Microelectronics
Circuit Analysis and Design

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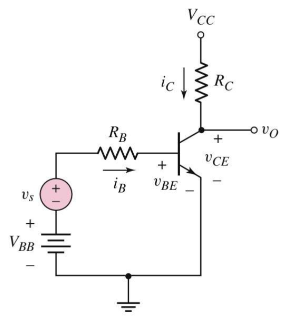
Chapter 6

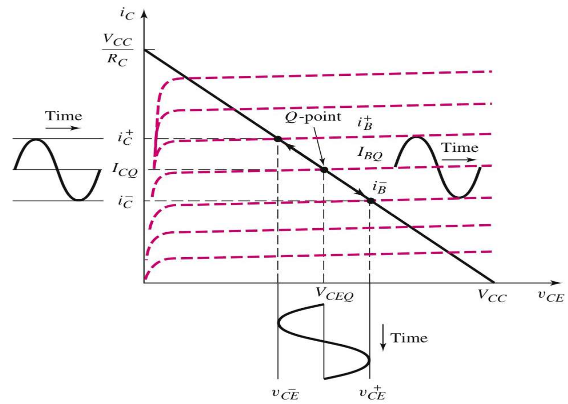
Basic BJT Amplifiers

In this chapter, we will:

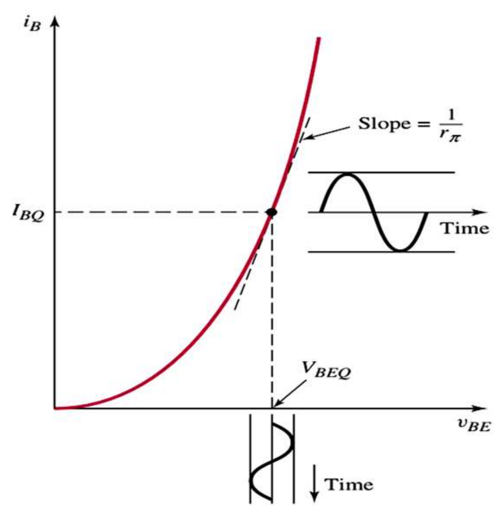
- Understand the concept of an analog signal and the principle of a linear amplifier.
  - Investigate how a transistor circuit can amplify a small, time-varying input signal.
- Discuss and compare the three basic transistor amplifier configurations.
  - Analyze the common-emitter amplifier.
    - Understand the ac load line & determine the maximum symmetrical swing of the output.
  - Analyze the emitter-follower amplifier.
  - Analyze the common-base amplifier.
- Analyze multitransistor or multistage amplifiers.
- Understand the concept of signal power gain in an amplifier

Common Emitter with Time-Varying Input



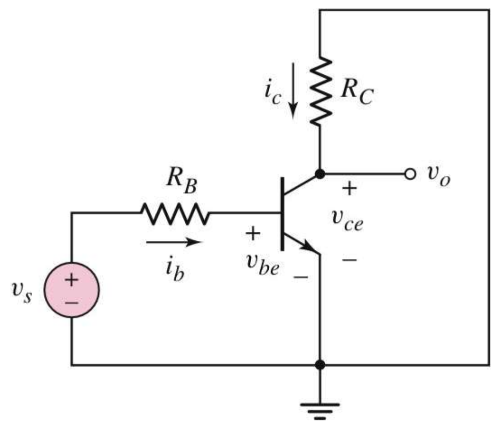


I_B Versus V_{BE} Characteristic

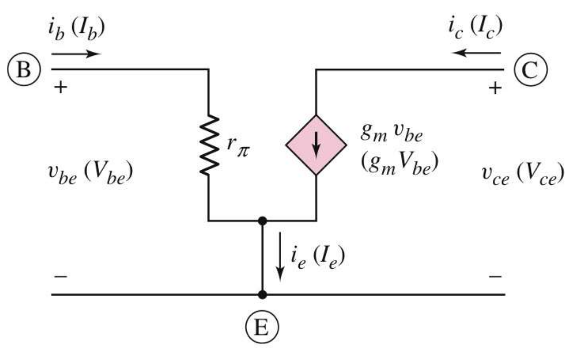


$$i_B \cong I_{BQ}(1+\frac{v_{be}}{V_T}) = I_B + i_b$$

ac Equivalent Circuit for Common Emitter



Small-Signal Hybrid π Model for npn BJT



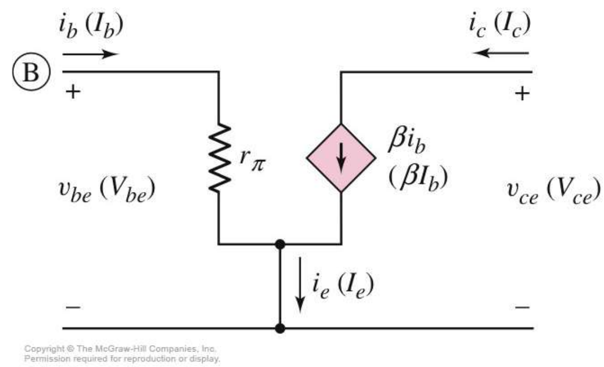
$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

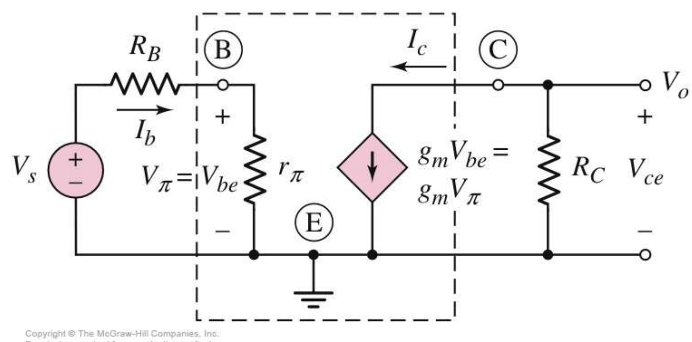
$$g_m r_\pi = \beta$$

Phasor signals are shown in parentheses.

Small-Signal Equivalent Circuit Using Common-Emitter Current Gain



Small-Signal Equivalent Circuit for npn Common Emitter circuit

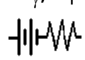
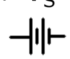
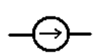


$$A_v = -(g_m R_C)(\frac{r_\pi}{r_\pi + R_B})$$

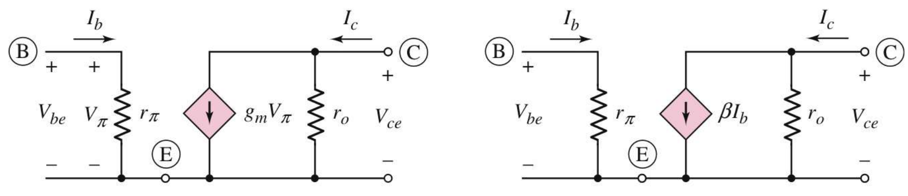
Problem-Solving Technique: BJT AC Analysis

1. Analyze circuit with only dc sources to find Q point.
2. Replace each element in circuit with small-signal model, including the hybrid π model for the transistor.
3. Analyze the small-signal equivalent circuit after setting dc source components to zero.

Transformation of Elements

Element	DC Model	AC Model
Resistor	R	R
Capacitor	Open	C
Inductor	Short	L
Diode	$+V_\gamma$, r_f − 	$r_d = V_T/I_D$
Independent Constant Voltage Source	+ V_S - 	Short
Independent Constant Current Source	I_S 	Open

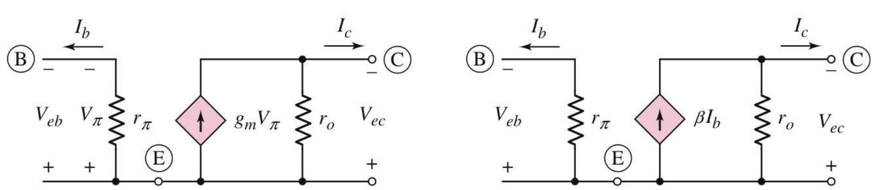
Hybrid π Model for npn with Early Effect



(a) (b)

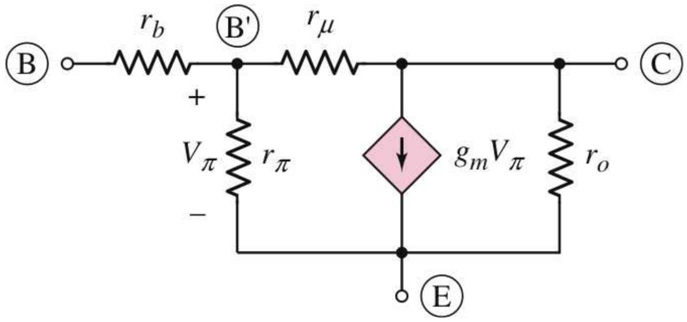
$$r_o = \frac{V_A}{I_{CQ}}$$

Hybrid p Model for pnp with Early Effect

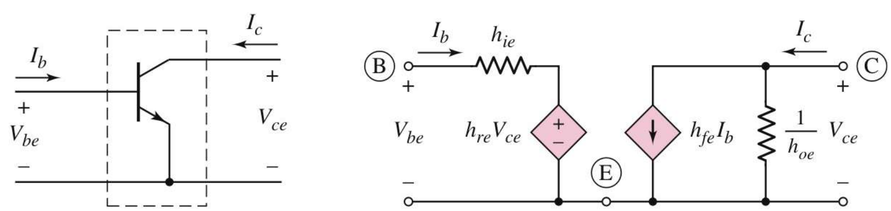


(a) (b)

Expanded Hybrid π Model for npn



h-Parameter Model for npn



(a) (b)

$$h_{ie} = r_b + r_\pi \| r_\mu$$

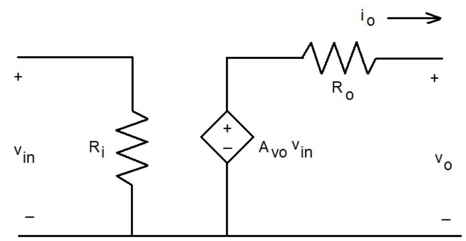
$$h_{fe} = \beta$$

$$h_{re} \cong \frac{r_\pi}{r_\mu}$$

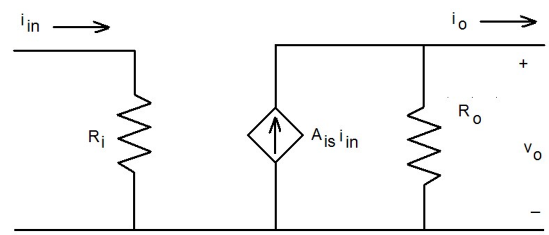
$$h_{oe} = \frac{1+\beta}{r_\mu} + \frac{1}{r_o}$$

4 Equivalent 2-port Networks

Voltage Amplifier



Current Amplifier



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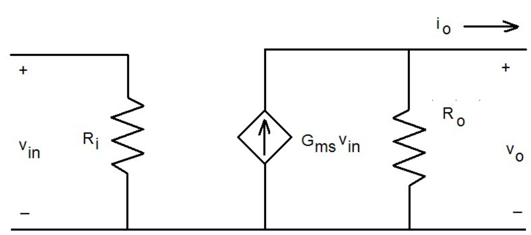
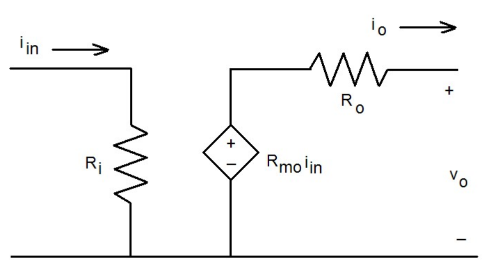
4 Equivalent 2-port Networks

Transconductance Amplifier



Transresistance Amplifier



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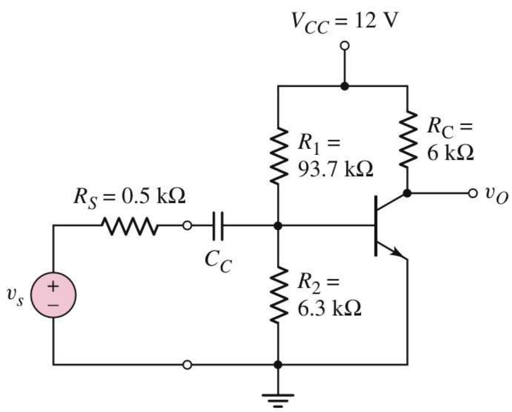
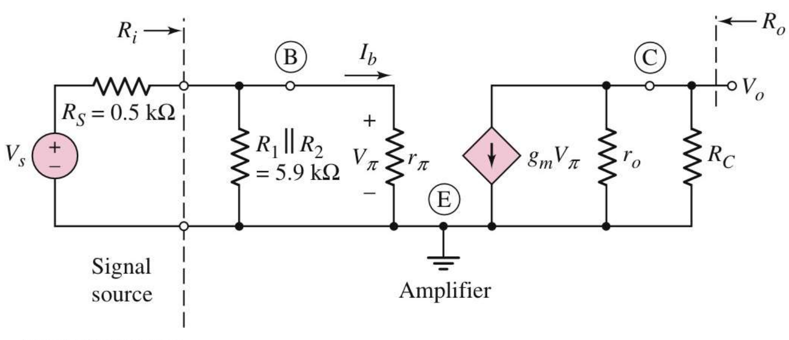
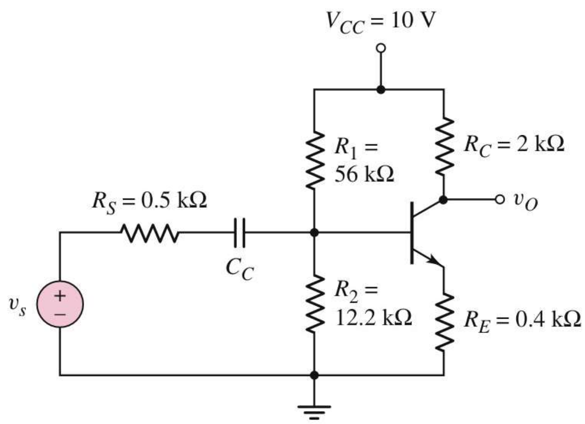
Common Emitter with Voltage-Divider Bias and a Coupling Capacitor



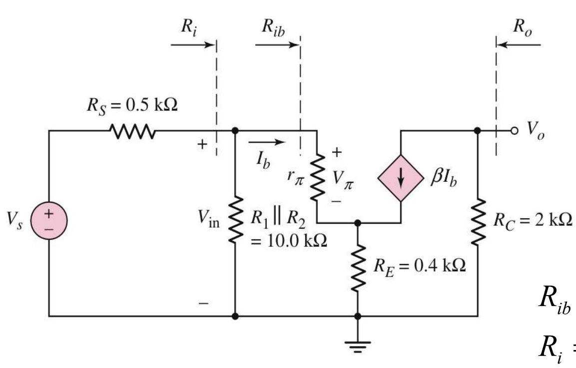
Small-Signal Equivalent Circuit – Coupling Capacitor Assumed a Short



npn Common Emitter with Emitter Resistor



Small-Signal Equivalent Circuit: Common Emitter with R_E

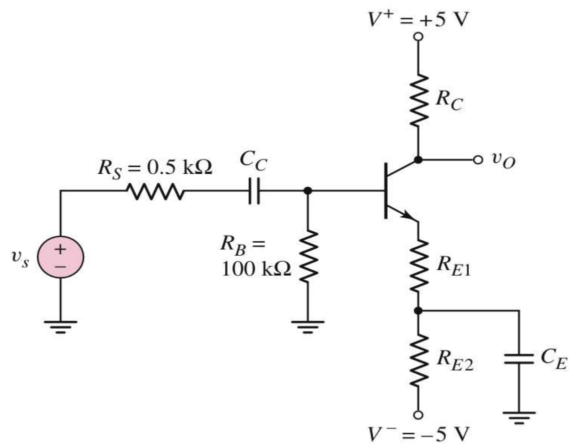


$$R_{ib} = r_\pi + (1+\beta)R_E$$

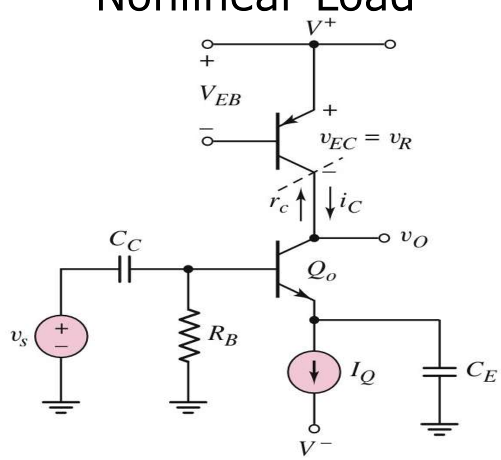
$$R_i = R_1 \| R_2 \| R_{ib}$$

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}\left(\frac{R_i}{R_i + R_S}\right)$$

R_E and Emitter Bypass Capacitor

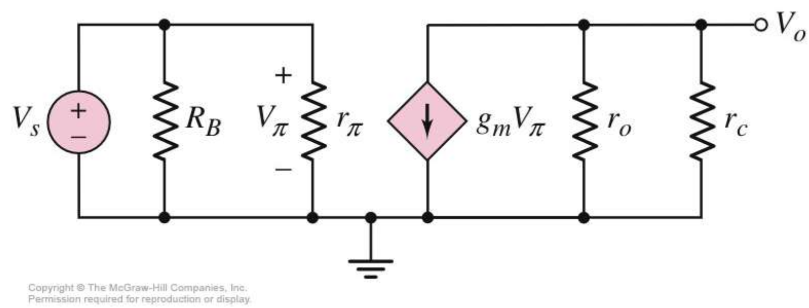


Current Source Biasing and Nonlinear Load



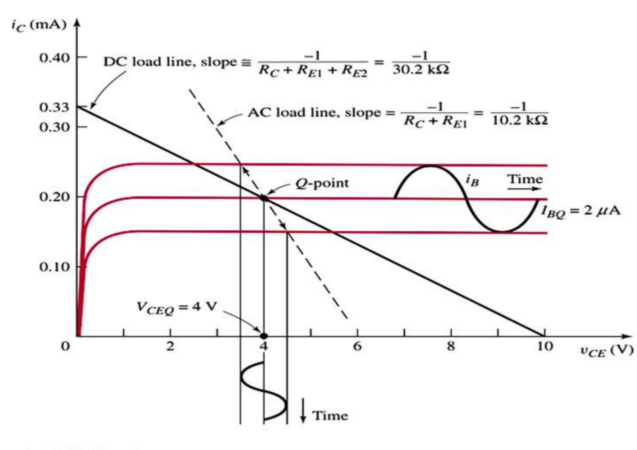
(c)

Small-Signal Equivalent Circuit with Current Biasing and Nonlinear Load



$$A_v = -g_m (r_o \| r_c)$$

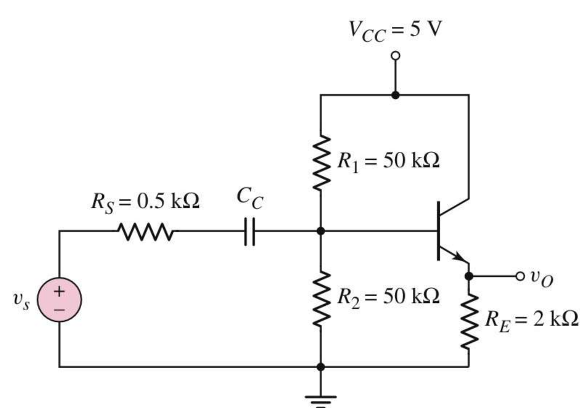
dc AND ac Load Lines: R_E and Emitter Bypass Capacitor



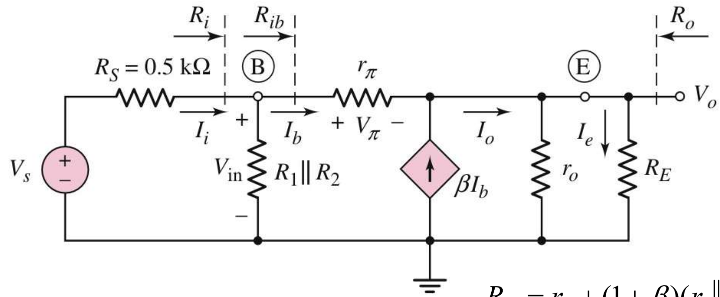
Problem-Solving Technique: Maximum Symmetrical Swing

1. Write dc load line equation that relates I_{CQ} and V_{CEQ}.
2. Write ac load line equations that relates ic and vce
3. In general, $i_c = I_{CQ} - I_C(\text{min})$, where $I_C(\text{min})$ is zero or other minimum collector current.
4. In general, $v_{ce} = V_{CEQ} - V_{CE}(\text{min})$, where $V_{CE}(\text{min})$ is some specified minimum collector-emitter voltage.
5. Combine above 4 equations to find optimum I_{CQ} and V_{CEQ}.

Common-Collector or Emitter-Follower Amplifier



Small-Signal Equivalent Circuit: Emitter Follower

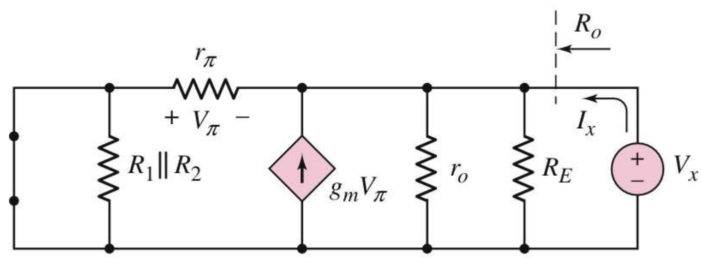


$$R_{ib} = r_\pi + (1+\beta)(r_o \| R_E)$$

$$R_i = R_1 \| R_2 \| R_{ib}$$

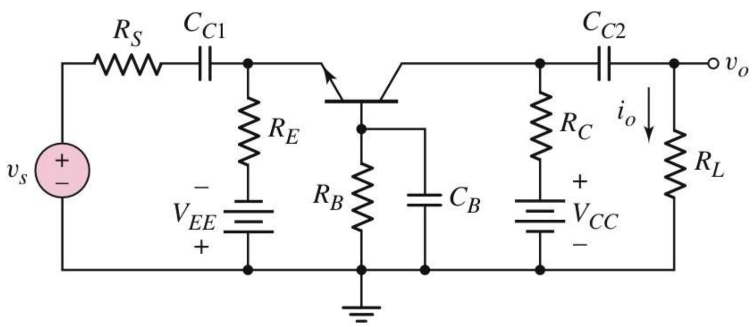
$$A_v = \frac{(1+\beta)(r_o \| R_E)}{r_\pi + (1+\beta)(r_o \| R_E)} \left(\frac{R_i}{R_i + R_S}\right)$$

Output Resistance: Emitter Follower

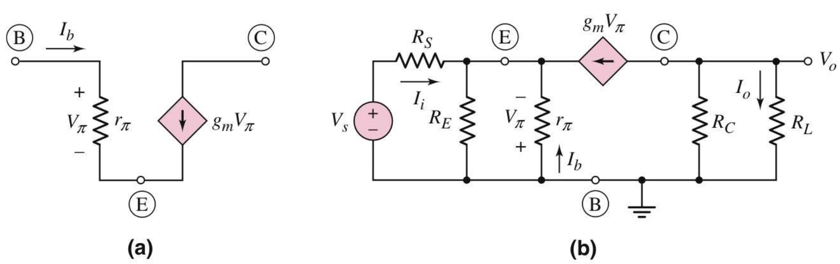


$$R_o = \frac{r_\pi}{1+\beta} \| R_E \| r_o$$

Common-Base Amplifier



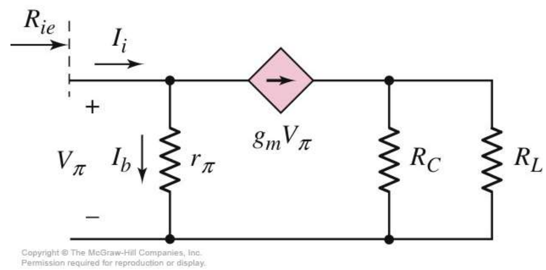
Small-Signal Equivalent Circuit: Common Base



$$A_v = g_m (R_C \| R_L)$$

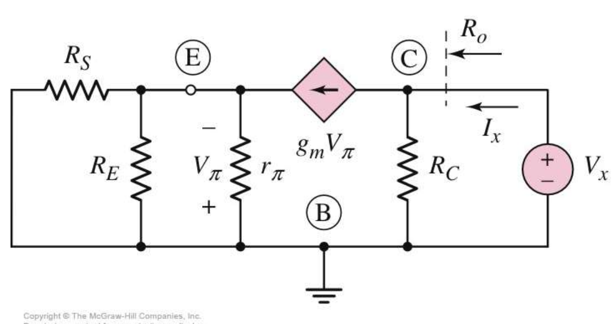
$$A_i = g_m \left(\frac{R_C}{R_C + R_L}\right)\left[\frac{r_\pi}{1+\beta} \| R_E\right]$$

Input Resistance: Common Base



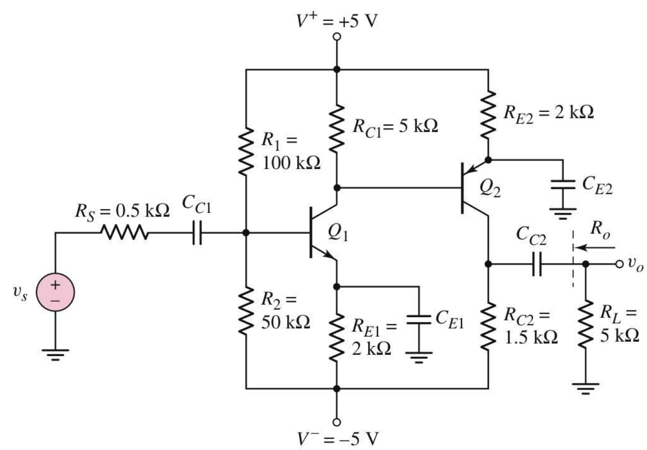
$R_{ie} = r_\pi/(1+\beta)$

Output Resistance: Common Base

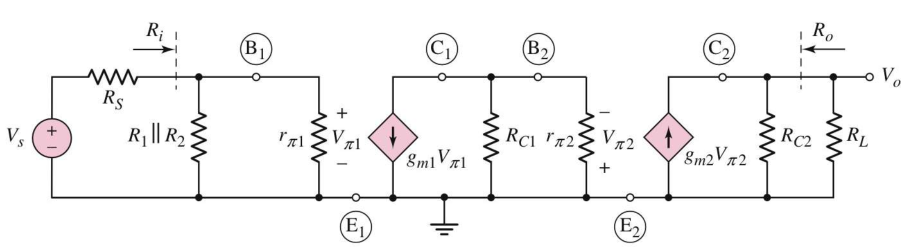


$R_O = R_C$

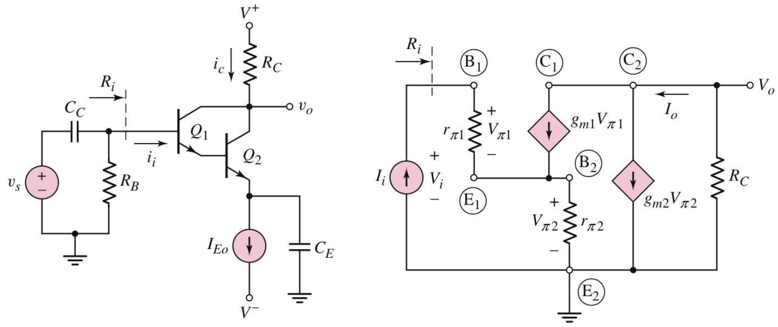
Common Emitter Cascade Amplifier



Small-Signal Equivalent Circuit: Cascade Amplifier



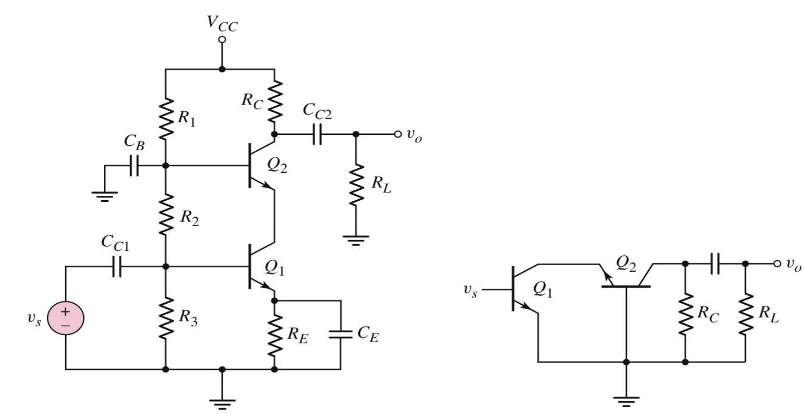
Darlington Pair



(a) (b)

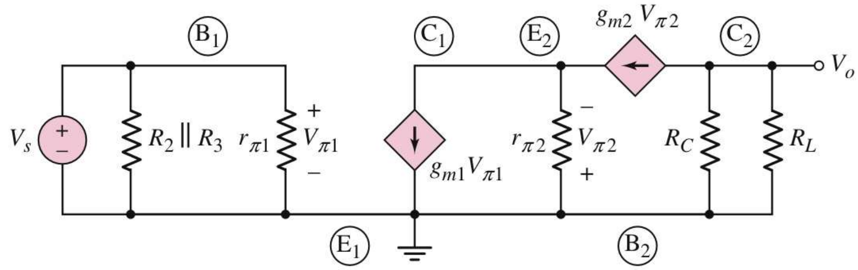
$$A_i \cong \beta_1 \beta_2$$

Cascode Amplifier



(a) (b)

Small-Signal Equivalent Circuit: Cascode Amplifier



$$A_v \cong -g_{m1}(R_C \| R_L)$$