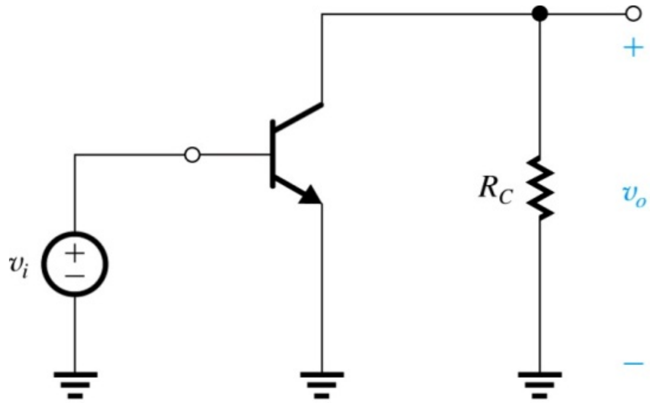
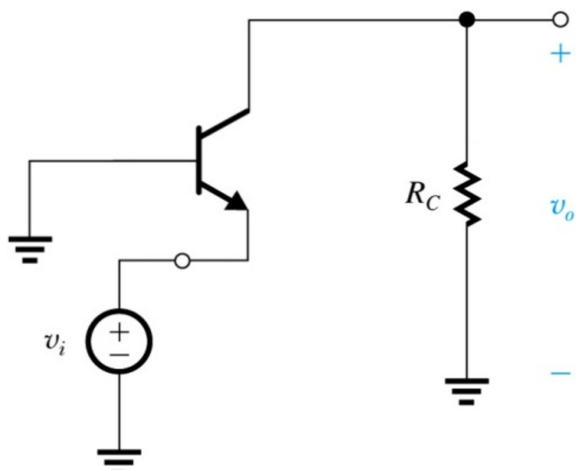
Lecture 12

The Bipolar Junction Transistor as an Amplifier

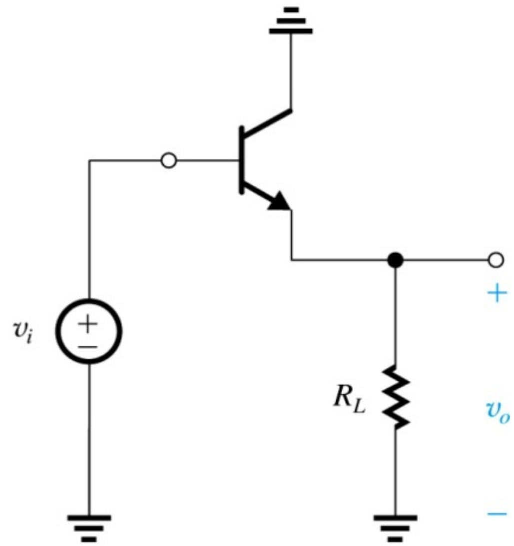
Three-Basic Configurations for BJT amplifier



(a) Common-Emitter (CE)



(b) Common-Base (CB)



(c) Common-Collector (CC)
or Emitter Follower

Of three configurations, the CE amplifier is most widely used.

Common emitter amplifier

- Similar strategy to MOSFET amplifier by using BJT as VCCS
- **Voltage transfer characteristic** (VTC) : Relation between output and input voltages
- Appropriate biasing is important to ensure linear gain, and appropriate input voltage swing.

Small-signal model is employed to model the amp's operation.

VTC of common emitter amplifier

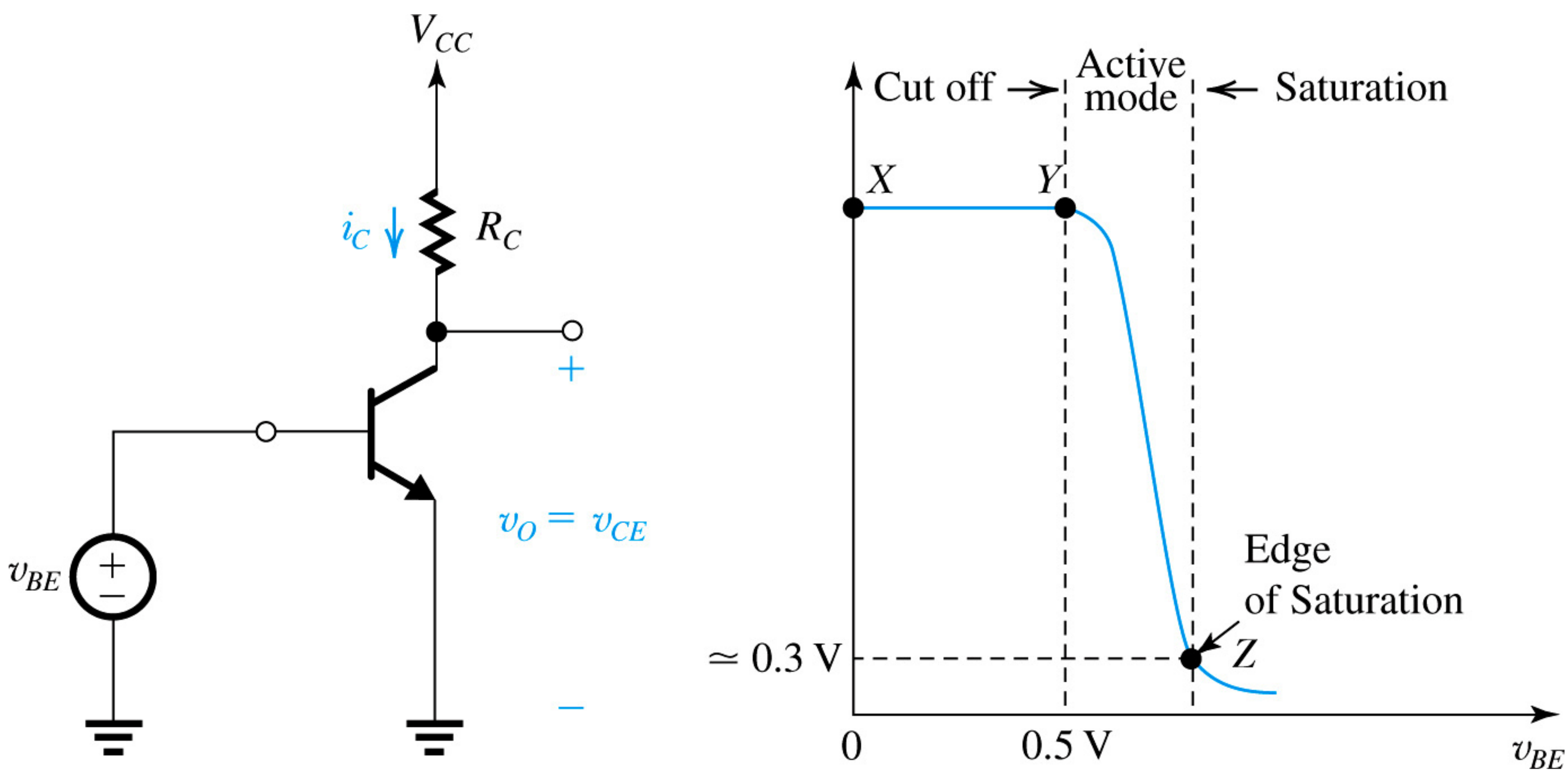


Figure 6.31 (a) Simple BJT amplifier with input v_{BE} and output v_{CE}. **(b)** The voltage transfer characteristic (VTC) of the amplifier in **(a)**. The three segments of the VTC correspond to the three modes of operation of the BJT.

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Biasing of common emitter amplifier

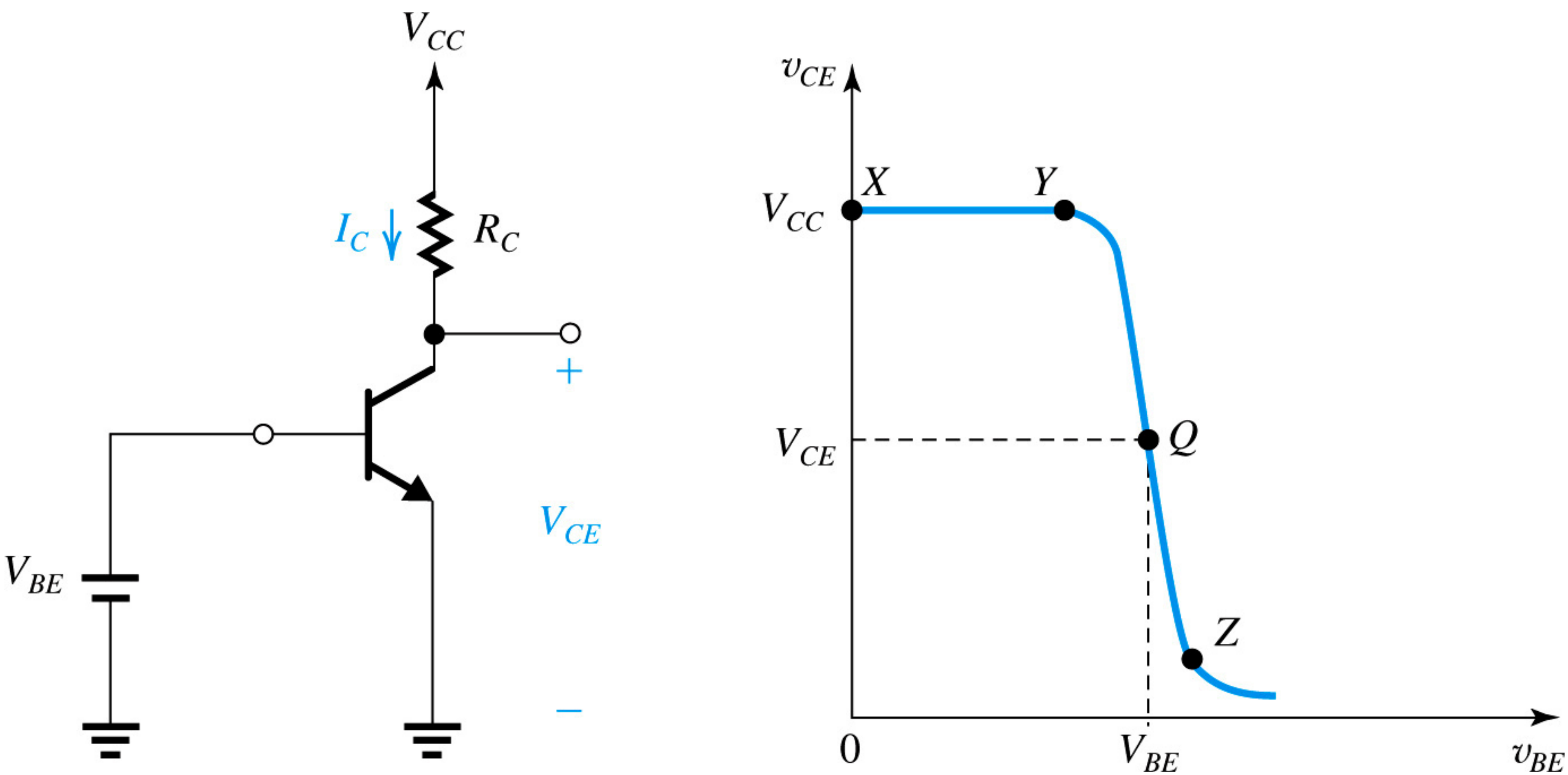
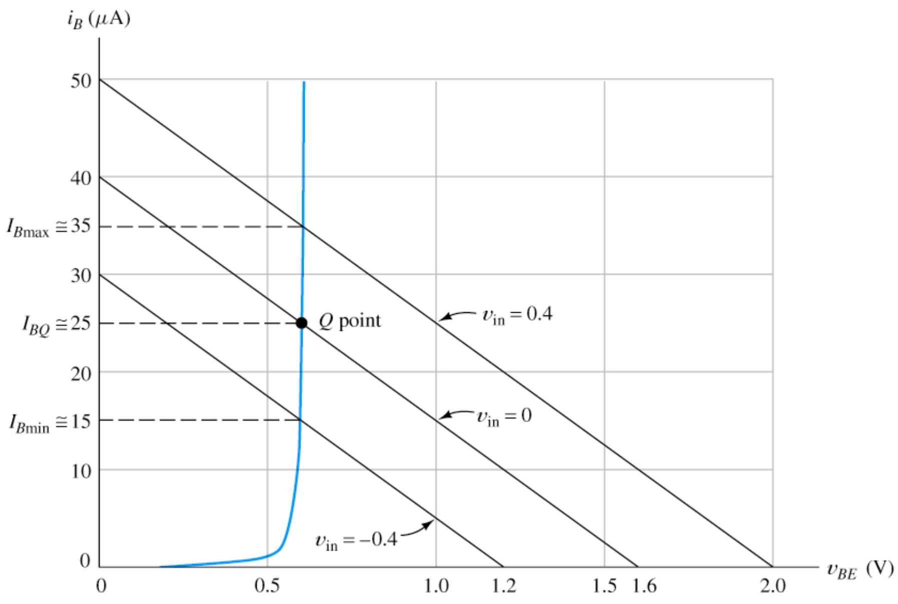
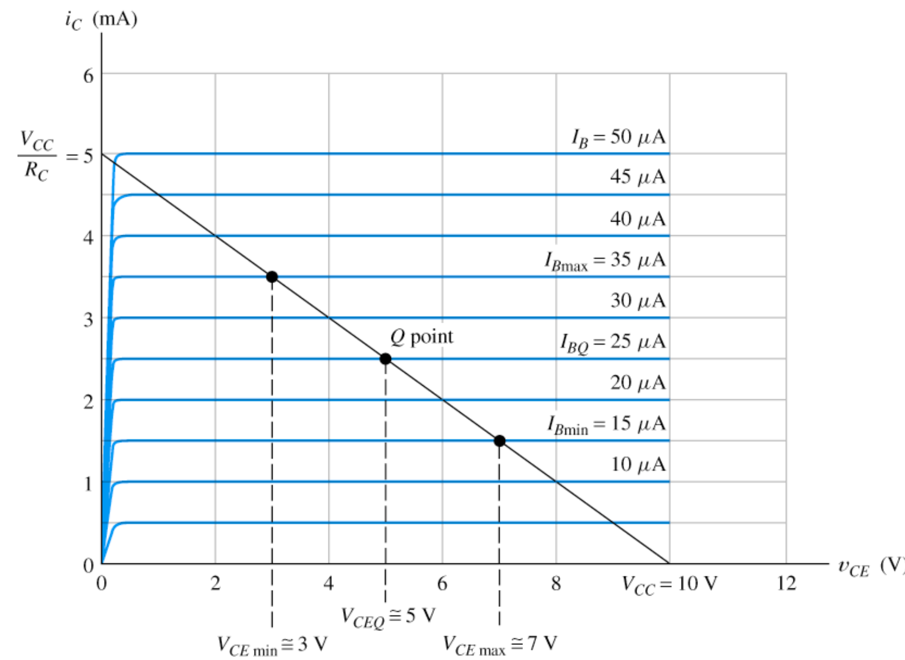


Figure 6.32: Biasing the BJT amplifier at a point Q located on the active-mode segment of the VTC.

Load line analysis



(a) Input



(b) Output

Input loadline

Output loadline

Principle of signal amplification

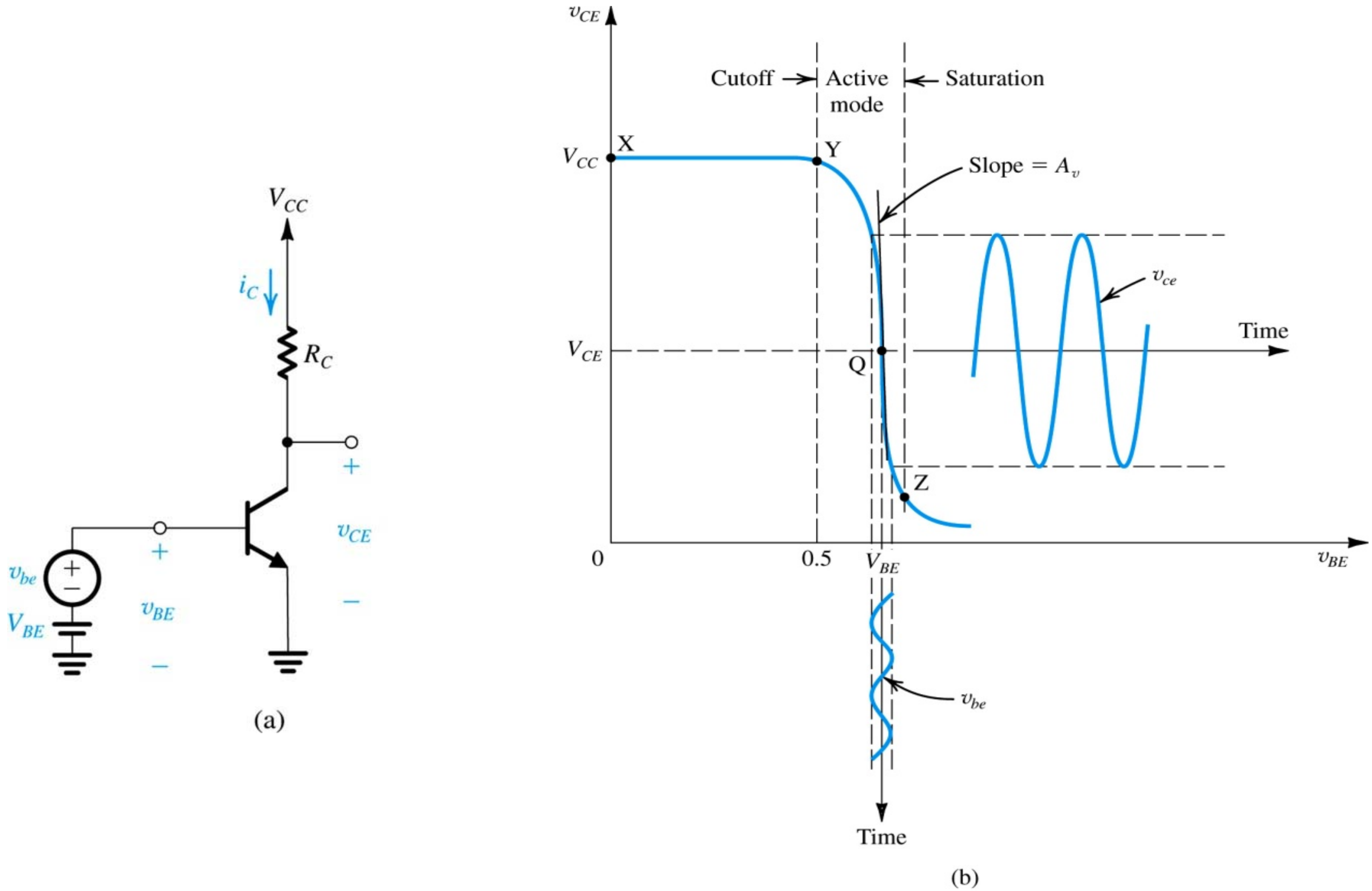
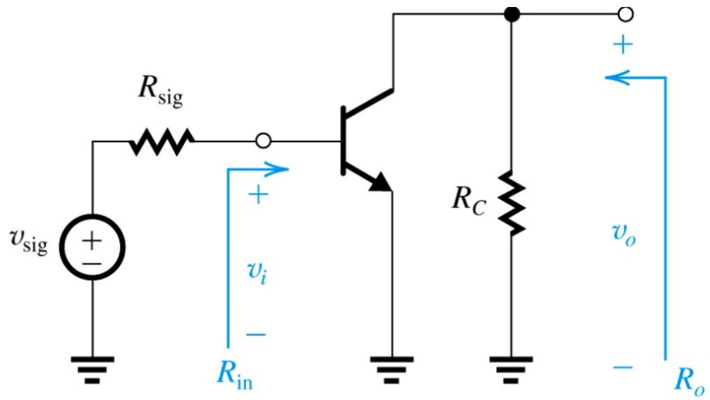


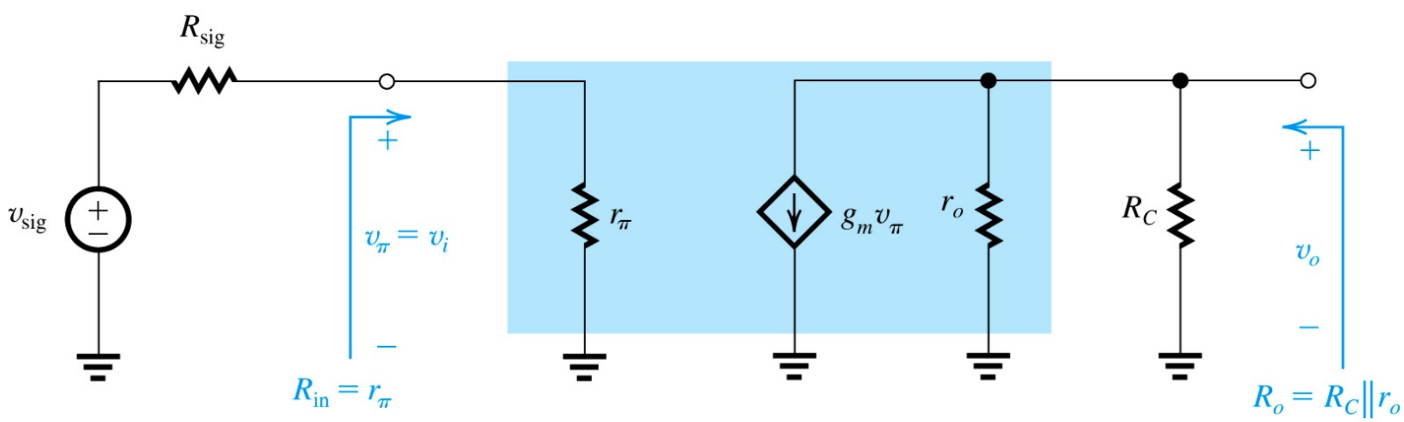
Figure 6.33 BJT amplifier biased at a point Q, with a small voltage signal v_{be} superimposed on the dc bias voltage V_{BE}. The resulting output signal v_{ce} appears superimposed on the dc collector voltage V_{CE}. The amplitude of v_{ce} is larger than that of v_{be} by the voltage gain A_v.

Low-fre BJT small signal "circuit" model



(a)

- signal course (v_{sig})
- source resistance (R_{sig})
- input resistance (R_{in})
- gain (A_{vo})
- output resistance (R_o)
- transconductance (G_v)



(b)

The CE amplifier circuit with the BJT replaced with its hybrid-pi model.

Characteristic Parameters of the CE Amplifier

- Replacing BJT with hybrid-pi model yields the expressions to right…

input resistance: $R_{in} = r_\pi$

output voltage: $v_o = -(g_m v_\pi)(R_C \,||\, r_o)$

open-circuit voltage gain: $A_{vo} = -g_m (R_C \,||\, r_o)$

$\underbrace{\text{oper-circuit voltage gain:}}_{\text{with } r_o \text{ neglected}}$ $A_{vo} = -g_m R_C$

output resistance: $A_{vo} = -g_m R_C$

Three Observations

The input resistance R_{in} = r_p = b/g_m is moderate to low in value.

The output resistance R_o = R_C is moderate to high in value.

The open-circuit voltage gain (A_{vo}) can be high – making the CE configuration the workhorse in BJT amplifier design.

Overall Voltage Gain

amplifier input voltage: $R_{in} v_i = v_{sig} \dfrac{r_\pi}{r_\pi + R_{sig}} = r_\pi$

voltage gain: $A_v = -g_m \left(R_C \,||\, R_L \,||\, r_o \right)$

not open-loop

overall voltage gain: $G_v = \dfrac{v_o}{v_{sig}} = \dfrac{-r_\pi}{r_\pi + R_{sig}} g_m \left(R_C \,||\, R_L \,||\, r_o \right)$

- The CE configuration is one of the best suited for realizing the bulk of the gain required in an amplifier. Depending on the magnitude of the gain required, either a single stage o a cascade of two or three stages may be used.
- Including a resistor R_e in the emitter lead of the CE stage provides a number of performance improvements at the expense of gain reduction.

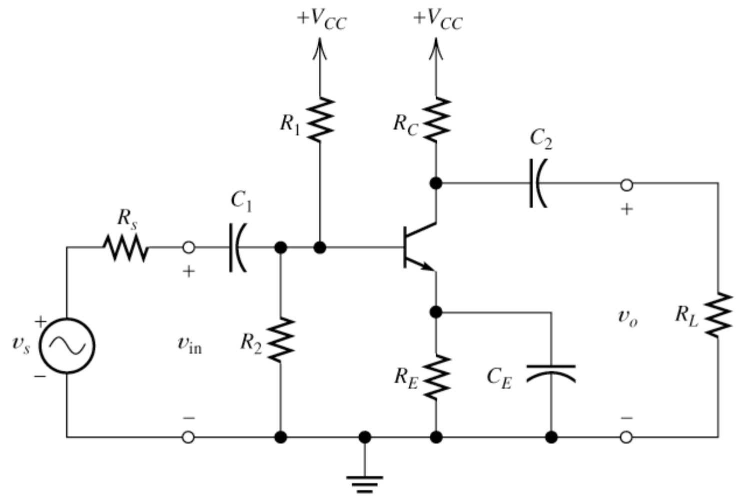
Characteristic summary of BJT amplifier

TABLE 6.5 Characteristics of BJT Amplifiers[a, b, c]

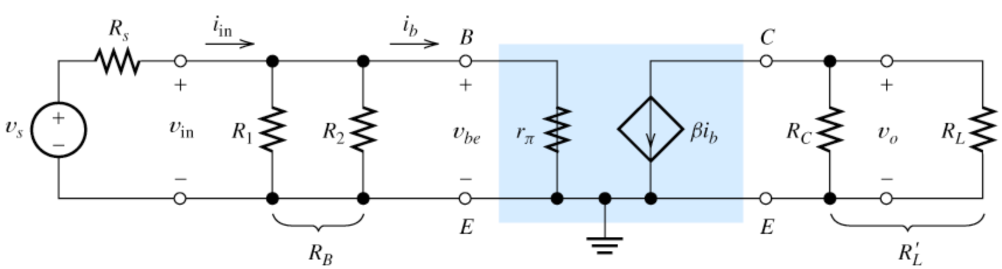
	R_{in}	A_{vo}	R_o	A_v	G_v
Common emitter (Fig. 6.50)	$(\beta+1)r_e$	$-g_m R_C$	R_C	$-g_m(R_C \parallel R_L)$ $-\alpha\dfrac{R_C \parallel R_L}{r_e}$	$-\beta\dfrac{R_C \parallel R_L}{R_{sig}+(\beta+1)r_e}$
Common emitter with R_e (Fig. 6.52)	$(\beta+1)(r_e+R_e)$	$-\dfrac{g_m R_C}{1+g_m R_e}$	R_C	$\dfrac{-g_m(R_C \parallel R_L)}{1+g_m R_e}$ $-\alpha\dfrac{R_C \parallel R_L}{r_e+R_e}$	$-\beta\dfrac{R_C \parallel R_L}{R_{sig}+(\beta+1)(r_e+R_e)}$
Common base (Fig. 6.53)	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. 6.55)	$(\beta+1)(r_e+R_L)$	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. 6.49.
[b] The BJT output resistance r_o has been neglected, which is permitted in the discrete-circuit amplifiers studied in this chapter. For integrated-circuit amplifiers (Chapter 7), r_o must always be taken into account.
[c] 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 5.4).

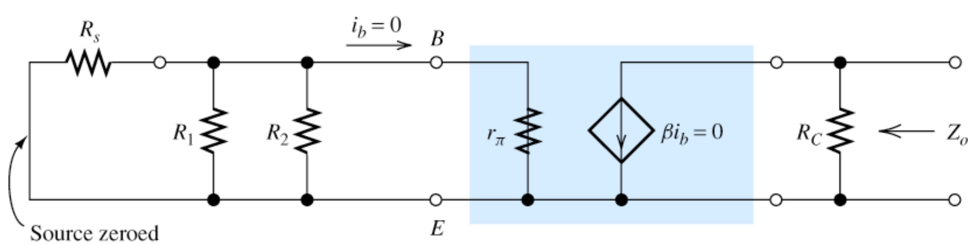
Small signal analysis- an example



(a) Actual circuit



(b) Small-signal ac equivalent circuit



(c) Equivalent circuit used to find Z_o

$$R_L' = R_L \| R_C = \frac{1}{1/R_L + 1/R_C}$$

$$A_v = \frac{v_o}{v_{in}} = -\frac{R_L'\beta}{r_\pi}$$

$$A_{vo} = \frac{v_o}{v_{in}} = -\frac{R_C\beta}{r_\pi}$$

$$Z_{in} \frac{v_{in}}{i_{in}} = \frac{1}{1/R_B + 1/r_\pi}$$

$$A_i = \frac{i_o}{i_{in}} = A_v \frac{Z_{in}}{R_L}$$

$$G = A_i A_v$$

$$Z_o = R_C$$

Summary

- Depending on the bias condition on its two junctions, the BJT can operate in one of three possible modes:

  cut-off (both junctions reverse biased)

  active (the EBJ forward-biased and CBJ reversed)

  saturation (both junctions forward biased)

- For amplifier applications, the BJT is operated in the active mode. Switching applications make use of the cutoff and saturation modes.

- A BJT operating in the active mode provides a collector current $i_C = I_S \mathbf{exp}\{v_{BE}/V_T\}$. The base current $i_B = i_C/b$, and emitter current $i_E = i_C + i_B$.

Summary (cont'd)

- To ensure operation in the active mode, the collector voltage of an *npn*-transistor must be kept higher than approximately 0.4*V* below the base voltage. For a *pnp*-transistor, the collector voltage must be lower than approximately 0.4*V* above the base voltage. Otherwise, the CBJ becomes forward-biased and the transistor will enter saturation.

- At a constant collector current, the magnitude of the base emitter voltage decreases by about 2*mV* for every 1°C rise in temperature.

- The BJT will be at the edge of saturation when $|v_{CE}|$ is reduced to about 0.3*V*.

Summary (cont'd)

- In the active mode, i_C shows a slight dependence on v_{CE}. This phenomenon, known as the Early Effect, is modeled by ascribing a finite output resistance to the BJT: $r_o = |V_A|/I'_C$ where V_A is the Early Voltage and I'_C is the dc collector current without the Early Effect taken into account.
- The dc analysis of transistor circuits is generally simplified by assuming $|V_{BE}| = 0.7V$.
- To operate as a linear amplifier, the BJT is biased in the active region and the signal v_{be} is kept small ($v_{be} << V_T$).
- Bias design seeks to establish a dc collector current that is as independent of β as possible.

Summary (cont'd)

- For small signals, the BJT functions as a linear voltage-controlled current source with transconductance $g_m = I_C/V_T$. The input resistance between base and emitter, looking into the base, is $r_\pi = \beta/g_m$. The input resistance between bae and emitter, looking into the emitter is $r_e = 1/g_m$.

- The common-emitter amplifier is inverting and has large voltage gain magnitude, large current gain, and large power gain.

Acknowledgments

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- Credit is acknowledged where credit is due. Please refer to the full list of references.