

EECE 2150 - Circuits and Signals: Biomedical Applications  
Lab 4, Basics of Signals: Frequency

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## Introduction

In this lab we will begin exploring signals. 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 and transducers to convert signals from other domains to voltage and current or from voltage and current to other domains. The first part of the lab asks you to experiment with the oscilloscope that you can use to view 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 LTSpice 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 a Fourier analysis in LTSpice, which will give you the frequency components making up the periodic signal.

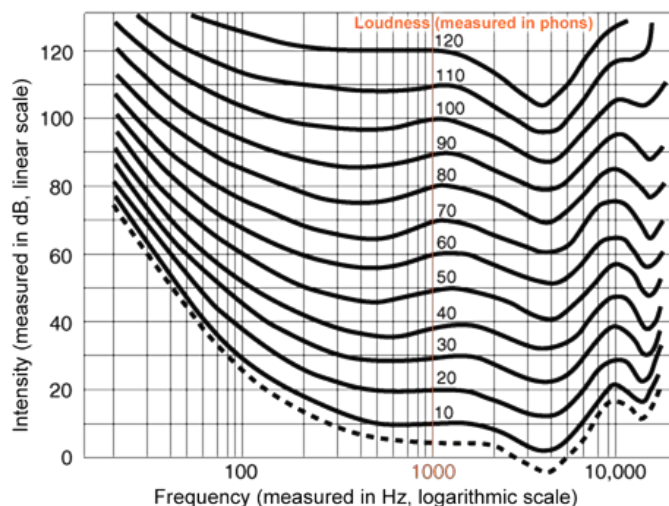
In a future lab you will use MATLAB to generate sounds and explore the frequency content of sounds you record.

## Part I - Frequency

1.1. In this part of the experiment, you will use a function generator (sometimes called a waveform generator) to drive an audio speaker. The waveform generator that is on your workbench can produce a sinusoidal waveform, a square wave, or a ramp wave.

- a. First, set the function generator to produce a sinusoidal signal at a frequency of  $600\text{ Hz}$  with a  $0.10\text{ volt}$  peak-to-peak amplitude. Make sure the function generator is set to High Z mode. To set it to the high Z mode, press the function key 'Setup' next to the channel number key, then press the soft key, 'Output Load', then press the soft key, 'High Z' to change to High Z mode. 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 (figure out which part of the plug to connect it to!). You can also use the speaker provided in your cables/connectors box. What happens when you change the amplitude of the signal coming from the signal generator? What happens when you change the frequency of the signal coming from the signal generator?

1.2. Determine the upper and lower frequency limits of the speaker/human ear system. 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  $20\text{ Hz}$  to  $20\text{ kHz}$ . 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 entirely by the sensitivity of the human ear, or does the speaker have something to do with it?

*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.*

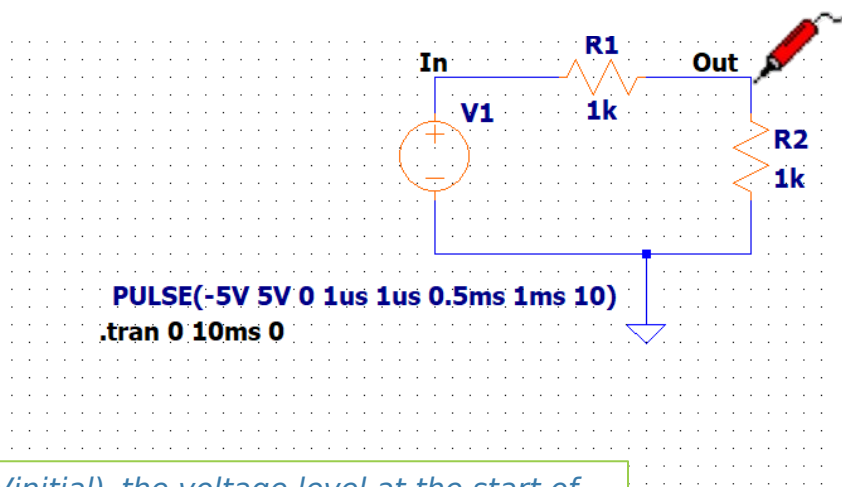
1.3. For this part, you will work with another group at a nearby work bench. Have one team drive a speaker with a sinusoidal waveform at a frequency between 500 Hz and 2 kHz. Without knowing the frequency, the second group should try to match its frequency to the first group's frequency by ear. How closely 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 match as close as you could.

1.4. Change the frequency back to 600 Hz. Compare the sounds emitted by your speaker when the driving signal with 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. Why do the waveforms sound different? Discuss this with the instructors.

1.5. Repeat part 1.4 at 6 kHz. What differences do you hear this time? Why is this result different? (There is an EE/Bio explanation!!). Again, discuss with your classmates and instructors.

## Part 2, LTSpice, transient and Fourier analysis

2.1. Build the following circuit. Use a PULSE source.



$V_1$  ( $V_{initial}$ ) the voltage level at the start of the pulse

$V_2$  ( $V_{on}$ ) the voltage level at the peak of the pulse

$T_{delay}$  the time delay before the start of the pulse

$T_{rise}$  the pulse rise time

$T_{fall}$  the pulse fall time

$T_{on}$  the pulse width at peak

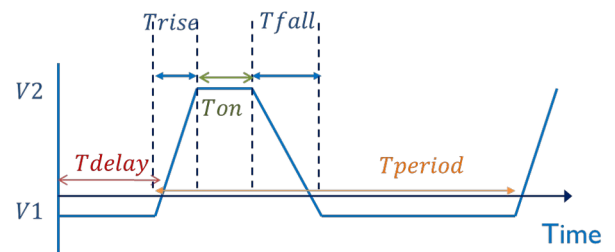
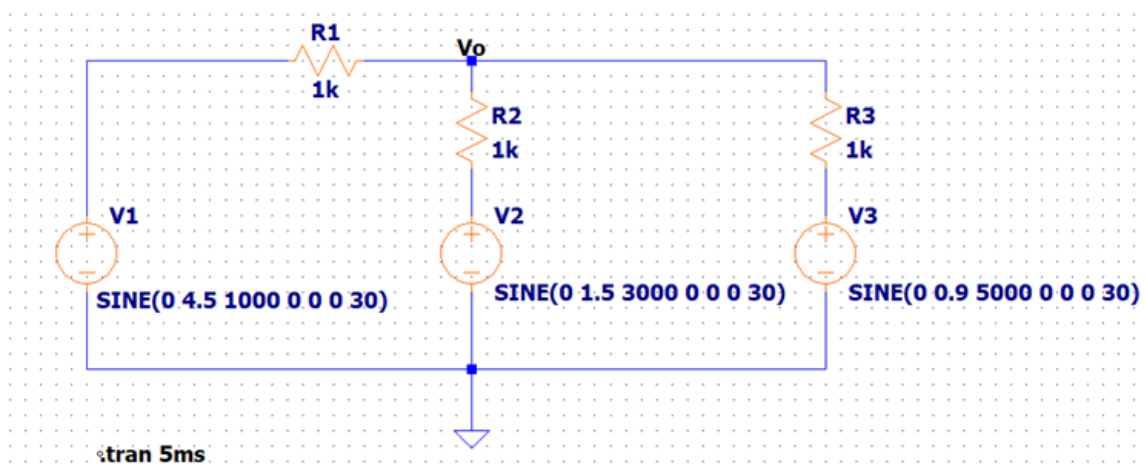


Figure 2. Circuit for part 2.1 and description of the PULSE source in LTSpice

2.2. Perform a transient analysis. Plot the voltage across  $R_2$  as a function of time. You can plot the voltage across  $R_1$  using a pair of differential probes. Click on one end of the resistor,  $R_1$ , when the red voltage probe appears, hold, and drag to the other end of the resistor, another black probe will appear, click to display the voltage difference between the two ends. Use a frequency of  $1000\text{ Hz}$  (period  $1\text{ ms}$ ). The analysis time for 10 cycles of the input waveform is  $10\text{ ms}$ . Select the waveform viewer window and click on View>FFT to display the Fast Fourier transform, FFT (frequency components) of the output signal. When the FFT is displayed, right click on the horizontal frequency axis, uncheck the logarithmic scale option, adjust the axis limits to have a start frequency of  $0\text{ Hz}$ , end frequency of  $30\text{ KHz}$  and step of  $1\text{ KHz}$ . Adjust the vertical scale for the magnitude in dB of the output voltage so

that the top level is  $20\text{ dB}$ , the bottom level is  $-50\text{ dB}$  and the step is  $10\text{ dB}$ . Remember that any periodic signal other than a sine wave has frequencies at multiples of the fundamental frequency. The FFT (or fast Fourier transform) takes the signal in the simulation and shows you what frequency components are present (you hear these when listening to a square wave vs a sine wave, for example). Take a screen shot of the plot so that you can compare it with what you get in step 2.3.

- 2.3. Repeat the analysis after changing the pulse width, 'ON' time ( $T_{on}$ ) to  $0.05\text{ ms}$ . What is different in the frequency components plot? Use the same settings for the horizontal and vertical axis in the FFT display as in 2.2.
- 2.4. Change the source to a sinusoid at the same frequency and repeat 2.2. Use SINE source as the source with a  $5\text{ V}$  amplitude and set  $\text{DC}=0$ ,  $\text{frequency}=1000\text{ Hz}$ , display  $10\text{ cycles}$ , all other SINE source parameters are set to zero.
- 2.5. Think about and discuss what all this means!! Discuss how this corresponds to what you heard in the lab. You will learn more about this in this course and over the next few years!!!!
- 2.6. Now build the next circuit in Figure 3 and perform transient analysis as shown. The circuit has three sinusoidal voltage sources,  $V_1, V_2$  and  $V_3$  at a fundamental frequency of  $1\text{ KHz}$ , third and fifth harmonic of  $3\text{ KHz}$  and  $5\text{ KHz}$  respectively. The voltage at node  $V_o$  can be expressed as  $v_o(t) = \frac{1}{3}(v_1(t) + v_2(t) + v_3(t))$ . Observe the voltage  $v_o$  as a function of time and describe the waveform. You can confirm what was discussed in class that adding sinusoidal waveforms at integer multiples of the fundamental frequency with the proper amplitudes and phases creates periodic waveforms of different shapes. Select the waveform viewer window and click on View>FFT to display the Fast Fourier transform of the voltage  $v_o$ , FFT (frequency



components). Confirm that the frequency components of  $v_o$  are at the same

frequencies of the three sinusoidal sources,  $V_1$ ,  $V_2$  and  $V_3$  respectively. You can use the same settings for the FFT display as in 2.2

Figure 3. Circuit for part 2.6

- 2.7. Modify the amplitudes and phases of the sources  $V_1$ ,  $V_2$  and  $V_3$  as shown in Figure 4. Notice that source  $V_2$  now has an initial phase of  $180^\circ$ . Observe the voltage  $v_o$  as a function of time, describe the waveform and compare to the waveform in 2.6. Comparing the output waveforms in 2.6 and 2.7, can you draw any conclusions about the relationship between the amplitudes of the harmonics and the shape of the waveform?

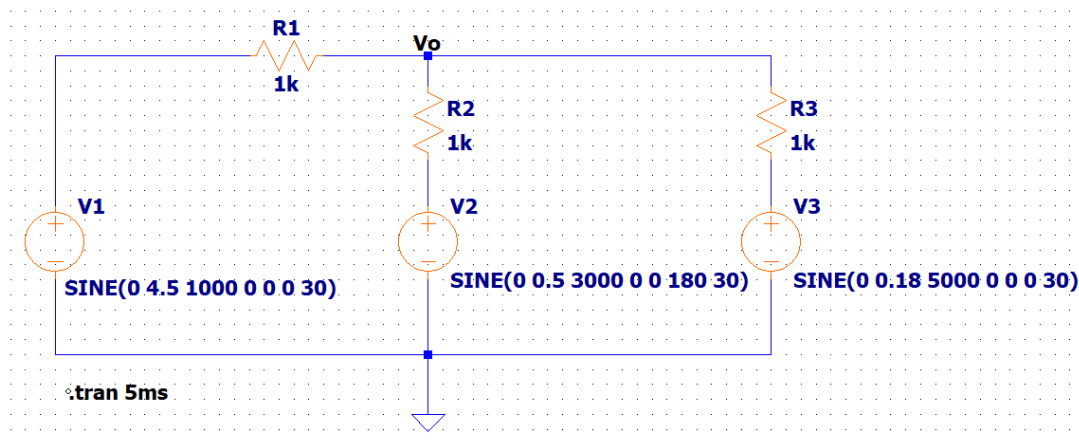


Figure 4. Circuit for part 2.7

- 2.8. If you have time, change  $R_2$  in Figure 2, part 2.1 to a 1 microFarad capacitor and repeat #2.2 above, with the square wave source. Compare the Fourier components of the input source voltage and the output voltage across the capacitor.

**IMPORTANT: BEFORE YOU LEAVE THE LAB:**

- a. Turn off all 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.

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Last updated: 9/19/2023, Iman Salama, 1/25/16, N. McGruerr; 9/10/12, D. Erdogmus and N. McGruer