

**University of Utah**  
**Electrical & Computer Engineering Department**  
 ECE 1250 Lab 4  
**Pulse Width Modulation Circuit**

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rev,

**Note:** Bring textbook & parts used last time to lab.

**Objective**

Build a Pulse-Width Modulation circuit using op-amps that can replace the signal generator used last time. Hook it to the MOSFET transistor to control the current through a bulb.

**Parts to be supplied by the student:**

- TL084 or LM324 quad operational amplifier IC (Integrated Circuit)
- 4 10 kΩ and 1 13 kΩ resistors
- 10 kΩ (103) trim potentiometer (pot)
- Small plastic screwdriver to adjust the trim pot
- 0.022 μF (223) capacitor
- Breadboard and wires
- 2 1N914 or 1N4148 small signal diodes
- IRLZ34N MOSFET (used in lab 3)

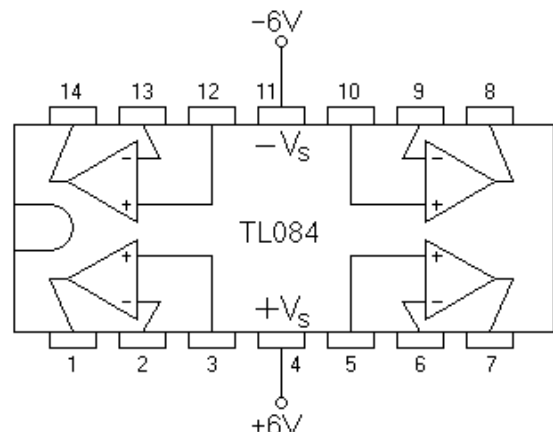
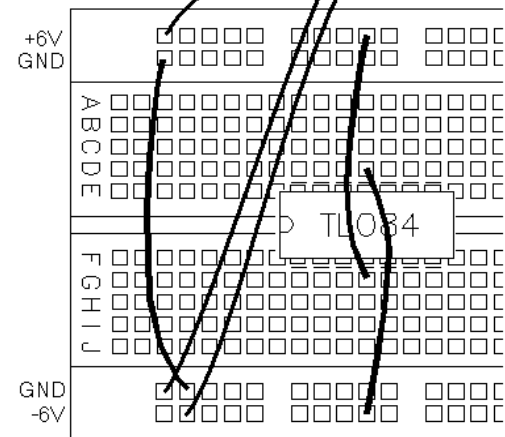
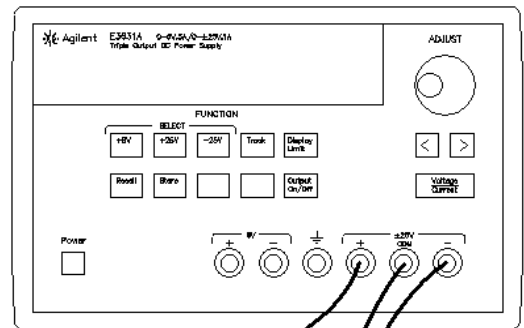
**Check out from window:**

- 1157 Light bulb with leads

**Experiment**

Plug the TL084 (or LM324) IC (Integrated Circuit) into the breadboard so that it spans the little center ditch. The notch and/or white band should be on the left and the writing on the IC should be right-side-up. The leads of the IC are numbered around in a CCW direction, starting in at the lower-left corner, as shown below.

The op-amps inside the TL084 (or LM324) are shown at right. This one IC contains four complete op-amps. All are powered by the same two power input terminals, +V<sub>S</sub> and -V<sub>S</sub>. To get both +6 and -6 V from the power supply, first push and hold the “Track” button for at least 1 second. Then push the “+25V” button and adjust the voltage to 6V. With tracking turned on the “-” output will “track” the “+” output and automatically be set to -6V. Hook up +6V to the +V<sub>S</sub> pin of the IC and -6V to the -V<sub>S</sub> pin.



Look carefully at the drawings, Don't hook the power up backwards– it's easy to do because the  $-V_s$  pin is on top (which is counter-intuitive). Finally, the  $-V_s$  and  $+V_s$  connections are **power** connections. DO NOT confuse them with the signal inputs to the op-amps (labeled - and +). Hit the "Output On/Off" switch to turn off the power supply output for now without losing the setting.

Most op-amp circuits won't work right unless the op-amp is powered with both + and - power supplies. This can be inconvenient, but using op-amps with single-sided supplies is more involved and can be tricky. One common mistake people make with op-amps is trying to use the simple with a single power supply. Variations of the basic circuit in this lab will use a single-supply, so you'll get a chance to see it.

The power supply's ground will be the ground for all your circuits and should be hooked to the breadboard somewhere, but is often not hooked up to the op-amp directly.

### Identifying Other Parts and Part Values

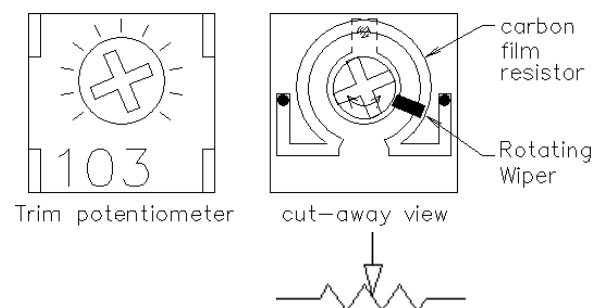
Examine the parts you've just bought. As you go through this section, list, sketch, show how you determine the type and/or value of each part in your lab notebook.

The resistors are the cylindrical parts with colored bands. The colored bands indicate the resistance according to a color code. Consult the 3<sup>rd</sup> page of your text (or page 317), learn how to read the color code and sort your resistors. Set the multimeter as an ohmmeter (Turn it on, hit the button marked " $\Omega$ " and make sure the test leads are in the right jacks.) Check the resistor values to see that you got 'em right. Note: when using an ohmmeter, it is best that you don't touch both leads at the same time while taking a measurement, otherwise the resistance of your body will be in parallel with the resistor you're measuring and will affect the measurement accuracy. This is especially important when measuring large-value resistors and/or when your hands are moist or sweaty.

The trim potentiometer (pot) will probably be a little blue cube with a round yellow "screw" on top and 3 leads out of the bottom. See page 332 and/or the sidebar to see how the pot works. Test with the ohmmeter until you are satisfied that you understand how it

### Potentiometers

A *potentiometer* is resistor with a special third connection. (The name comes from its old-time use in voltage measurements.) The third (center) connection can be made anywhere along the length of the resistor and it's position is adjustable. All potentiometers (pots) and volume controls work in a similar manner, with a moveable slider or "wiper" that makes contact with a resistor somewhere between its two ends. A rotary potentiometer is shown here, first in its package, then as bare workings, and finally as a schematic symbol. The resistance



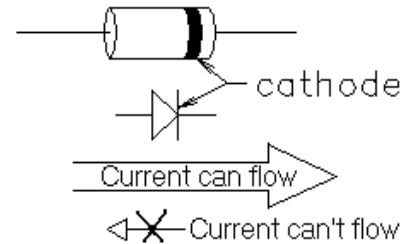
of a pot is the full resistance between the two outside terminals and is usually written on the part somewhere.

The resistor in a potentiometer can have a linear or an audio "taper". Audio taper potentiometers are used as volume controls in audio circuits. Your hearing does not respond linearly to changes in loudness, so the resistor in a volume control is nonlinear to compensate. The potentiometer used in this lab has a linear taper.

works internally. (This may be easier to do with the pot in the breadboard and using some extra wires.

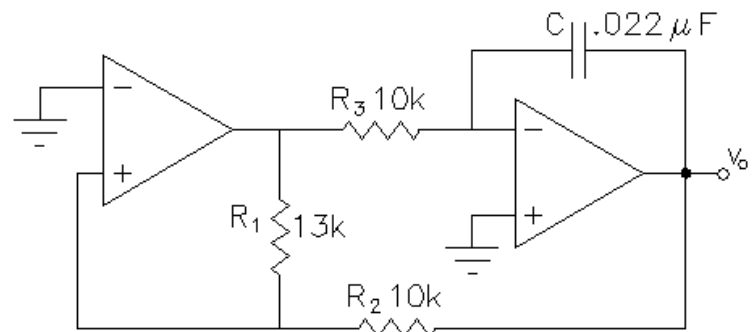
The capacitor will probably come in a disk shape and be marked "223" ( $22 \times 10^3$  pF). Consult the 4<sup>th</sup> page of your text (or page 354) to identify your capacitor.

The diodes are the 2 smallest parts. Small signal diodes are usually red and glassy. They will have a single dark band at one end, see page 420 and at right. Diodes allow current to flow in one direction but not the other.



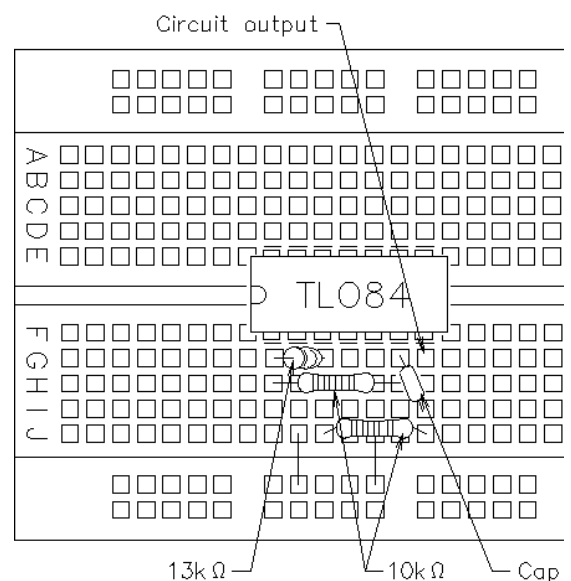
### Building the Triangle-Wave Generator

The circuit shown here is a triangle wave generator. (Notice that the power supply connections are not shown, That is common when drawing op amp circuits.) The left op amp acts as a Schmitt trigger (a comparator with some positive feedback so that it tends to latch the output at one rail voltage or the other). The second op amp acts as an integrator, so it's working within its active region.



In order to follow through one cycle of operation, let's assume the output of the first op amp is high (+ rail). The second op amp is in its active region, so it's keeping its two inputs at virtually the same voltage— 0V. (We say that its noninverting (-) input is a "pseudo-ground".) The voltage across  $R_3$  is constant, so a constant current will flow through  $R_3$  and that current will continue through the capacitor. The op amp does this by forcing its output to ramp downward at a constant slope. When that output reaches  $\sim -4V$ , the inverting input of the first op amp reaches  $\sim 0V$ . The first op amp switches from high to low and the current through  $R_3$  reverses. In order to feed that current back through the capacitor, the second op amp ramps its output voltage up at a constant rate. When that output reaches  $\sim +4V$ , the inverting input of the first op amp reaches  $\sim 0V$ , the first op amp switches from low back to high, and the process repeats.

Build this circuit on your breadboard. You may wish to use the drawing at right as a guide to help you, but don't just mimic it without understanding how each part is connected. You need to learn from this drawing— not just copy it! Notice that the power connections you added earlier are not shown in this drawing to keep it simple. DO NOT remove them.



Remember, whenever you make a circuit in the lab you must draw it in your notebook and whenever you take measurements, you should record them. That includes sketching waveforms you see on the scope screen with peak voltage values and time and/or frequency measurements. Add IC pin numbers to your circuit schematic. IE, if you built your circuit like I did, then the inputs to the first op amp should be labeled "2" and "3" and the output should be labeled "1".

Turn on the power supply output and test this circuit with the scope. The output of the second op amp should be a triangle wave and the output of the first op amp should be a square wave. Observe these two waveforms together using the scope's dual trace ability. Identify the two regions of operation on your drawing of the waveform and describe what's happening in each region (see earlier paragraph).

**If it doesn't work...**

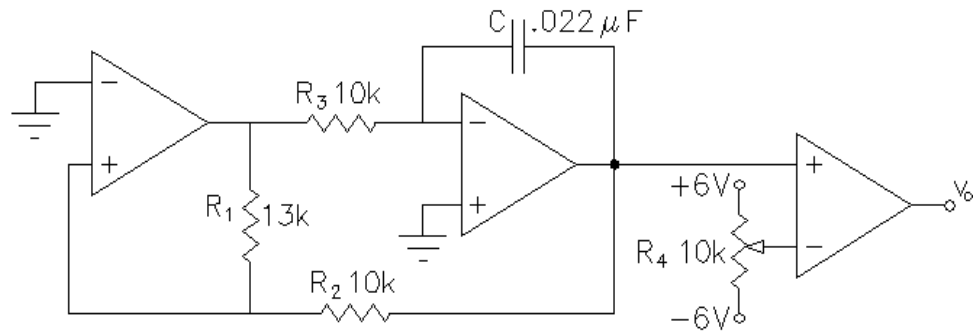
1. Use a voltmeter to check the voltages at the power pins & confirm the power supply ground connection.
2. Make sure you've made all the ground connections shown on the schematic.
3. Check all the other parts and connections, especially look for shorts between tall, bare leads.
4. Try other op-amps within the IC).
5. Have your circuit checked by the TA and if it's OK, replace the IC with another. The ICs can be damaged, especially if the power was hooked up backwards.

You should also observe the voltage waveforms at the op amp inputs, even those that are grounded. Are the two inputs of the first op amp virtually the same? Why or why not? Are the two inputs of the second op amp virtually the same? Why or why not?

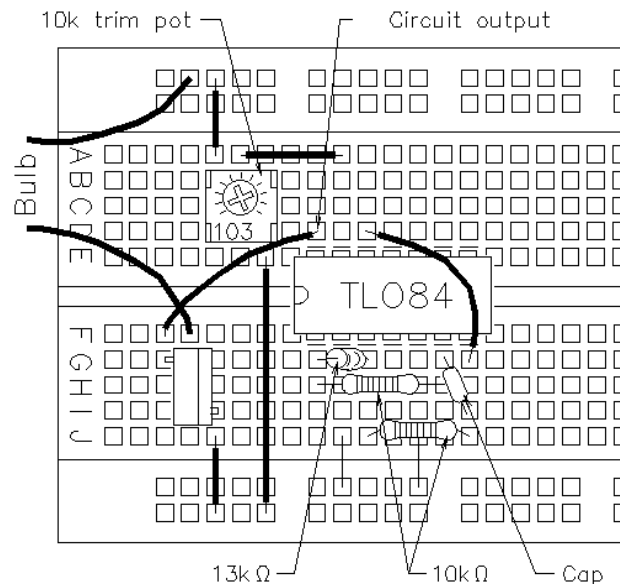
Finally, explain why you built the triangle wave generator. That is, how can this waveform be used to create variable-width pulses.

**Add a Comparator**

Look at the third op amp in the schematic. It's wired up as a simple comparator with no feedback, neither negative like an amplifier nor positive like a Shmitt trigger. The inverting input is connected to the wiper connection of a potentiometer. What do you expect to happen to the voltage at that terminal as the pot is turned from one extreme to the other? Given that the other input is hooked to the triangle wave, what will happen at the output of the comparator?



Add the comparator to your existing circuit. Again, you may use my drawing as a guide if you understand it, but don't connect the MOSFET or bulb yet. Test the circuit using the scope. Observe the output as you turn the pot



back and forth with the little screwdriver tool. Compare what you see to what you expected to see. Note any unexpected results or anomalies especially at the extremes of the pot. Turn the pot about midway.

Note that the output voltage doesn't transition from one level to another instantly. This is because the op amp is limited in how fast it can change its output. This limit is called the "slew rate" of the op amp and is usually expressed in  $V/\mu s$ . Adjust the scope so that you can better observe the slew and use the cursors to make measurements needed to determine the slew rate. (If you don't remember how to do this, consult the previous lab writeup in your notebook. If that doesn't help, your writeup wasn't good enough— check out the Training Guide again.) Find and record the slew rate of this op amp. Readjust the scope to see the whole waveform again.

### Power Stage

The op amp, like the signal generator used last week, cannot supply enough current to operate the light bulb. Last week you used a power-MOSFET transistor as a simple switch to control the bulb current. Find the drawing of that circuit in your lab notebook. (If you didn't draw it then, you should have lost points. If you don't draw it again this week, you will lose points this time. Once again: you need to **draw every circuit** you build and **draw every waveform** you observe.) Remake that circuit now with two modifications— use your new PWM circuit in place of the signal generator and hook the source (S) to the negative power supply instead of ground. Test this circuit operation. Use the scope to look at both the input and output of the MOSFET at the same time. Determine from this how the MOSFET works. IE what input (gate voltage) turns it on and what input turns it off?

Compare the operation of your circuit with that made with the signal generator last time.

Note: If you're not in a Monday lab section, you may finish this lab in the next lab session.

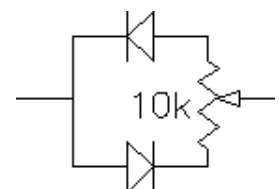
### Circuit variation 1, Single-sided power supply

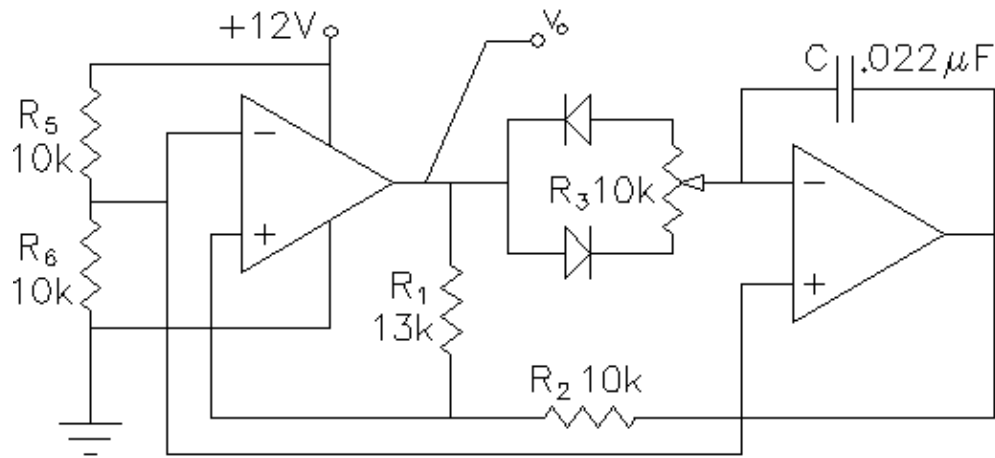
Look at the PWM schematic in your notebook. Note that there are only two connections to ground and that neither of them carry significant current. That makes this circuit particularly easy to convert to operate from a single-sided power supply.

Disconnect the power supply and reset it to produce a single 12V output. Add the two remaining  $10\text{ k}\Omega$  resistors to your breadboard such that one is hooked from the old +6V to the old ground and the other is hooked from the old -6V to the old ground. Together they are a simple voltage divider which provide a voltage midway between the two power supply connections. Now hook up the power supply, +12V to the old +6V location and ground to the old -6V location. Test your circuit to make sure it still works. Draw at least the new power supply connections and explain why this works in your notebook.

### Circuit variation 2, Simpler PWM

Remove the comparator from your circuit and replace  $R_3$  with the pot and two diodes shown at right. Your new PWM schematic should now





be that shown next. Note that crossing lines DO NOT denote connections unless there is a solid dot at the crossing.

Test this circuit, first by itself and then again attached to the MOSFET and bulb. Take whatever other measurements you need to in order to figure out how this circuit works. Explain how it works in your notebook.

### Conclude

Check off and write a normal conclusion in your notebook. If you have any time left over, you may want to check out the R/C car and play. Before leaving, make sure everything is turned off and return the stuff you checked out and took from the posts.

