Learning to solder

This is an optional lab for students who have little soldering experience or who have soldered before but would like more practice. The basic goal is gain some knowledge about soldering and then apply what's been learned by soldering together a simple circuit.

The example used here is a simple version of a *pulse-width modulation* (PWM) circuit, built using components from the 201/230/333 lab kits. There are other ways to achieve pulse-width modulation, including using a micro-controller or the venerable 555 timer chip. Pulse-width modulation will be a key feature in some our EE 333 topics.

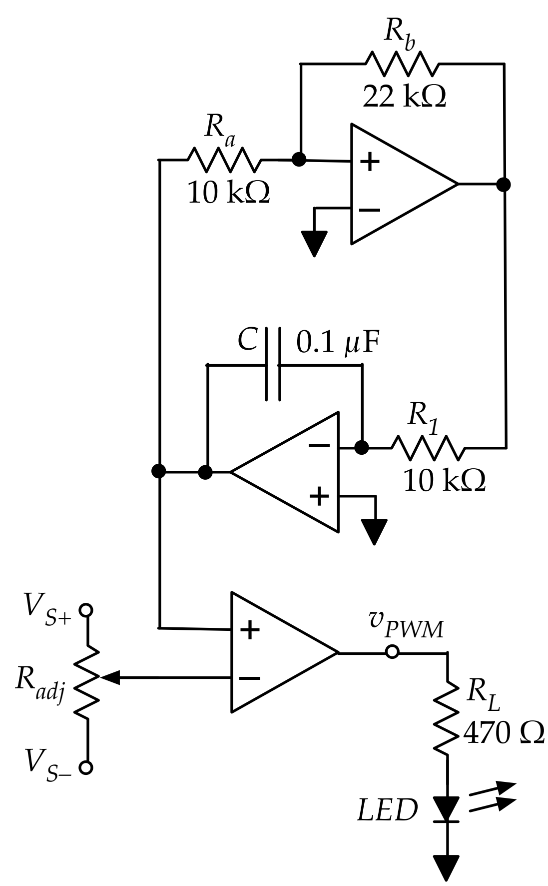
Although students with more extensive soldering experience are not required to do this lab, they still might benefit from building and testing the circuit, if they have not seen PWM operation before.

Prior to Lab

To help prepare, you probably should spend some time watching a couple of soldering tutorials. There are many available on the internet. There are links on the web page to a few of the videos that I like.

The circuit

The PWM circuit is shown at right. The operation is fairly simple. The top op amp is configured as a non-inverting comparator. The middle op-amp is connected as an inverting integrator. The comparator and integrator are cross-coupled to form a simple oscillator with square wave and triangle wave outputs. (The circuit should have been covered in EE 230. If it has been a while since you last studied this oscillator, it might be a good idea to review.) The chosen components should give an oscillation frequency of about 550 Hz. It is OK to change the frequency if you want, but if you speed up the circuit significantly, be careful about slew rate limitations.



The bottom op amp is also a non-inverting comparator. The inverting terminal is connected to a potentiometer, which serves as an adjustable reference. The non-inverting terminal is connected to the triangle-wave output of the oscillator. The output of the lower comparator will consist of pulses at a rate of 550 Hz. The width of the pulses can be varied by adjusting the potentiometer. The LED provides a convenient visual indication of pulses. The oscillation frequency is too fast for you to see the individual pulses turning on and off, but the changing average of the PWM pulses will cause the LED brightness to change.

Circuit BOM and circuit details

(Most of the components are available in your EE 201 and 230 kits.)

1. LMC 660 quad op amp (http://tuttle.merc.iastate.edu/ee230/lab/data_sheets/lmc660.pdf)
2. 14-pin socket (available from lab instructor)
3. 22 kΩ resistor, 0.25 W, 5% — R_b
4. 10 kΩ resistor, 0.25 W, 5% — R_a
5. 10 kΩ resistor, 0.25 W, 5% — R_I
6. 0.1 μF capacitor (ceramic)— C
7. 470 Ω resistor, 0.25 W, 5% — R_L
8. 6.8 kΩ resistors (2 of these), 0.25 W, 5% — part of R_{adj}
9. 10 kΩ potentiometer — part of R_{adj}
10. LED (any color)
11. small perf board (from 333 kit)
12. 3 input connector (optional)

The power supplies for the op-amps and for the PWM adjustment resistors are ± 5 V, taken from the triple-output lab supply.

The pulse-width "adjustor" consists of two 6.8-kΩ resistors and a 10-kΩ potentiometer in series. The 6.8-kΩ resistors go on either side of the potentiometer. This configuration limits the adjustment voltage to the range of about $-2.11\text{ V} < V_{adj} < +2.11\text{ V}$, approximately matching the swing of the triangle wave.

Use the 14-pin socket for the op-amp chip — solder the socket to the board and then insert the chip into the socket.

From your kits, you will also need wire cutter, wire stripper, and needle-nosed pliers. Lab instructors will provide solder and hook-up wire.

Prototype it

First, build and test the circuit on a solder-less breadboard. (Like 201 and 230 lab.) Observe the outputs of the various op-amp outputs on the oscilloscope. Confirm the operation of the circuit. The basic oscillator should have a frequency around 550 Hz (if you used the prescribed components) with clean triangle and square wave outputs. The square wave levels should be ±5 V and the triangle wave limits should be about ±2.25 V. The PWM output should be adjustable from less than 10% duty cycle to more than 90% duty cycle. Make sure that the circuit works before you begin soldering anything.

Planning

It is difficult and frustrating to trouble-shoot a circuit that has already been soldered. A bit of planning initially may save you a lot potential grief in the future. Start by coming up with a rough plan for how you will arrange the parts parts on the perf board. A simple approach to planning is to placing the parts on the perf board without soldering them. Just set the parts on top of the perf board. Or go a step further and insert the leads through the plated through-holes.

(Hold the parts in place by bending over the leads on the backside or using a bit of tape.) Re-arrange the parts as needed until you are satisfied with the layout. When arranging the parts, be sure to consider how the connections will be made. (See comments on making connections below.)

An alternative (and maybe a better) approach to planning would be draw out the circuit on graph paper first. (If you make a lot of changes as you progress, it is easier erase the figures on a drawing than it is to unbend the leads and pull the components off the perf board.) There is a link to a printable perf board diagram that you can download and print out for making a drawing.

A third approach to planning the perf board layout is to use lay-out software. The software from Fritzing seems to be good choice for simple perf board planning. There is a link on the lab page if you want to download and try Fritzing. (I haven't used Fritizing extensively myself, but it appears to be useful. Keep in mind that it may take longer to learn how to use Fritizing than do the actual soldering itself. However, given that we will be making several prototypes during the semester, the time invested in learning Fritzing might be worthwhile.)

Solder it

Once you are certain that you have built a properly functioning prototype and have a rough plan in place, solder up the circuit on the perf board. If you have enough components, it is a good idea to leave the breadboard prototype intact and solder together a second version of the circuit using new components. Then, if you have trouble with the soldered circuit, you will have something to compare against as you try to trouble-shoot.

On the lab web page, there is an example of complete perf-board build. The example is not the PWM circuit (the example is from audio club), but the procedure is similar. You can use the photographs to see how to place and connect components.

Be sure to solder every lead or pin of every component in place. Don't leave anything "loose" — components that are free to wiggle might break mechanically or have a bad electrical connection.

You can solder all of the components into place first and then make all of the connections afterwards. Or you can solder the components one at a time and make connections as you go. In either approach, it is a good idea to periodically check the continuity of connections with the multi-meter.

There are two ways to make connections between components. You will probably use a combination of both methods when building the perf-board prototype. The first method is to bend over the long leads of the resistors or capacitors make and the make connections on the backside directly with these. After the connections are soldered, cut off any extraneous portions of the lead wires. Note that since these wires are bare, there can be no "crossings", since those would short out.

The second method is to use "hook-up" wire. Estimate the length of a required connection and cut off a section of wire that is about a half-inch longer. Use the wire strippers to strip about 0.25-in of the insulation at each end. Put the stripped end through the holes and solder the wire to the plated through holes. On the back-side, bend the wire ends over and solder them to the components. Trim off any excess wire. It might be tempting to use wires that are much longer than necessary, since you would not have to spend as much time measuring, trimming, and fitting. But the end result would be probably be big loops of wire sticking out all over the place, similar to what an EE-201 student might do on the first day of lab. Keeping the wires short and the overall circuit tidy will help when it comes time for (usually inevitable) trouble shooting stage.

There are two approaches to attaching power supply leads. A simple (but inelegant) approach would solder on three long jumper wires for +5 V, –5 V, and ground and insert the free ends into a solder-less breadboard. Then regular lab leads from the power supply can then connect to the breadboard, like in EE 201/230. A better approach is to use a three-position connector from your 333 kit for the power and ground connections, and then hook the regular lab leads directly from the power supply to the on-board connectors.

Reporting

Prepare a short report describing the operation of the finished soldered circuit. Be sure to include enough annotated oscilloscope traces to show the complete operation of the circuit. Also include some good photographs of the soldered circuit. You might want to make a sequence of photos showing the progression as you solder the circuit together. If you are really into "Covid life", you could even make a video of the process. (But don't expect me to watch it.) The report is due one week after you finish the lab — submit it to your lab instructors.