University of Utah
Electrical & Computer Engineering Department
ECE 2210
Diodes & Transistors

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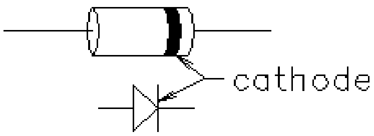
Objective
Observe the workings of diodes and transistors. Since this lab is primarily build and observe. Your lab notebook should be a record of those observations.

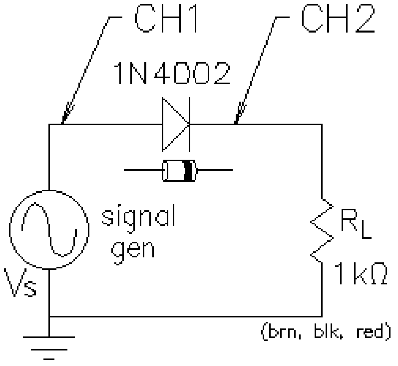
Parts: (Parts in **bold** are new to this lab)
- **56 Ω** (grn,blu,blk), **510 Ω** (grn,brn,brn),100 Ω (brn,blk,brn),1 kΩ (brn,blk,red), 22 kΩ (red,red,org), and 100 kΩ (brn,blk,yel) resistors
- 0.22 µF (224) and a 47 to 220 µF capacitor (use this cap where schematic calls for or 100 µF)
- **1N4002 or 1N4004 diode** (black plastic)
- **Red, green, and yellow LEDs**
- **1N4734 5.6 V zener diode** (gray) (may use 1N4730)
- **2N3904 transistor**



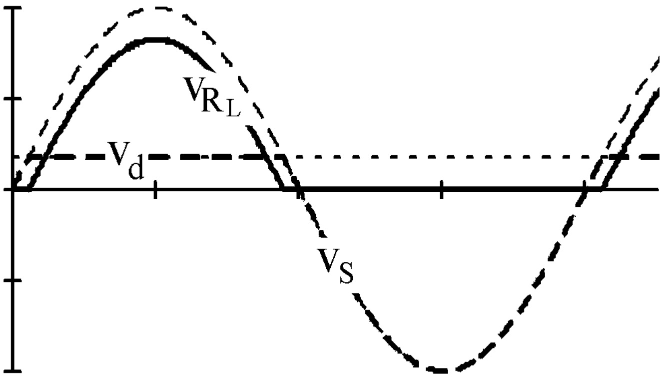
Equipment and materials from stockroom:
- Servo

Note: You will build lots of circuits in this lab—some quite complex. Build them carefully, or you'll spend too much time troubleshooting. Make your observations and sketches quickly so you can move on. Your sketches don't have to be perfect, just fast.

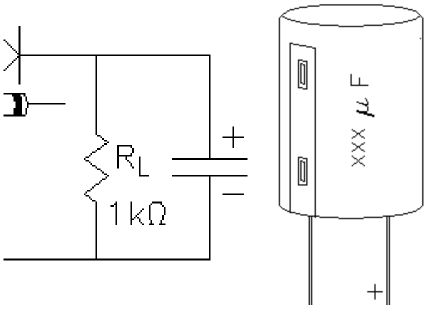
Experiment 1, Rectification
Half-wave rectifier: Wire the circuit shown at right. The 1N4002 parts are *power* diodes and they have large leads. These leads can be hard to get into the breadboard holes. If you look closely at the lead ends, you'll see that many are cut with a wire cutter that leaves a beveled end. If you line the bevel up with the holes that are connected inside the board, they go in a lot easier. Otherwise, wiggle and twist them as you push them in the board.



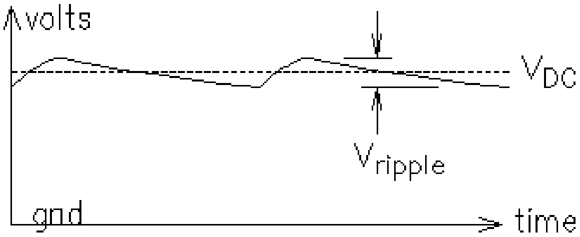
Hook up the scope, and make sure that both scope inputs are set to "DC" coupling. Turn on the signal generator. Set the signal generator amplitude to 4 Vpp (which will actually give 8 Vpp) and it's frequency to about 60 or 100 Hz sine wave. Observe and sketch the two waveforms that you see (v_S and v_L). Note the half-wave rectification. The load voltage is now "DC", although it's not very "pure".



Place a 47 to 220 µF capacitor in parallel with the load resistor (**remember the capacitor polarity—you don't want to blow up the capacitor**). Observe and sketch the filtering effect of the capacitor. The load voltage is better than it was, but it's still not great. The DC voltage still has significant "ripple". Measure the peak-to-peak voltage of this ripple. Add a second capacitor in parallel with the first. Comment about how the added capacitance effects the ripple.



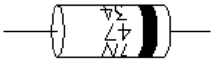
Notice that the capacitors also distort the input voltage during the short time that they charge. The current during this time is quite high and the distortion is caused by the voltage drop across the 50 Ω output resistance of the signal generator. The same thing happens in power supplies, although the currents are usually higher and the resistances are usually lower. Remove the capacitors.



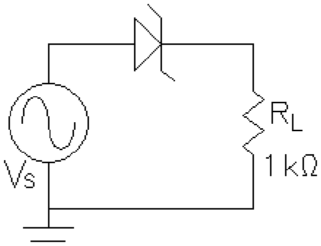
Change the input to a triangular wave. Observe the waveforms.

Experiment 2, Other Types of Diodes

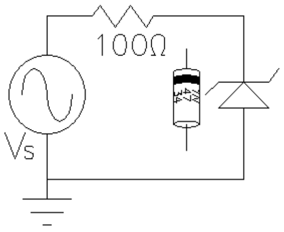
Zener Diodes



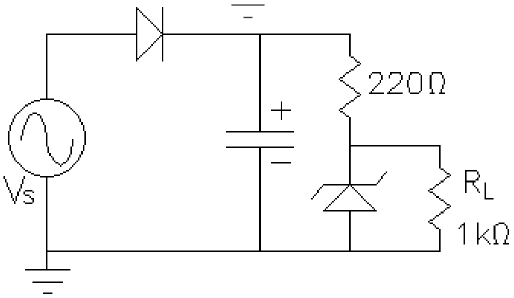
Set the signal generator amplitude to 8 Vpp (which will actually give 16 Vpp). Replace your diode with the 1N4734 zener diode as shown. Notice that the while the diode works exactly like a regular diode in the forward direction, it also lets current flow in the reverse direction when the input is more than 5.6 V negative. The voltage across R_L is proportional to that current. Sketch v_S and v_L you see on the scope.



Change the circuit to that shown at right (notice the resistor is a different value). Now the waveform is *clipped* at about +5.6 V and -0.7 V. A zener diode has a specific reverse breakdown voltage and is often used as a voltage reference or regulator. Sketch v_S and v_D you see on the scope.

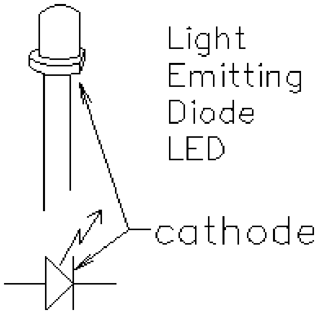


The circuit at right shows a more normal use of a zener diode as a voltage regulator. You DO NOT have to make this circuit. This is called a "shunt" regulator. As long as there is always a reverse current through the zener, the voltage across the zener will be regulated to about 5.6 V. Turn off the function generator.

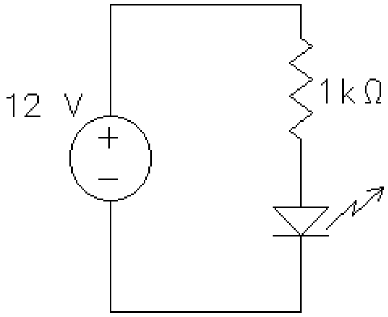


Light Emitting Diodes

Make the circuit on the next page using the DC power supply and one of the LEDs (red, green, or yellow). Notice the resistor is 1kΩ again. Calculate the LED current assuming the voltage drop across the LED is about 2 V. This is a pretty good assumption for LEDs. In fact, to design an LED circuit you usually make this 2 V assumption and calculate a resistor value which will allow about 10 to 20 mA to flow



through the LED. Never just hook an LED up directly to a voltage source--unless you *want* to let the smoke out. Measure the actual LED and resistor voltages and calculate the actual current flow in the circuit. Compare this to what you calculated from your assumption. Try the other two LEDs in this circuit and measure the voltage drop across each.

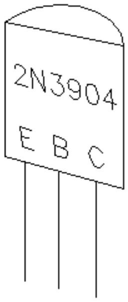


Experiment 3, Transistors

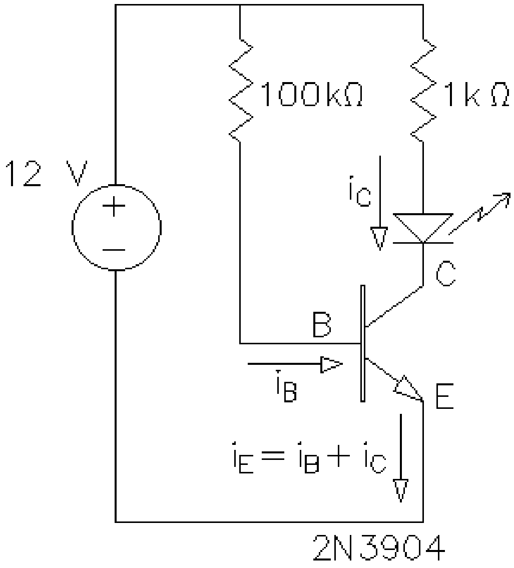
Transistor switch

A transistor is a nifty little device which controls current flow. It has three terminals--the *base*, the *collector*, and the *emitter*. The current flow from the collector to the emitter (through the transistor) is controlled by the current flow from the base to the emitter. You can think of this as the base current controlling the collector current. A small base current can control a much larger collector current. They are related by a simple factor, called *beta* (β). For a given base current, the transistor will allow β times as much collector current. Big power transistors usually have a β between 20 and 100. For little signal transistors, β is usually between 100 and 300. Because a small current can control a large current a transistor can be used as an *amplifier*. That is, it can make a larger signal from a smaller one. (A signal is a voltage or current that carries information. In the lab we usually simulate signals with sine waves.)

A transistor can also be used as a current controlled switch. When there's no base current, it acts like a switch that's off. When there *is* a base current, it's on. When it's on there are two possibilities. 1. The transistor is in control and limiting the collector current to β times the base current (βI_B). Or, 2. the transistor does the best it can to let βI_B current flow but circuitry outside the transistor won't let that happen. In that case the transistor turns on completely, like a closed switch and *other* elements in the circuit limit the collector current to less than β times the base current. In the first case the transistor is said to be operating in the *active region* because the transistor is in *active* control of the current. In the second case the transistor in the *saturated* region and is working like a switch.



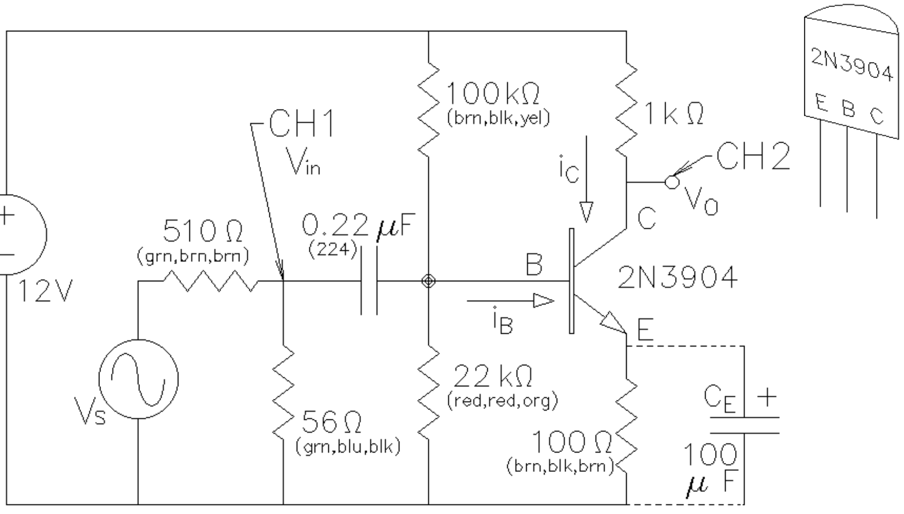
Find your 2N3904 transistor. It's a small black part with three leads. The leads may be labeled on the part as E, B, and C or else look at the drawing to the left. E, B, and C denote the **E**mitter, **B**ase, and **C**ollector. Expand your LED circuit to the one shown at right. Note the symbol for the transistor, and it's E, C, and B labels.



The LED should be lit, indicating that the transistor is "on". Disconnect the 100 kΩ resistor and the transistor turns "off", reconnect it and the LED lights again. Repeat this several times to convince yourself that the base current controls the collector current. Notice now that the base current flows through a 100 kΩ resistor whereas the collector current flows through only a 1 kΩ resistor. The base current (the controller) is roughly 1% of the collector current (which it controls)! A very small current controls a much larger current.

Transistor amplifier
In the final circuit we'll use a transistor to amplify a voltage signal. I won't try to explain the circuit. I just want you to build it and see that it works.

Construct the circuit shown at right. Use the function generator as v_s and set the frequency to about 5 kHz. DO NOT connect the 100 µF capacitor at this time.



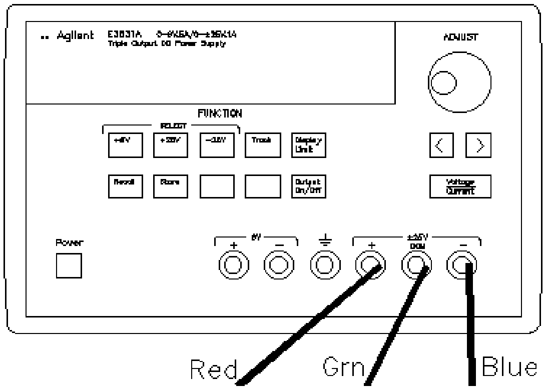
Please note that the 510 Ω and 56 Ω resistors are NOT part of the amplifier. They are needed because the function generator output (V_{pp}) cannot be turned down low enough for this circuit. Together they constitute a voltage divider which reduces v_s by about a factor of 10. The actual v_{in} of the amplifier circuit is measured where CH1 is connected.

Increase (or decrease) the function generator (v_s) V_{pp} so that the output signal (v_o, CH2) shows just a little clipping. Clipping is a form of distortion that "chops-off" some of the top and/or bottom of the output waveform. Now turn the input down somewhat so that the output looks good, with no visible distortion or clipping. The output voltage is a combination of the AC output signal and a DC *bias* voltage. You may have to adjust the vertical position knob on the scope or set the CH2 scope coupling to "AC" in order to see the signal on the scope. Measure the input (v_{in}) and output (v_O) signal voltages (AC peak-to-peak). Calculate the circuit voltage *gain* (gain = v_o/v_{in}). It should be about 10. Notice that the output signal is inverted with respect to the input. This is normal for this circuit. Sometimes the gain is reported as a negative number to indicate this inversion (-10).

Add the 100 µF capacitor (47 µF or 220 µF will also do) and repeat the previous step. The gain should be much bigger now (I measured 200) but is not so easy to predict. It is now dependant on variations within the transistor. Also notice that the output has a more distorted appearance (top is more rounded, bottom is sharper). Nevertheless, you must admit that this is a pretty remarkable gain for such a simple circuit. I hope you can see where such a circuit might come in handy.

Diodes and Transistors in the Servo

Look at the Servo and at its schematic diagram (last page of this lab). Find LED0 and LED1 which are actually two LEDs in the same package, hooked up in opposite directions. They light green if the power is correct or red if backwards. Look at the schematic and calculate how much current should flow through these LEDs.



Turn off the power switch on the servo and hook it up to the power supply. Adjust the power supply to provide ± 6V as you did in the first lab. If you've forgotten how to do this, refer back to the lab handout for lab 1. Remember that you may be able to recall the ± 6 V configuration by simply hitting the **Recall** button twice (If no one else changed it).

Find the 390 resistors, R19 and R20 on the servo circuit board. Measure the voltage across R20 and calculate the actual current through LED1. Measure the voltage across LED1 (the easiest way to this is to place one lead of the voltmeter on the Positive input terminal and the other on the end of R20 closest to LED1). Compare your measurement to the 2-V assumption.

Find diodes D1, & D2 near the motor disable jumper (between the big electrolytic capacitors and the transistors. Find them on the schematic as well. Why are these diodes there? Find the bi-color LED3. It lights red with one direction of current, green with the opposite direction, and yellow with an AC current. Why do you get yellow If the current is AC? What is the purpose of R22? Turn the input position pot back and forth quickly to see the LED light red and green.

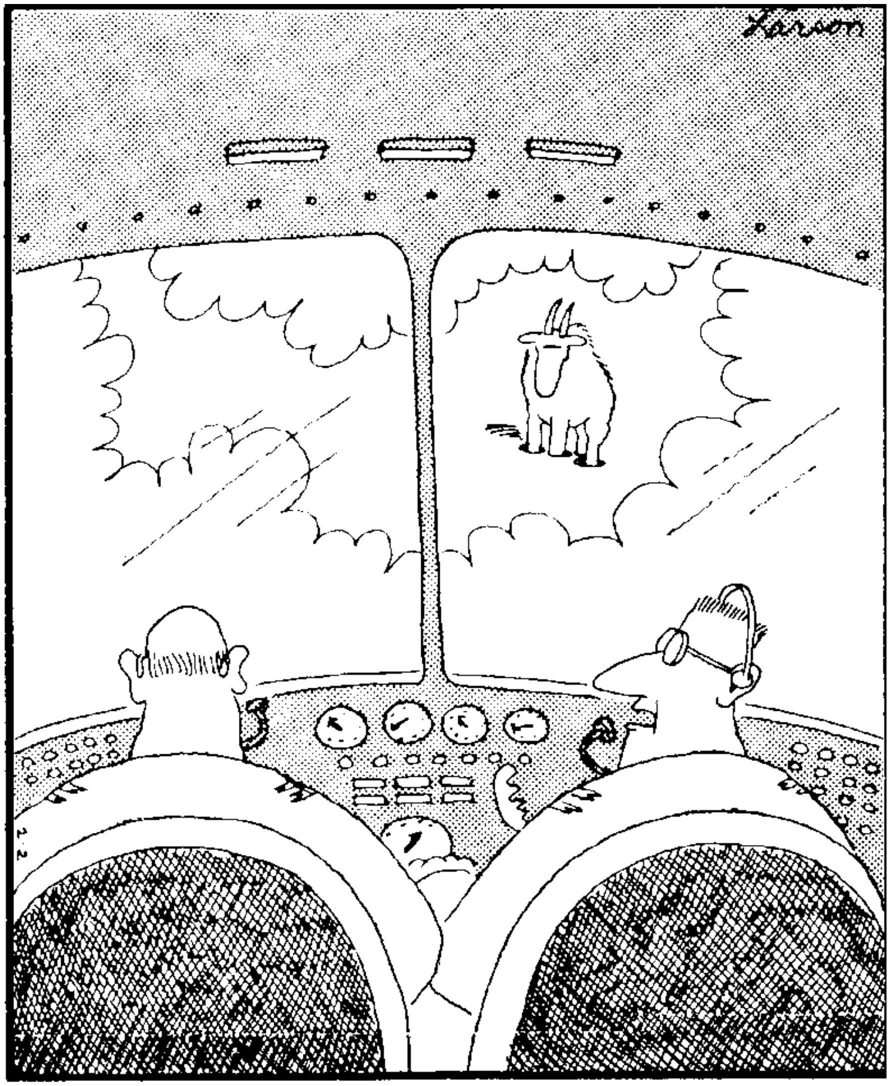
Find the transistors Q1, & Q on the schematic. What is the purpose of these transistors and why are there two? Why do you suppose the actual transistors are attached to the pieces of aluminum? Turn the input position pot to about midway. Touch both aluminum heatsinks at the same time. Now turn the red gear by hand until you feel significant resistance from the motor. Hold this position until you feel one of the transistors heat up. (You may have to turn up the gain.) Let go of the red gear and then turn it the other way. Does the other transistor heat up? Why do the transistors heat up? Why does the heating depend on which direction the motor is trying to turn?

Conclusion

Page back through this lab and just look at all the circuits that you built today. You've come a long way this semester, and you should pat yourself on the back. I hope that it wasn't too painful. The transistor that you used in this lab is known as an "active device". Active devices are the basis of *electronics*.

Keep the schematic on the last page of this lab. You will refer to it again in the next lab.

As always, get your notebook checked off and write a conclusion.



"Say . . . What's a mountain goat doing way up here in a cloud bank?"