EECE 2150 - Circuits and Signals: Biomedical Applications

Lab 4

Basics of Signals: Frequency

Introduction:

In this lab we will begin exploring signals. We will learn more about signals, both formally and in other labs, as we go along, and of course we will record and process ECG signals before we are done, but in this lab we ask you to experiment with certain types of signals to build some intuition before we hit you over the head with the theory!

In electrical and computer engineering, signals are most often voltages or currents, but they might also be sound (pressure), force, position, temperature, power, light intensity, chemical concentration, stress or any number of other variables. Electrical engineers use many kinds of sensors to measure signals and transducers to convert signals from other domains to voltage and current or from voltage and current to other domains.

The first part of this lab asks you to experiment with the oscilloscope to view voltage signals that vary rapidly in time. You will use the oscilloscope to look at the shape, amplitude, and period of some typical signal waveforms as a function of time (or in the time domain, as ECEs sometimes say). You will also experiment with how these signals sound.

Next, you will continue to use Spice to analyze circuits. You will be looking at a circuit with a periodic, time varying signal, rather than at a DC circuit. You will do what is called a “Fourier analysis” in Spice, which runs a program that analyzes and plots different frequency “components” that can be used to synthesize almost all useful (in an engineering sense) periodic signals.

In a future HWs and labs you will use MATLAB to generate sounds and explore the frequency content of sounds you record.

Part I - Frequency

1. In this part of the experiment you will use a function generator to drive an audio speaker. The function generator that is on your workbench can produce a sinusoidal waveform, a square wave or a ramp wave, as well as achieve various other effects.

    a. First, set the function generator to produce a sinusoidal signal at a frequency of 600 Hz with a 0.10 volt peak-to-peak amplitude (remember that you will have to set the signal generator for 0.05 volts p-p because of its default settings, or change the default settings). Observe the function generator output waveform on the oscilloscope by connecting them using a BNC cable. Determine the frequency of the waveform using the oscilloscope. How well do the oscilloscope and the signal generator agree?

    b. Use the BNC "T" to connect the function generator output signal to both the oscilloscope and to the input of the computer speaker (you will need to figure out which part of the plug to connect it to!). **Q1 (a):** What happens to the sound when you change the amplitude of the signal coming from the signal generator? **(b):** What happens to the sound when you change the frequency of the signal coming from the signal generator?

2. Determine approximate upper and lower frequency limits of the speaker/human ear system. **Q2:** What is the highest frequency that you can hear? Do all members of your team have comparable low and high frequency limits on what they can hear? The commonly quoted limits of human hearing are 20 Hz to 20 kHz (see Figure 1 below for some typical data on this). Can you get close to those values? If not, any idea why not? How does the apparent loudness of the sound change as you change frequencies? Which frequencies sound loudest? Why do you think this is? Are your results explained adequately by the sensitivity of the human ear, or does the speaker have something to do with it? **(Note there are 8 parts to this question, answer all of them!)**

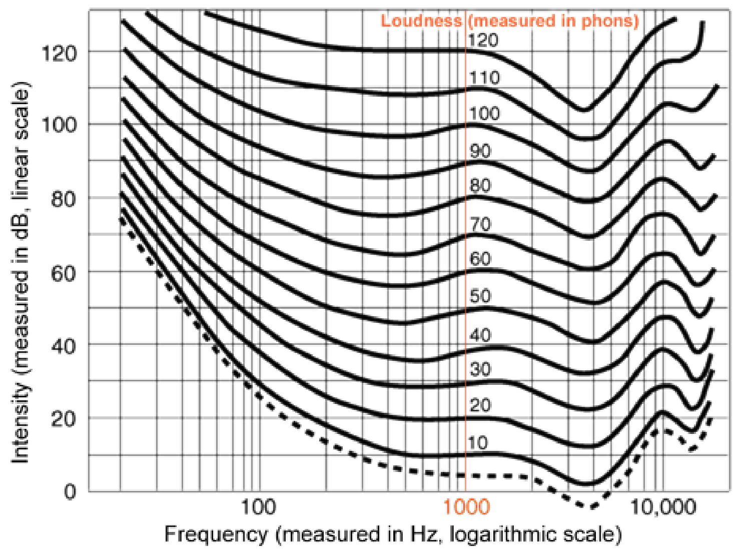


Figure 1. Human hearing sensitivity. This is a plot of the sound intensity required to reach a given perceived loudness as a function of frequency. This is known as the Fletcher-Munson curve. Note that the horizontal axis shows frequency on a logarithmic scale (100 to 1000 is the same distance as 1000 to 10000) The vertical axis shows actual sound intensity using a unit called decibels, abbreviated dB, which you will learn more about soon enough. Decibels are themselves a logarithmic unit, so although the axis here is linear in dB, it is in effect logarithmic in actual intensity. Also dB is always a <u>relative</u> unit, computed with respect to a reference. These units here is probably what is called Sound Pressure Level, abbreviated SPL, for which the reference is a sound taken to be at the low threshold of hearing. Finally, the different curves show different <u>perceptual</u> levels, measured in a unit called <u>phons</u> that is calibrated to compensate for the frequency sensitivity of the human ear. The perception level of a sound is technically called "loudness", to distinguish it from the physical intensity of the sound waveform. Phons are also measured in SPL. Thus each curve shows the difference in intensity, in dB, to keep the sound <u>perception</u> constant, at a given constant loundness. Complicated!

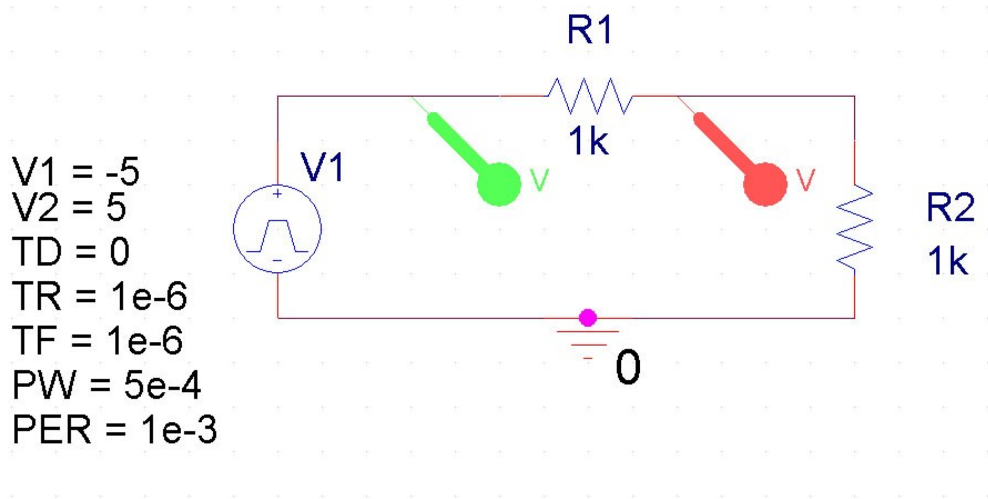
3. For this part, you will work with another nearby group. Have one team drive a speaker with a sinusoidal waveform at a frequency between 500 Hz and 2 kHz. Without knowing the frequency, the second group should try to match its frequency to the first group's frequency by ear. **Q3:** How closely can you match up the tones using your ears? Record your quantitative results, that is, how close you got to matching frequencies, and describe how you got the frequency to match as closely as you could.

6. Change the frequency back to 600 Hz. Compare the sounds emitted by your speaker when the driving signal is a sine wave versus a square wave versus a ramp wave. Describe how the waveforms sound different in addition to whether they sound louder or softer. **Q4:** Why do you think the waveforms sound different? Discuss this with the instructors.

7. Repeat 6 at 6 kHz. **Q5:** What differences do you hear this time? **Q6:** Why do you think this result is different that the one at 600 Hz? (There is an EE/Bio explanation!!). Again discuss with your classmates and instructors.

Part 2, Spice, transient and Fourier analysis

1. Build the following circuit. Use VPULSE in the source library.



2. Do a transient analysis over 5 cycles of the waveform. Use a frequency of 1000 Hz (period = 1ms). **Q7:** What analysis time corresponds to 5 cycles of the input? The voltage across R1 as a function of time should be plotted if you use the differential voltage probes as above. When you are looking at the plot, click the FFT (which stands for Fast Fourier Transform, we will discuss this more later) button to view the frequency components of the signal. It turns out that any periodic signal other than a sine wave has frequencies at multiples of the lowest non-zero frequency, which is called the "fundamental frequency". The FFT takes the signal in the simulation and calculates and plots the frequency components that are present. Take a screen shot of the plot so that you can compare it with what you get in step 3 and put it into your notebook. Hit the FFT button again to go back to the time-domain view of the signal.

3. Repeat the analysis after changing the pulse width (PW) to 0.05 ms. **Q8:** What is different in the frequency components plot?

4. Change the source to a sinusoid at the same frequency and repeat. Use VSIN as the source with a 5 V amplitude and set AC=0.

5. Think about and discuss what all this means!! Discuss how this information corresponds to what you heard in the lab. You will learn more about this in this course and over the next few years!!!!

6. If you have time, Change R1 to a 1 microFarad capacitor and repeat #2 above, with the square wave source. Compare the Fourier components of the source and the capacitor. This is a simple filter circuit, that you will learn more about later in the semester.

Part 3 – Instructions For the Lab Reflection

DiMarzio Section Only: There is no written assignment for this lab. Answer questions in your notebook and make sure the page is signed.

The lab reflection for this lab is due as per the instructions on Blackboard.

IMPORTANT: BEFORE YOU LEAVE THE LAB:

(a) **Turn off all of the equipment you have used on your workbench.**

(b) **Make sure you return your protoboard, the equipment wires and your reusable container to the front window.**

(c) **Make sure to have your notebook signed by an instructor before you leave the lab.**

Department of Electrical Engineering, Northeastern University. 85 minutes.
Last updated: 9/20/16, D. Brooks, 9/20/16, N. McGruerr; 9/10/12, D. Erdogmus and N. McGruer