Lab 9: Transistors II

Prelab

Watch this video on single transistor amplifiers. You will be building the second type (common collector / emitter follower) in lab.
https://www.youtube.com/watch?v=zXh5gMc6kyU

Q. Compare the input impedance of each amplifier type.

Q. Compare the output impedance of each type.

Q. Compare the voltage gain of each type.

Q. Compare the current gain of each type.

- Be sure you know the features of the common collector amplifier for the quiz.

Read the following article (in two parts):

http://amasci.com/amateur/transis.html
http://amasci.com/amateur/transis2.html

Q. Summarize your understanding of transistors as if you were trying to explain them to a fellow physics major. You should address their physical makeup as well as basic usage and behavior.

Reference diagrams

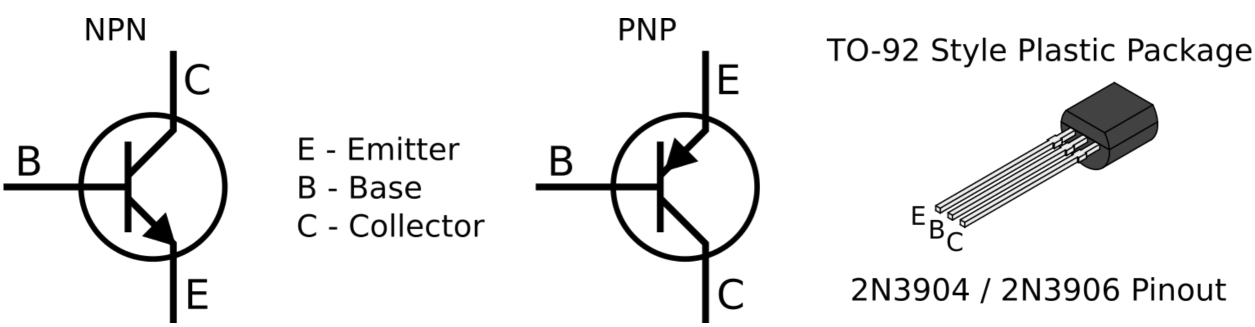

Figure 1: BJT (Bi-polar Junction Transistor) symbols and pinout.

Part I: Emitter Follower (Common Collector) Amplifier

Last week you used a transistor to turn a light on and off, that is, you were using it as a switch. This week you'll examine the ways in which a transistor can be used as an amplifier. The output voltage of the emitter follower circuit attempts to match the input voltage, but allows greater current. It is an impedance transformer, having a high input impedance (so as to not load the voltage source) and a low output impedance (so as to be able to provide larger amounts of current to a load).

1.1 Unbiased Emitter Follower

The first incarnation of this circuit which you will construct is shown in figure 2.

- Construct this circuit.
- Display the input on channel 1 (AC coupled) and the output on channel 2 (DC coupled).
- Set the function generator to the smallest possible output (using the -20dB setting) at a frequency of approximately 100 Hz.
- Answer the following questions as you increase the amplitude.

Q. Why do you initially see a total lack of signal on the output?

Q. At what input amplitude do you start seeing something on the output? Why this amplitude?

Q. What eventually happens to the top of the output as you keep increasing the input amplitude? Explain.

Q. Near the maximum input amplitude, what new feature appears on the output? Explain. (Hint: Consider the reverse breakdown voltage from the datasheet.)

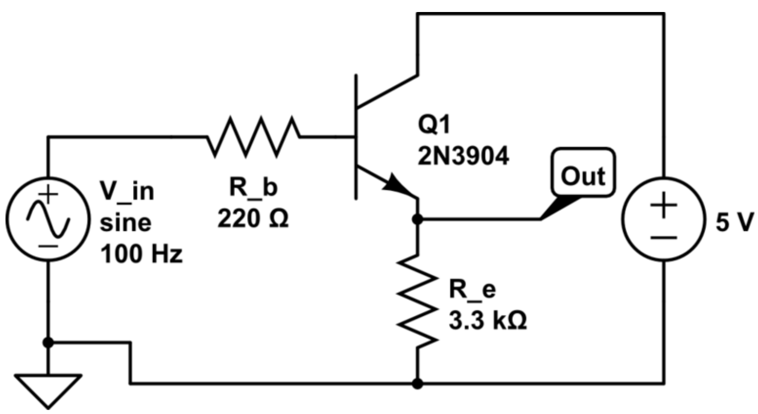

Figure 2: Unbiased Emitter Follower

1.2 Biased Emitter Follower (Common Collector Amplifier)

The unbiased emitter follower has several issues, such as not being able to output any negative voltages. Figure 3 shows a solution to this. The voltage divider formed by R1 and R2 is used to keep the transistor always on and to let the AC voltage ride on top of a constant DC voltage.

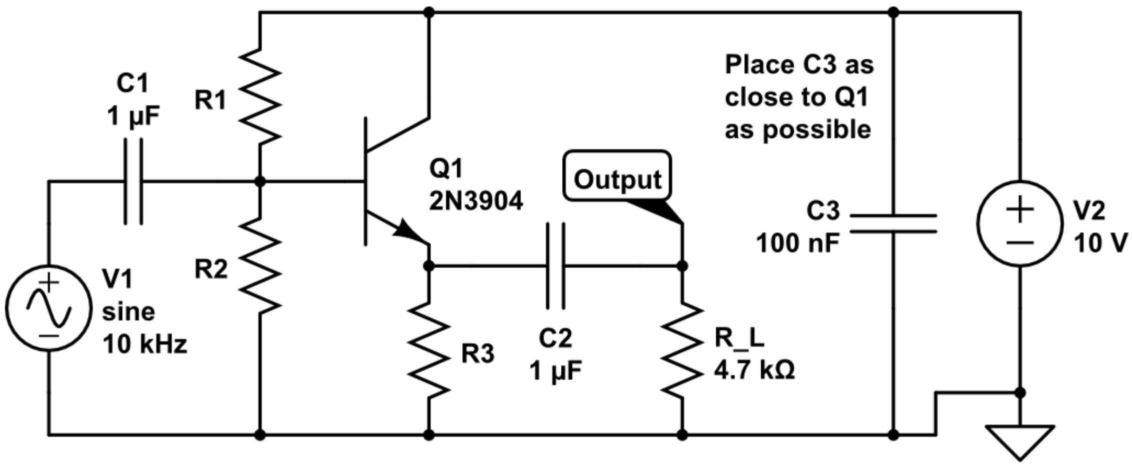

Figure 3: Biased Emitter Follower

1.2.1 Calculations

The following steps will guide you through determining appropriate resistor and capacitor values. The state of the circuit when only the DC voltage is applied is called the "quiescent point." **Record all calculations and values in your report.**

1. The goal of DC biasing is to have the emitter at $V_{cc}/2$ when no signal is applied (where V_{cc} is the collector voltage). This allows the maximum 'swing' for the signal. **Call this voltage V_E.**

2. Now that you know what you want V_E to be, **what would the base voltage, V_B, have to be?** (Recall the voltage for a diode drop is about 0.7 volts.)

3. The quiescent collector current is set by R3 and should be a small value, say 5 mA. Given that $I_C \approx I_E = I_3$, **what must R3 be?**

4. The base current, I_B, is given by I_C/β. Assuming a beta of approximately 100, **what is I_B?**

5. The current through R1 and R2 should be at least a factor of 10 larger than the base current to swamp out its effect on the voltage divider. Go ahead and use a factor of 20 (for extra margin) to **find this current, I_{12}.**

6. Given I_{12}, what must R1 + R2 equal? Given this, and V_B, **calculate the theoretical values for R1 and R2. What real world resistors get you the closest?** (Don't worry about combining resistors to try and get exact values, close is fine.)

You should now have values for R1, R2 and R3.

1.2.2 Construction and Testing

- Without connecting the function generator, construct the rest of the circuit **on the top half of your breadboard**. (This will leave room for the next circuit.)

Q. Measure the quiescent voltage at the emitter, V_E, and at the base V_B, and compare to the values you were aiming for.

Q. Use your multimeter to measure the quiescent current being provided by the power supply and calculate the quiescent power. (This is the 'wasted' power which would be minimized in a good design.)

- Connect the function generator set to the smallest amplitude using the -20 dB setting and at approx 10 kHz.
- Display the input (Cha 1, AC coupled) and output (Cha 2, DC Coupled, w/ averaging) on the scope. *(If you get lots of high frequency noise, try adding a 0.1uF capacitor between emitter and collector.)*
- Set up the trigger to use external triggering and connect the TTL signal from the function generator.

Q. What max peak to peak voltage do you expect the output will be able to replicate? (Think about the max ”swing”.)

Q. Increase the amplitude until you begin to see clipping on the output waveform. Measure the min and max voltage. Is the clipping symmetric?

Q. With your scope, examine the voltage at the emitter. Describe what you see and how it relates to the biasing.

Q. What effect does C2 have?

Keep this circuit on your bread board, you'll need it for the next section!

Part II: Emitter Coupled LC Oscillator

One of the key features of an amplifier is the ability to feed part of the output back into the input, thereby causing the circuit to perpetually oscillate. Without this feedback, any oscillations would quickly die out. This how to turn DC into AC. Figure 4 shows one method using an LC tank circuit as a bandpass filter to pass back a specific frequency for amplification.

You might be wondering how the oscillations get started in the first place. This is one case where noise is actually a requirement for proper operation. When power is connected, there is are startup transients and bits of noise which could be mathematically decomposed into a wide range of frequencies. The tank circuit filters out specific frequency components from the noise and feeds those back in, initiating the feedback loop which quickly reaches the steady state condition.

Note that this circuit uses a negative DC voltage! Use the negative rail on your breadboard power supply.

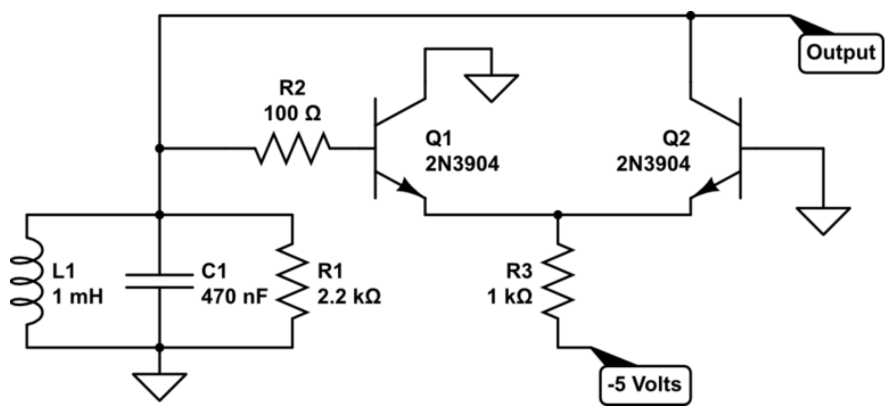

Figure 4: Emitter Coupled LC Oscillator

Q. Recalling the formula for the resonant frequency of an LC tank circuit (and using the measured values of your components), what frequency do you expect this circuit to oscillate at?

- Construct the circuit and examine the output on your scope (Cha 1, DC coupled, averaging, trigger on cha 1).

Q. Measure the peak-to-peak voltage and the frequency. Compare the frequency to what you expected.

- Now connect a 100 Ohm load to the output.

Q. What does this do to V_{out}? The loaded voltage is what percent of the unloaded voltage?

Oscillator circuits can only drive a very small load (that is, they have a very high output impedance). This is why they are usually fed into an amplifier (high input impedance, low output impedance).

- Remove the 100 Ohm load resistor.
- Connect the output of this circuit to the input of the emitter follower. *(Also be sure to connect the grounds of the two circuits together, if you get lots of high frequency noise, try adding a 0.1uF capacitor between emitter and collector on the emitter follower circuit.)*)
- Remove the 4.7 kΩ load from the emitter follower.

Q. Measure the no-load output peak-to-peak voltage of the oscillator and the emitter follower.

- Connect the 100 Ohm load to the output of the emitter follower.

Q. Once again measure the output peak-to-peak voltage of the oscillator and the emitter follower.

Q. When the load is added to the emitter follower, the output of the oscillator drops by how much? What percent of the unloaded value is the new value?

Q. By how much does the output of the emitter follower drop? This loaded voltage is what percent of the unloaded voltage?

Q. Explain the results in terms of input and output impedances.