Physics 623

Transistor Characteristics and Single Transistor Amplifier

Sept. 8, 1997

1 Purpose

- To measure and understand the common emitter transistor characteristic curves.
- To use the base current gain (β), and load line analysis to predict and experimentally to verify the DC operating point (often called the "Q point") for your transistor in the common emitter configuration.
- To predict, using the transresistance model, the AC properties of your amplifier circuit and to verify them experimentally.
- To distinguish between current and voltage driven base signals.
- To understand the effect of emitter resistor by-pass (degenerative feedback) through a transresistance analysis.

2 Procedure

1. **Characteristic Curves** (common emitter)

   The first step in this experiment is to measure and record the common emitter characteristic curves for a silicon NPN 2N1480 transistor. These are diffused junction transistors with a fairly small base current gain.

   (a) Your lab instructor will illustrate the basic principles of operation of the Fairchild 6200 curve tracer and you will then photograph the resulting curves.

   (b) Be sure to record the appropriate scale readings for your transistor for later analysis. Note also the wide variation between your transistor and those of your neighbors. In the Appendix we give the specifications for this transistor as listed by the manufacturer.

   (c) Compare your measured β (β is sometimes called h_{fe} on the spec sheet) to the range given on the spec sheet.

2. **The "Q point" (or DC quiescent point)**

   So far we have been concerned only with the properties of the transistor itself. In practical amplifier applications, it is desirable to design a circuit whose properties are predictable, ie which don't depend strongly on your accidental choice of a specific transistor. In Fig. 1 we show a very common configuration of base and emitter biasing for the common emitter configuration of amplifier. This circuit is reasonably stable against variations in transistor properties (for $\beta = h_{fe}$ ranging from 14 to 40, the Q point stays within 20% of $V_{CE} \simeq 6.5\,V$).

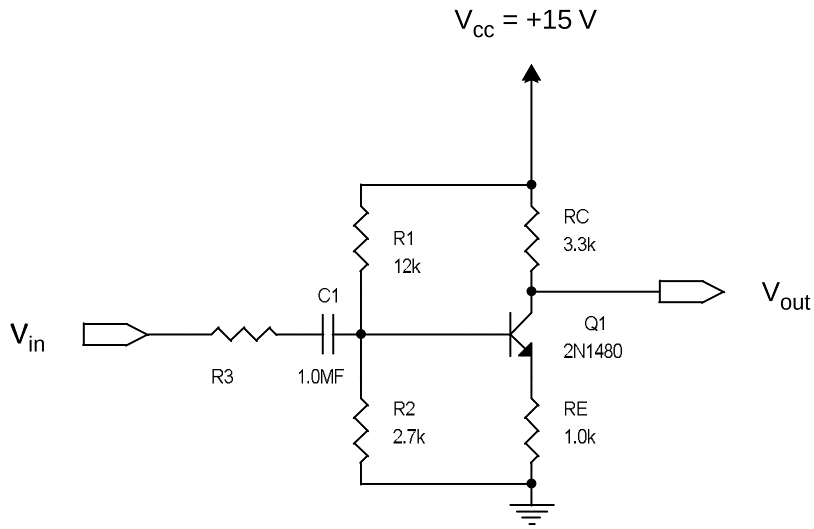

Figure 1: Basic Single Transistor Amplifier

3. Before you connect your circuit, predict what the DC operating point (Q point) will be. This may be done in the following way:

   (a) Construct the Thevenin equivalent circuit for the base bias circuit.

   (b) The base-emitter voltage drop for a turned on Si transistor is 0.6 V. Therefore

   $$V_E = V_B - 0.6\ V$$

   (c) The emitter current I_E, will be $I_E = \frac{V_E}{R_E}$ from Ohm's law. The base current $I_B = \frac{I_E}{\beta}$. You can load your Thevenin equivalent of the base bias circuit with the current I_B and calculate a new V_B. You could solve these equations simultaneously to get the exact operating point, but this is seldom necessary. If the design is good (meaning not too sensitive to β, a single iteration will yield a very accurate approximation to the operating point.

   (d) Using Ohm's law, calculate I_E, and, thus I_C, since they are about the same.

   (e) From the equation for the collector-emitter circuit:

   $$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

   calculate V_{CE}. You have now determined the DC operating point (the Q point). The equation for the load line can be written (assuming $I_C = I_E$),

   $$I_C = \frac{(V_{CC} - V_{CE})}{(R_E + R_C)}$$

4. Draw the load line on your characteristic curves and mark your calculated Q point.

5. Next connect the circuit as shown schematically in Fig. 1. Be sure to check the transistor base diagram at the end of the transistor data sheet. (**Transistors** are normally drawn as if you were **looking at the transistor leads from the lead side** while integrated circuits are normally drawn as if you were looking at the pins from above the circuit board, ie from the side away from the IC pins.) Measure V_{CE},V_E,V_B, and V_{BE} and compare with your calculated values. (They should agree within $\sim$ 10%). *Note: A layout similar to that shown in Fig. 3 will require few changes to complete the investigations.*

6. **AC properties.** Three important parameters determine the AC behavior of the amplifier. They are

   - the input impedance (r_i),
   - the output impedance (r_o) and
   - the voltage gain ($A_v = v_o/v_i$).

   Before actually measuring these quantities, it is enlightening to estimate them.

   Use the transresistance model, in which the transistor is replaced by an equivalent circuit containing a current generator $i_c = \beta i_b$ in series with the base emitter resistor r_{tr} (called the transresistance). The equivalent circuit is shown in Fig. 2. By differentiating the basic diode equation (for a p-n junction), it has been shown in class that the dynamic base emitter resistance or "transresistance" is inversely proportional to the current I_E.
   $r_{tr} = \frac{\partial V}{\partial I} = \frac{0.026\ ohm/A}{I_e}$.

   > [This is commonly expressed in mixed non-SI units by measuring I_E in milliamps $I_{E(mA)}$ and expressing the ratio as; "$r_{tr} = \frac{26}{I_{E(mA)}}$". However, we prefer you to avoid this expression and use the normal equations given above and below with consistent SI units as $r_{tr} = \frac{0.026\ ohm/A}{I_E}$ which is the same as $r_{tr} = \frac{0.026\ volt}{I_E}$.]

   Thus, the transresistance is:

   $$r_{tr} = \left(\frac{0.026\ \text{ohm}/A}{I_C} + 2\ \text{ohm}\right)$$

   where we have assumed $I_C \simeq I_E$ and the "2 ohm" is a rough average value for the ohmic resistance (r_b) between the lead and the base emitter junction. Note that an AC signal introduced on the base lead can pass to AC ground through three paths, R_1, R_2, and through the transistor. So, r_i (input impedance) is calculated (with "$\|$" meaning "in parallel" so you add reciprocals to get the reciprocal of the combination) as:

   $$r_i = R_1 \parallel R_2 \parallel (r_b = \beta(r_{tr} + R_E))$$

   The AC voltage gain is:

   $$A_v = \frac{v_o}{v_b} = \frac{i_c R_C}{i_c(r_{tr} + R_E)} = \frac{R_C}{(r_{tr} + R_E)}$$

   The output impedance $r_o = R_C$ in this approximation.

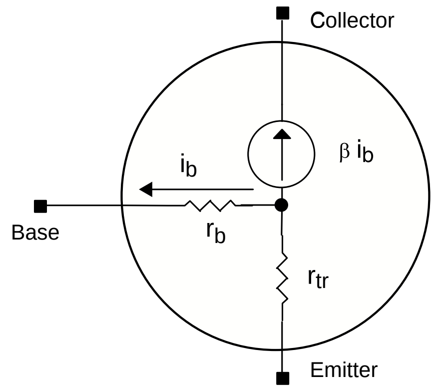

Figure 2: Transresistance Model Equivalent Circuit

7. (a) Now introduce a AC signal (a sine wave from the waveform generator) of frequency $f = 5\ KHz$ into the base through a coupling capacitor $C_c \geq 1.0\ \mu$F and measure r_i, A_v and r_o. To measure r_i , introduce a series resistor (R_3), and calculate r_i using the voltage divider equations.

   (b) Vary the magnitude of the input signal and note any distortion in the output signal which results.

   (c) Interpret the distortion using the output characteristics and the load line.

   (d) Measure the frequency response (or band width) of your amplifier ($A_v(\omega)$) and try to identify the lower corner frequency in terms of the component values.

8. **Emitter Resistor Bypass ... Current and Voltage Drive.** To have a true common emitter configuration for an amplifier, the emitter resistor R_E, is bypassed by a large capacitor ($\sim$ 1 to 2 μF). The result is that the emitter is at AC ground, while at the same time preserving DC stability. In the previous measurements when R_E was not bypassed, much of the input signal was "fed back" onto the emitter, greatly reducing v_{be}, from its value when the emitter is at AC ground. This situation is an example of "degenerative (or negative) feedback" and has several results. One desirable effect is to enable the amplifier to linearly amplify for a larger range of input signals. Another is that the gain of the amplifier is determined mainly by the choice of circuit parameters R_C and R_E and not by variations in transistors. The price we pay for these advantages is a reduction in gain.

9. (a) Connect a 1 to 2 μF capacitor across R_E and remeasure r_i, r_o and A_v. Again use the transresistance model to estimate the voltage gain and compare to your measurements. *Note: The input signal must be reduced in magnitude by a factor* $\sim 20 - 50$, *which can be accomplished using the attenuator provided.*

   (b) Verify the reduction and connection at the input to the amplifier using the scope. Note the increased gain (and also the smaller bandwidth compared to the circuit incorporating feedback. The distortion is due to the fact that we are supplying the transistor with a voltage signal, whereas transistors are primarily current amplifiers.

   (c) To produce a current signal for the input, introduce a 50k resistor in series with the function generator output to produce a high impedance (current) source.

(d) Note that now v_o is undistorted while v_{be} is considerably distorted. Try to interpret this effect in your report.