



Electronic Principles and Circuits / BEC303

Module-1

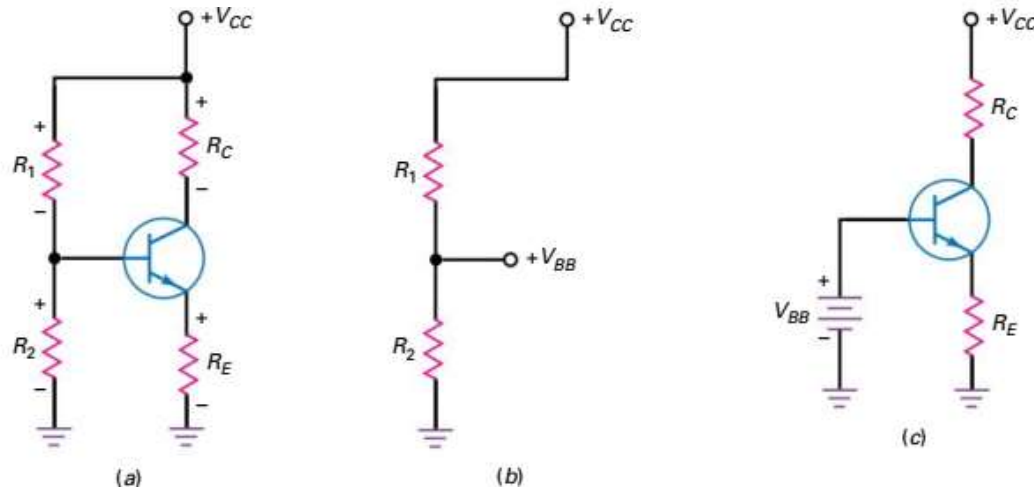
Transistor Biasing: Voltage Divider Bias, VDB Analysis, VDB Load line and Q point, Two supply Emitter Bias, Other types of Bias.

BJT AC models: Base Biased Amplifier, Emitter Biased Amplifier, Small Signal Operation, AC Beta, AC Resistance of the emitter diode, Two transistor models, Analyzing an amplifier.

Voltage Amplifiers: Voltage gain, Multistage Amplifiers.

CC and CB Amplifiers: CC Amplifier, Output Impedance, Cascading CE and CC, Darlington Connections, Voltage regulation, The Common base Amplifier

Voltage-Divider Bias



Voltage-divider bias. (a) Circuit; (b) voltage divider; (c) simplified circuit

$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$V_E = V_{BB} - V_{BE}$$

$$I_E = \frac{V_E}{R_E}$$

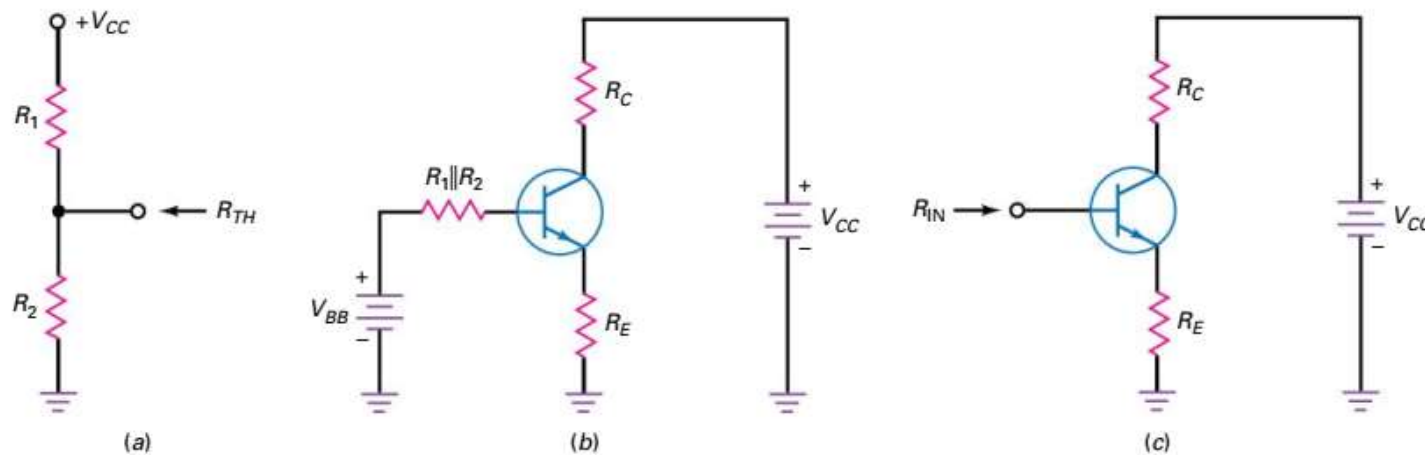
$$I_C \approx I_E$$

$$V_C = V_{CC} - I_C R_C$$

$$V_{CE} = V_C - V_E$$

Accurate VDB Analysis

What is a well-designed VDB circuit? It is one in which the voltage divider appears stiff to the input resistance of the base.



(a) Thevenin resistance; (b) equivalent circuit; (c) input resistance of base

Stiff voltage source: $R_S < 0.01R_L$

When this condition is satisfied, the load voltage is within 1 percent of the ideal voltage. Now, let us extend this idea to the voltage divider.

$$R_1 \parallel R_2 < 0.01R_{IN}$$

Accurate VDB Analysis

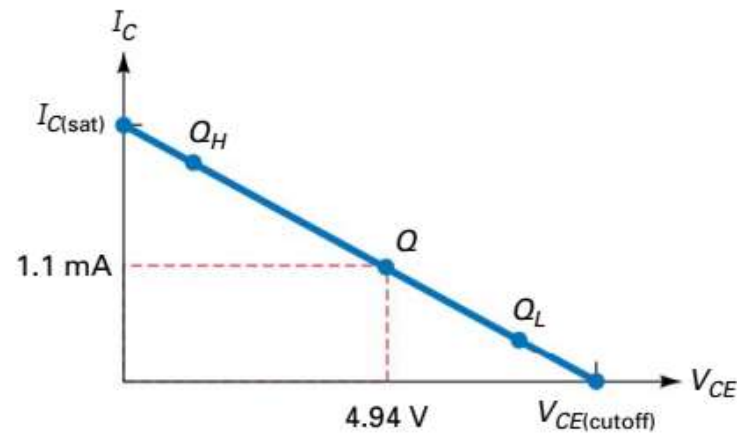
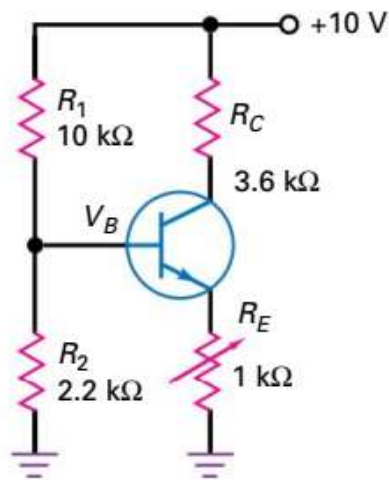
$$R_{IN} = \beta_{dc} R_E$$

Stiff voltage divider: $R_1 \parallel R_2 < 0.01 \beta_{dc} R_E$

Firm voltage divider: $R_1 \parallel R_2 < 0.1 \beta_{dc} R_E$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + (R_1 \parallel R_2) / \beta_{dc}}$$

VDB Load Line and Q Point



Start by making the emitter voltage approximately one-tenth of the supply voltage:

$$V_E = 0.1 V_{CC}$$

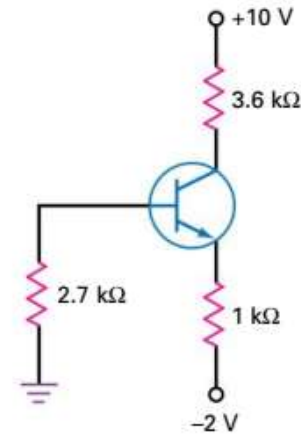
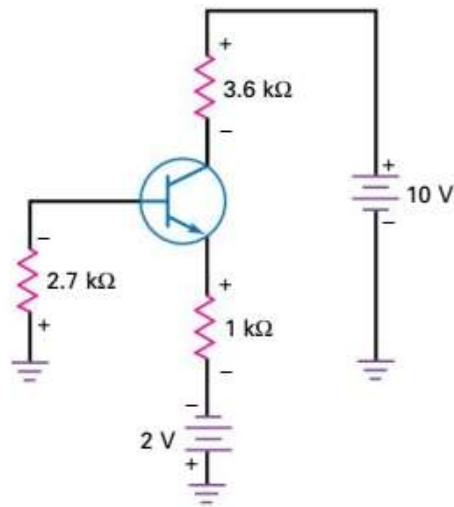
Next, calculate the value of R_E to set up the specified collector current:

$$R_E = \frac{V_E}{I_E}$$

Since the Q point needs to be at approximately the middle of the dc load line, about $0.5 V_{CC}$ appears across the collector-emitter terminals. The remaining $0.4 V_{CC}$ appears across the collector resistor; therefore:

$$R_C = 4 R_E$$

Two-Supply Emitter Bias



$$V_B \approx 0$$

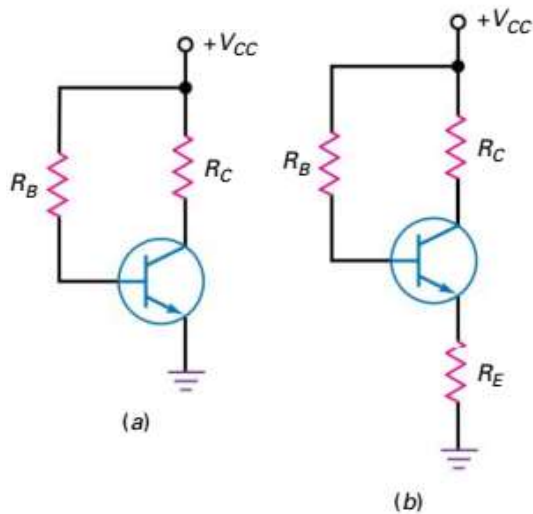
$$I_E = \frac{V_{EE} - 0.7 \text{ V}}{R_E}$$

$$V_C = V_{CC} - I_C R_C$$

$$V_{CE} = V_C + 0.7 \text{ V}$$

Other Types of Bias

Emitter-Feedback Bias



(a) Base bias; (b) emitter feedback bias.

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{dc}}$$

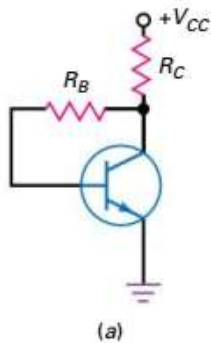
$$V_E = I_E R_E$$

$$V_B = V_E + 0.7 \text{ V}$$

$$V_C = V_{CC} - I_C R_C$$

Other Types of Bias

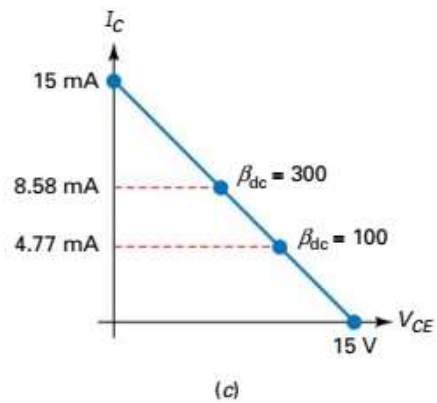
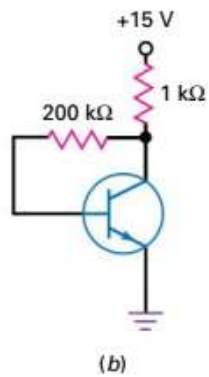
Collector-Feedback Bias



$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{dc}}$$

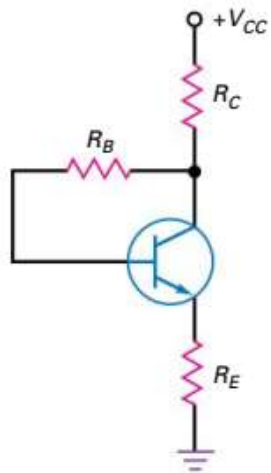
$$V_B = 0.7 \text{ V}$$

$$V_C = V_{CC} - I_C R_C$$



Other Types of Bias

Collector- and Emitter-Feedback Bias



$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_E + R_B/\beta_{dc}}$$

$$V_E = I_E R_E$$

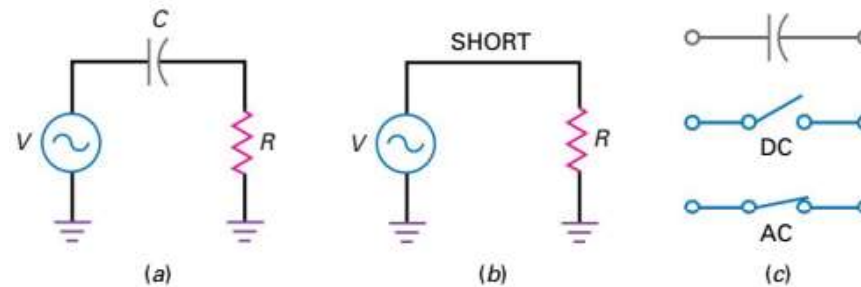
$$V_B = V_E + 0.7 \text{ V}$$

$$V_C = V_{CC} - I_C R_C$$

Base-Biased Amplifier

A base-biased amplifier has instructional value because its basic ideas can be used to build more complicated amplifiers.

Coupling Capacitor

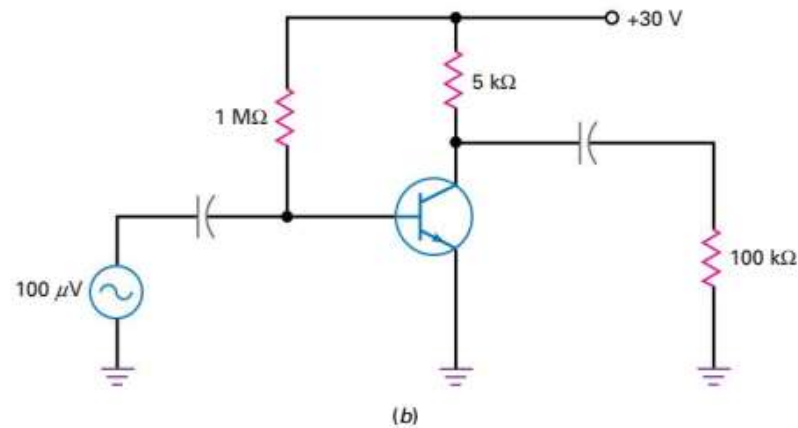
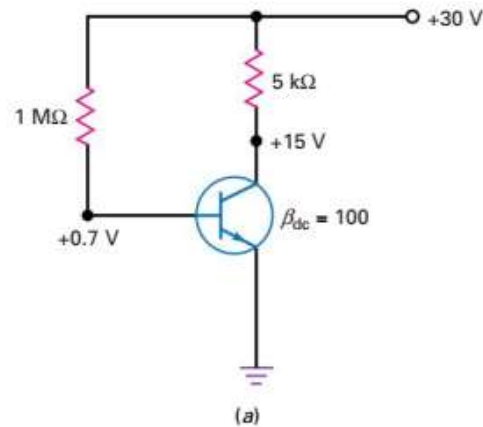


Good coupling: $X_c < 0.1R$

A final point about coupling capacitors: Since dc voltage has a frequency of zero, the reactance of a coupling capacitor is infinite at zero frequency. Therefore, we will use these two approximations for a capacitor:

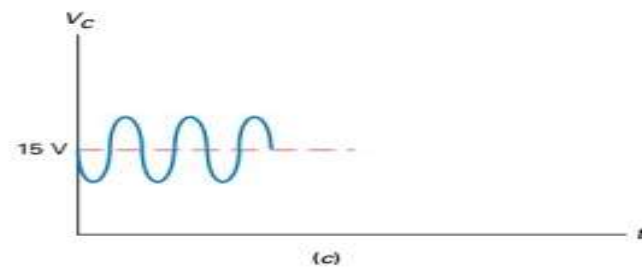
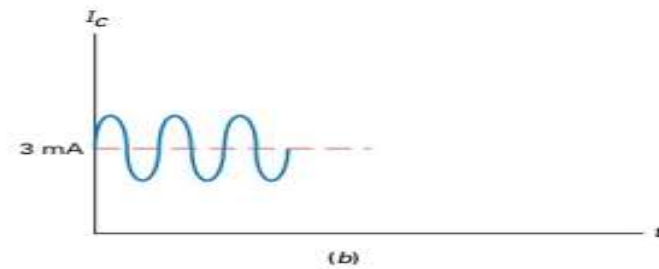
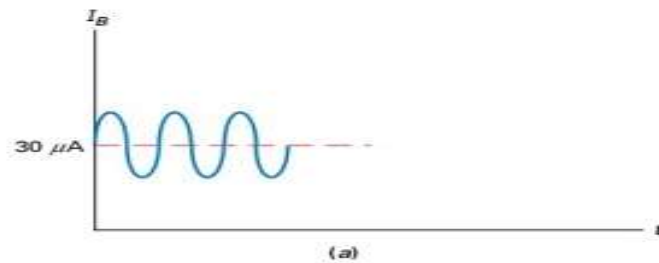
1. For dc analysis, the capacitor is open.
2. For ac analysis, the capacitor is shorted.

Base-Biased Amplifier



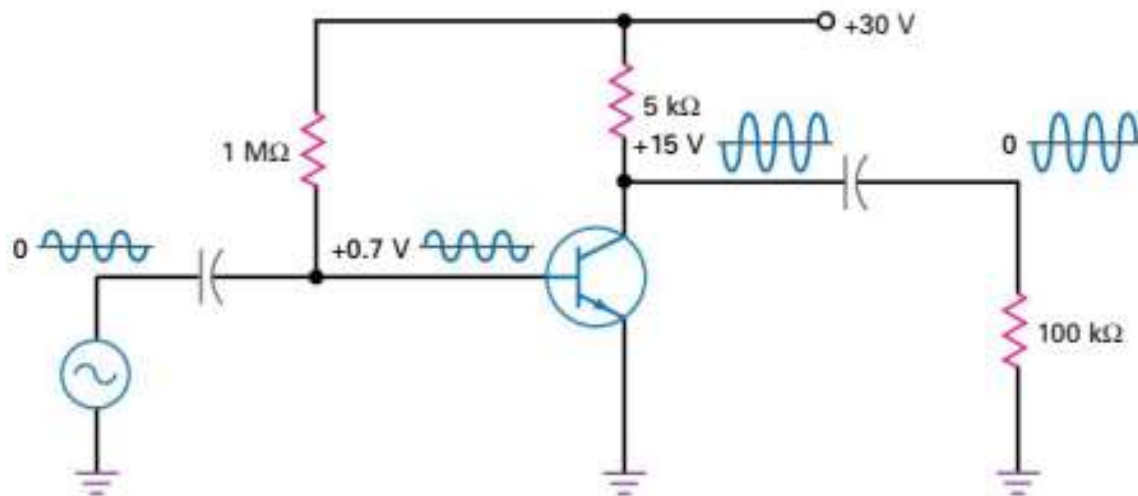
(a) Base bias; (b) base-biased amplifier

Base-Biased Amplifier



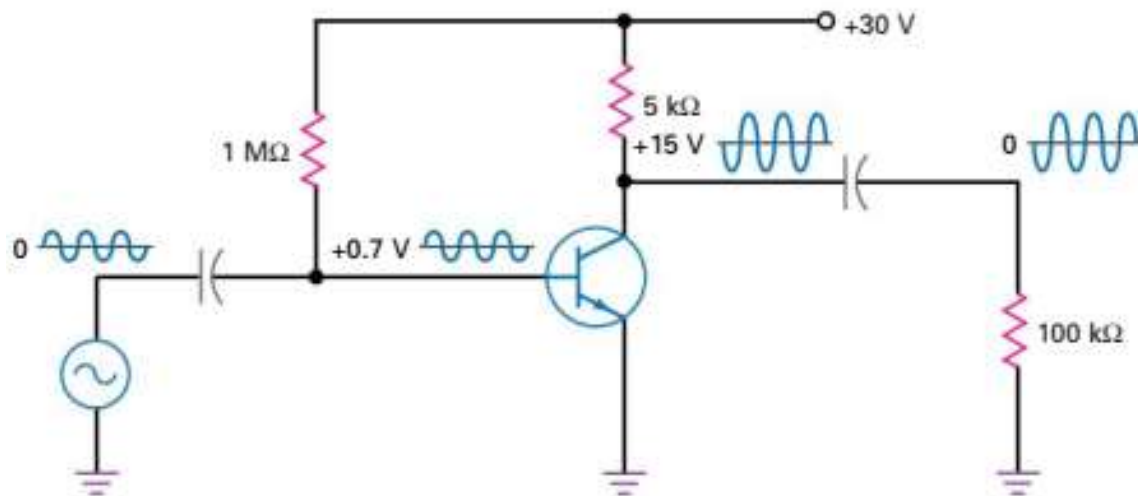
DC and ac components. (a) Base current; (b) collector current; (c) collector voltage.

Base-Biased Amplifier



Base-biased amplifier with waveforms

Base-Biased Amplifier



Base-biased amplifier with waveforms

Base-Biased Amplifier

Voltage Gain

The voltage gain of an amplifier is defined as the ac output voltage divided by the ac input voltage. As a definition:

$$A_V = \frac{v_{out}}{v_{in}}$$

Calculating Output Voltage

$$v_{out} = A_V v_{in}$$

Calculating Input Voltage

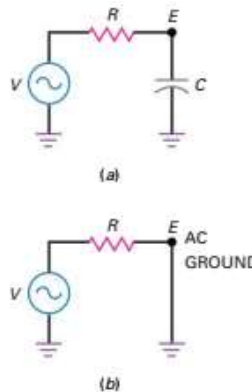
$$v_{in} = \frac{v_{out}}{A_V}$$

Emitter-Biased Amplifier

The base-biased amplifier has an unstable Q point. For this reason, it is not used much as an amplifier. Instead, an emitter-biased amplifier (either VDB or TSEB) with its stable Q point is preferred.

Bypass Capacitor

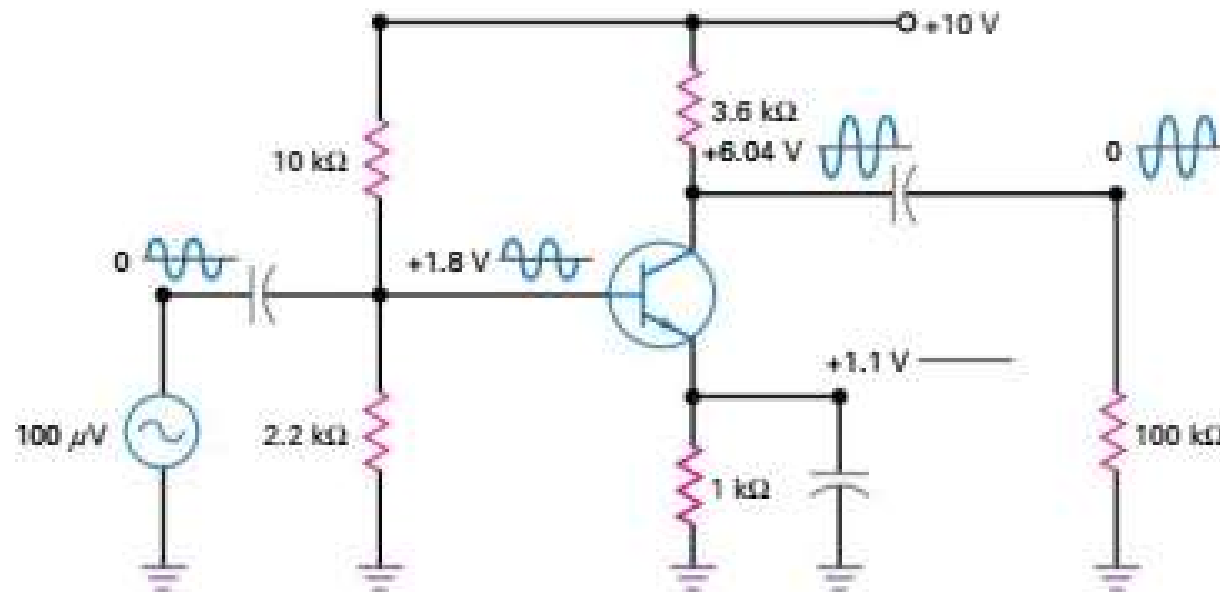
A bypass capacitor is similar to a coupling capacitor because it appears open to direct current and shorted to alternating current. But it is not used to couple a signal between two points. Instead, it is used to create an ac ground.



(a) Bypass capacitor; (b) point E is an ac ground.

Emitter-Biased Amplifier

VDB Amplifier

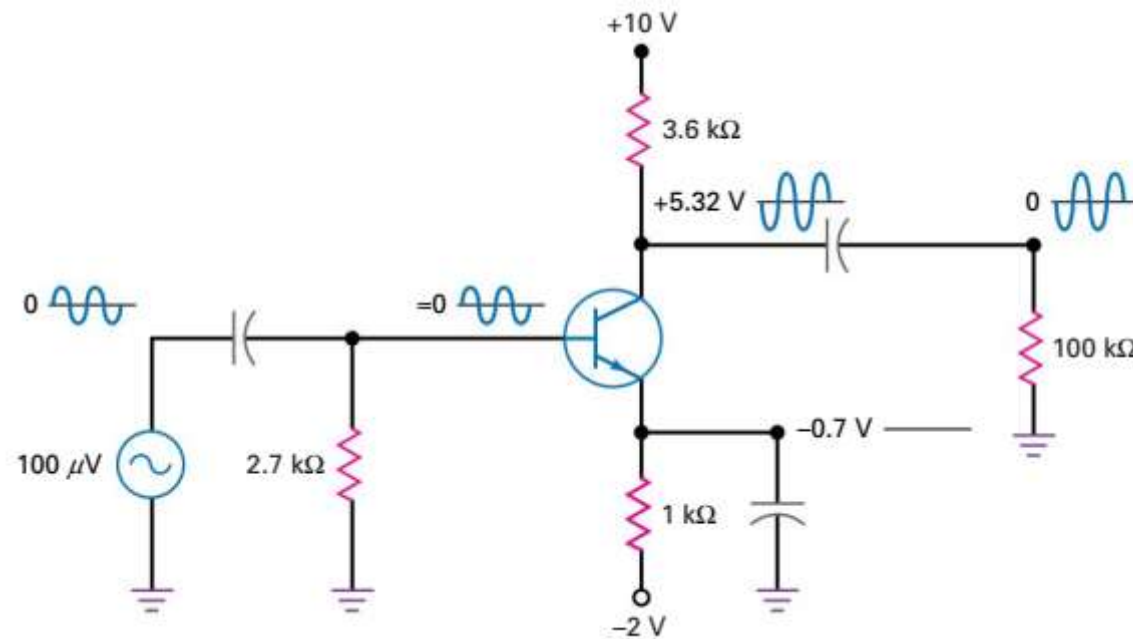


$$\begin{aligned} V_B &= 1.8 \text{ V} \\ V_E &= 1.1 \text{ V} \\ V_C &= 6.04 \text{ V} \\ I_C &= 1.1 \text{ mA} \end{aligned}$$

VDB amplifier with waveforms.

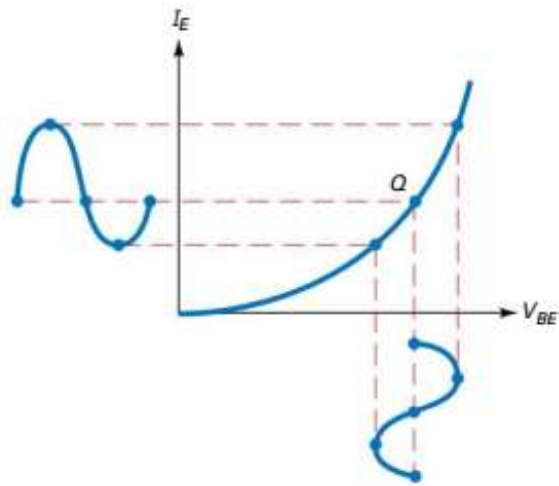
Emitter-Biased Amplifier

TSEB Circuit



A two-supply emitter bias (TSEB) amplifier

Small-Signal Operation



Distortion when signal is too large.

$$I_E = I_{EQ} + i_e$$

where I_E = the total emitter current

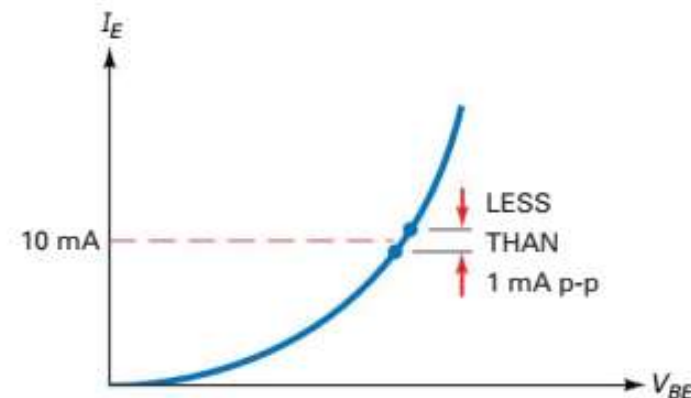
I_{EQ} = the dc emitter current

i_e = the ac emitter current

To minimize distortion, the peak-to-peak value of i_e must be small compared to I_{EQ} . Our definition of small-signal operation is:

$$\text{Small signal: } i_{e(pp)} < 0.1 I_{EQ}$$

(9-6)



Definition of small-signal operation

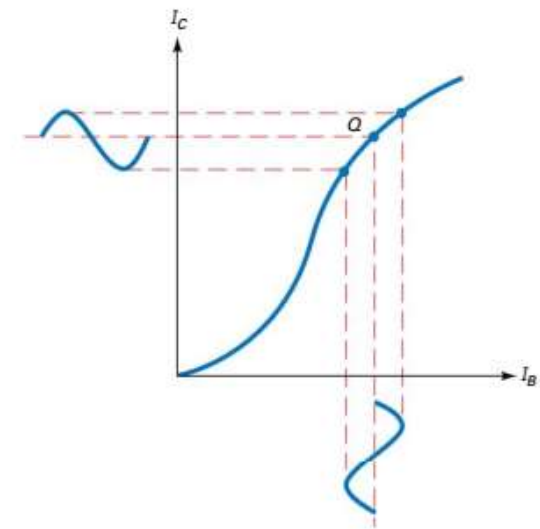
AC Beta

The current gain in all discussions up to this point has been dc current gain. This was defined as:

$$\beta_{dc} = \frac{I_C}{I_B}$$

The **ac current gain** is different. It is defined as:

$$\beta = \frac{i_c}{i_b}$$



AC current gain equals ratio of changes.

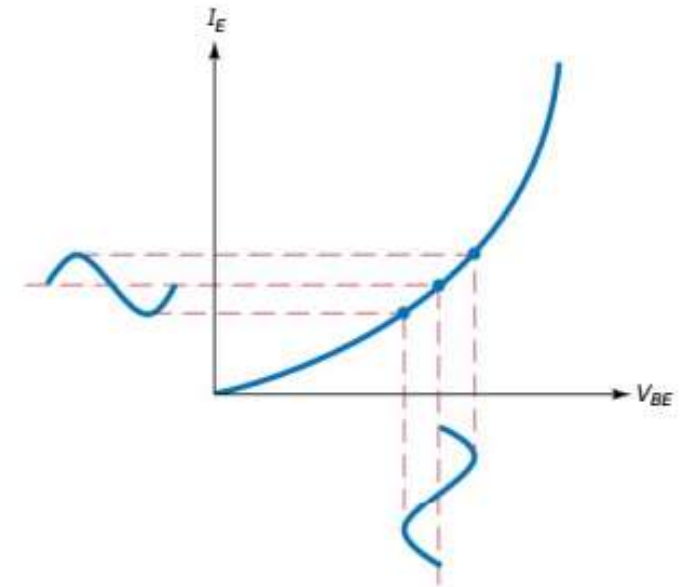
AC Resistance of the Emitter Diode

When a small ac voltage is across the emitter diode, it produces the ac emitter current shown. The size of this ac emitter current depends on the location of the Q point. Because of the curvature, we get more peak-to-peak ac emitter current when the Q point is higher up the graph

The **ac emitter resistance** of the emitter diode is defined as:

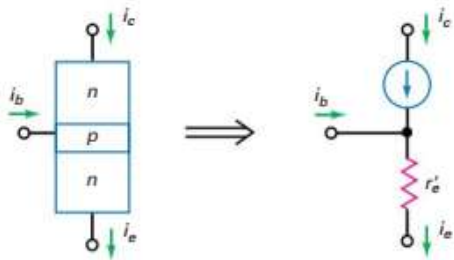
$$r'_e = \frac{v_{be}}{i_e}$$

AC resistance of emitter diode.

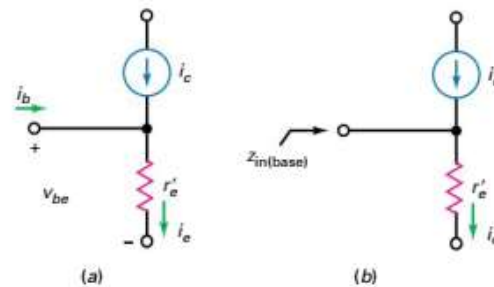


Two Transistor Model

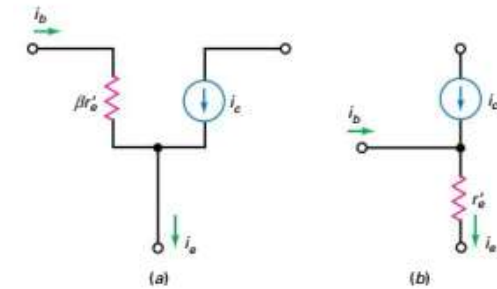
T model of a transistor.



Defining the input impedance of the base.



π model of a transistor.



Looking into the base of the transistor, the ac voltage source sees an input impedance $z_{in(base)}$. At low frequencies, this impedance is purely resistive and defined as:

$$z_{in(base)} = \frac{v_{be}}{i_b}$$

Applying Ohm's law to the emitter diode of Fig. 9-17a, we can write:

$$v_{be} = i_e r'_e$$

Substitute this equation into the preceding one to get:

$$z_{in(base)} = \frac{v_{be}}{i_b} = \frac{i_e r'_e}{i_b}$$

Since $i_e \approx i_c$, the foregoing equation simplifies to:

$$z_{in(base)} = \beta r'_e$$

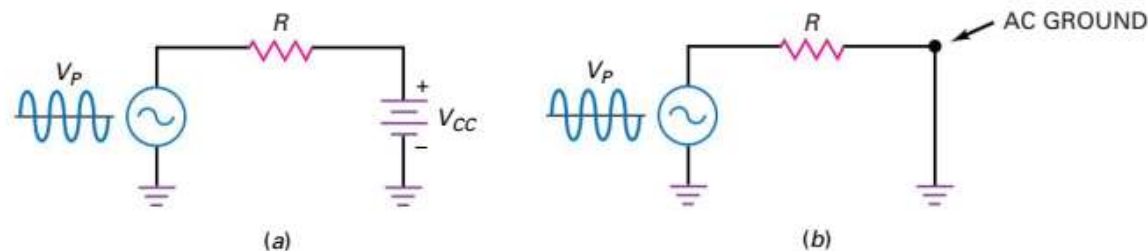
Analyzing an Amplifier

Amplifier analysis is complicated because both dc and ac sources are in the same circuit. To analyze amplifiers, we can calculate the effect of the dc sources, and then the effect of the ac sources. When using the superposition theorem in this analysis, the effect of each source acting alone is added to get the total effect of all sources acting simultaneously.

The DC Equivalent Circuit

The simplest way to analyze an amplifier is to split the analysis into two parts: a dc analysis and an ac analysis. In the dc analysis, we calculate the dc voltages and currents. To do this, we mentally open all capacitors. The circuit that remains is the dc equivalent circuit. Needed to calculate r_e'

AC Effect of a DC Voltage Source



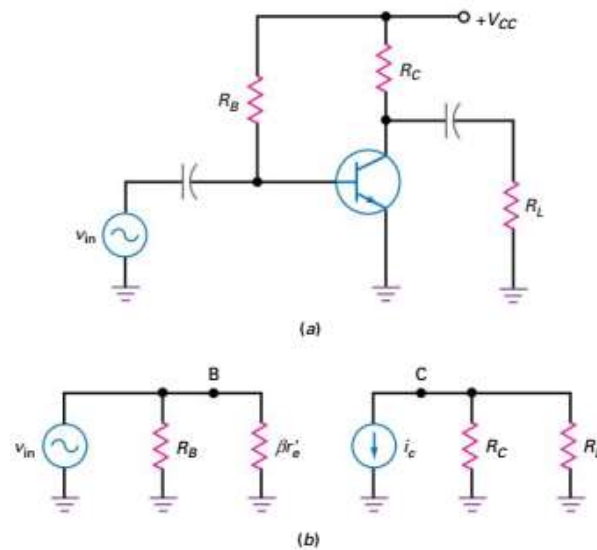
Analyzing an Amplifier

AC Equivalent Circuit

After analyzing the dc equivalent circuit, the next step is to analyze the ac equivalent circuit. This is the circuit that remains after you have mentally shorted all capacitors and dc voltage sources. The transistor can be replaced by either the model or the T model.

Base-Biased Amplifier

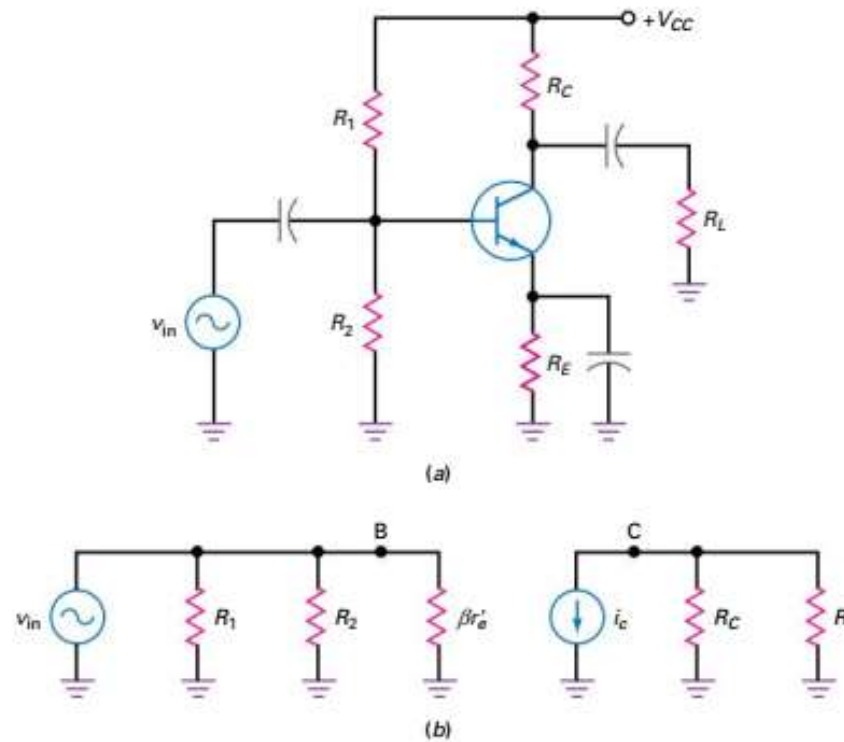
(a) Base-biased amplifier; (b) ac equivalent circuit.



Analyzing an Amplifier

VDB Amplifier

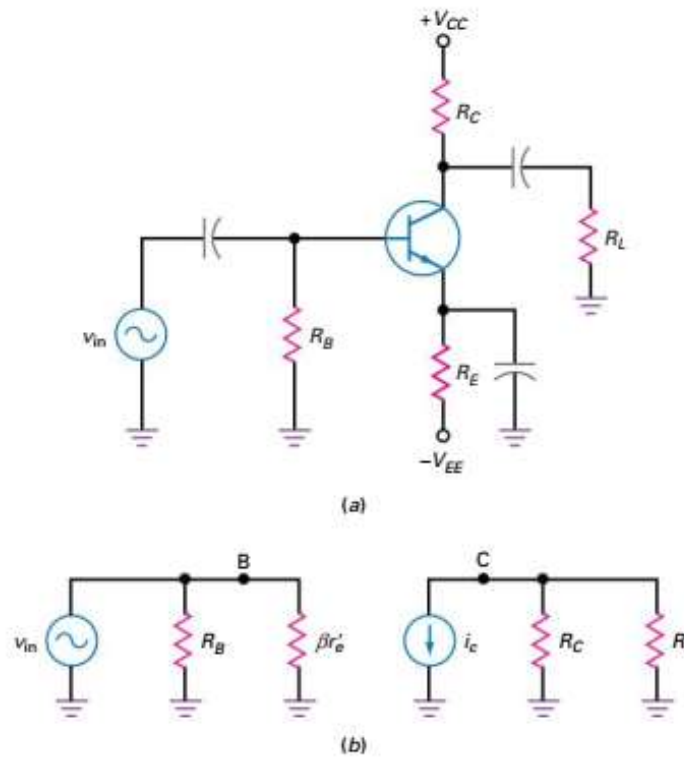
(a) VDB amplifier; (b) ac equivalent circuit.



Analyzing an Amplifier

TSEB Amplifier

Figure 9-22 (a) TSEB amplifier; (b) ac equivalent circuit.



Analyzing an Amplifier

CE Amplifier

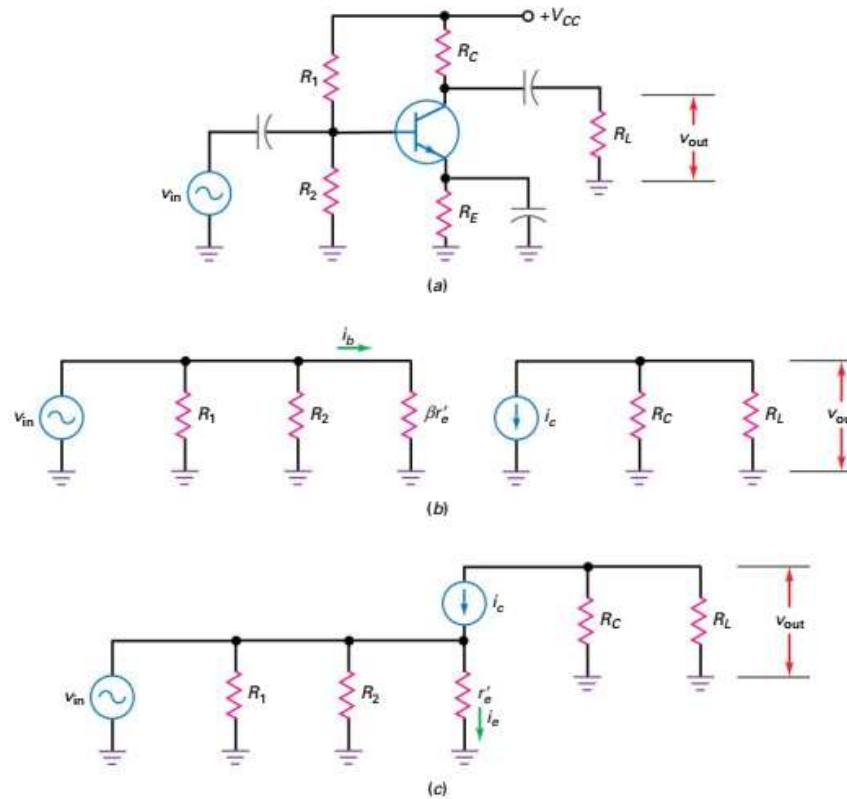
Main Idea

1. Short all coupling and bypass capacitors.
2. Visualize all dc supply voltages as ac grounds.
3. Replace the transistor by its or T model.
4. Draw the ac equivalent circuit.

Voltage Amplifiers: Voltage gain

Voltage gain was defined as the ac output voltage divided by the ac input voltage. With this definition, we can derive another equation for voltage gain that is useful in troubleshooting.

Figure 10-1 (a) CE amplifier; (b) ac equivalent circuit with π model; (c) ac equivalent circuit with T model



Voltage Amplifiers: Voltage gain

The ac base current i_b flows through the input impedance of the base (r_e). With Ohm's law, we can write:

$$v_{in} = i_b \beta r_e'$$

In the collector circuit, the current source pumps an ac current i_c through the parallel connection of R_C and R_L . Therefore, the ac output voltage equals:

$$v_{out} = i_c (R_C \parallel R_L) = \beta i_b (R_C \parallel R_L)$$

Now, we can divide v_{out} by v_{in} to get:

$$A_V = \frac{v_{out}}{v_{in}} = \frac{\beta i_b (R_C \parallel R_L)}{i_b \beta r_e'}$$

which simplifies to:

$$A_V = \frac{(R_C \parallel R_L)}{r_e'}$$

Voltage Amplifiers: Voltage gain

In Fig. b, the total ac load resistance seen by the collector is the parallel combination of R_C and R_L . This total resistance is called the ac collector resistance, symbolized r_c . As a definition:

$$r_c = R_C \parallel R_L$$

Now, we can rewrite Eq. (10-1) as:

$$A_V = \frac{r_c}{r'_e}$$

Derived from the T Model

Figure c shows the ac equivalent circuit using the T model of the transistor. The input voltage v_{in} appears across r_c . With Ohm's law, we can write:

$$v_{in} = i_e r'_e$$

Voltage Amplifiers: Voltage gain

In the collector circuit, the current source pumps an ac current i_c through the ac collector resistance. Therefore, the ac output voltage equals:

$$v_{\text{out}} = i_c r_c$$

Now, we can divide v_{out} by v_{in} to get:

$$A_V = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{i_c r_c}{i_e r'_e}$$

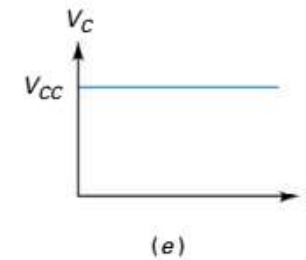
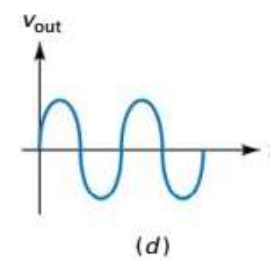
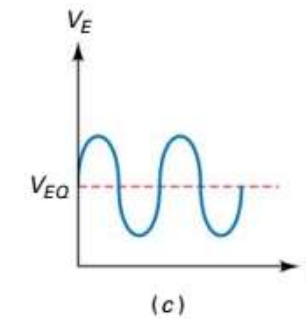
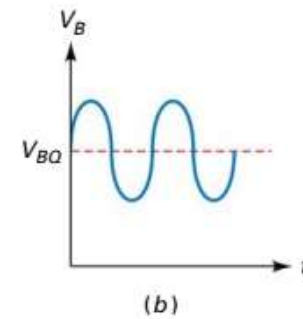
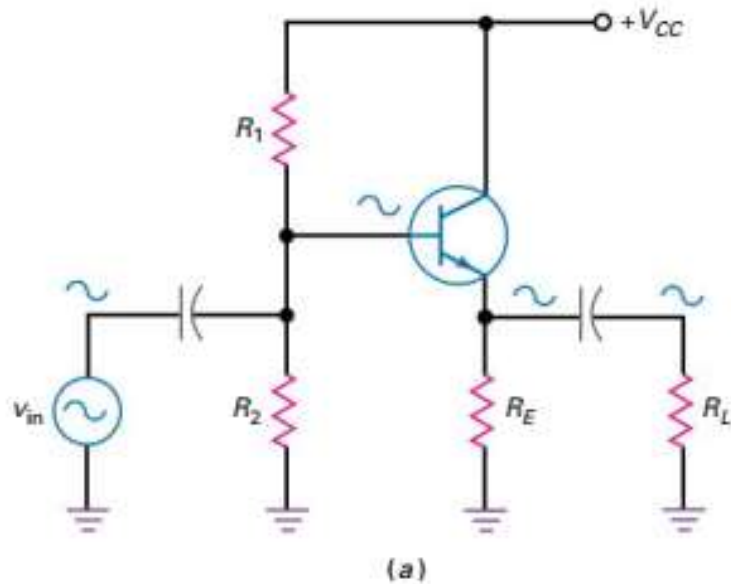
Since $i_c \approx i_e$, we can simplify the equation to get:

$$A_V = \frac{r_c}{r'_e}$$

This is the same equation derived with the π model. It applies to all CE amplifiers because all have an ac collector resistance of r_c and an emitter diode with an ac resistance of r'_e .

CC Amplifier

Fig. 11-1 Emitter follower and waveforms.



CC Amplifier

AC Emitter Resistance

$$r_e = R_E \parallel R_L$$

Voltage Gain

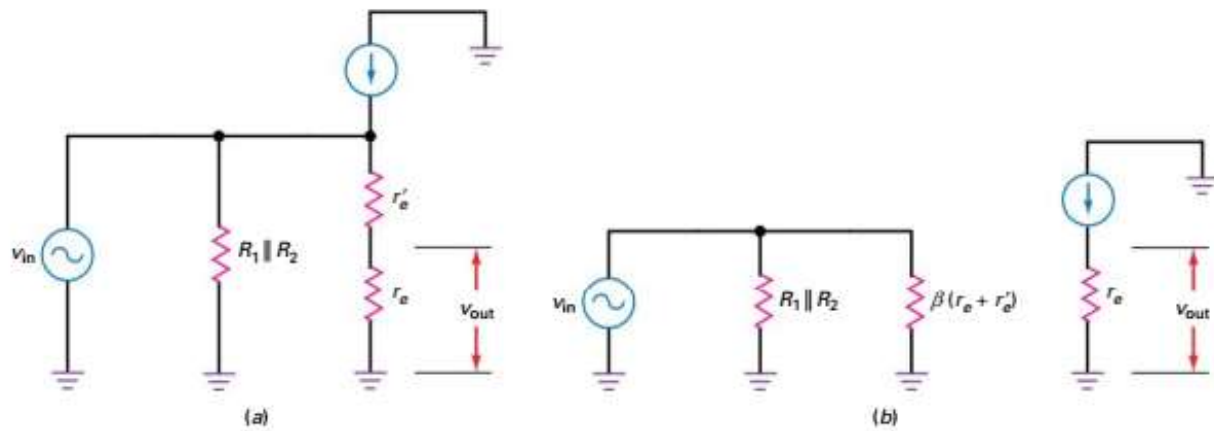
$$v_{\text{out}} = i_e r_e$$

$$v_{\text{in}} = i_e (r_e + r'_e)$$

Divide the first equation by the second, and you get the voltage gain of the emitter follower:

$$A_V = \frac{r_e}{r_e + r'_e}$$

CC Amplifier



AC equivalent circuits for emitter follower.

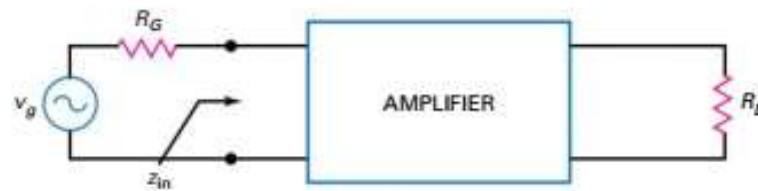
Input Impedance of the Base

$$z_{in(base)} = \beta(r_e + r_e')$$

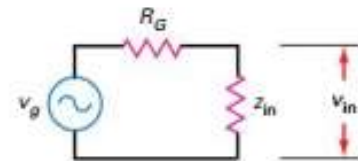
Input Impedance of the Stage

$$z_{in(stage)} = R_1 \parallel R_2 \parallel \beta(r_e + r_e')$$

Output Impedance



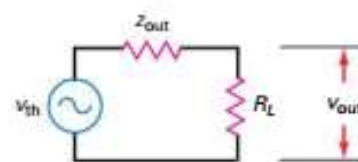
(a)



(b)



(c)

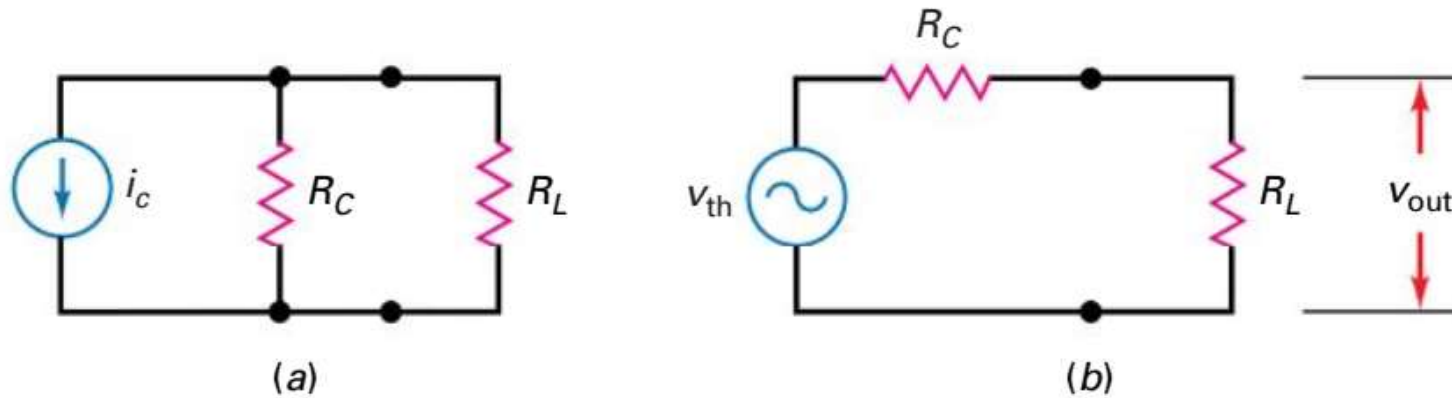


(d)

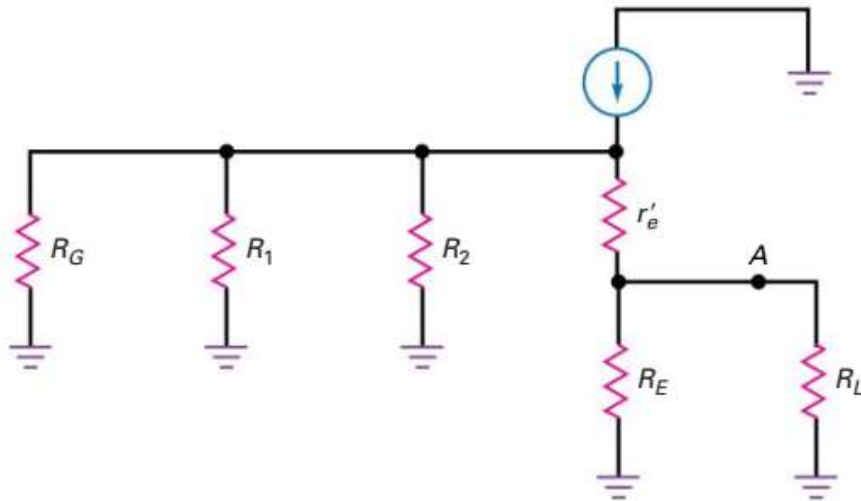
Input and output impedances

Output Impedance

Output impedance of CE stage.



Output Impedance

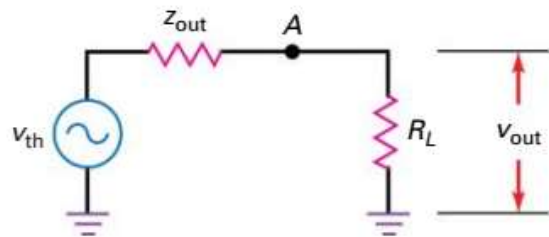


(a)

$$z_{out} = R_E \parallel \left(r'_e + \frac{R_G \parallel R_1 \parallel R_2}{\beta} \right)$$

Ideal Action

$$z_{out} = \frac{R_G}{\beta}$$



(b)

Output impedance of emitter follower.