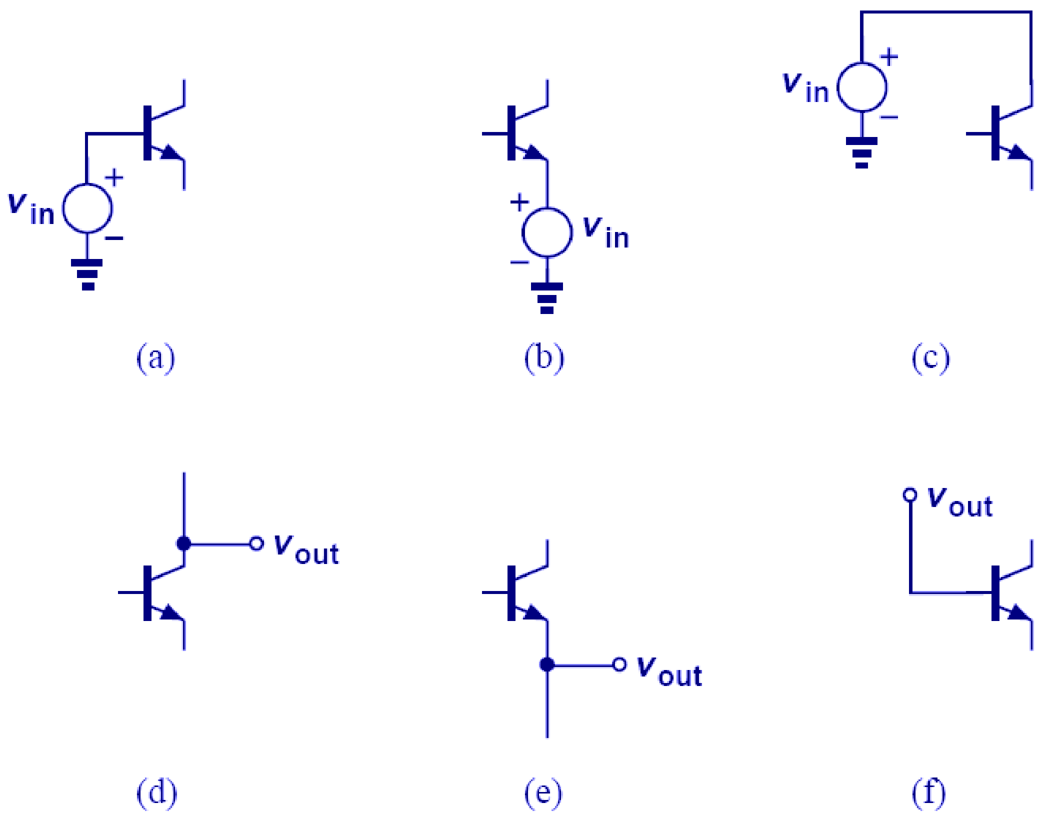
# Lecture 7

## OUTLINE

- Bipolar Amplifier Topologies (1)
  – Common-Emitter Amplifiers

Reading: Chapter 5.3.1

# Possible Bipolar Amplifier Topologies

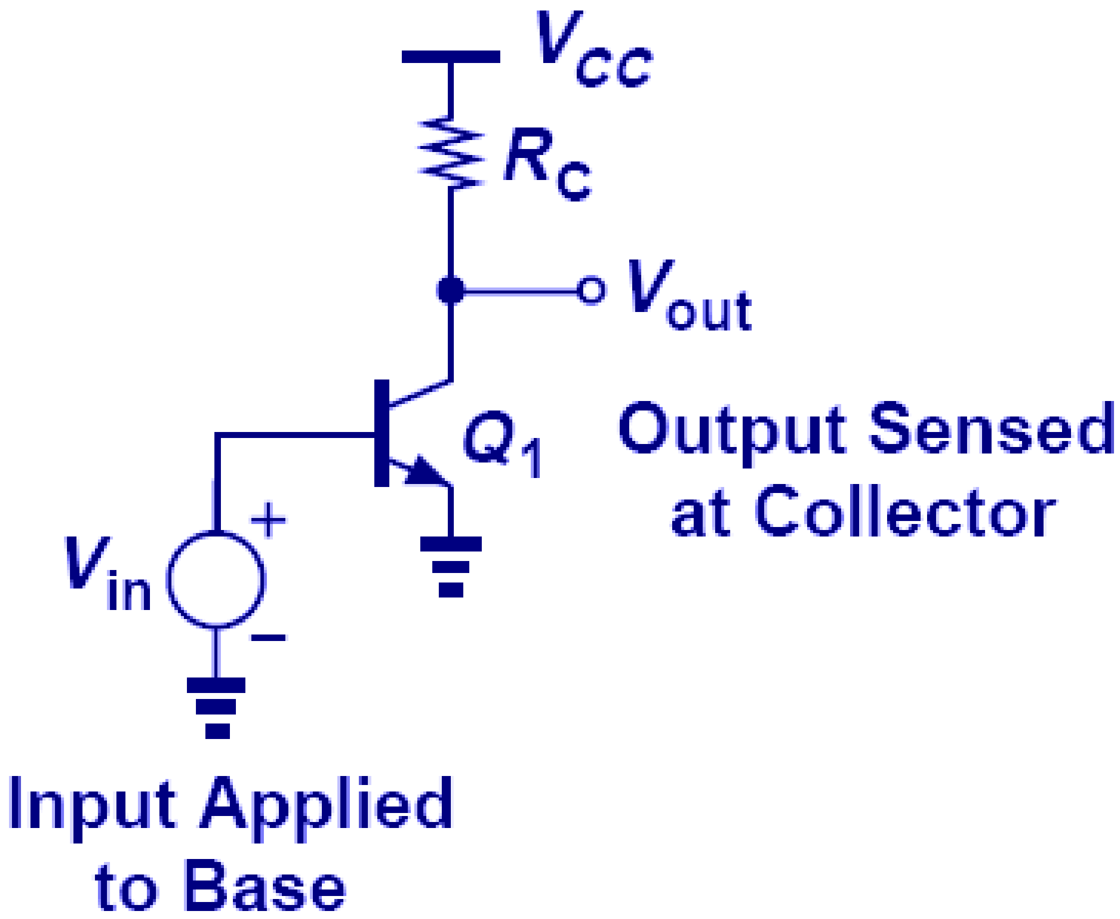



- Three possible ways to apply an input to an amplifier and three possible ways to sense its output.
- However, in reality only three of six input/output combinations are useful.

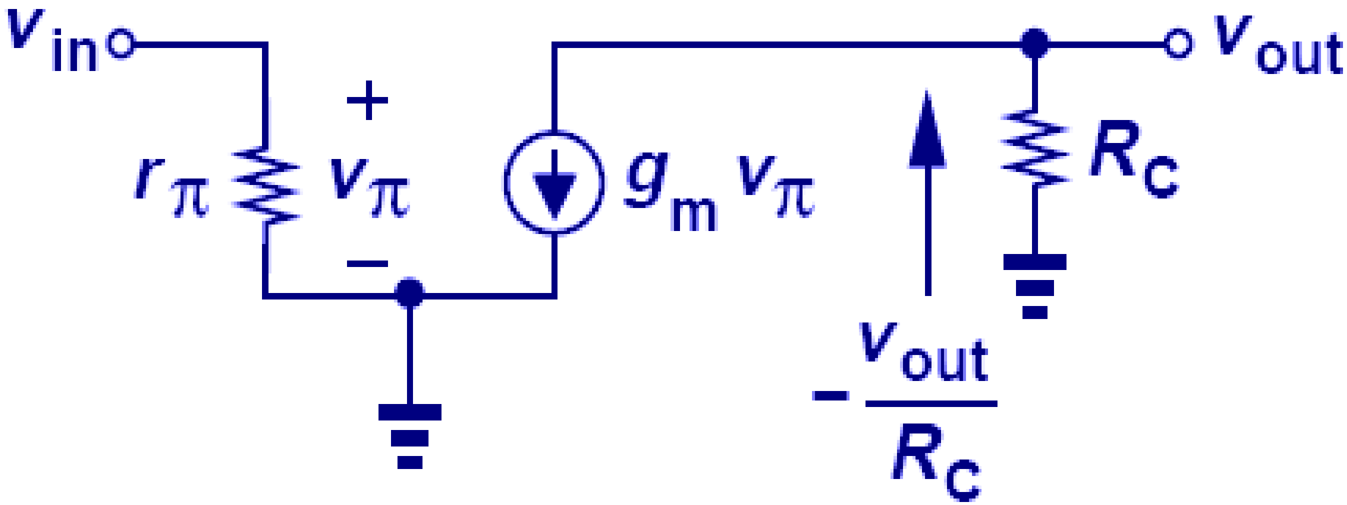
# Study of Common-Emitter Topology

- Analysis of CE Core
  - Inclusion of Early Effect
- Emitter Degeneration
  - Inclusion of Early Effect
- CE Stage with Biasing

# Common-Emitter Topology



# Small Signal of CE Amplifier

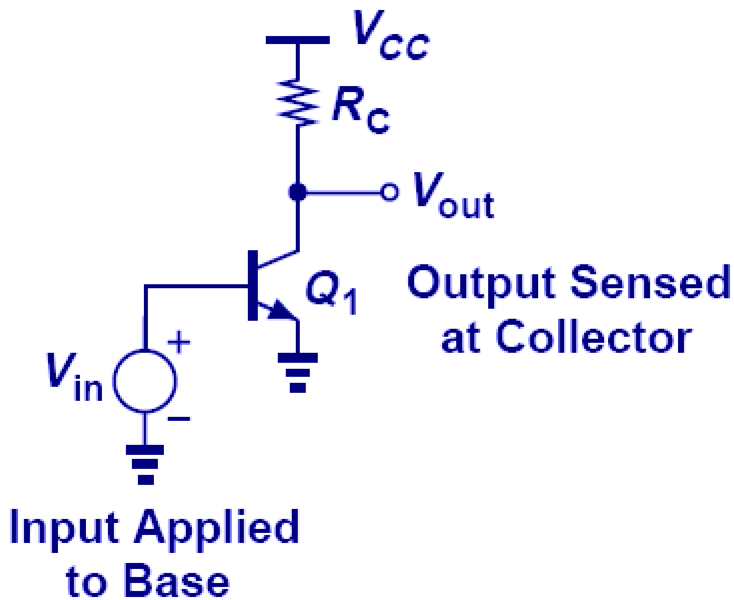



$$A_v = \frac{v_{out}}{v_{in}}$$

$$-\frac{v_{out}}{R_C} = g_m v_\pi = g_m v_{in}$$

$$A_v = -g_m R_C$$

# Limitation on CE Voltage Gain



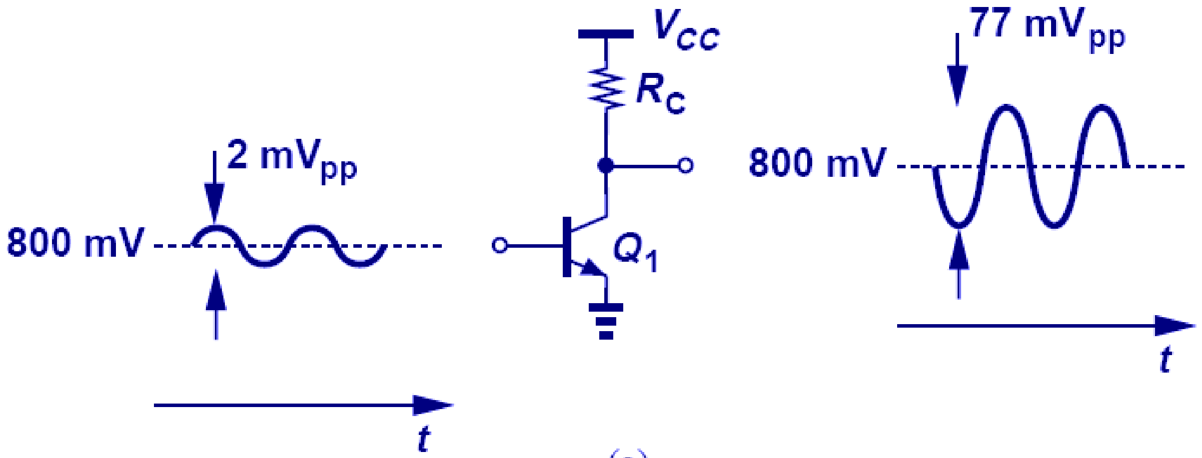

$$|A_v| = \frac{I_C R_C}{V_T}$$

$$|A_v| = \frac{V_{RC}}{V_T}$$

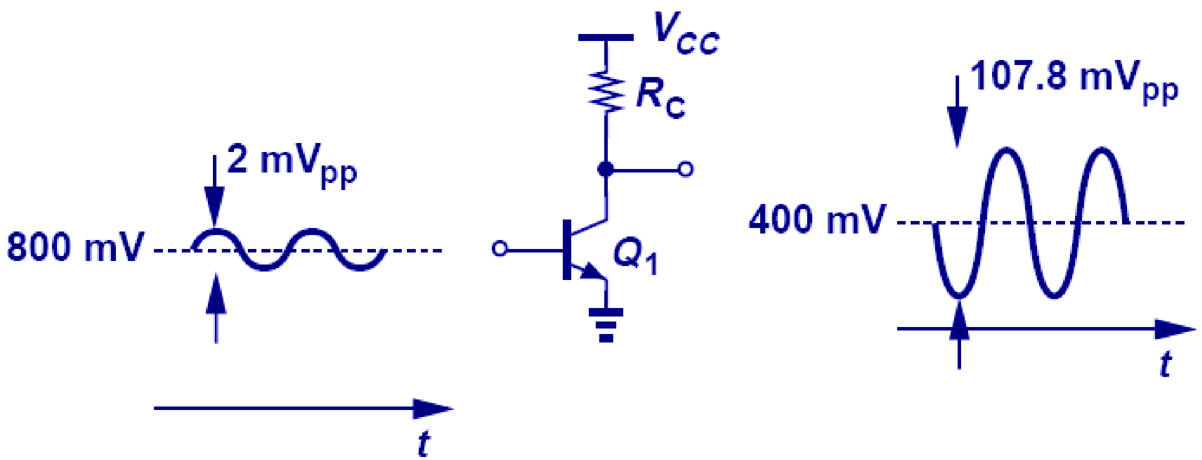
$$|A_v| < \frac{V_{CC} - V_{BE}}{V_T}$$

- Since $g_m$ can be written as $I_C/V_T$, the CE voltage gain can be written as the ratio of $V_{RC}$ and $V_T$.
- $V_{RC}$ is the potential difference between $V_{CC}$ and $V_{CE}$, and $V_{CE}$ cannot go below $V_{BE}$ in order for the transistor to be in active region.

# Tradeoff between Voltage Gain and Headroom

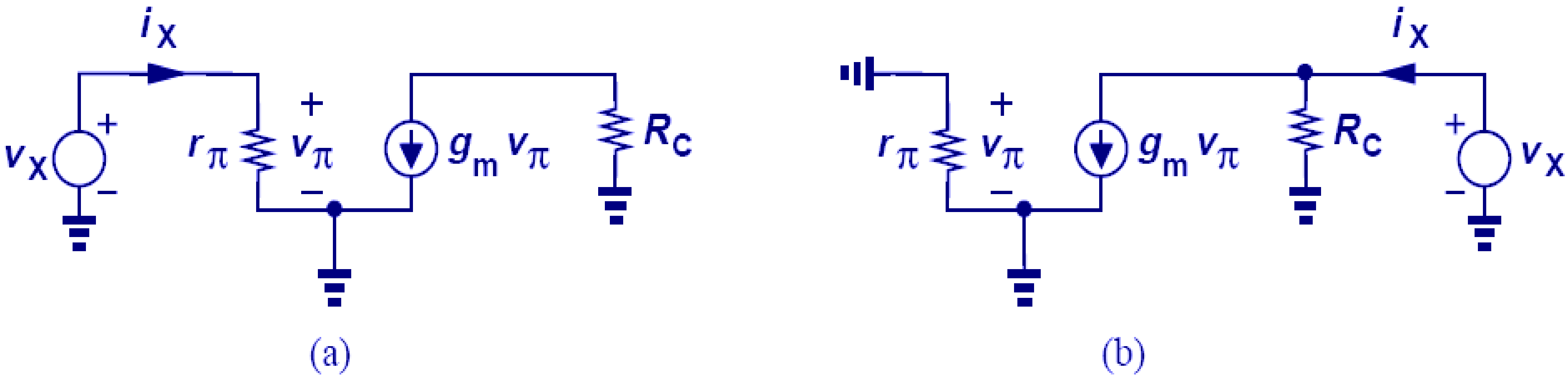



(a)




(b)

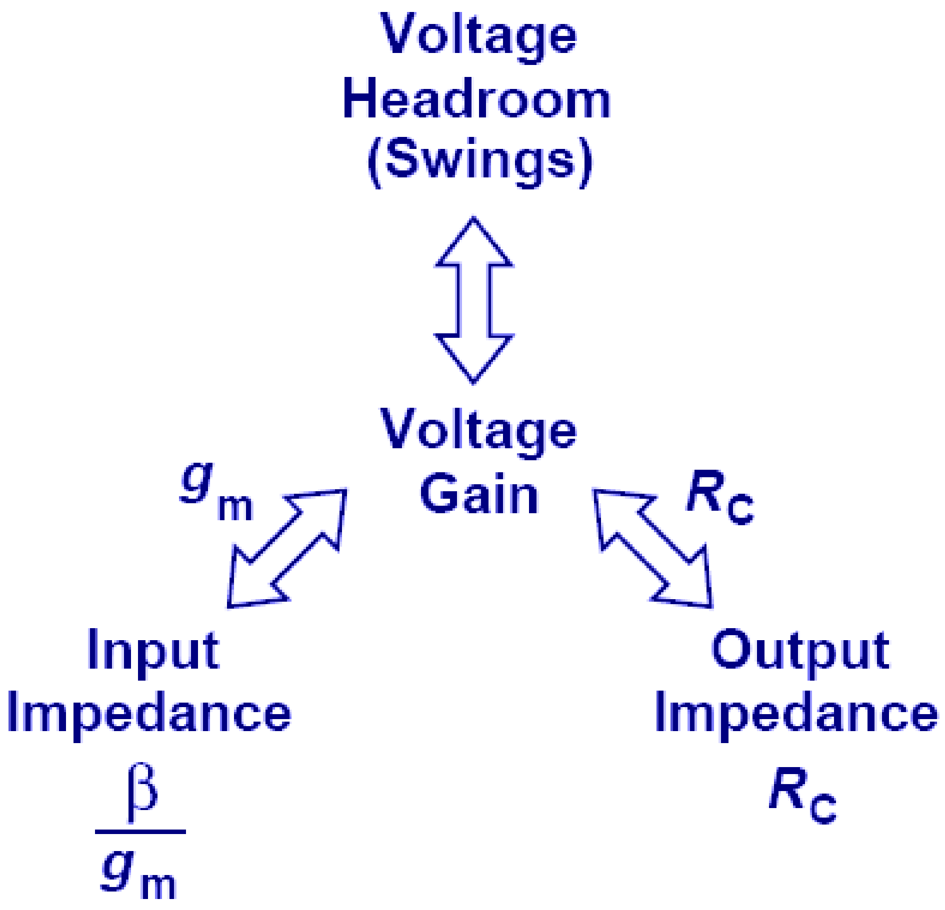
# I/O Impedances of CE Stage



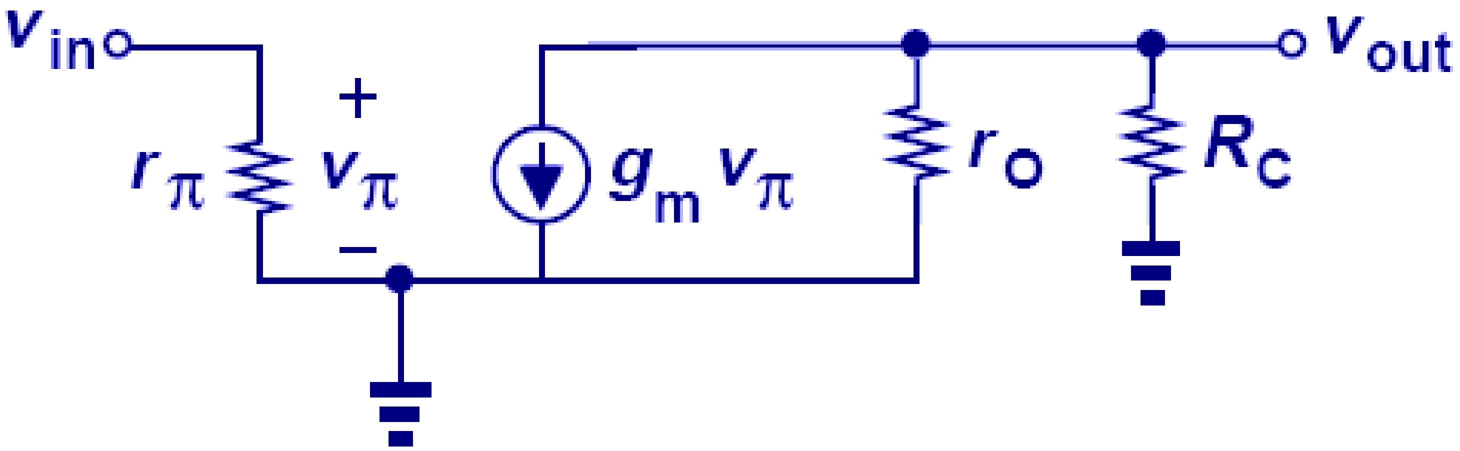

$$R_{in} = \frac{v_X}{i_X} = r_\pi \qquad R_{out} = \frac{v_X}{i_X} = R_C$$

- When measuring output impedance, the input port has to be grounded so that $V_{in} = 0$.

# CE Stage Trade-offs



# Inclusion of Early Effect




$$A_v = -g_m (R_C \parallel r_O)$$
$$R_{out} = R_C \parallel r_O$$

- Early effect will lower the gain of the CE amplifier, as it appears in parallel with RC.

# Intrinsic Gain

$$A_v = -g_m r_O$$

$$\left|A_v\right| = \frac{V_A}{V_T}$$

- As $R_C$ goes to infinity, the voltage gain reaches the product of $g_m$ and $r_O$, which represents the maximum voltage gain the amplifier can have.
- The intrinsic gain is independent of the bias current.

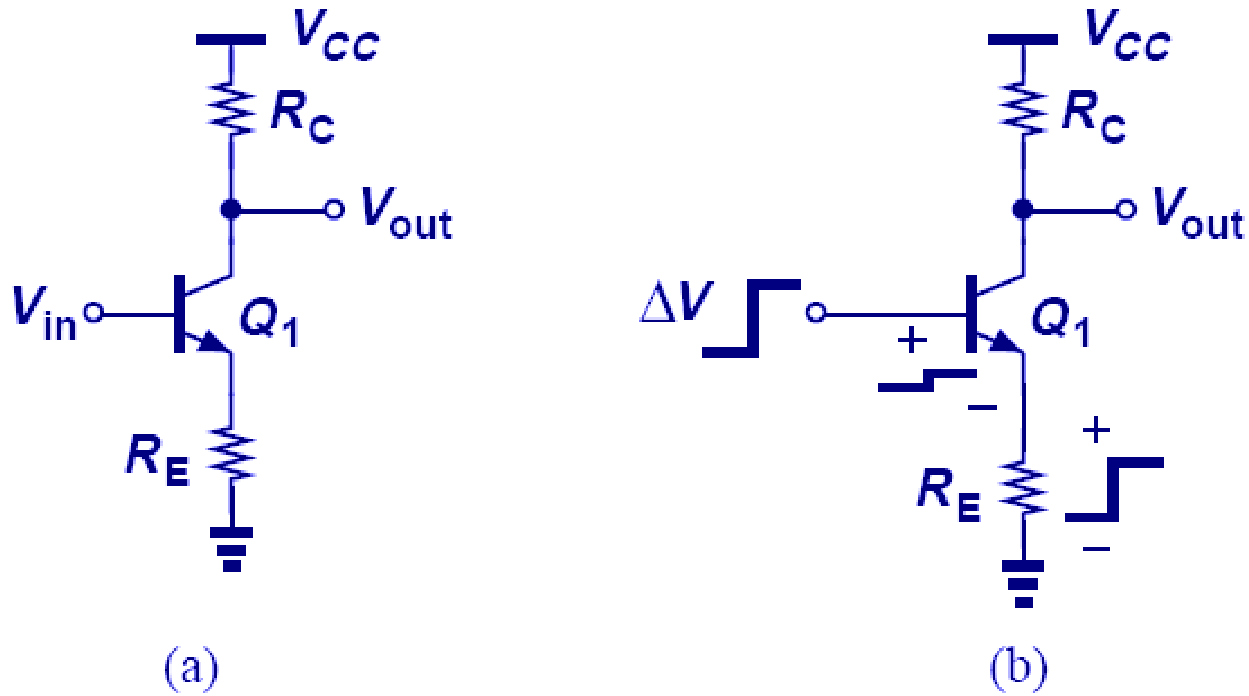
# Current Gain

$$A_I = \frac{i_{out}}{i_{in}}$$

$$A_I \Big|_{CE} = \beta$$

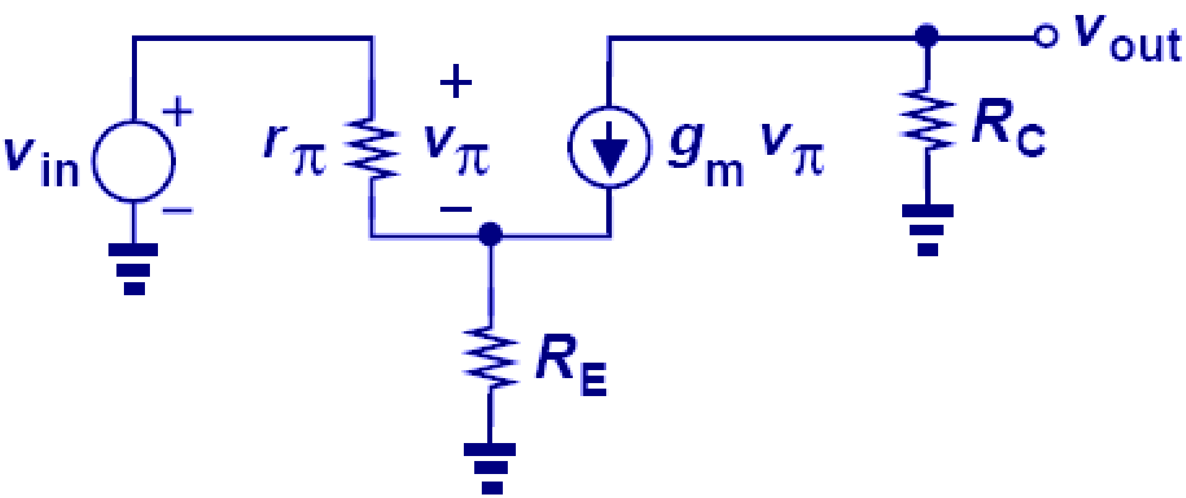
- Another parameter of the amplifier is the current gain, which is defined as the ratio of current delivered to the load to the current flowing into the input.
- For a CE stage, it is equal to $\beta$.

# Emitter Degeneration




- By inserting a resistor in series with the emitter, we “degenerate” the CE stage.
- This topology will decrease the gain of the amplifier but improve other aspects, such as linearity, and input impedance.

# Small-Signal Model

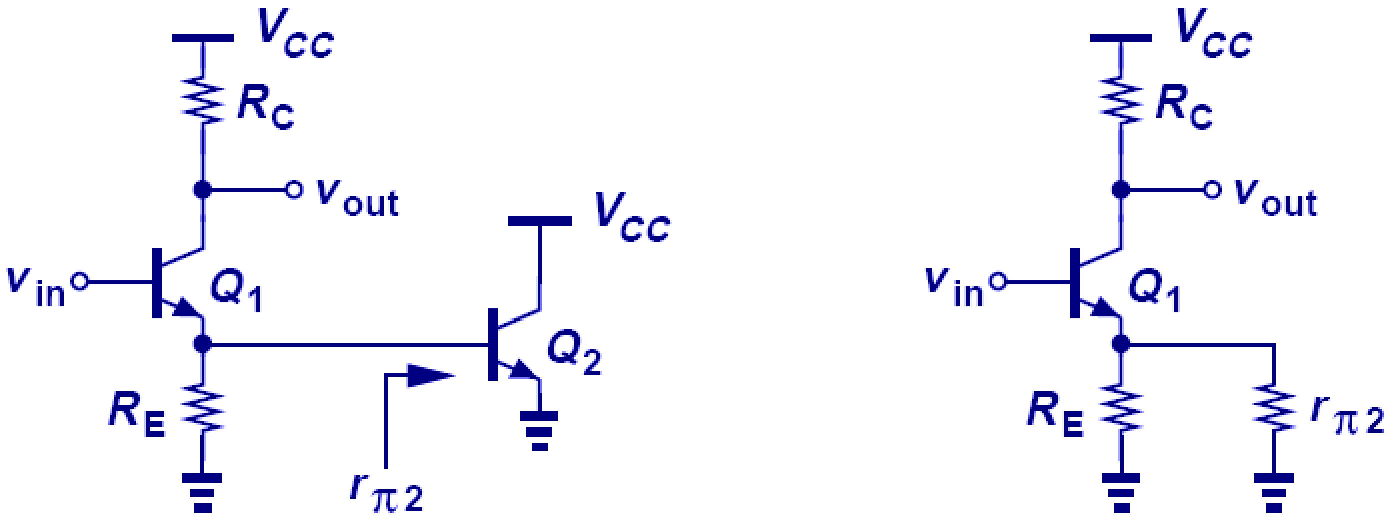



$$A_v = -\frac{g_m R_C}{1 + g_m R_E}$$

$$A_v = -\frac{R_C}{\frac{1}{g_m} + R_E}$$

- Interestingly, this gain is equal to the total load resistance to ground divided by $1/g_m$ plus the total resistance placed in series with the emitter.

# Emitter Degeneration Example I

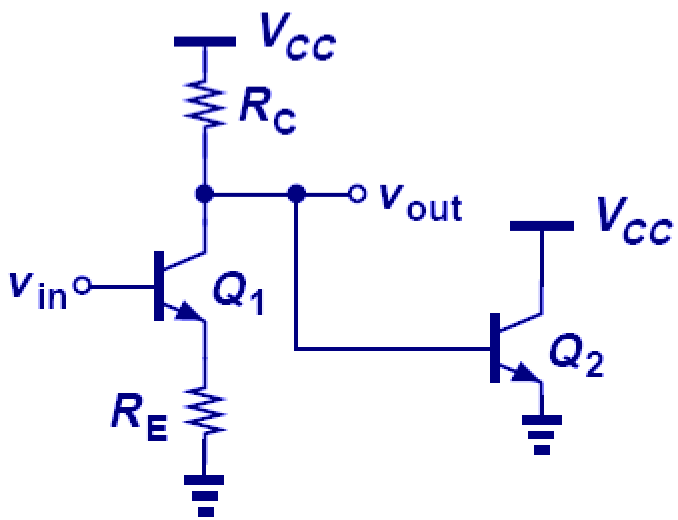



(a) (b)

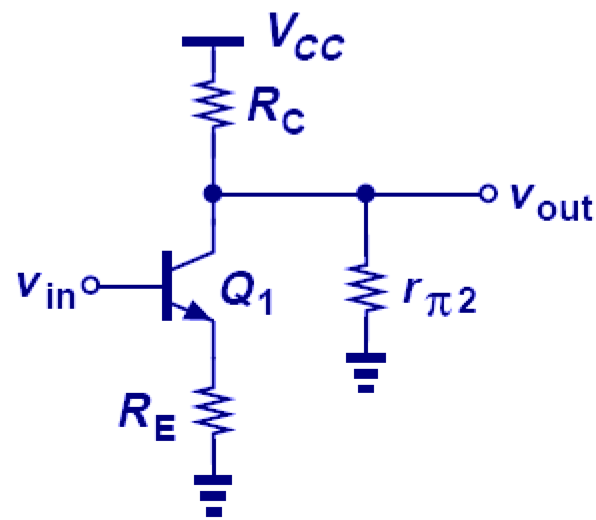
$$A_v = -\frac{R_C}{\frac{1}{g_{m1}} + R_E \parallel r_{\pi 2}}$$

- The input impedance of $Q_2$ can be combined in parallel with $R_E$ to yield an equivalent impedance that degenerates $Q_1$.

# Emitter Degeneration Example II




(a)

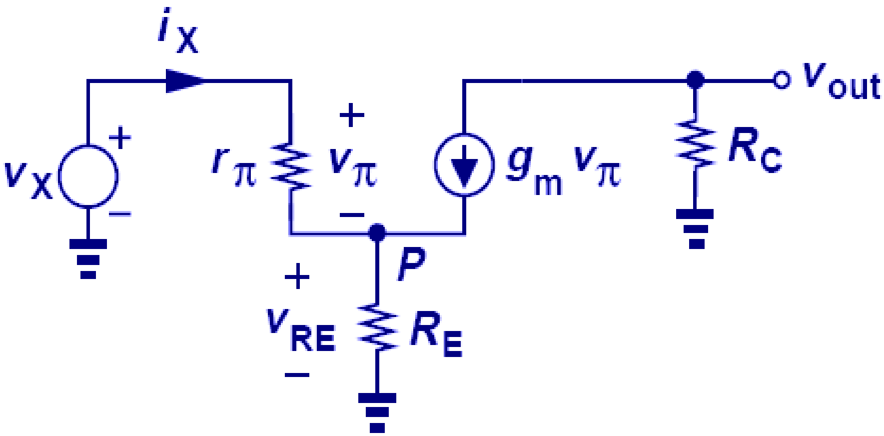



(b)

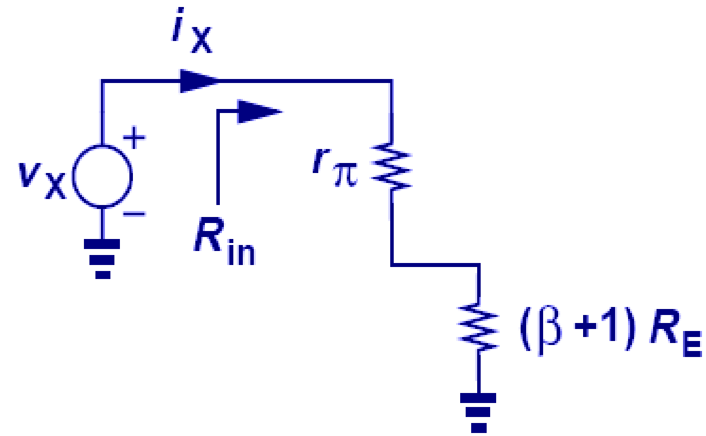
$$A_v = -\frac{R_C \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + R_E}$$

- In this example, the input impedance of $Q_2$ can be combined in parallel with $R_C$ to yield an equivalent collector impedance to ground.

# Input Impedance of Degenerated CE Stage



(a)



(b)

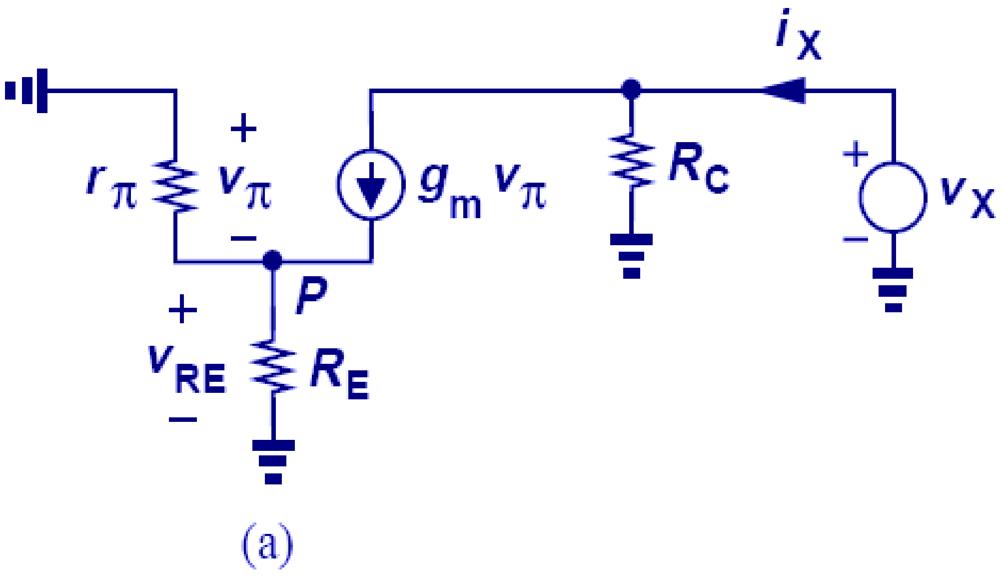
$$V_A = \infty$$

$$v_X = r_\pi i_X + R_E(1+\beta)i_X$$

$$R_{in} = \frac{v_X}{i_X} = r_\pi + (\beta+1)R_E$$

- With emitter degeneration, the input impedance is increased from $r_\pi$ to $r_\pi + (\beta+1)R_E$; a desirable effect.

# Output Impedance of Degenerated CE Stage without Considering Early Effect




$$V_A = \infty$$

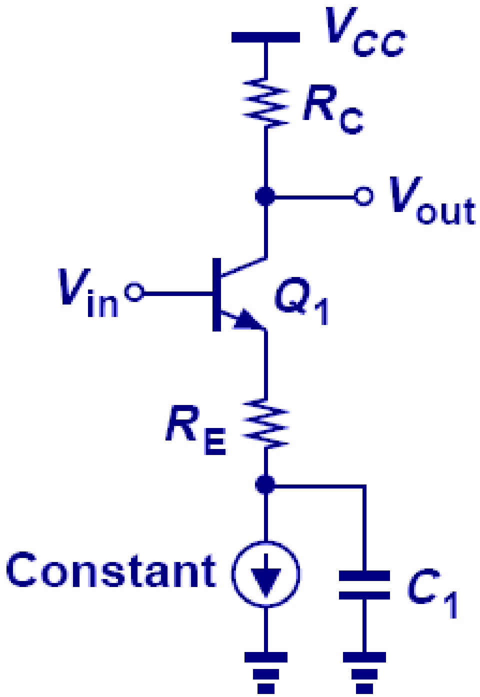
$$v_{in} = 0 = v_\pi + \left( \frac{v_\pi}{r_\pi} + g_m v_\pi \right) R_E$$

$$\Rightarrow v_\pi = 0$$

$$R_{out} = \frac{v_X}{i_X} = R_C$$

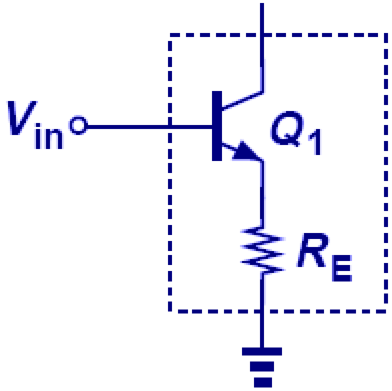
- Emitter degeneration does not alter the output impedance in this case. (More on this later.)

# Capacitor at Emitter

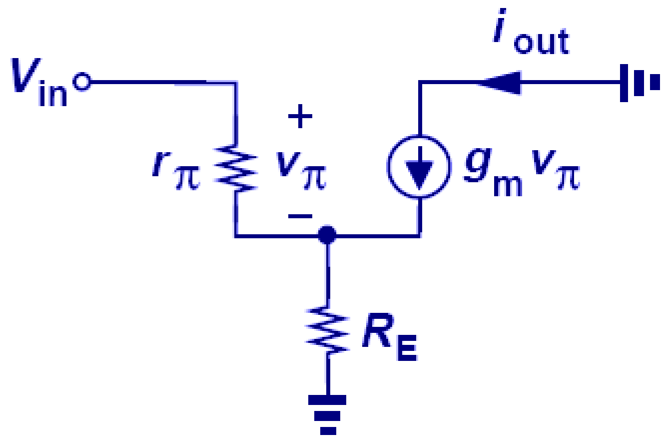



- At DC the capacitor is open and the current source biases the amplifier.
- For ac signals, the capacitor is short and the amplifier is degenerated by RE.

# Example: Design CE Stage with Degeneration as a Black Box




(a)




(b)

$$V_A = \infty$$

$$i_{out} = g_m \frac{v_{in}}{1 + (r_\pi^{-1} + g_m) R_E}$$

$$G_m = \frac{i_{out}}{v_{in}} \approx \frac{g_m}{1 + g_m R_E}$$

- If $g_m R_E$ is much greater than unity, $G_m$ is more linear.