Physics 323

Experiment # 7 - Transistor Biasing

Purpose: You will build 2 amplifying circuits that are based on the pnp transistor that you studied last week. In doing so you will need to *bias* the transistor so that it is maintained at a specified *operating* or *Q point.*

Reference: Storey 4e, pp. 403-407, pp. 412-432

Prelab- Simple Base Resistor Biasing

Our output Q-point will be $-I_C = 1.2$ mA and $-V_{CE} = 7.0$ V. Locate this point on your output characteristics from last week. You have several $-I_B$ curves; what value do you estimate that $-I_B$ would have had to intersect the specified ($-I_C$, $-V_{CE}$) point? How does it compare to 1.2 mA / h_{FE}?

As you saw when dealing with op-amps the DC *power supply voltages* play an important role and actually provide the energy to the output. In Fig. 1 we show the power supply (V_CC or V_{CC}) connected to the collector resistor. Set V_{CC} =-15 V. In addition to providing power to the output we would like to use V_{CC} to supply the base current that you calculated in the previous paragraph.

For the sake of argument suppose that you have h_{FE}=100 (please use your value for the actual calculation), so if the effect of the output admittance h_{oe} is fairly small then you expect $-I_B$=12 μA. Now consult your input curves: what is the value of $-V_{CE}$ that would give you $-I_B$=12 μA? (in the sample data in Experiment #6 it looks like $-V_{CE}$= 0.155 V). Select a base resistor that will give the desired $-I_B$ = 12 uA for $V_{CC} - V_{CE}$ = -14.85 V: R_B=1.24 MΩ. Now select R_C to give the proper V_{CE}. The potential drop from V_{CC} to the collector should be 8 V and the collector current running through R_C is -1.2 mA. Choose R_C =6.7 kΩ for *this particular transistor and Q-point.*

Repeat this analysis to calculate the proper values of R_B and R_C for your transistor. You will all have the same values for $-I_C$, $-V_{CE}$, and $-V_{CC}$ but your other values should differ.

Lab: Q-point

Construct the circuit in Fig. 1 with your calculated values for the resistors (start without the wave generator and the load). You will likely need to use combinations of resistors. Use the Simpson meter to verify that the base current is correct. Use your multimeter to verify the other values of the transistor *Q-point.*

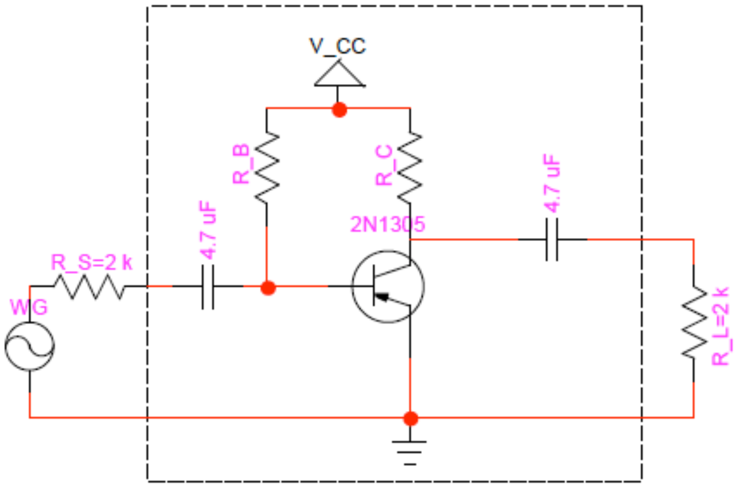

Figure 1: Single base-resistor amplifier circuit. The AC source and load are explicitly shown outside of the dashed box. See the text to see when they are added.

Prelab

The theoretical value of the ideal small signal voltage gain is $-g_m R_C$. g_m is the *transconductance* defined as $i_c = g_m v_{be}$. It can be calculated from your characteristics as h_{FE}/h_{ie}. h_{ie} is the small signal input resistance at the operating point i.e. $(dI_B/dV_{BE})^{-1}$. You could make a theoretical calculation based on the diode model $I_B = I_{sat}\exp(40\ V_{BE})$ but I would like you to calculate it from the curves obtained in Experiment #6.

Predict the small signal voltage gain for the non-loaded case. Also predict the loaded case where you take the voltage gain to be v_l/v_s, i.e. the source to load voltage gain.

Lab- Gain and low frequency cut-off

1. Connect the wave generator without R_S and R_L i.e. the non-loaded case. Use a frequency of 2 kHz and an input signal small enough that you don't see distortions of the output. What is the voltage gain (with correct sign)? What is the maximum size of the output before distortions become evident?

2. The capacitors are in place to block DC signals so that the Q-point is not affected by the input or the load (high-pass filters). They are called *coupling capacitors.* To isolate the effect of the input coupling capacitor measure the output "in front" of the output capacitor. This would be at the collector. Use the AC mode of the oscilloscope. Turn the frequency down to measure f_{3dB}.

3. Now include the source and load resistors and measure the loaded voltage gain at 2 kHz. You should also be able to measure the *current* gain. The input current can be determined by measuring the voltage difference across the source resistor. If v_s is

the voltage at the node between the wave generator and R_S and v_i is the voltage at the node between R_S and the input coupling capacitor then[1]

$$i_s = \frac{v_s - v_i}{R_S}$$

The current through the load is simply $i_l = v_l / R_L$.

4. Determine the input and output resistance or impedance of the amplifier. If you consult the chapter on amplifiers you can see how this is done by treating the amplifier as an equivalent circuit. You already have the measurements to obtain $R_i = v_i / i_s$. The output resistance is a bit trickier. Make a measurement of the open circuit output voltage (like you did in Exp. #1) by removing the load resistor. Call this $v_{o,\mathrm{OC}}$. The output voltage with the load resistor is v_l. Then

$$R_o = \frac{R_L\left(v_{o,\mathrm{OC}} - v_l\right)}{v_l}$$

Prelab- Feedback amplifier

You will now make some improvements to the earlier design where the specific value of h_{FE} will not be so crucial to the final operation. This improved design is shown in Fig. 2.

The first improvement is to the input bias. Rather than injecting a current we will use a voltage divider to fix $-V_{\mathrm{B}}$.

The second improvement is to use feedback to sense and maintain the desired value of $-I_{\mathrm{C}}$.

R_{E} is used to provide the feedback. The collector current and emitter current are essentially identical. If some change in conditions makes $-I_{\mathrm{C}}$ increase then $-V_{\mathrm{E}}$ will also increase. This will reduce $-V_{\mathrm{BE}}$, which will reduce $-I_{\mathrm{B}}$ and $-I_{\mathrm{C}}$. Since the initial change in output is reduced we have negative feedback. We would like $-V_{\mathrm{E}}$ to be large enough that it can change sufficiently to provide the feedback. Since we are interested here in demonstrating the effect let's choose $-V_{\mathrm{E}}= 1$ V. For $-I_{\mathrm{C}} = 1.2$ mA we would want $R_{\mathrm{E}}=0.833$ kΩ. 820 Ω is the closest available value so we will choose that. This would give $-V_{\mathrm{E}}= 0.98$ V. The germanium-based transistor will operate with $-V_{\mathrm{BE}}\approx 0.2$ V so we want $-V_{\mathrm{B}}= 1.18$ V. This is 0.079 times V_{CC} so suitable voltage divider resistors to give $R_2 / (R_1 + R_2) = 0.079$ are $R_1=100$ kΩ and $R_2=8.2$ kΩ.[2]

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[1] There is neat way to measure $v_s - v_i$ directly. Connect Channel 1 to v_s and Channel 2 to v_i. Make sure the "V/div" is the same for both channels. Then "INVERT" Channel 2 using a control on the oscilloscope and switch to "ADD" mode. The resulting trace is $v_s - v_i$.

[2] There is another condition here on the maximum value of $R_1 + R_2$ that is more fully explained in Exp. #8 and in class.

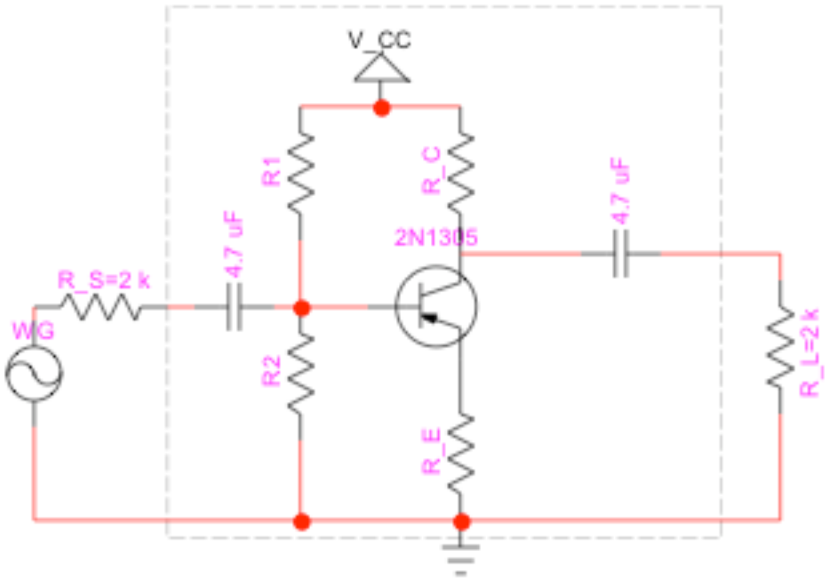

Figure 2: Series feedback amplifier

The last element to choose is R_C. **Calculate it** so that $-V_{CE}$=7.0 V.

What is the predicted source to load gain of this circuit? What is the predicted ideal voltage gain? What approximations are appropriate to use?

Lab- Properties of feedback amp.

Now make measurements similar to what you did before to verify the Q-point, the low frequency cutoff, the ideal voltage gain (i.e. the non-loaded voltage gain), the maximum output signal swing, the loaded voltage gain, the loaded current gain, and the input and output resistances.

There is a way to have high gain and a stable Q-point. Put a 100 μF capacitor in parallel with R_E (make sure the polarity is correct; the emitter is negative relative to ground). Measure the ideal voltage gain at 2 kHz. This is called a *decoupling* capacitor. (Yes, this does introduce another frequency, but we will investigate that next week).

You will be using the same basic circuit next week so just have the lab instructor sit this one aside.

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