Physics 334
Notes for Lab 4 – Transistors

January 29, 2010

Lab manual sections **4-1 to 4-4, 4-7**; Try to do **4-6** as well if you're not running too short on time. Section **4-9** is optional.

A couple general points and hints:

You will find the transistors will give you less trouble making contact in the breadboard if you just lightly spread the leads and use adjacent 3 adjacent breadboard rows. (If you spread them widely apart, like a tiny lunar lander (or really large bacteriophage)it is difficult to get good contact in the breadboard.

We are now moving into the realm of active, powered circuits. Things will begin to get more complicated and tougher to problem solve. We highly suggest the following.

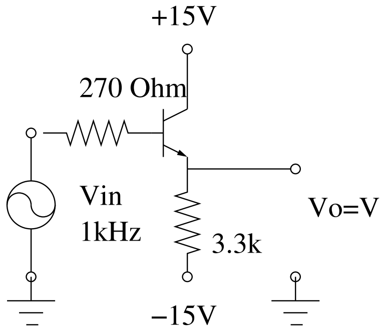
- Use color coding: RED for + supply voltage, BLACK for negative supply voltage, GREEN (or WHITE) for ground, and some other color for other signal lines.
- Build your circuits LEFT to RIGHT... so the signal goes in on the left side and after some modification, comes out on the right side.
- If you need power to more than one chip, consider using the buss bars on the breadboard (more on this in coming weeks when you really need it)
- Clip short probe wires to the scope probes when looking at signals in your circuit. They're easy to stick into the breadboard and move around and they are less likely to short to adjacent pins, resistors, etc while you troubleshoot your circuit.
- If things don't behave as you expect them to check that your transistors, chips, etc have power (most circuits work better with power supplies connected and on) and if so begin tracing the signal from the input through each component to the output. If you see something you don't expect, start looking closer until what you are measuring makes sense.

4-1 Use a BNC to aligator clips cable with a BNC to double banana adapter to plug into the Fluke meter. Turn to the diode test position and verify the meter reads very roughly 0.6V or so in the forward direction but OL in the backbiased direction.

Note that a PNP transistor like the 2N3906 will have opposite polarities when testing. The emitter lead is always the lead indicated by the emitter arrow on the schematic diagram.

4-2 Do as described.

The second circuit should look like:



Remember our fancy tricks with floating supplies (and why we love the versatility of a floating supply). To make both +15V and -15V from the dual supplies:

- Connect the - terminal of one 15 V supply to circuit ground.
- Connect the + terminal of the other 15V supply to circuit ground.

Make your measurements with a roughly 1 kHz sine wave.

Again, it's always a good idea to set the voltages before hooking up your leads (so you don't hook up too high of a voltage and blow things up) and also to turn the power supply off whenever making connections to your circuit. Turn the supply on only after you've convinced yourself you've wired the circuit perfectly.

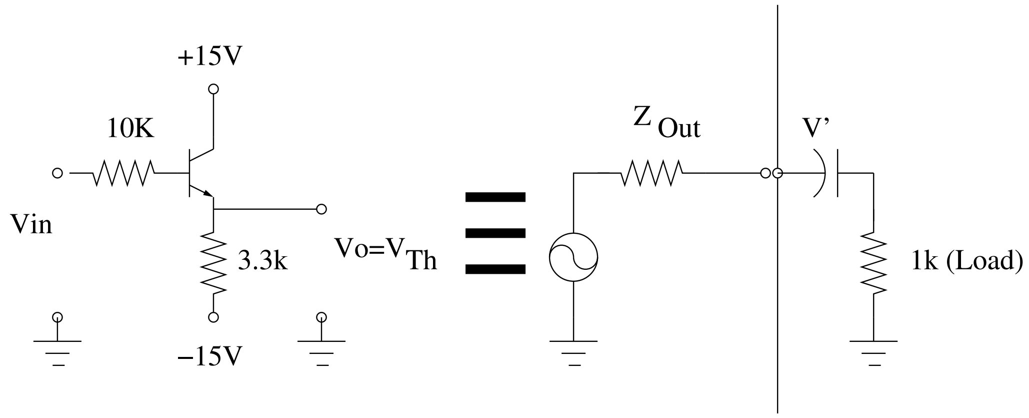
4-3 Do as described.

Note the polarity of the blocking capacitor. A small mark near one of the leads often indicates the polarity of polarized capacitors such as the tantalum capacitors that are common in this capacitance range. If you put your capacitor in backwards, large currents can flow and smoke genies may make an unwelcomed appearance.

When measuring both the input and output impedance of the circuit, you will be using the idea of Thevenin equivalent circuits.

4-3a To measure Z_{Out}, we assume the transistor circuit has a Thevenin equivalent resistance and deduce what it is by putting an extra load on it and observing how much the AC voltage decreases. The extra load forms a voltage divider with Z_{Out}. In other words, Z_{Out} is the upper resistor in the classic voltage divider circuit you've come to know and love.

In a picture (worth a kiloword):

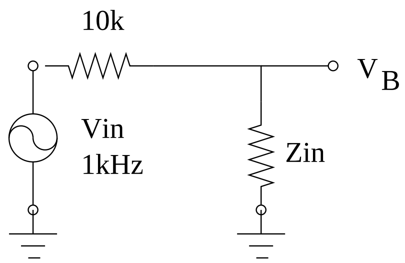


Neglecting the impedance of the blocking capacitor, which is small at signal frequencies:

$$V' = V_{Th} \frac{Z_{Load}}{Z_{Out} + Z_{Load}} \tag{1}$$

Ignore the comment about percent markings in the suggestion box. Use the scope to measure in a manner that you see fit – You know how now (Measure function, graticule, whatever makes you happy) Hopefully you find $Z_{Out,Thevenin}$ is small – In other words we can easily drive a load.

4-3b When measuring Z_{In} in part b, we have an analogous situation. For Z_{In}, the input impedance of the transistor amplifier and the 10k resistor form a voltage divider. The equivalent circuit looks like:



Again, in a similar manner:

$$V_B = V_{Th} \frac{Z_{In}}{Z_{In} + 10k} \tag{2}$$

Measure the AC voltage on both sides of the 10k resistor and deduce Z_{In}. What Z_{In} do we expect? We expect $Z_{In} = (\beta + 1)Z_{Load}$ where Z_{Load} is now just the 3.3k resistor.

Remember, a a transistor is a master at increasing the current a circuit can deliver. And since $V = IR$, if I can effectively increase a circuits ability to deliver current to a load, I'm effectively decreasing the effective Thevenin resistance of the source. In other words, the source "feels" the load less because the transistor is able to supply some of the needed current.

Or you might similarly think about it in the following way: If I hook up a small resistance to the output of a Thevenin circuit (ideal voltage source in series with a resistance) , I will see it's voltage drop because I'm drawing more current through the Thevenin resistance. If I can provide that current by some other means (via a transistor) then I'm only pulling a portion of the current through the Thevenin resistance, hence I have a smaller voltage drop (i.e. loading is decreased).

Transistor β's vary wildly, even for the same transistor type and batches. Don't be surprised if a person at an adjacent lab station gets a different value, but they should be of the order of magnitude of 100 or so for a standard small signal transistor like the 3904.

An aside: Be impressed... Really...

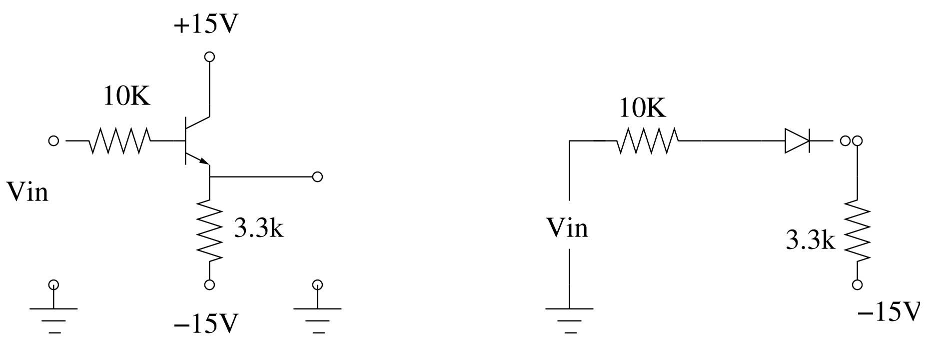
Again, we find ourselves bewildered and saddened that sometimes people aren't impressed by this circuit. You should be.

For those of you who STILL aren't impressed... perhaps your reasoning is something like this:

"The circuit is just the input waveform with a diode drop! The transistor could just be replaced by a diode and nothing would be different!"

Well, not quite – Try it if you don't believe us (this is optional... just for those of you who still aren't impressed)... You can prove it to yourself with the following circuits... The transistor circuit you just built and it's "Diode Replacement" (not really a replacement, as you'll see).

i.e. try the following circuits:



If you do try this, you'll see the difference immediately! Not only is there a DC offset, one waveform is significantly attenuated, the other is minimally so... See, current gain is a wonderful thing! Notice that due to the large DC offset on the diode circuit, it is useful to view that circuit with the scope input AC coupled.

4-4 This is of course similar to the previous circuit. Note that we're doing clever things now to bias the transistor. The resistor voltage divider provides the bias voltage. The capacitor's handy frequency dependent impedence cuts off DC component from the signal source (At DC, the capacitor looks like an open circuit). At high enough frequencies, the capacitor looks like a short (has low impedance).

Again, note the polarity of the capacitor, if you have a polarized capacitor. (Tantalum capacitors have a particular operating polarity – Ceramic capacitors do not. Always look for polarity markers, often a minus or a plus).

So the circuit passes the AC portion of the signal only. Note also that the output at the emitter is centered around the bias voltage (minus a diode drop, of course).

You may ignore the “Fine Point” paragraph.

4-6 Try this if you are not running out of time. Section 4-7 is probably more important, though, if you’re feeling the crunch of the bell.

4-7 If you’re STILL unimpressed by the emitter follower, perhaps you’ll be more impressed with this circuit.Now we have a true voltage amplifier! An inverting amplifier, but the signal going out is bigger than the signal going in. It takes less imagination to see places where this is useful. Heck, voltage amplifiers are everywhere and these days. We all have enough experience with amplifiers in everything from car stereos to iPods now that you should appreciate this.

Most amplifiers in use are far more integrated in today’s world, but this is where it all started . . . With single transistor amps. (OK, with vacuum tubes before that, but the principles are the same – Amplify a current, then if you want a voltage amplifier, pass that current through a resistor to turn it into a voltage change)

Answer the book questions. This basic circuit is one of the traditional “favs” of physicists who teach electronics. (hint) You should understand it.

4-7 Transistor switches – Optional