Assignment # 2
ENGN/PHYS 207—Fall 2022
Two Roads Diverged on a Breadboard: Series-Parallel Audio Volume Control

Real World Circuits You'll Build

1. Audio volume control

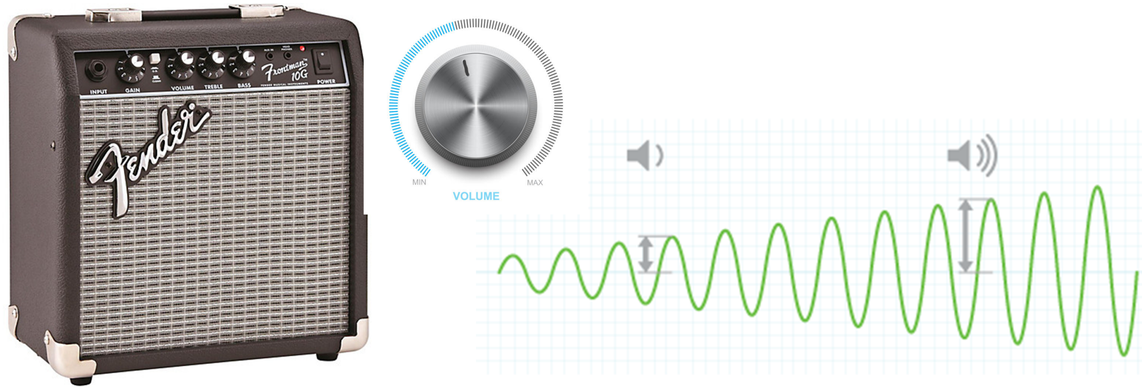

Figure 1: Classic Fender guitar amp. We'll build a sophisticated volume control. Image credits: Apple sound, Fender

Lab Skills You'll Learn

1. Series-parallel resistor applications
2. Voltage dividers in action (again!)

1 Audio Volume Control

Calling all the music lovers out there! Let's build an audio volume control circuit per Figure 1. How does it work in practice? Turn the knob one way volume goes up, turn it the other way, volume goes down. What exactly does that knob do? Could it be a potentiometer? After all, a changing resistance can lead a changing output voltage (volume), if properly connected in a circuit. You now have enough circuits knowledge under your belt to fully understand how this works!

Figure 2 shows the schematic of one high-quality audio volume control. Take note of the potentiometer: R_2 is quite literally the *piece de resistance*. (Be sure you can interpret the circuit diagram correctly...where are the 3 terminals of the pot connected?). The variable α specifies the position of the pot's wiper terminal—i.e. the percent rotation of the volume knob. A value of $\alpha = 1$ means that the wiper is turned all the way to the "top" of the circuit diagram; $\alpha = 0$ means all the way to the "bottom".

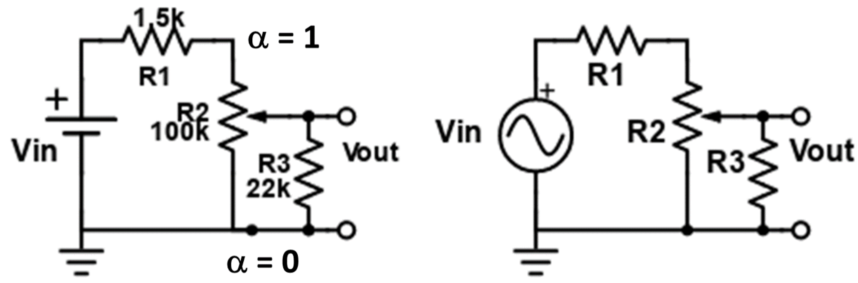

Figure 2: Audio volume control. Left: Volume control circuit for measuring V_{out}/V_{in} as a function of potentiometer rotation α. The resistor ratios are critical; the exact values are not (e.g. you could scale all values by a factor of 2). Note the dc power source. Right: Audio test-drive circuit, replacing dc power source with ac music source. Circuit design adapted from Elliott Sound Products: `https://sound-au.com/project01.htm`

Our typical pots in lab are the "linear" type, meaning the resistance measured between the wiper (central) contact and one of the outside contacts changes linearly with rotation:

$$R_{pot} = R_{min} + \alpha(R_{max} - R_{min}).$$

Here, the min and max refer to the pot's resistance dialed, respectively, to one extreme or the other (all the way CCW or CW). Typically the pot will turn through something like $\theta \approx$ 180-270 degrees total. So be sure to **take sufficient measurements using a protractor etc that will allow you to carefully calibrate and correlate the angle of rotation θ to variable** α. To help make this concrete, imagine the pot you pick up swings through 200 degrees total. In this case, $\alpha = 0.1$ when $\theta = 20$ deg and $\alpha = 0.5$ when $\theta = 100$ degrees, and so on.

One more important tidbit before you start building: This volume control circuit was designed such that V_{out}/V_{in} has an approximately exponential dependence on the pot position α, i.e. $V_{out}/V_{in} \approx e^{\alpha}$. The reason why is because the human ear perceives sound loudness on a logarithmic scale of sound wave intensity: $S \approx \log(V_{out}/V_{in})$. The net effect is that the sound intensity increases linearly with pot position—a very, very nice user feature (no touchy spots on the knob):

$$S \approx log(V_{out}/V_{in}) \approx log(e^{\alpha}) \approx \alpha$$

With that prelude, time to build, test, and analyze. On the agenda:

1. Theory I: Provide an intuitive explanation which way the pot should be turned for maximum volume. Think carefully about series-parallel combos of resistors as well as voltage division.
2. Theory II: Generate an expression for V_{out}/V_{in} in terms of α, R_1, R_2, and R_3.
3. Compute the expected value for V_{out}/V_{in} for $\alpha = 0, 0.1, 0.2, \ldots, 1$
4. Build the circuit. For now, set V_{in} to be a constant (dc) 3.3 or 5V source; your choice. Use the Arduino or your bench top BK precision brand power supply; your choice. Make measurements with the DMM or using your Arduino or both; your choice. (Notice a theme?). Measure V_{out}/V_{in} for $\approx$ 10 equally spaced pot positions (10 values for α). Suggestion: Compare empirical values to expected (theoretical) values as you go and do a quick sniff test: Are they in reasonable agreement?

5. Plot your empirical results for sound intensity level $\log(V_{out}/V_{in})$ versus. α Does the trend look reasonably linear? Remember: your ear/auditory cortex take the log to perceive sound intensity level.

6. Take your circuit for a real world audio test drive! Replace the dc power source with an (ac) audio source per Figure 2, right panel. Instead of measuring output with the DMM or MCU, we'll connect the output to an audio amplifier. Note that the audio amp "measures" V_{out} to play back the volume accordingly. Higher voltage out, the higher audio volume. Necessary wiring connections are illustrated in the "Audio Amp Connections" section (last 2 pages of this manual). Please ask the instructor or TAs for help making these connections, as needed. Enjoy the music!

2 What to Turn In

Audio Control

Submit a report with the following elements included. Your report **must not exceed 2 pages total**, including figures, tables, etc. You may include an extra page for an Appendix, if desired.

1. Brief description of what the system does. What is its intended usage in the real world? (1-2 sentences if fine)

2. Circuit schematic, appropriately labeled. Draw your own with Digikey's schemeit (or another app of your choice).

3. Briefly describe the working principles of the circuit. For example, how does turning the pot knob cause a change in measured output? Intuitively explain what happens when the pot knob is turned fully up or down.

4. Provide formula(e) for the input-output relation of the circuit $V_{out}/V_{in} = \ldots$. Derivation details belong in an appendix

5. Make a beautiful graphic ***using MATLAB*** that illustrates your results compared to theory. Specifically, your graphic should include a curve (not discrete points) for the predicted (theoretical) relation V_{out}/V_{in} vs. α with empirical values (data points) overlaid. Alternatively, plot the log of this ratio. Either way, include a brief caption describing what is plotted, and what it means. This graphic and caption is the center piece of your report.

6. Compare and contrast theory and experiment, highlighting regions of similarity or difference between them. Explain plausible rationale for any differences you note.

7. Briefly describe qualitative observations from your actual audio test drive (2 sentences should be sufficient)—how did the system work in practice?

8. Critique the overall design and behavior of the circuit. Any suggested modifications to your circuit to improve its overall behavior and/or user friendliness?

The Potentiometer (aka "Pot")

A ***potentiometer*** is just a variable resistor. Take a look at Fig. 3. You'll see there are 3 contacts with labels A, B, and W. Contacts A and B are essentially just two terminals of a normal resistor. The magic happens at ***the wiper*** (W). As you turn the dial, the resistance between contacts A and W (or B and W) changes. Pretty much anywhere you see a rotating knob changing the output of electronics equipment (stereo, guitar pedal, etc.), rest assured it's just a pot.

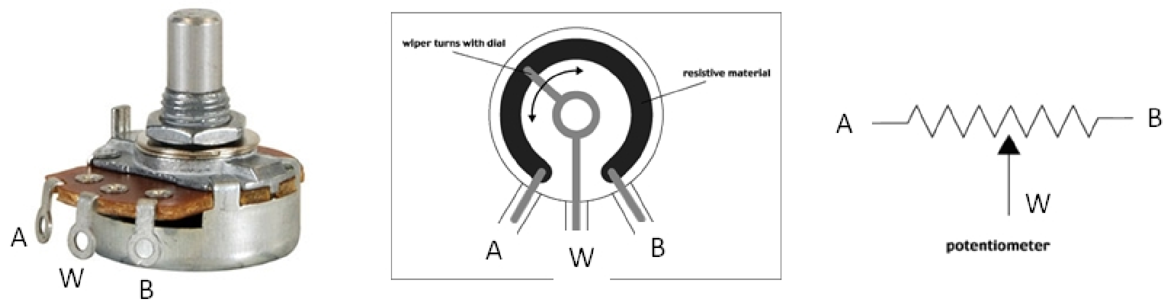

Figure 3: Potentiometer aka "Pot". Left: What you'll find in lab. Center: what's inside/theory of operation. Right: circuit component schematic. The magic really happens at the ***wiper terminal***, labeled W.

Audio Amp Connections

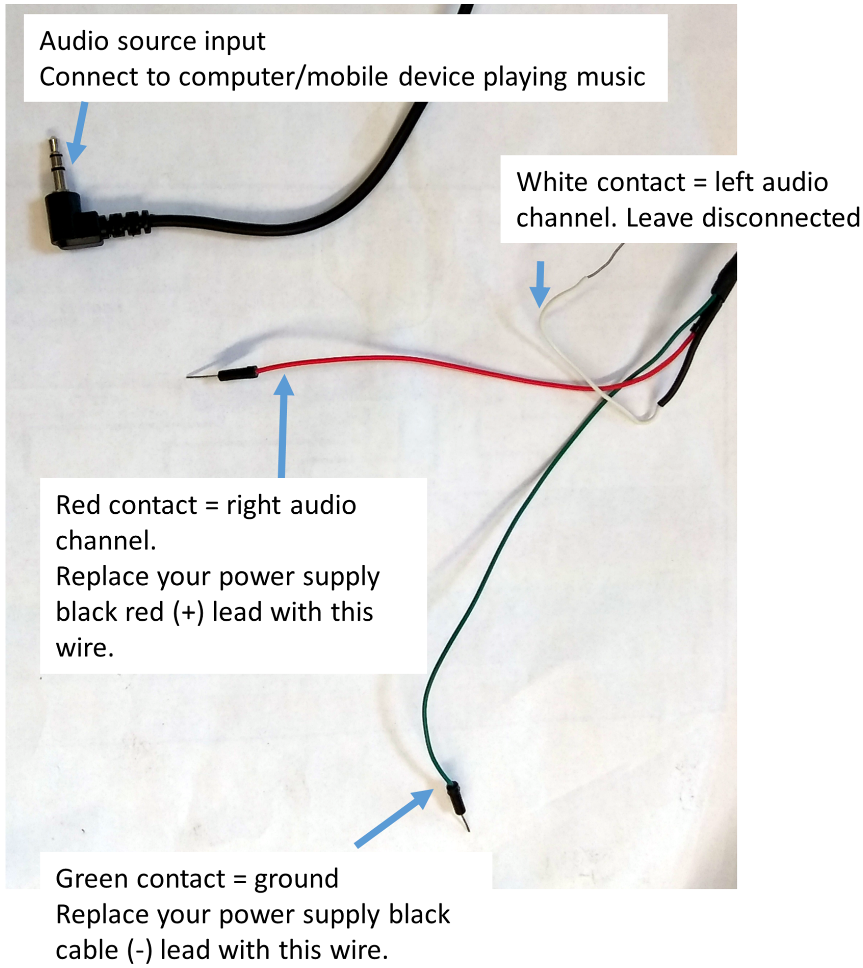

Figure 4: Connecting to mobile device music source to breadboard

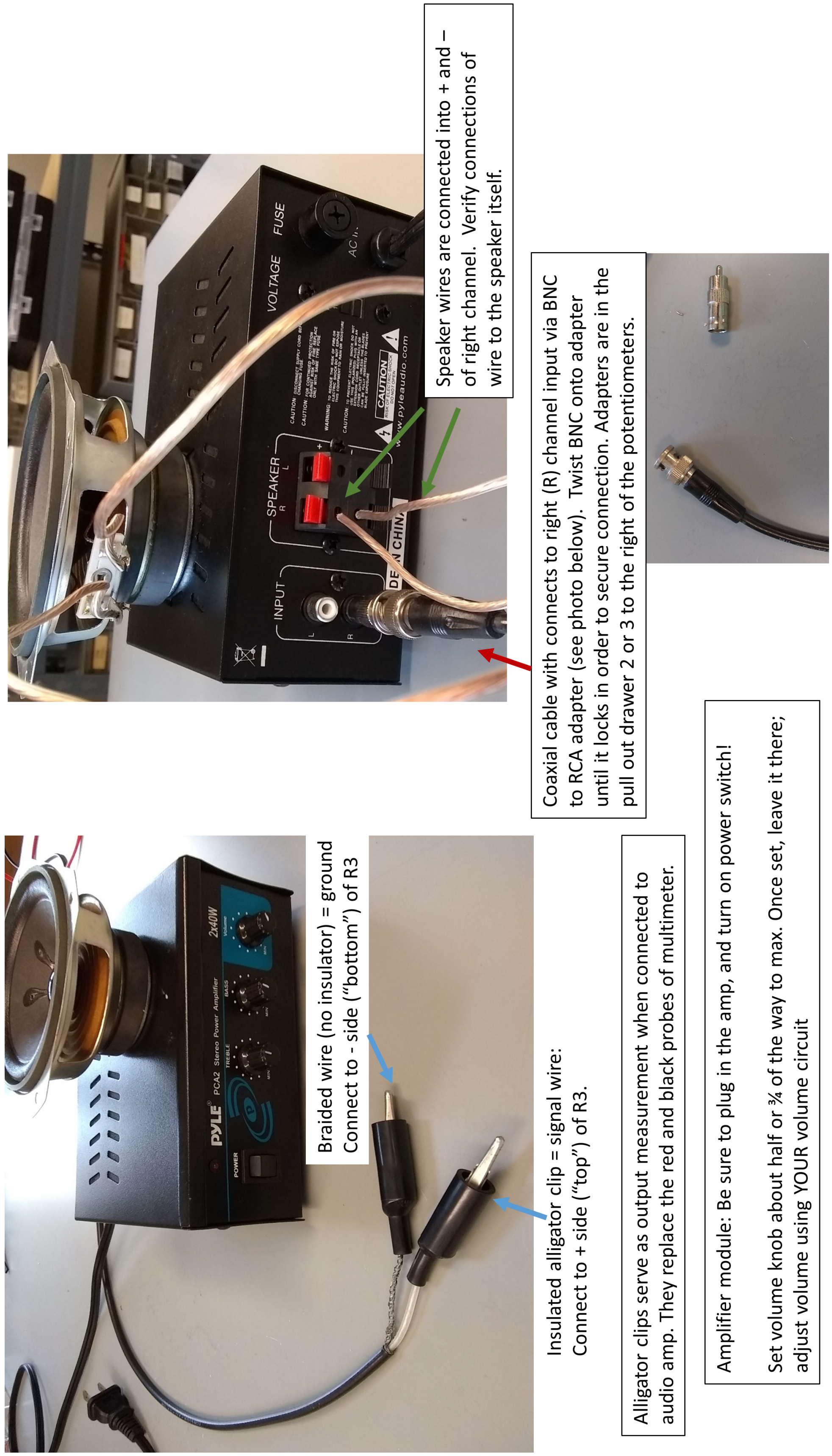

Figure 5: Connecting output of circuit/breadboard to audio amp and speaker