Lecture 10

OUTLINE

• BJT Amplifiers (3)
  – Emitter follower (Common-collector amplifier)
    – Analysis of emitter follower core
    – Impact of source resistance
    – Impact of Early effect
    – Emitter follower with biasing

Reading: Chapter 5.3.3-5.4
Emitter Follower (Common Collector Amplifier)
Emitter Follower Core

- When the input is increased by $\Delta V$, output is also increased by an amount that is less than $\Delta V$ due to the increase in collector current and hence the increase in potential drop across $R_E$.
- However the absolute values of input and output differ by a $V_{BE}$. 
Small-Signal Model of Emitter Follower

- As shown above, the voltage gain is less than unity and positive.

\[ V_A = \infty \]

\[ \frac{v_{out}}{v_{in}} = \frac{1}{1 + \frac{r_{\pi}}{\beta + 1} \cdot \frac{1}{R_E}} \approx \frac{R_E}{R_E + \frac{1}{g_m}} \]
Unity-Gain Emitter Follower

- The voltage gain is unity because a constant collector current (= $I_1$) results in a constant $V_{BE}$, and hence $V_{out}$ follows $V_{in}$ exactly.

$$V_A = \infty$$

$$A_v = 1$$
Analysis of Emitter Follower as a Voltage Divider

\[ V_A = \infty \]
Emitter Follower with Source Resistance

\[ V_A = \infty \]

\[ \frac{V_{out}}{V_{in}} = \frac{R_E}{R_E + \frac{R_S}{\beta + 1} + \frac{1}{g_m}} \]
Input Impedance of Emitter Follower

\[ V_A = \infty \]

\[ \frac{v_X}{i_X} = r_\pi + (1 + \beta)R_E \]

- The input impedance of emitter follower is exactly the same as that of CE stage with emitter degeneration. This is not surprising because the input impedance of CE with emitter degeneration does not depend on the collector resistance.
Emitter Follower as Buffer

- Since the emitter follower increases the load resistance to a much higher value, it is suited as a buffer between a CE stage and a heavy load resistance to alleviate the problem of gain degradation.
Output Impedance of Emitter Follower

• Emitter follower lowers the source impedance by a factor of $\beta + 1 \rightarrow$ improved driving capability.
Emitter Follower with Early Effect

\[ A_v = \frac{R_E \parallel r_\circ}{R_E \parallel r_\circ + \frac{R_S}{\beta+1} + \frac{1}{g_m}} \]

\[ R_{in} = R_s + r_\pi + (\beta + 1)(R_E \parallel r_\circ) \]

\[ R_{out} = \left( \frac{R_s}{\beta+1} + \frac{1}{g_m} \right) \parallel R_E \parallel r_\circ \]

• Since \( r_\circ \) is in parallel with \( R_E \), its effect can be easily incorporated into voltage gain and input and output impedance equations.
• There is a current gain of \((\beta+1)\) from base to emitter.
• Effectively speaking, the load resistance is multiplied by \((\beta+1)\) as seen from the base.
Emitter Follower with Biasing

- A biasing technique similar to that of CE stage can be used for the emitter follower.
- Also, $V_b$ can be close to $V_{cc}$ because the collector is also at $V_{cc}$. 
Supply-Independent Biasing

• By putting a constant current source at the emitter, the bias current, $V_{BE}$, and $I_B R_B$ are fixed regardless of the supply value.
Summary of Amplifier Topologies

- The three amplifier topologies studied so far have different properties and are used on different occasions.
- CE and CB have voltage gain with magnitude greater than one, while follower’s voltage gain is at most one.
Amplifier Example I

The keys in solving this problem are recognizing the AC ground between $R_1$ and $R_2$, and Thevenin transformation of the input network.

$$
\frac{v_{out}}{v_{in}} = - \frac{R_2 \parallel R_C}{R_1 \parallel R_S + \frac{1}{\beta + 1} g_m + R_E} \cdot \frac{R_1}{R_1 + R_S}
$$
Amplifier Example II

Again, AC ground/short and Thevenin transformation are needed to transform the complex circuit into a simple stage with emitter degeneration.

\[
\frac{v_{out}}{v_{in}} = - \frac{R_C}{R_S || R_1 + \frac{1}{\beta + 1} + R_2} \cdot \frac{R_1}{R_1 + R_S}
\]
Amplifier Example III

- The key for solving this problem is first identifying $R_{eq}$, which is the impedance seen at the emitter of $Q_2$ in parallel with the infinite output impedance of an ideal current source. Second, use the equations for degenerated CE stage with $RE$ replaced by $R_{eq}$.

$$R_{in} = r_{\pi 1} + R_1 + r_{\pi 2}$$

$$A_v = \frac{-R_C}{\frac{1}{g_{m1}} + \frac{R_1}{\beta + 1} + \frac{1}{g_{m2}}}$$
Amplifier Example IV

- The key for solving this problem is recognizing that CB at frequency of interest shorts out R₂ and provide a ground for R₁.
- R₁ appears in parallel with RC and the circuit simplifies to a simple CB stage.

\[ A_v = \frac{R_C \parallel R_1}{R_S + \frac{1}{g_m}} \]
Amplifier Example V

The key for solving this problem is recognizing the equivalent base resistance of $Q_1$ is the parallel connection of $R_E$ and the impedance seen at the emitter of $Q_2$.

$$R_{in} = \frac{1}{\beta + 1} \left[ \left( \frac{R_B}{\beta + 1} + \frac{1}{g_{m2}} \right) \parallel R_E \right] + \frac{1}{g_{m1}}$$
Amplifier Example VI

- The key in solving this problem is recognizing a DC supply is actually an AC ground and using Thevenin transformation to simplify the circuit into an emitter follower.

\[ V_{out} = \frac{R_E \parallel R_2 \parallel r_O}{R_E \parallel R_2 \parallel r_O + \frac{1}{g_m} + \frac{R_s \parallel R_1}{\beta + 1}} \]

\[ R_{out} = \left( \frac{R_s \parallel R_1}{\beta + 1} + \frac{1}{g_m} \right) \parallel R_E \parallel R_2 \parallel r_O \]
Amplifier Example VII

- Impedances seen at the emitter of $Q_1$ and $Q_2$ can be lumped with $R_C$ and $R_E$, respectively, to form the equivalent emitter and collector impedances.

$$R_{in} = r_{\pi 1} + (\beta + 1) \left( R_E + \frac{R_{B1}}{\beta + 1} + \frac{1}{g_{m2}} \right)$$

$$R_{out} = R_C + \frac{R_{B2}}{\beta + 1} + \frac{1}{g_{m3}}$$

$$A_v = - \frac{R_C + \frac{R_{B2}}{\beta + 1} + \frac{1}{g_{m3}}}{\frac{R_{B1}}{\beta + 1} + \frac{1}{g_{m2}} + \frac{1}{g_{m1}}}$$