ROSE-HULMAN INSTITUTE OF TECHNOLOGY
Department of Electrical and Computer Engineering

Basic Signal Spectra

Lab 6

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Objectives

- To become familiar with the signal spectrum as a means to represent and analyze signals
- To become acquainted with the various tools available for viewing the signal spectrum.

Equipment

Agilent 4402B Spectrum Analyzer
Agilent Function Generator
Oscilloscope
BNC T-Connector

Background

In the previous lab, we learned to view the Fourier Series representation of a signal in the frequency domain using a spectrum analyzer. We called this display of signal power vs frequency the *power spectrum* of the signal. There are several tools available for viewing the *spectrum* of the signal, which is what we call the display of signal voltage magnitude (*magnitude spectrum*) or phase (*phase spectrum*) versus frequency. In this lab, we will combine several of these tools to confirm our understanding of what a signal spectrum tells us about a signal.

The FFT, or Fast Fourier Transform, is an estimate of the signal spectrum computed using an algorithm based on the concept of the Fourier Series. Technically, the FFT is not the same as the Fourier Transform. Often, however, we accept the fft output as a display of the signal's true spectrum, although care must be taken that the fft algorithm is set up properly and that it displays results in the units we expect. Since those details will be covered in ECE 380, we will focus today on the use of the fft as a means of displaying the signal spectrum, and not worry so much about the finer points of its calculation and interpretation.

Recall that the "power spectrum" of a periodic signal was found by creating a *two-sided spectrum* with the "height" of each spectral component equal to the square of the corresponding a_k. A *one-sided spectrum* was then created by displaying only DC and positive frequencies, and doubling the power of each positive frequency component (i.e. $2|a_k|^2$). The same can be done using the FFT of a signal. We will be focusing on one-sided spectra throughout this lab.

There is no Prelab for this Lab

Procedure

Visualizing Signal Spectra

1. Calculate the Fourier series coefficients $a_k,\ k = 0, \pm 1, \pm 2, \ldots, \pm 9$ for the signal $x_1(t) = 0.2\cos\left(2\pi 1\times 10^6 t\right)$ V. Draw the one-sided *power spectrum* for this signal, properly labeled and with correct units indicated. The “height” or level of each spectral component (line) should be given in both Watts and dBmV.

2. Using one of the function generators, produce the signal $x_1(t)$. Display this signal on the oscilloscope and discuss how “perfect” this sinusoidal waveform is – e.g. are there any features of the waveform which deviate from that expected for a sinusoid. Include your display data and comments in your lab notebook. (Be sure to verify that the signal has proper amplitude, offset, and frequency.)

3. Display the signal spectrum for the signal $x_1(t)$ on the spectrum analyzer. Sketch the spectrum in your lab notebook and compare your results to those predicted in the by hand analysis. Are there any deviations from what you expect? (Try setting the reference level to 30 dBmV and the displayed frequency span to 2-3 MHz.)
   a. If there are deviations, of what power level are they (in dBmVs)?
   b. Explain the presence of these anomalous spectral features.
   c. Would you consider the deviations “harmonics”? Explain.

4. Now, vary the amplitude and frequency of $x_1(t)$, noting the changes in the spectrum in your lab notebook. Use precise and accurate language to describe what you see. A picture of how to visualize the spectrum of a simple sinusoid should be growing in your mind.

Using the MATLAB FFT Tools to View Signal Spectra

5. Write a Matlab script to use the provided MATLAB function `baf_fft.m` to display the *two-sided magnitude spectrum* of $x_1(t)$. View the comment lines in the m-file to understand the correct usage of the function. Simulate the waveform $x_1(t)$ for 16 periods using 32 samples per period.

6. Write a MATLAB function to display a *one-sided power spectrum* given the two-sided spectrum calculated by the `baf_fft.m` function. The level of the terms should be expressed in dBmV. Include a call to this function in the script you produced in Step 5. Compare these results to what you measured from the spectrum analyzer in Step 2. Produce a display of the signal power spectrum and include it in your notebook.

Using the Oscilloscope FFT Tool to View Signal Spectra

7. Use the oscilloscope’s built-in fft capability to examine the signal spectrum. Include a screen capture of the spectral display in your lab notebook, specifically indicating that the results match those obtained using the other methods in the previous steps. Note that this display is not a power spectrum, but rather is a one-sided magnitude spectrum.
   a. Display the signal on Channel 1, and press “autoscale” to produce a convenient display. All other channel displays should be off.

b. Press the "math" button beside the Channel 1 button. This gives access to various math functions available built-in to the scope. Select "FFT" to activate the scope's built-in FFT feature.

c. When you press the FFT button, a second curve will appear on the display. It will not be recognizable because the FFT settings are not yet optimized for our signal. Press the "Settings" button to change the FFT display. Set the span to 5 MHz. This is the range of frequencies which will be displayed on the screen. Set the center frequency to 2.5 MHz. This defines the frequency of the center of the screen. Given this information, you should be able to determine the frequencies of any spectral component on the screen.

d. Next, adjust the display to be able to read the dBV level of the signal. Set the scale to10 dB/div (vertical). The 0 dBV reference level is the center horizontal line of the screen. (note the change in units!) The offset moves the signal spectrum up or down relative to the reference level. If the offset is adjusted so that the peak of the spectral component of interests touches the reference level line, the offset value is equal to the spectral component level in dBV (think about this…).

e. The final setting to be adjusted is the sampling rate. This is set by turning the horizontal (time) display knob. Turn the horizontal display knob until the sampling rate is 10 Msamples/sec. (You may have to readjust the center frequency and span after adjusting the sample rate.) The time display of the waveform may be less recognizable as a sinusoid, but the spectrum is correctly displayed.

8. Verify that the proper spectral components (frequencies and levels) as predicted by your MATLAB magnitude spectrum are present on the FFT display. How do the magnitudes of the spectral components compare with those predicted by MATLAB? Be sure to show consistency between all of your results.

9. Questions for reflection: (Record your responses in your lab notebook. Your response should be of reasonable length and complexity.)

   a. What would you expect the spectrum of the signal $x_2(t)$ to be?

   $$x_2(t) = 0.2\cos\left(2\pi 0.5\times10^6 t\right) + 0.1\cos\left(2\pi 1\times10^6 t\right)\text{V}$$

   b. Interpret your results from the Fourier Coefficients lab in terms of what you learned today. Specifically, how can you use what you learned about the spectrum of a sinusoid to explain the spectrum of a periodic signal?

   c. How should the spectrum of an aperiodic signal compare to that for a periodic signal?

Report

In your lab notebook present your theoretical results, measured results, comparisons, comments, and answers to the questions posed above. Be sure that all members of your lab group sign the lab notebook, and hand the notebook in at the end of lab.