Lab 7: Introduction to Transistors: the emitter follower

- 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 $+15\,\mathrm{V}$ and $-15\,\mathrm{V}$, 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.

Emitter Follower

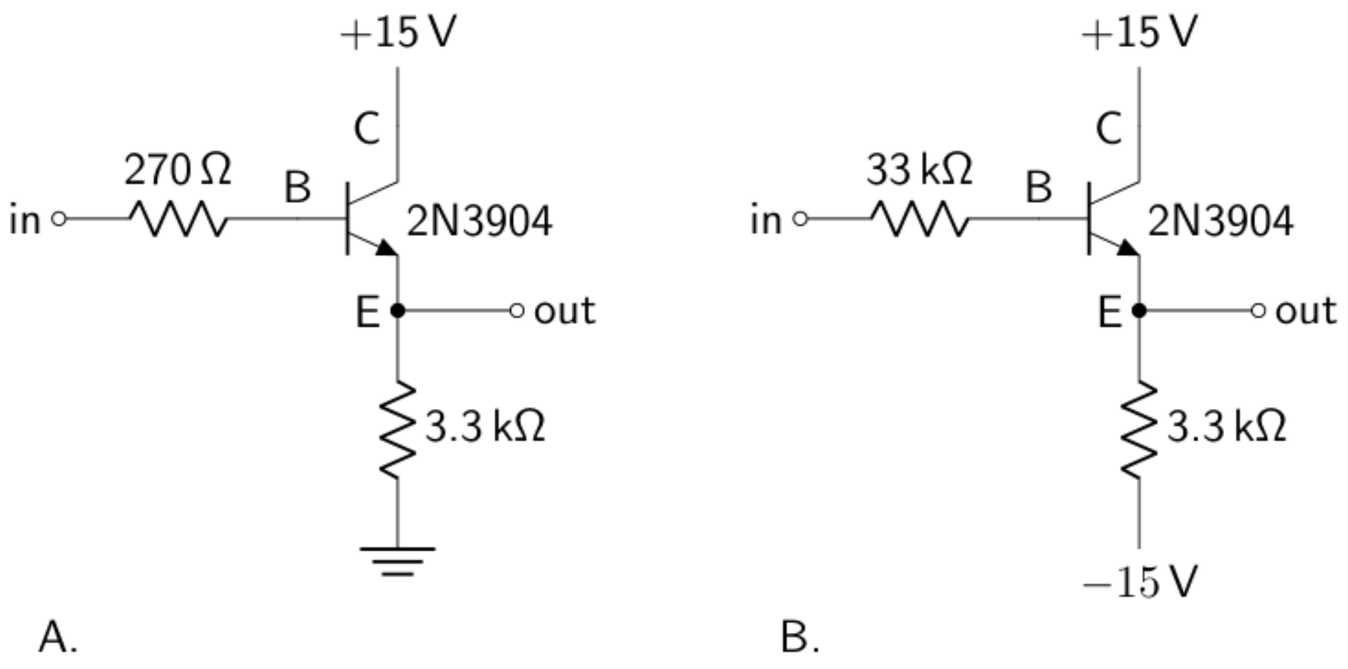
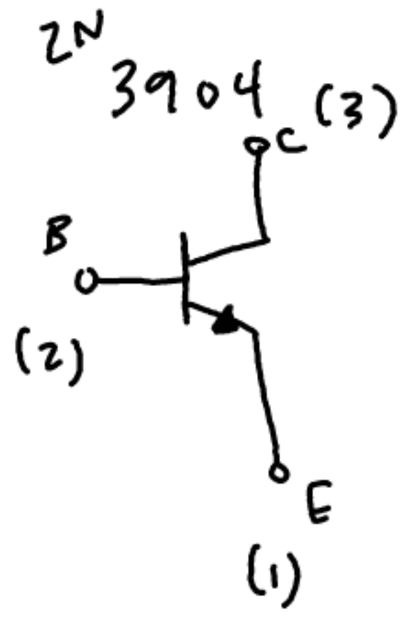


Figure 2: Emitter followers.

(a) Before you start, you need to know the pinout of the BJT, which is found in the 2N3904 datasheet (available on Canvas), in order to orient the part on the breadboard. Mark the pinout on the image above for your reference. Also find the DC current gain of the 2N3904 (which is interchangeably called β or h_{FE}). Do you see why we say that β is *approximately* 100?



β between 30-300

depends on the current drawn from collector design should not depend on a fixed value of β!

(b) Build the emitter follower circuit of Figure 2A.

(c) Drive the circuit with 1 kHz sine waves. Start with an amplitude of about 5 Vpp, and probe input and output with CH1 and CH2. In what voltage range can it "follow" the input, and why?

can only follow $0.6\,V < V_{in} < 15\,V$

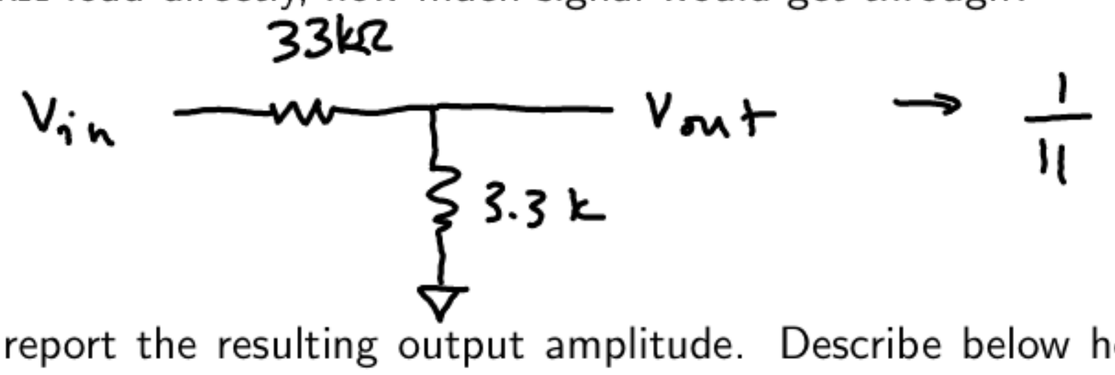
(d) Connect the emitter resistor (3.3 kΩ) to −15 V instead of ground. What happens, and why? Think about the direction of current flow.

need to move reference back to ground!

(not −15 V) ← −15 − +15 limit

$V_{out} = V_{in} - 0.6\,V$ no limits

(e) To learn what this circuit is useful for, add a 33 kΩ resistor in series with the signal input (Fig. 2B), thus simulating a "wimpy" signal source of relatively large source impedance. If a source with $R_s = 33\,k\Omega$ were to drive a 3.3 kΩ load directly, how much signal would get through?



(f) Try the circuit of Fig. 2B and report the resulting output amplitude. Describe below how the emitter follower's high input impedance and low output impedance fix the problem of trying to drive a 3.3 kΩ load with a 33 kΩ source.

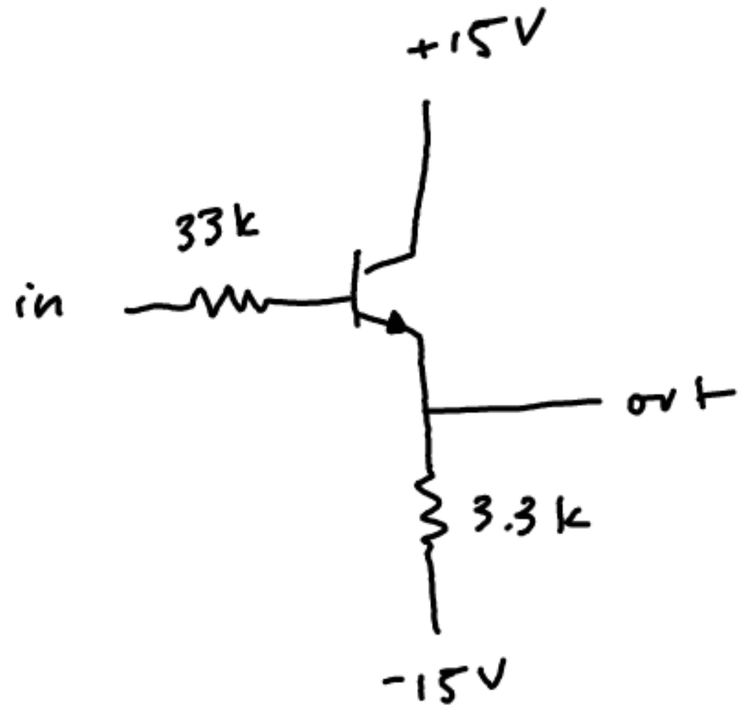
~ 1 V drop instead of 0.6 V drop.

$V_{in} = 16.6\,V$

$V_{out} = 16\,V$

Push-Pull Follower

(a) The emitter follower you have built, also called a Class A amplifier, dissipates a lot of power just to keep the output voltage at its so-called *quiescent point* near zero volts (i.e., the DC voltage where it rests with no signal applied). For the circuit of Fig. 2B, how much power is dissipated when $V_{\text{in}} = 0\,\text{V}$?



$P = IV$

$V_{in} = 0\,V \rightarrow V_{out} = -0.6\,V$

$P_R = \frac{V_R^2}{R} = \frac{(15 - 0.6)^2}{3.3\,k} = \frac{(14.4\,V)^2}{3.3\,k\Omega}$

$P_R = 0.0628\,W$

$= 62.8\,mW$

$P_T = I_E V_{CE} = \frac{14.4\,V}{3.3\,k\Omega} \cdot 15.6\,V = 68\,mW \rightarrow$ $P_{tot} = 131\,mW$

To remedy this, we will build what is known as a push-pull stage or Class B amplifier, which uses two complementary transistors: one to *source* current and one to *sink* current.

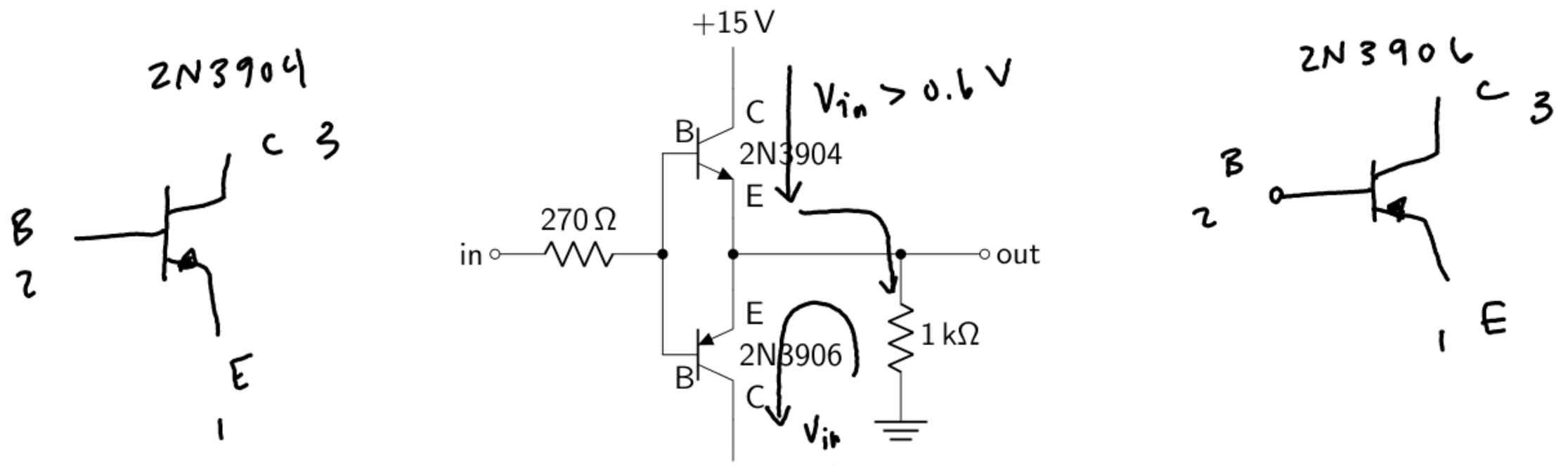
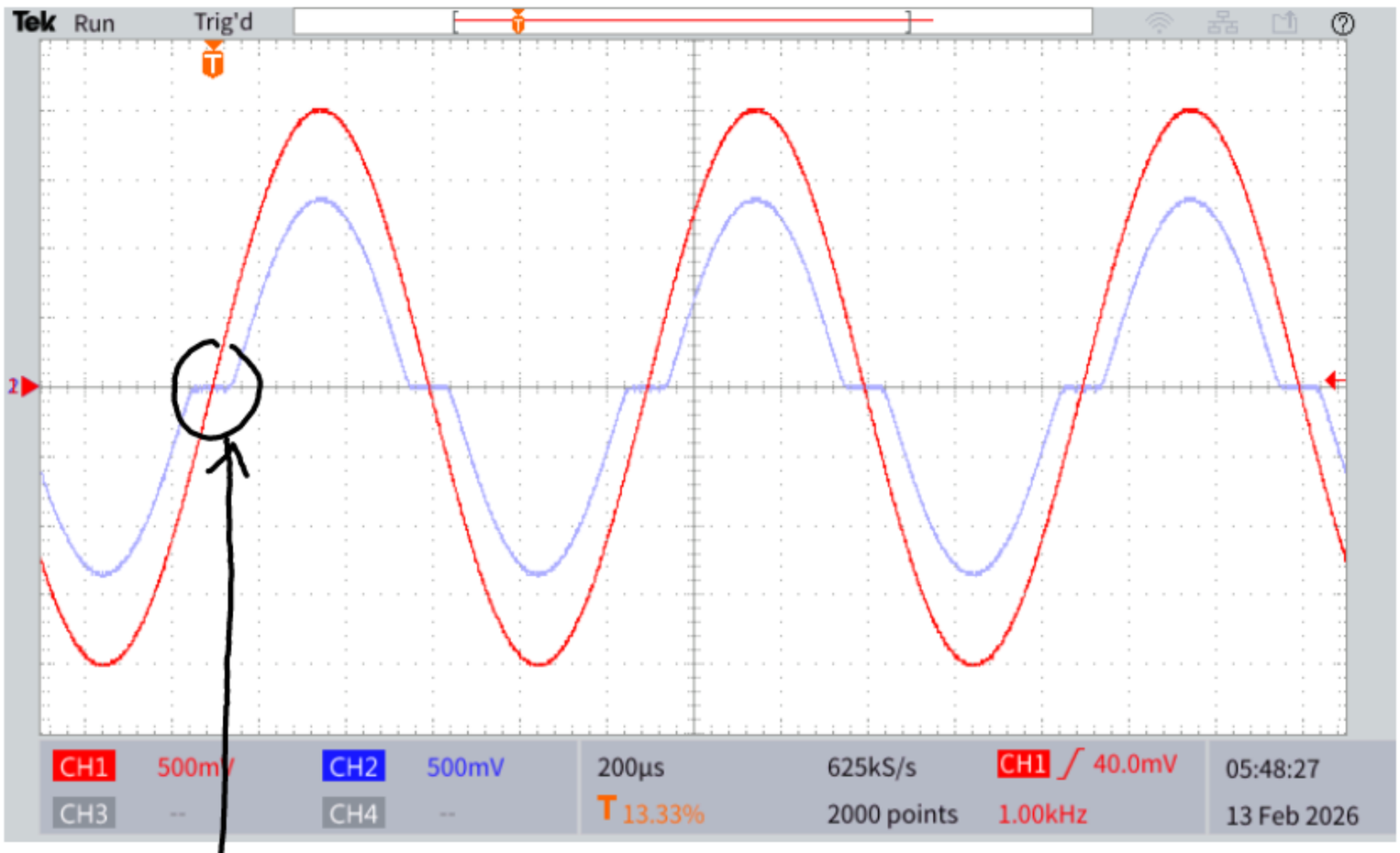


Figure 3: Push-pull emitter follower.

(b) On Figure 3, draw the direction of current flow when the input voltage is greater than 0.6 V. Then, draw the direction of current flow when the input voltage is less than −0.6 V.

(c) Build the circuit. The 2N3906 is a new type of component: a pnp transistor. Be sure to open the datasheet and closely examine the symbol and pinout (draw the pinout next to the circuit diagram if that helps). The terminal marked by the arrow is still the emitter, even though the orientation in the circuit is different from the npn.

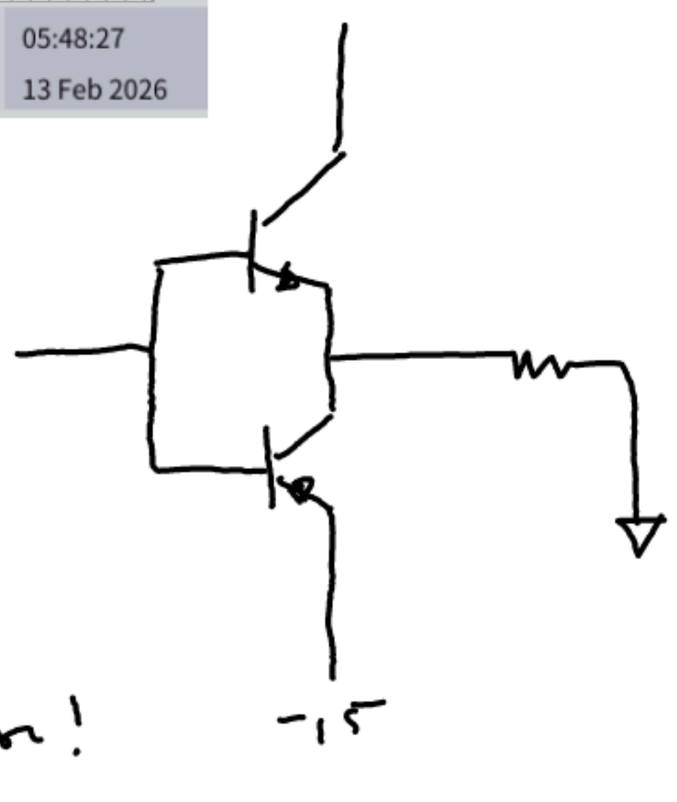
(d) Drive the circuit with a 100 Hz, 2 Vrms sine wave. Observe the output voltage on the scope and sketch it below. What is the limitation of this circuit as a "follower"? What causes this limitation, which is called *crossover distortion*?



crossover distortion

at $-0.6\,V < V_{in} < 0.6\,V$

$V_{in} = 0$ not large enough for flow from either transistor!



Keep your push-pull circuit built, as we will use it next time (and come up with a solution for the crossover distortion!) Use a different part of the breadboard for the remaining circuits in this lab.