

# Physics 623

## Transistor Characteristics and Single Transistor Amplifier

Sept. 12, 2017

### 1 Purpose

- To measure and understand the common emitter transistor characteristic curves.
- To use the base current gain ( $\beta$ ), 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 curve tracer. The curve tracer will be used to measure the characteristics of your transistor and to make hard copies for your notebook.
- (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  $\beta = I_C/I_B$  to the range given on the spec sheet. Except for Q-point calculations, the generally more useful quantity is the small signal parameter  $h_{fe} = dI_C/dI_B$ . The difference in value is usually not important.

#### 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, i.e. 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

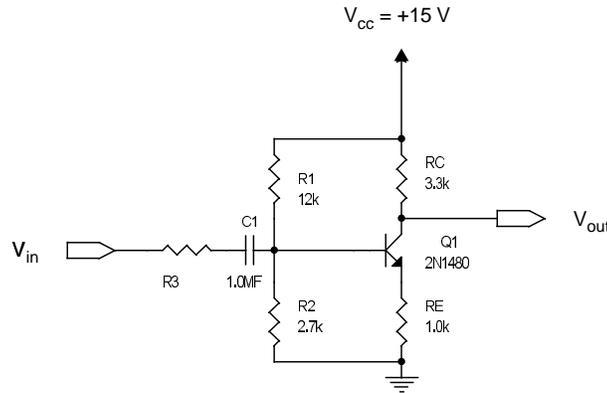


Figure 1: Basic Single Transistor Amplifier

biasing for the common emitter amplifier configuration. 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  $V_{CE} \simeq 6.5 \text{ V}$ ).

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 forward-biased Si transistor is 0.6 V. Therefore  $V_E = V_B - 0.6 \text{ V}$ .
  - (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 could load your Thevenin equivalent of the base bias circuit with the current  $I_B$ , calculate a new  $V_B$  and solve these equations simultaneously to get the exact operating point, but this is seldom necessary. If the bias network design is good (meaning not too sensitive to  $\beta$ , 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  $I_C = I_E$ ),

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

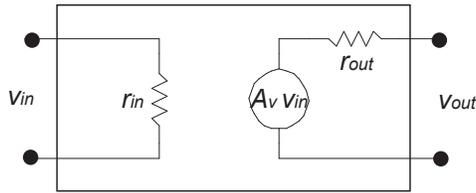


Figure 2: Thevenin Equivalent Circuit for an Amplifier.

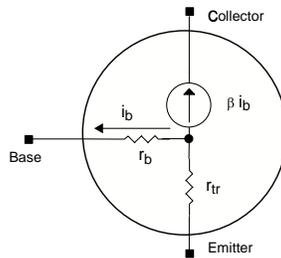


Figure 3: Transresistance Model Equivalent Circuit.

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 pin-out 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  $\sim 10\%$ ).
6. **AC properties.** Three important parameters, defined by the coupled Thevenin equivalent circuits of the amplifier input and output shown in Fig. 2, determine the AC behavior of the amplifier. They are:
  - (a) The input impedance ( $r_i$ ),
  - (b) The output impedance ( $r_o$ ), and
  - (c) The voltage gain ( $A_v = v_o/v_i$ ).

Before actually measuring these quantities, it is instructive 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. 3. By differentiating the basic diode equation (for a p-n junction) we find that the dynamic base emitter resistance or “transresistance” is inversely proportional to the current  $I_E$ .

$$r_{tr} = \frac{\partial V}{\partial I} = \frac{0.026 \Omega \cdot A}{I_E}.$$

Thus, the transresistance is:

$$r_{tr} = \left( \frac{0.026 \Omega \cdot A}{I_C} + 2 \Omega \right)$$

where we have assumed  $I_C \simeq I_E$  and the “2 ohm” is a rough average value for the ohmic resistance of the internal connection to the 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,  $r_i$  (common emitter input impedance) is calculated as:

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

(with “ $\parallel$ ” meaning “in parallel” so you add reciprocals to get the reciprocal of the combination).

The common emitter AC voltage gain is then:

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

In this approximation. the output impedance  $r_o = R_C$ .

7. (a) Now introduce a AC signal (a sine wave from the waveform generator) of frequency  $f = 5 \text{ KHz}$  into the base through a coupling capacitor  $C_c \geq 1.0 \mu\text{F}$  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.

Interpret the distortion using the output characteristics and the load line.

- (c) 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  $2 \mu\text{F}$ ). 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  $\mu\text{F}$  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: To avoid saturating the transistor, 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  $i_C$  depends exponentially on  $v_{BE}$ .
- (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 notebook.