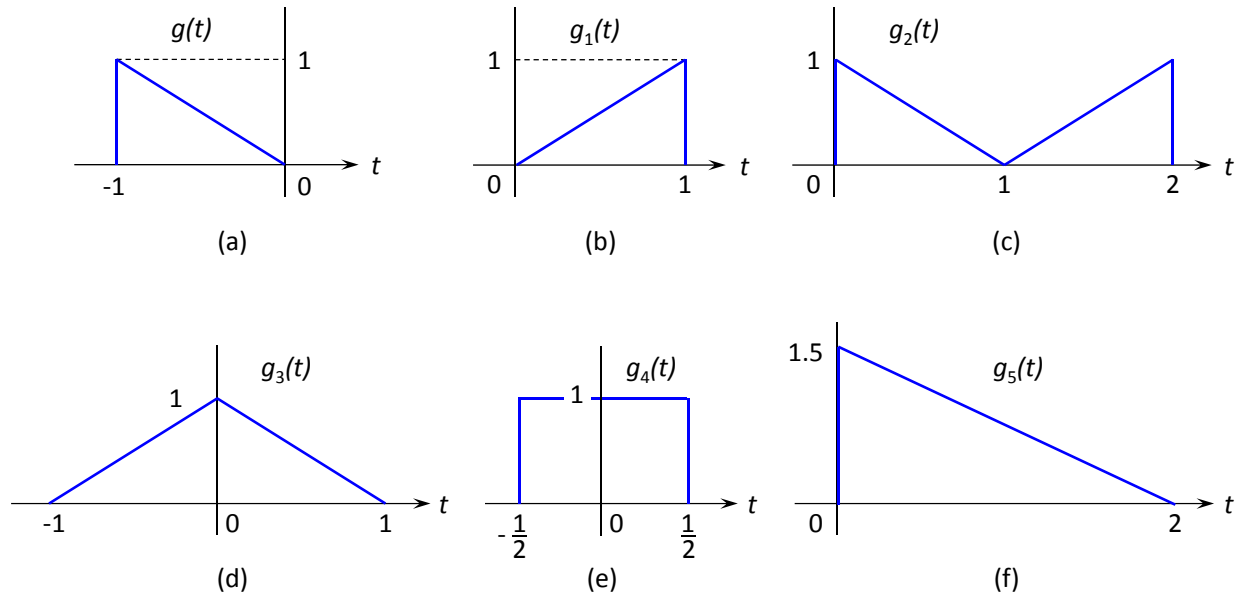


Figure 2.2: Problem 4

Extra Question

Here is an optional question for those who want more practice.

Problem 5. Listen to the Fourier's Song (Fouriers_Song.mp3) which can be downloaded from

<http://sethares.engr.wisc.edu/mp3s/fourier.html>

Which properties of the Fourier Transform can you recognize from the song? List them here.