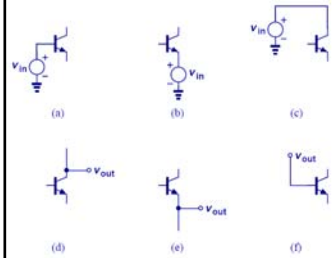
Lecture 7

OUTLINE

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

Reading: Chapter 5.3.1

Possible Bipolar Amplifier Topologies

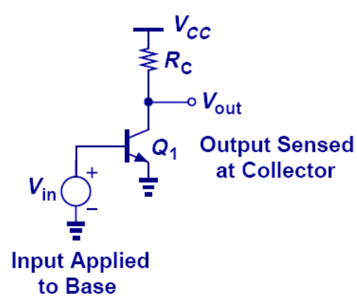


- Three possible ways to apply an input to an amplifier and three possible ways to sense its output.
- However, in reality only three of six input/output combinations are useful.

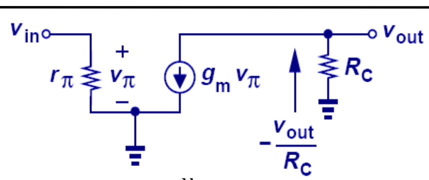
Study of Common-Emitter Topology

- 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

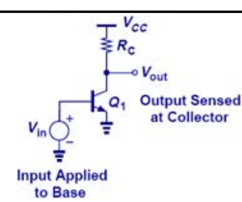


$$A_v = \frac{v_{out}}{v_{in}}$$

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

$$A_v = -g_m R_C$$

Limitation on CE Voltage Gain



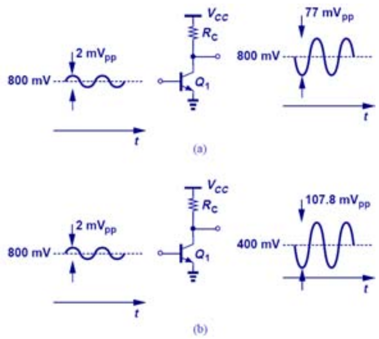
$$|A_v| = \frac{I_C R_C}{V_T}$$

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

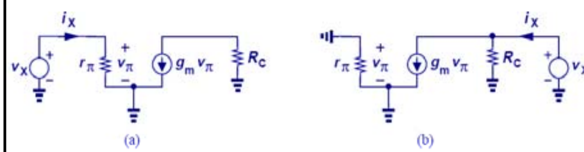
$$|A_v| < \frac{V_{CC} - V_{BE}}{V_T}$$

- 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



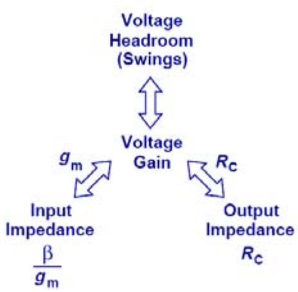
I/O Impedances of CE Stage



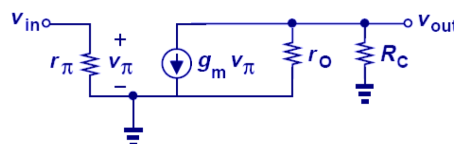
$$R_{in} = \frac{v_X}{i_X} = r_\pi \qquad R_{out} = \frac{v_X}{i_X} = R_C$$

- 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

$$A_v = -g_m r_O$$
$$|A_v| = \frac{V_A}{V_T}$$

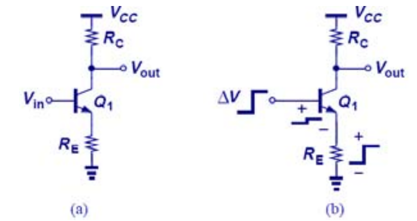
- As R_C goes to infinity, the voltage gain reaches the product of g_m and r_O, which represents the maximum voltage gain the amplifier can have.
- The intrinsic gain is independent of the bias current.

Current Gain

$$A_I = \frac{i_{out}}{i_{in}}$$
$$A_I\big|_{CE} = \beta$$

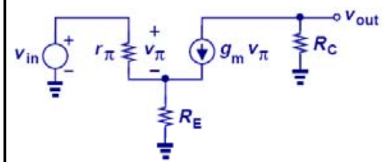
- Another parameter of the amplifier is the current gain, which is defined as the ratio of current delivered to the load to the current flowing into the input.
- For a CE stage, it is equal to β.

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

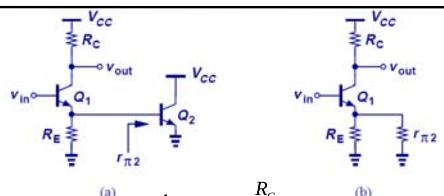


$$A_v = -\frac{g_m R_C}{1 + g_m R_E}$$

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

- 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.

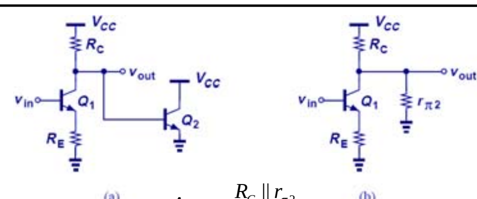
Emitter Degeneration Example I



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

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

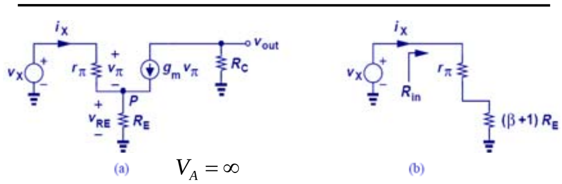
Emitter Degeneration Example II



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

- 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



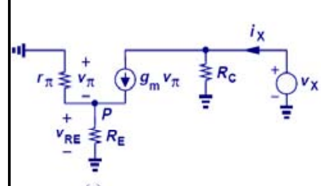
$$V_A = \infty$$

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

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

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

Output Impedance of Degenerated CE Stage without Considering Early Effect



$$V_A = \infty$$

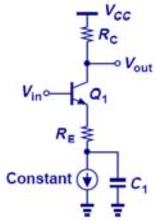
$$v_{in} = 0 = v_\pi + \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E$$

$$\Rightarrow v_\pi = 0$$

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

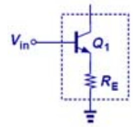
- Emitter degeneration does not alter the output impedance in this case. (More on this later.)

Capacitor at Emitter

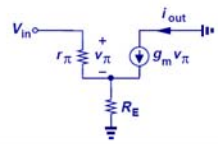


- At DC the capacitor is open and the current source biases the amplifier.
- For ac signals, the capacitor is short and the amplifier is degenerated by RE.

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.