ANNOUNCEMENTS

• A summary of frequently misunderstood/missed concepts is now posted on the class website, and will be updated regularly.
• Graded HW assignments can be picked up in lab (353 Cory).
  → Please indicate your lab section on your HW assignments!

OUTLINE

• BJT Amplifiers (cont’d)
  – Common-emitter topology
    – CE stage with emitter degeneration
    – Impact of Early effect ($r_o$)

Reading: Finish Chapter 5.3.1
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.

![Diagram of Emitter Degeneration]
Small-Signal Analysis

- The gain of a degenerated CE stage = the total load resistance seen at the collector divided by $1/g_m$ plus the total resistance placed in series with the emitter.

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

Note that the input impedance of $Q_2$ is in parallel with $R_E$.

$$A_v = -\frac{R_C}{\frac{1}{g_m} + R_E || r_{\pi 2}}$$
Emitted Degeneration Example 2

Note that the input impedance of $Q_2$ is in parallel with $R_C$.

$$A_v = -\frac{R_C \ || \ r_{\pi 2}}{1 + \frac{1}{g_{m1}} + R_E}$$
Input Impedance of Degenerated CE Stage

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

\[ (V_A = \infty) \]

\[ v_x = r_{\pi} i_x + R_E (1 + \beta) i_x \]

\[ R_{in} \equiv \frac{v_x}{i_x} = r_{\pi} + (\beta + 1)R_E \]
Output Impedance of Degenerated CE Stage

- Emitter degeneration does not alter the output impedance, if the Early effect is negligible.

\[
(V_A = \infty) \quad v_{in} = 0 = v_\pi + \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E \Rightarrow v_\pi = 0
\]

\[
R_{out} \equiv \frac{v_x}{i_x} = R_C
\]
Degenerated CE Stage as a “Black Box”

\[
(V_A = \infty) \quad \text{(a)}
\]

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

\[
G_m \equiv \frac{i_{out}}{v_{in}} \approx \frac{g_m}{1 + g_m R_E}
\]

- If \( g_m R_E \gg 1 \), \( G_m \) is more linear.

EE105 Fall 2007

Lecture 8, Slide 8

Prof. Liu, UC Berkeley
Degenerated CE Stage with Base Resistance

\( (V_A = \infty) \)

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{V_A}{V_{\text{in}}} \cdot \frac{V_{\text{out}}}{V_A}
\]

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-\beta R_C}{r_\pi + (\beta + 1)R_E + R_B}
\]

\[
A_v \approx \frac{-R_C}{\frac{1}{g_m} + R_E + \frac{R_B}{\beta + 1}}
\]
Degenerated CE Stage: Input/Output Impedances

- $R_{in1}$ is more important in practice, because $R_B$ is often the output impedance of the previous stage.

\[
\begin{align*}
(V_A &= \infty) \\
R_{in1} &= r_\pi + (\beta + 1)R_E \\
R_{in2} &= R_B + r_\pi + (\beta + 1)R_E \\
R_{out} &= R_C
\end{align*}
\]
Emitter Degeneration Example 3

\[ A_v = \frac{- (R_C \parallel R_1)}{1 + R_2 + \frac{R_B}{g_m} + \frac{1}{\beta + 1}} \]

\[ R_{in} = r_{\pi} + (\beta + 1)R_2 + R_B \]

\[ R_{out} = R_C \parallel R_1 \]
Output Impedance of Degenerated CE Stage with $V_{A}^{<\infty}$

- Emitter degeneration boosts the output impedance.
  - This improves the gain of the amplifier and makes the circuit a better current source.

\[
R_{\text{out}} = \left[1 + g_m (R_E \parallel r_\pi)\right]r_O + R_E \parallel r_\pi \\
R_{\text{out}} = r_O + (g_m r_O + 1)(R_E \parallel r_\pi) \\
R_{\text{out}} \approx r_O \left[1 + g_m (R_E \parallel r_\pi)\right]
\]
Two Special Cases

Stage with explicit depiction of $r_o$:

1) $R_E \gg r_\pi : R_{out} \approx r_O (1 + g_m r_\pi) \approx \beta r_O$

2) $R_E \ll r_\pi : R_{out} \approx (1 + g_m R_E) r_O$
Analysis by Inspection

• This seemingly complicated circuit can be greatly simplified by first recognizing that the capacitor creates an AC short to ground, and gradually transforming the circuit to a known topology.

\[
R_{out} = R_1 \parallel R_{out1} \quad R_{out1} = \left[1 + g_m (R_2 \parallel r_\pi)\right] r_o \quad R_{out} = \left[1 + g_m (R_2 \parallel r_\pi)\right] r_o \parallel R_1
\]
Example: Degeneration by Another BJT

\[
R_{out} = [1 + g_{m1}(r_{O2} \parallel r_{\pi1})]r_{O1}
\]

- Called a “cascode”, this circuit offers many advantages that we will study later...
Since the microphone has a very low resistance (connecting the base of $Q_1$ to ground), it attenuates the base voltage and renders $Q_1$ with a very small bias current.
Use of Coupling Capacitor

- A capacitor is used to isolate the DC bias network from the microphone, and to short (or “couple”) the microphone to the amplifier at higher frequencies.
DC and AC Analysis

- The coupling capacitor is replaced with an open circuit for DC analysis, and then replaced with a short circuit for AC analysis.

\[ A_v = -g_m \left( R_C \parallel r_O \right) \]
\[ R_{in} = r_\pi \parallel R_B \]
\[ R_{out} = R_C \parallel r_O \]
Bad Output Connection

- Since the speaker has an inductor with very low DC resistance, connecting it directly to the amplifier would ~short the collector to ground, causing the BJT to go into deep saturation mode.
Use of Coupling Capacitor at Output

- The AC coupling indeed allows for correct biasing. However, due to the speaker’s small input impedance, the overall gain drops considerably.
CE Stage with Voltage-Divider Biasing

\[ A_v = -g_m \left( R_C \parallel r_o \right) \]
\[ R_{in} = r_\pi \parallel R_1 \parallel R_2 \]
\[ R_{out} = R_C \parallel r_o \]
CE Stage with Robust Biasing

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

\[ R_{in} = \left[ r_\pi + (\beta + 1)R_E \right] \parallel R_1 \parallel R_2 \]

\[ R_{out} = R_C \]
Elimination of Emitter Degeneration for AC Signals

- The capacitor $C_2$ shorts out $R_E$ at higher frequencies to eliminate the emitter degeneration.

\[
A_v = -g_m R_C \\
R_{in} = r_\pi \parallel R_1 \parallel R_2 \\
R_{out} = R_C
\]
Complete CE Stage

\[ A_v = \frac{-R_C \| R_L}{1 + \frac{R_s \| R_1 \| R_2}{g_m} + \frac{R_1 \| R_2}{\beta + 1}} \cdot \frac{R_1 \| R_2}{R_1 \| R_2 + R_s} \]
Summary of CE Concepts

\[ A_v = -g_m R_C \]

- Headroom
  - Gain
  - \( R_{in} \) and \( R_{out} \)

\[ A_v = -g_m (R_C \parallel r_o) \]

- \( A_v \), \( R_{in} \)

- \( R_{out} \)

- \( R_E \)

- \( C_1 \)

- \( R_1 \)

- \( R_2 \)

- \( R_E \)

- \( C_2 \)

- \( Q_1 \)

- \( R_C \)