ECE 255, BJT Examples

1 March 2018

In this lecture, we will cover some examples. Before we cover the examples, we will review the formulas in Table 7.5 from the textbook.

Table 7.5 Characteristics of BJT Amplifiers[a,b]

	R_{in}	A_{vo}	R_o	A_v	G_v
Common emitter (Fig. 7.36)	$(\beta+1)r_e$	$-g_m R_C$	R_C	$-g_m(R_C \parallel R_L)$ $-\alpha \dfrac{R_C \parallel R_L}{r_e}$	$-\beta \dfrac{R_C \parallel R_L}{R_{sig}+(\beta+1)r_e}$
Common emitter with R_e (Fig. 7.38)	$(\beta+1)(r_e+R_e)$	$-\dfrac{g_m R_C}{1+g_m R_e}$	R_C	$\dfrac{-g_m(R_C \parallel R_L)}{1+g_m R_e}$ $-\alpha \dfrac{R_C \parallel R_L}{r_e+R_e}$	$-\beta \dfrac{R_C \parallel R_L}{R_{sig}+(\beta+1)(r_e+R_e)}$
Common base (Fig. 7.40)	r_e	$g_m R_C$	R_C	$g_m(R_C \parallel R_L)$ $\alpha \dfrac{R_C \parallel R_L}{r_e}$	$\alpha \dfrac{R_C \parallel R_L}{R_{sig}+r_e}$
Emitter follower (Fig. 7.43)	$(\beta+1)(r_e+R_L)$	1	r_e	$\dfrac{R_L}{R_L+r_e}$	$\dfrac{R_L}{R_L+r_e+R_{sig}/(\beta+1)}$ $G_{vo}=1$ $R_{out}=r_e+\dfrac{R_{sig}}{\beta+1}$

[a] For the interpretation of R_{in}, A_{vo}, and R_o refer to Fig. 7.34.
[b] Setting $\beta=\infty$ $(\alpha=1)$ and replacing r_e with $1/g_m$, R_C with R_D, and R_e with R_s results in the corresponding formulas for MOSFET amplifiers (Table 7.4).

Next, we will review Example 7.6 from the previous lecture.

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Example 7.6

To gain more insight into the operation of transistor amplifiers, we wish to consider the waveforms at various points in the circuit analyzed in the previous example. For this purpose assume that v_i has a triangular waveform. First determine the maximum amplitude that v_i is allowed to have. Then, with the amplitude of v_i set to this value, give the waveforms of the total quantities $i_B(t)$, $v_{BE}(t)$, $i_C(t)$, and $v_C(t)$.

Solution

One constraint on signal amplitude is the small-signal approximation, which stipulates that v_{be} should not exceed about 10 mV. If we take the triangular waveform v_{be} to be 20 mV peak-to-peak and work backward, Eq. (7.81) can be used to determine the maximum possible peak of v_i,

$$\hat{v}_i = \frac{\hat{v}_{be}}{0.011} = \frac{10}{0.011} = 0.91 \text{ V}$$

To check whether the transistor remains in the active mode with v_i having a peak value $\hat{v}_i = 0.91$V, we have to evaluate the collector voltage. The voltage at the collector will consist of a triangular wave v_o superimposed on the dc value $V_C = 3.1$ V. The peak voltage of the triangular waveform will be

$$\hat{v}_o = \hat{v}_i \times \text{gain} = 0.91 \times 3.04 = 2.77 \text{ V}$$

It follows that when the output swings negative, the collector voltage reaches a minimum of $3.1 - 2.77 = 0.33$ V, which is lower than the base voltage by less than 0.4 V. Thus the transistor will remain in the active mode with v_i having a peak value of 0.91 V. Nevertheless, to be on the safe side, we will use a somewhat lower value for $\hat{v}_i$ of approximately 0.8 V, as shown in Fig. 7.29(a), and complete the analysis of this problem utilizing the equivalent circuit in Fig. 7.28(d). The signal current in the base will be triangular, with a peak value $\hat{i}_b$ of

$$\hat{i}_b = \frac{\hat{v}_i}{R_{BB} + r_\pi} = \frac{0.8}{100 + 1.09} = 0.008 \text{ mA}$$

This triangular-wave current will be superimposed on the quiescent base current I_B, as shown in Fig. 7.29(b). The base–emitter voltage will consist of a triangular-wave component superimposed on the dc V_{BE} that is approximately 0.7 V. The peak value of the triangular waveform will be

$$\hat{v}_{be} = \hat{v}_i \frac{r_\pi}{r_\pi + R_{BB}} = 0.8 \frac{1.09}{100 + 1.09} = 8.6 \text{ mV}$$

The total v_{BE} is sketched in Fig. 7.29(c).

The signal current in the collector will be triangular in waveform, with a peak value $\hat{i}_c$ given by

$$\hat{i}_c = \beta \hat{i}_b = 100 \times 0.008 = 0.8 \text{ mA}$$

This current will be superimposed on the quiescent collector current I_C ($= 2.3$ mA), as shown in Fig. 7.29(d).

The signal voltage at the collector can be obtained by multiplying v_i by the voltage gain; that is,

$$\hat{v}_o = 3.04 \times 0.8 = 2.43 \text{ V}$$

Figure 7.29(e) shows a sketch of the total collector voltage v_C versus time. Note the phase reversal between the input signal v_i and the output signal v_o.

Finally, we observe that each of the total quantities is the sum of a dc quantity (found from the dc circuit in Fig. 7.28b), and a signal quantity (found from the circuit in Fig. 7.28d).

Example 7.6 *continued*

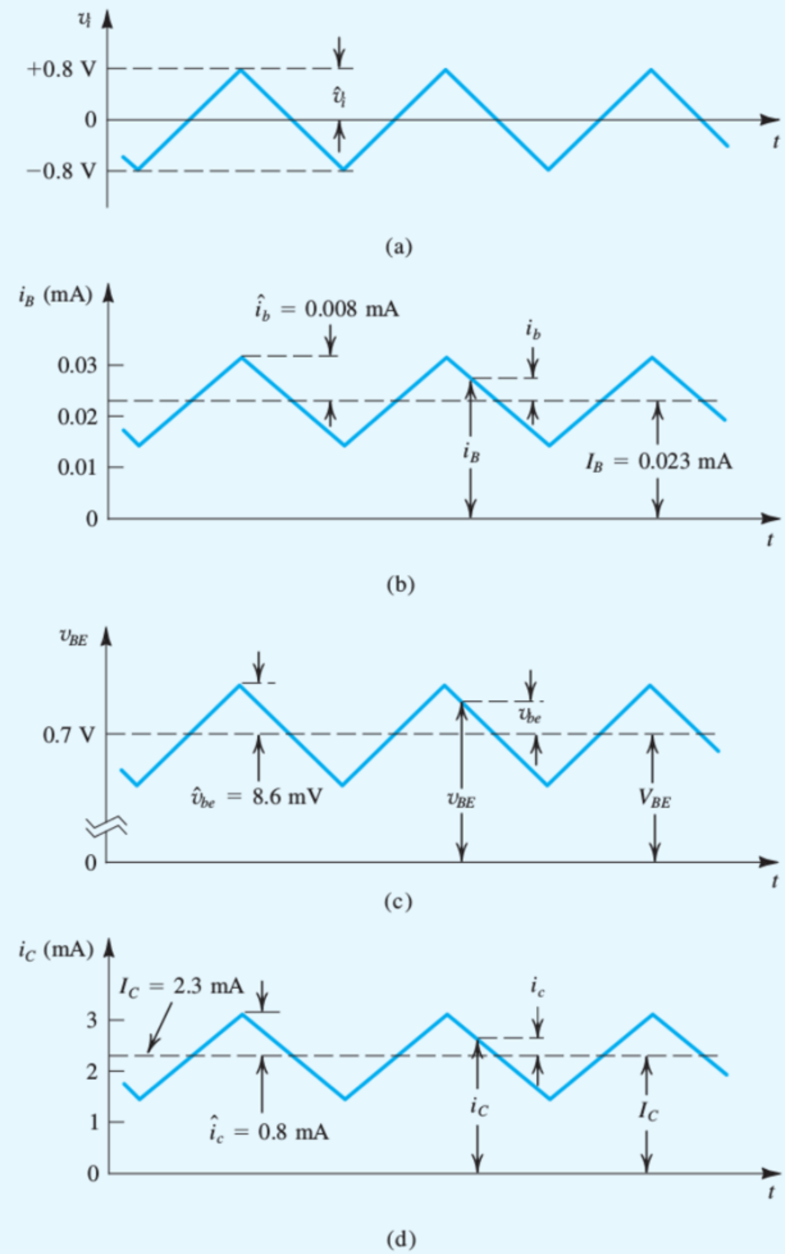

Figure 7.29 Signal waveforms in the circuit of Fig. 7.28.

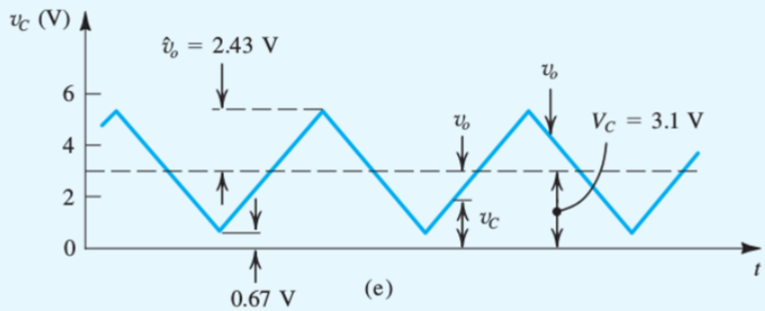

Figure 7.29 *continued*

Then we will review the examples related to basic configurations.

Example 7.8

A CE amplifier utilizes a BJT with $\beta = 100$ is biased at $I_C = 1$ mA and has a collector resistance $R_C = 5\ \text{k}\Omega$. Find R_{in}, R_o, and A_{vo}. If the amplifier is fed with a signal source having a resistance of 5 kΩ, and a load resistance $R_L = 5\ \text{k}\Omega$ is connected to the output terminal, find the resulting A_v and G_v. If $\hat{v}_\pi$ is to be limited to 5 mV, what are the corresponding $\hat{v}_{\text{sig}}$ and $\hat{v}_o$ with the load connected?

Solution

At $I_C = 1$ mA,

$$g_m = \frac{I_C}{V_T} = \frac{1\ \text{mA}}{0.025\ \text{V}} = 40\ \text{mA/V}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40\ \text{mA/V}} = 2.5\ \text{k}\Omega$$

The amplifier characteristic parameters can now be found as

$$R_{in} = r_\pi = 2.5\ \text{k}\Omega$$

$$A_{vo} = -g_m R_C$$

$$= -40\ \text{mA/V} \times 5\ \text{k}\Omega$$

$$= -200\ \text{V/V}$$

$$R_o = R_C = 5\ \text{k}\Omega$$

With a load resistance $R_L = 5\ \text{k}\Omega$ connected at the output, we can find A_v by either of the following two approaches:

$$A_v = A_{vo} \frac{R_L}{R_L + R_o}$$

$$= -200 \times \frac{5}{5+5} = -100\ \text{V/V}$$

Example 7.9

For the CE amplifier specified in Example 7.8, what value of R_e is needed to raise R_{in} to a value four times that of R_{sig}? With R_e included, find A_{vo}, R_o, A_v, and G_v. Also, if $\hat{v}_\pi$ is limited to 5 mV, what are the corresponding values of $\hat{v}_{sig}$ and $\hat{v}_o$?

Solution

To obtain $R_{in} = 4R_{sig} = 4 \times 5 = 20\ \text{k}\Omega$, the required R_e is found from

$$20 = (\beta + 1)(r_e + R_e)$$

With $\beta = 100$,

$$r_e + R_e \simeq 200\ \Omega$$

Thus,

$$R_e = 200 - 25 = 175\ \Omega$$

$$A_{vo} = -\alpha \frac{R_C}{r_e + R_e}$$

$$\simeq -\frac{5000}{25 + 175} = -25\ \text{V/V}$$

$$R_o = R_C = 5\ \text{k}\Omega\ \text{(unchanged)}$$

$$A_v = A_{vo} \frac{R_L}{R_L + R_o} = -25 \times \frac{5}{5+5} = -12.5\ \text{V/V}$$

$$G_v = \frac{R_{in}}{R_{in} + R_{sig}} A_v = -\frac{20}{20+5} \times 12.5 = -10\ \text{V/V}$$

For $\hat{v}_\pi = 5$ mV,

$$\hat{v}_i = \hat{v}_\pi \left(\frac{r_e + R_e}{r_e} \right)$$

$$= 5\left(1 + \frac{175}{25}\right) = 40\ \text{mV}$$

$$\hat{v}_{sig} = \hat{v}_i \frac{R_{in} + R_{sig}}{R_{in}}$$

$$= 40\left(1 + \frac{5}{20}\right) = 50\ \text{mV}$$

$$\hat{v}_o = \hat{v}_{sig} \times |G_v|$$

$$= 50 \times 10 = 500\ \text{mV} = 0.5\ \text{V}$$

Thus, while $|G_v|$ has decreased to about a third of its original value, the amplifier is able to produce as large an output signal as before for the same nonlinear distortion.

Example 7.10

It is required to design an emitter follower to implement the buffer amplifier of Fig. 7.46(a). Specify the required bias current I_E and the minimum value the transistor β must have. Determine the maximum allowed value of v_{sig} if v_π is to be limited to 5 mV in order to obtain reasonably linear operation. With $v_{sig} = 200$ mV, determine the signal voltage at the output if R_L is changed to 2 kΩ, and to 0.5 kΩ.

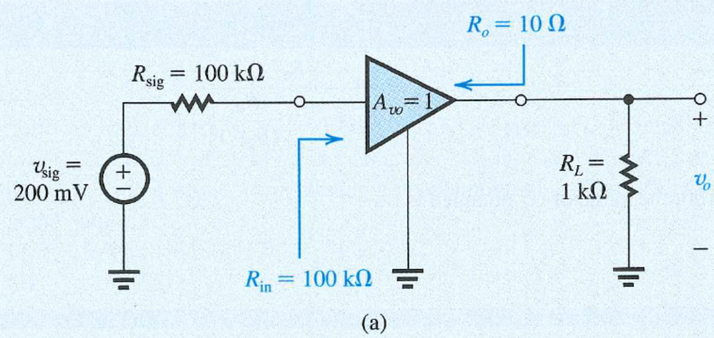

Figure 7.46 Circuit for Example 7.10.

Example 7.10 *continued*

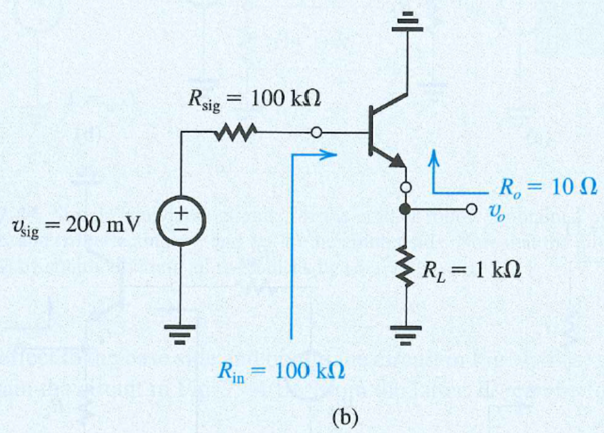

Figure 7.46 *continued*

Solution

The emitter-follower circuit is shown in Fig. 7.46(b). To obtain $R_o = 10\ \Omega$, we bias the transistor to obtain $r_e = 10\ \Omega$. Thus,

$$10\ \Omega = \frac{V_T}{I_E}$$

$$I_E = 2.5\ \text{mA}$$

The input resistance R_{in} will be

$$R_{in} = (\beta+1)(r_e + R_L)$$

$$100 = (\beta+1)(0.01+1)$$

Thus, the BJT should have a β with a minimum value of 98. A higher β would obviously be beneficial.

The overall voltage gain can be determined from

$$G_v \equiv \frac{v_o}{v_{sig}} = \frac{R_L}{R_L + r_e + \dfrac{R_{sig}}{(\beta+1)}}$$

Assuming $\beta = 100$, the value of G_v obtained is

$$G_v = 0.5$$

Thus when $v_{sig} = 200$ mV, the signal at the output will be 100 mV. Since the 100 mV appears across the 1-kΩ load, the signal across the base–emitter junction can be found from

$$v_\pi = \frac{v_o}{R_L} \times r_e$$

$$= \frac{100}{1000} \times 10 = 1 \text{ mV}$$

If $\hat{v}_\pi = 5$ mV then v_{sig} can be increased by a factor of 5, resulting in $\hat{v}_{sig} = 1$ V.

To obtain v_o as the load is varied, we use the Thévenin equivalent of the emitter follower, shown in Fig. 7.45(a) with $G_{vo} = 1$ and

$$R_{out} = \frac{R_{sig}}{\beta + 1} + r_e = \frac{100}{101} + 0.01 = 1 \text{ k}\Omega$$

to obtain

$$v_o = v_{sig} \frac{R_L}{R_L + R_{out}}$$

For $R_L = 2$ kΩ,

$$v_o = 200 \text{ mV} \times \frac{2}{2+1} = 133.3 \text{ mV}$$

and for $R_L = 0.5$ kΩ,

$$v_o = 200 \text{ mV} \times \frac{0.5}{0.5+1} = 66.7 \text{ mV}$$