Lab 8: Bipolar Junction Transistors (BJTs)

Before you begin today's lab

- In this lab, we will use the variable "split" supply on your protoboard. Before you begin, use a multimeter and the knobs at the top of the protoboard to set V_+ (yellow rail) and V_- (blue rail) to $+15\,\text{V}$ and $-15\,\text{V}$, respectively.
- We will use two kinds of BJTs today, which look very similar. Make sure to check the part number on the flat face of the transistor (see Figure 1).

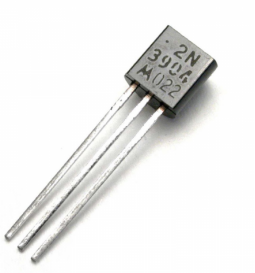


Figure 1: 2N3904 npn transistor.

Common-Emitter Amplifier

One of the most useful applications of BJTs is in *amplifying* signals. In a lab context, we will almost always use a convenient integrated circuit called an "operational amplifier" or "op-amp" for this purpose (more on this next week). But it's good to have some intuition for *how* op-amps amplify signals using transistor-based amplifier circuits like the one below.

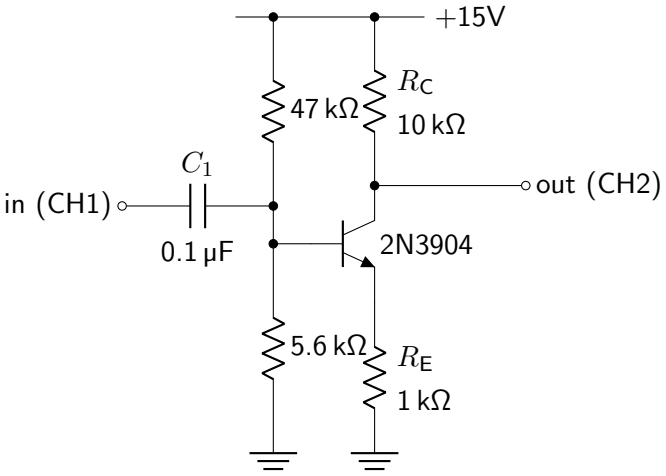


Figure 2: Common-emitter amplifier.

(a) What is the expected gain of the common-emitter amplifier of Figure 2?

$$G = \frac{v_{\text{out}}}{v_{\text{in}}} = -\frac{R_{\text{C}}}{R_{\text{E}}} = -10.$$

(b) What is the purpose of C_1 and the 47 kΩ/5.6 kΩ voltage divider?

(Hint: assume that the input voltage V_{in} is oscillating around 0 V.)

In lecture, we invoked a DC power source in series with the signal generator to provide a positive bias voltage at the base that ensured that the transistor would always be conducting. Here, since both our power supplies and our function generator are grounded, we cannot put them in series. Instead, we create a 1.6 V DC bias voltage using the voltage divider, and then AC couple the oscillating input signal through the capacitor (i.e., place a high-pass filter between the ground-referenced oscillating signal and the DC voltage divider).

(c) Build the circuit. There are a lot of components, so try to make your circuit readable (and laid out as similarly to the diagram as possible); don't be afraid to space it out across your breadboard!

(d) Drive it with a 1 kHz, 100 mVpp sine wave from the Siglent function generator. Observe the gain of the circuit by measuring the amplitude of the waveform at the input and output: first use DC coupling on the scope, which allows you to see the collector's DC quiescent point. Then switch channel 2 to AC coupling to get rid of the DC offset, so you can crank up the scope's sensitivity. How does the measured gain compare with expectations?

Hopefully it agrees! If you used 5% resistors, you might see a noticeable difference from the expectation due to the uncertainty of the resistor values.

(e) How does the common-emitter amplifier achieve power gain (more power in the output signal than was carried in the input signal)? Does it violate thermodynamics?

Of course we cannot violate thermodynamics! The additional power in the output was drawn from the power supply through the collector.

(f) Does an emitter follower, in contrast to a common-emitter amplifier, have voltage gain? Does it have power gain?

While the emitter follower did not have voltage gain (the amplitude in and out were the same), it did have current gain (by a factor of β). Since $P = IV$, it still has power gain.

This type of circuit underlies the magic of *operational amplifiers* (op-amps), which we will look at next time. You will rarely (if ever) build a common-emitter amplifier again, but it is good to know what's going on behind the curtain of the op-amp's incredible convenience. Of more relevance, you'll also be able to understand in depth, and accommodate, the (mostly minor) shortcomings of op-amps.