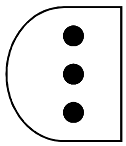
Lab 4: Bipolar transistors and transistor circuits

Objectives:

- investigate the current-amplifying properties of a transistor
- build a follower and investigate its properties (especially impedances)
- build a transistor voltage amplifier and investigate its properties
- use a transistor to switch large currents on and off

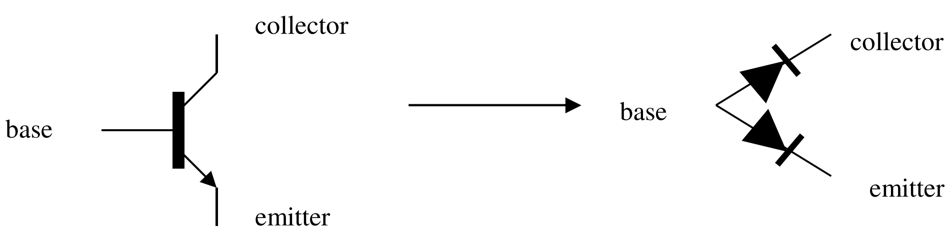
<u>Special notes:</u>
The transistors we'll use are in a TO-92 package; the leads are arranged like this:

(top view,
leads pointing
away from you)



Use frequencies in the kHz range for your signals in this lab.
Power your breadboard down before changing components in your circuits.
Use care in bending the transistor leads and inserting them in the breadboard: minimize random exposed connections!

4-1: Basic transistor properties
A semiconductor diode is formed from a pn junction. A bipolar semiconductor transistor is either npn or pnp. For an npn transistor such as the 2N3904, the junctions act in some sense like back-to-back diodes as shown below (but don't take this too seriously: a working transistor does not behave <u>in a circuit</u> like two back-to-back diodes). There's just enough truth in this picture to make it possible to use the diode test function of a meter to spot check a transistor that's suspected to be bad.



Get a 2N3904 transistor and use the BK meter's diode test function to measure the voltage drop across the BC junction and the BE junction in the forward and the reverse direction. (The meter applies a small current and reads the junction voltage that corresponds to that current.) Are the results similar to what you got for a Si diode (such as the 1N914)?

The BC junction may be distinguished from the BE junction by looking at the forward voltage drops: since the BC junction is physically larger than the BE junction, the BC junction has a slightly lower current density and therefore a slightly lower voltage drop. Is this true for your transistor?

The BK meter also has a transistor test function. Put the transistor in the appropriate place on the meter and record the reading. This reading is the current gain (h_{FE} or β) of the transistor, defined as the ratio of the collector current to the base current, that is, $h_{FE} = \beta = I_C/I_B$. (The BK meter uses a base current of 10 μA and a collector-emitter voltage of V_{CE}=3.45 V as the conditions for the measurement of β.)

Finally, the oscilloscope-based curve tracer can be used to look at I_C vs. V_{CE} for different values of I_B. Have me show you how it works. Sketch or print and label the resulting curves in your lab book. Plot and label on these curves the operating point the BK meter uses when measuring β.

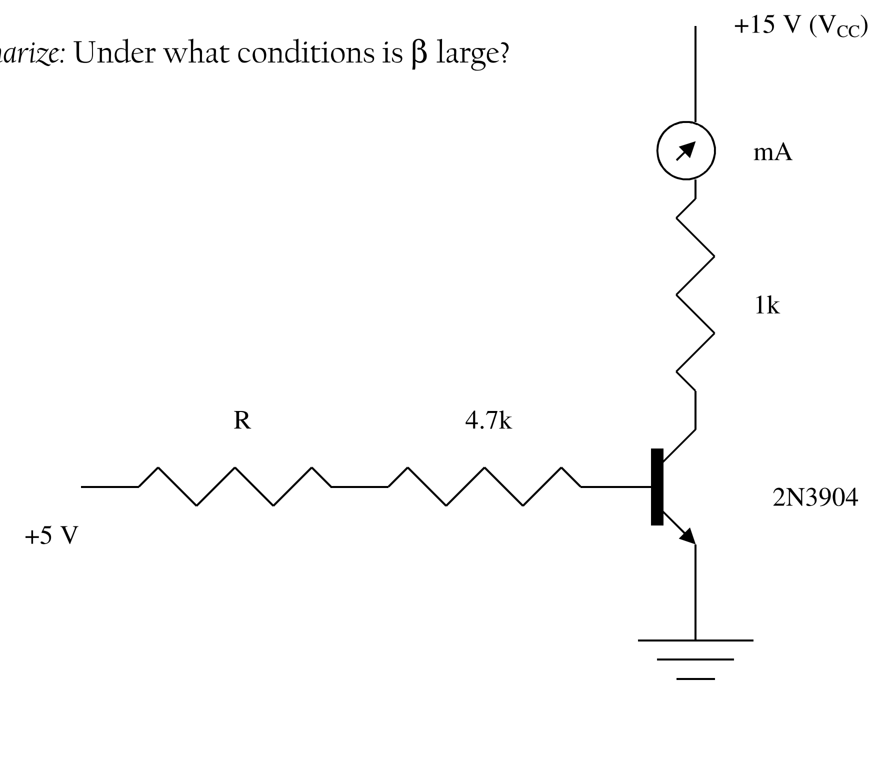
4-2 Direct measurement of transistor current gain

In order to measure the current gain for different I_B and V_{CE} values, set up the circuit below. Include another meter to measure V_{CE}. The goal is to measure I_C (the collector current) and V_{CE} (the collector-emitter voltage) for a number of different values of I_B. Then you can calculate β (h_{FE}) for each of those values.

To vary I_B, use different values for R (e.g. 0, 4.7k, 10 k, … 1 M). For each value of R you use, estimate the base current I_B, assuming that V_{BE}=0.6 V (alternatively, you could measure the voltage drop across the 4.7k resistor and calculate I_B); then measure I_C and V_{CE}. Calculate β (h_{FE}) for each of these measurements. Plot these values at the appropriate points on your characteristic curves.

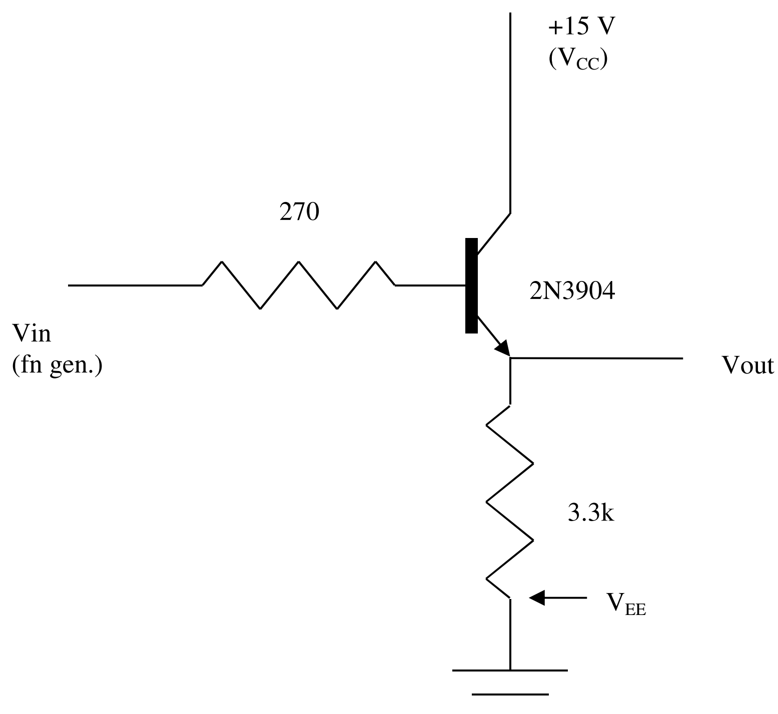
Does the maximum value for β agree fairly well with what the BK meter says β is for your particular transistor? Why is β sometimes considerably below this value? (Hint: look at what V_{CE} is doing.)

Summarize: Under what conditions is β large?



4-3 Emitter follower (common collector)
Build the circuit shown below (use a 2N3904). Drive it with a sine wave and look at the output with the scope. Try varying V_{in} from about 1 V_{pp} to about 10 V_{pp} and see how V_{out} changes.

For V_{in} of about 10 V_{pp}, sketch V_{in} and V_{out}. Describe the major differences between V_{in} and V_{out}, and explain what causes V_{out} to differ from V_{in} (be quantitative).



Now try connecting the emitter return (the point marked V_{EE}) to −15 V instead of ground and look at the output again. Why is there an improvement? (Hint: think about what's going on with V_B and V_{EE}.)

Is there any voltage gain (that is, is $V_{out}/V_{in} > 1$? Remember that V_{out} and V_{in} refer to amplitude, V_{pp}, or V_{rms}.) Is there any current gain? Explain your reasoning.

What causes the offset between V_{out} and V_{in}?

What is the range of V_{in} values for which V_{out} will "follow" V_{in}—that is, for which the output signal looks like the input signal with no distortion other than an offset?

<u>Impedances:</u> Leave V_{EE} at −15V. Replace the 270 ohm resistor with a 100k resistor (we will think of the signal generator plus this 100k as the Thevenin equivalent of a source with a high output impedance, this will make the overall output impedance of the source plus the circuit large enough to measure!). Using the values of the resistances in the circuit and the measured value of your transistor's β, predict the input and output impedances for the follower (don't include the

100k resistor in making your prediction for R_{in} and for R_{out}, treat the 100k as your source resistance).

Determine the input impedance (R_{in}) for the follower. (Hint: think of it as a voltage divider with the 100k resistor being one resistor and the follower (transistor ckt including the emitter resistor) being the other “resistor.”) Use a fairly small signal voltage.

Now determine the output impedance (R_{out}) by measuring V_{out} with a load of a 4.7 uF cap in series with a 1k resistor between V_{out} and ground and then measuring V_{out} with no load. (Such a capacitor is sometimes called a blocking capacitor. The blocking capacitor keeps the load from changing the DC biasing scheme while still having a very low impedance at frequencies in the kHz range—for example, a 4.7 μF capacitor has X_C=34 Ω at 1 kHz. We'll see a blocking capacitor on the input and output of the next circuit also.

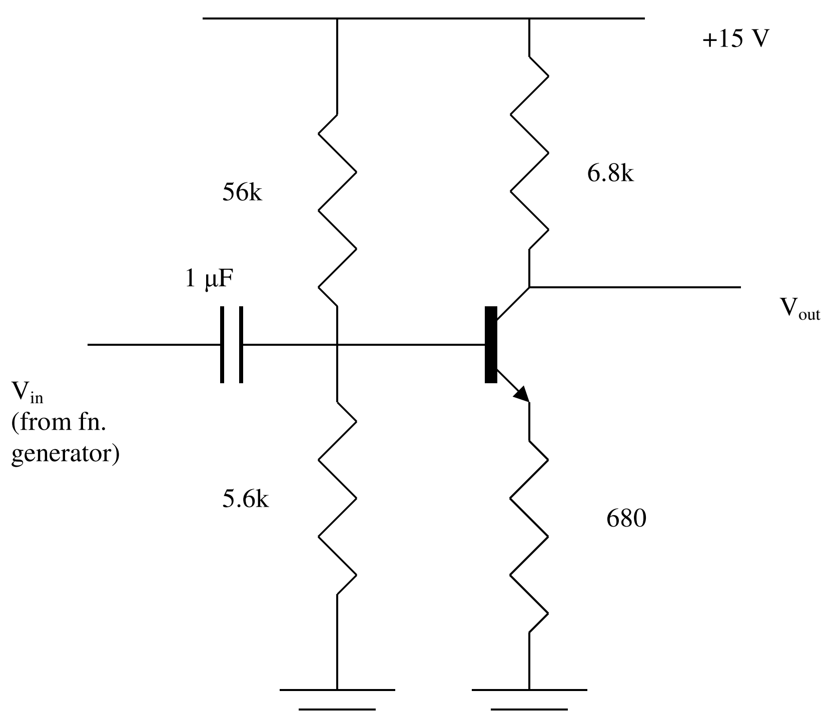
When you have experimental values for R_{in} and R_{out}, compare them to your predictions.

Summarize: What good is the follower, given that it doesn't produce any voltage gain?

Optional: Have me show you how to build a single-supply follower (one that will operate from a single +15 V supply over a range of several V without clipping.) Sketch the circuit, sketch V_{in} and V_{out}, and describe why this works better than the original follower circuit operating from a single supply.

4-4 Common emitter amplifier (single supply)

Build the common emitter amplifier shown below with a 2N3904. Predict the quiescent operating voltages (the voltages with no input signal) at the base, collector, and emitter. Measure them and compare to your predictions.



Predict this amplifier's voltage gain for a fairly small signal (about 1 V_{pp}), and then measure the gain and compare to your prediction.

Is the output inverted with respect to the input signal? Should it be, and why?

Is there any DC offset in V_{out} (that is, is the signal centered around a voltage other than 0V)? Should there be, and why?

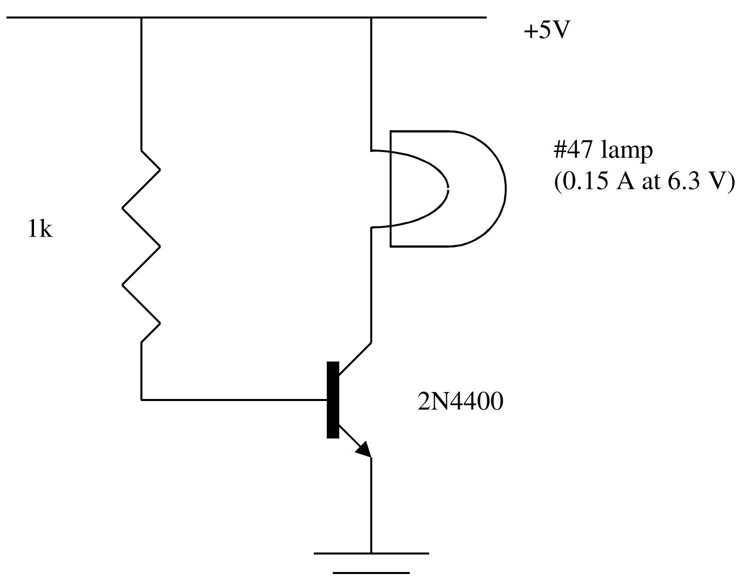
Increase the amplitude of the input signal till you see distortion or clipping on the output signal. At what input amplitude does this distortion first occur? Why does it occur there?

What is the purpose of the 56k and the 5.6k resistors? (Could you accomplish a similar thing by using a −15V power supply? Hint: think about what we did with the emitter follower.)

Measure the output impedance of the amplifier and compare with what you expect. Again, use an appropriate resistive load in series with a 4.7 microfarad capacitor.

4-5 Transistor switch

The following circuit illustrates the use of a transistor for switching rather than amplification. We provide enough base current to saturate the transistor—that is, to produce so much collector current that V_{CE} will be driven as low as it will go, close to 0 V, so that the transistor becomes essentially a short circuit. In this way, switching a relatively small current on and off can control a much larger current (in this case, through the lamp). We use a 2N4400, which is similar to the 2N3904, but can dissipate more power.



Turn the base current on and off by pulling one end of the resistor out of the breadboard. What happens?

Measure V_{CE} with the switch open and with it closed, and use the value with the switch closed to estimate the voltage across and the current through the lamp. (The lamp is a non-ohmic device, so a calculation of current using Ohm's law will be only an estimate; if you wish, you may measure the current directly, but an estimate should be good enough for our purposes.) Calculate I_B. Use your results to estimate the current gain β for the transistor. Now measure β with the BK meter. Why is the current gain of the transistor lower in this circuit than the BK meter indicates? (Hint: the answer is in section 4-2 of the lab.)