Lab 9: Transistors II

Prelab

Read the following article (in two parts):

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

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.

Reminder: Read whole paragraphs before starting any of the instructions.

Reference diagrams

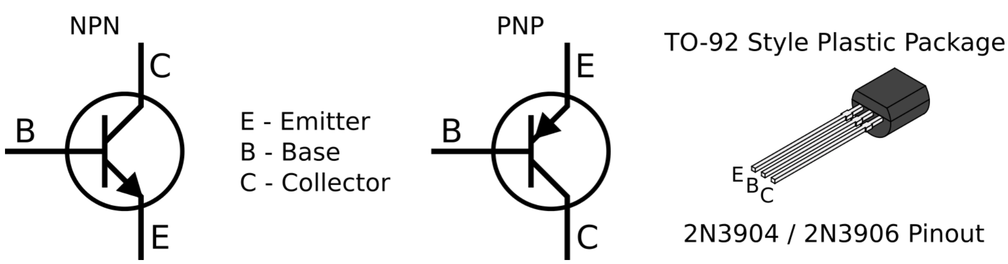

Figure 1: BJT (Bi-polar Junction Transistor) symbols and pinout.

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 emitter follower tracks the input voltage, but allows greater current. It is a 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. Display the input and output on the scope. Set the function generator to the smallest possible output (using the -20dB setting) and slowly increase the amplitude all the way to the maximum possible value. *Explain the various outputs you see and include pictures in your report. (There should be at least 4 distinct things to explain, starting with why you don't initially see any output.) What are the* *constraints on the output?* (Tip: Use the measure menu to display the max and min values for each channel.)

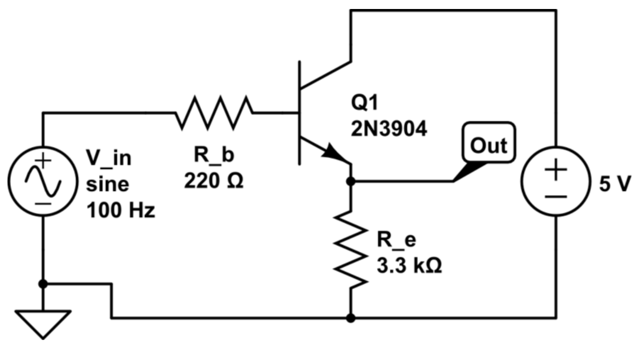

Figure 2: Unbiased Emitter Follower

1.2 Biased Emitter Follower

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.

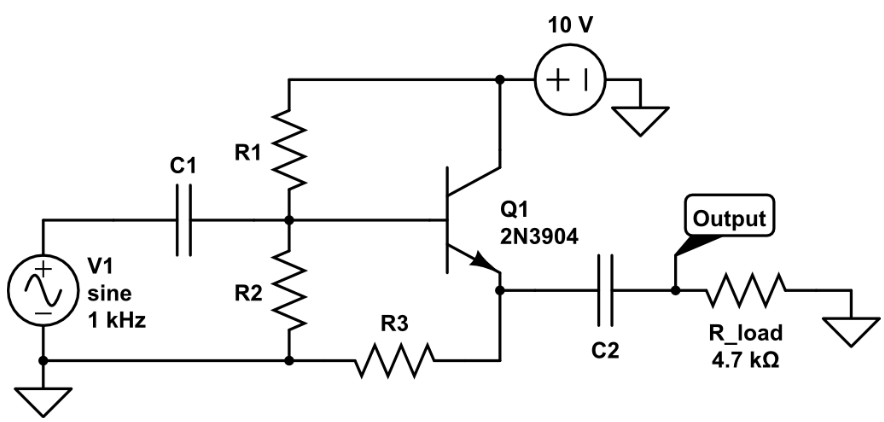

Figure 3: Biased Emitter Follower

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 the DC biasing is to have the emitter at $V_{cc}/2$ when no signal is applied. 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 to find this current, I_{12}

6. Given I_{12}, what must R1 + R2 equal? Use that and the voltage divider equation to find R1 and R2 (or apply Ohm's law). What real world resistors can you use?

7. The input impedance of the transistor is approximately $R3 \times \beta$, call this Zin(trans).

8. From the point of view of the AC signal, both DC ground and Vcc are "signal ground". This means R1, R2 and the input impedance of the transistor are all effectively in parallel. Calculate this value, Req. The capacitor C1 combined with Req forms a high pass filter. C1 is required to separate the DC voltage from the function generator, but since there is a high pass filter at the input, the signal will become attenuated at low frequencies. Recalling that the cutoff frequency is given by $f = 1/(2\pi RC)$, calculate what capacitor value you need for a cut off frequency at 200Hz. Choose the next higher real world value.

9. The capacitor C2 forms a high pass filter with the load, determine what capacitor value will put the cutoff frequency for this filter at 200 Hz or lower.

Now that you have all the values, construct the circuit but don't yet attach the function generator.

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

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) and display the input and output on the scope. (If the signal is really noisy try putting a 1000 pF capacitor in parallel with the collector and emitter.)

What max peak to peak voltage do you expect the output will be able to replicate? Increase the amplitude until you begin to see clipping on the output waveform. Compare this value with the expected. Is the clipping symmetric?

Examine the voltage at the emitter. Describe what you see and how it relates to the biasing. What does C2 do?

Decrease the frequency to 200 Hz. What fraction of the input voltage is the output at? What would you expect?

Keep this circuit on your bread board for now, 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, initiated 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.

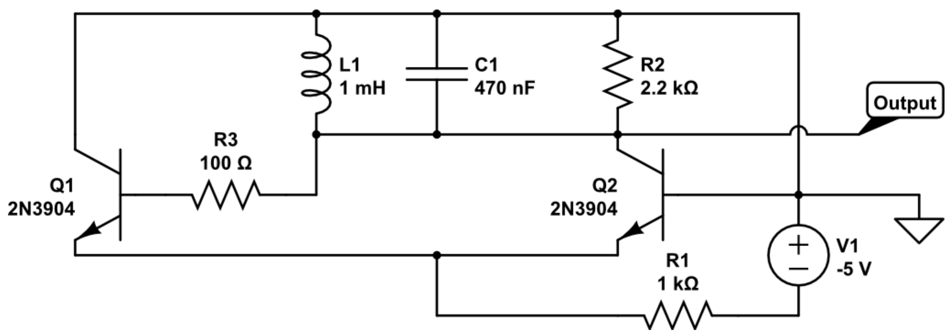

Figure 4: Emitter Coupled LC Oscillator

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.

Measure the peak-to-peak voltage and the frequency.

Now connect a 100 Ohm load to the output. *What does this do to the output voltage? What fraction of the unloaded voltage is the loaded voltage?*

Oscillator circuits can only drive a very small load, which is why they are usually fed into an amplifier.

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.) *Measure the output voltage without a load. Connect the 100 Ohm load and compare to the unloaded voltage. What fraction of the unloaded voltage is the loaded voltage?*

Explain the results in terms of input and output impedances.

Part III: Curve Tracer

In prior labs you've created plots of current vs voltage by painstakingly measuring many data points. Now you'll build a circuit which can quickly display the IV curve for any component.

3.1 Setup

The curve tracer works by measuring the voltage across the device under test (DUT) on channel 1, and the voltage across the 1 kΩ resistor on channel two. For this to be possible, the varying

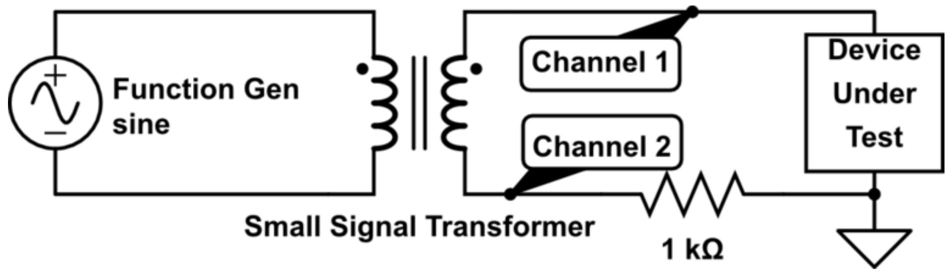

Figure 5: Curve Tracer Setup

voltage signal must be floating with respect to the scope ground, which is achieved by decoupling the function generator signal through a transformer.

- Use the small yellow transformers called "1:1 audio transformers" to electrically separate the function generator from the circuit. These will output almost the same voltage as what is input.
- Use one of the blue 1% 1 kΩ resistors
- Setup the circuit such that there is a place to easily connect and disconnect various components for testing
- Set both scope probes (and channels!) to 1X mode and DC coupling
- Start with the function generator set at about 150 Hz and the amplitude set to maximum

3.2 Normal (YT) mode

1. Connect a 1N4148 small signal diode as the device under test (with the low side toward ground).
2. Under the channel 2 menu, set Invert to On. *Explain why this needed.*
3. Channel one displays the voltage across the component, while channel 2 displays the voltage across the 1k resistor. *What current would 1 volt across the 1k resistor correspond to?*
4. *What max voltage do you measure on channel 1? Explain this value.*
5. *What max voltage do you measure on channel 2? What max current does that correspond to?*

3.3 Parametric (XY) mode

While viewing the voltage and current as a function of time can be useful, we would like to show current as a function of voltage. This can be done by having the scope plot channel 2 vs channel 1.

1. Under "Display" change the format to "XY" increase the "persist" to 1 second.
2. Under the menu for each channel, changing "coupling" to "Ground" (one channel at a time) will allow you to see where the zero point is. Center the zero point point for each channel.

3. The cursors and measure menu don't work in XY mode, *estimate the max voltage and current for the diode by eye and compare to the measured values from YT mode.*

4. *Include a picture of the IV curve in your report.*

3.4 Additional Components

Test the following components. Include pictures of all outputs in your report.

- 5.6V Zener diode (1N5232). *Approximate the forward and reverse breakdown voltages.*
- Red, Green and Blue diodes. *What are the breakdown voltages for each?*
- 100 Ohm resistor *What is the slope of the line? How does the slope relate to the resistance?*
- 0.33μF capacitor. *What shape is made? Why? What effect does changing frequency have? Explain the behavior with changing frequency using the fact that you are applying a voltage of the form* $v(t) = A\sin(\omega t)$ *and that the current through a capacitor is* $i(t) = Cdv/dt$.
- 1000 μH inductor. *What shape is made?* (You will need to significantly increase the frequency to see it.) *What effect does changing the frequency have, how does that compare to the capacitor? Explain using the equation for the current through an inductor,* $i(t) = (1/L)\int v(t)dt$.
- NPN Transistor (2n3904). (See the following steps)
  - Set the frequency back to about 150 Hz.
  - Connect the emitter to ground. Connect both the base and collector to the channel 1 node.
  - In this setup the base is going both above and below the emitter. *What voltage breakdowns do you observe? Compare the reverse voltage breakdown to the data sheet.*
  - Continual reverse breakdown of the base-emitter junction will damage it. Install a protection diode (1N4148) from emitter to base/collector which the negative (low) side of the diode connected to the base/collector. *Explain how this prevents the reverse breakdown of the base-emitter junction.*