Lecture 9

ANNOUNCEMENTS

• Friday discussion section (103) has been moved back to 5 Evans.
• HW#5 is now posted.
• List of frequently misunderstood/forgotten points has been updated.

OUTLINE

• BJT Amplifiers (cont’d)
  – Common-base topology
    – CB core
    – CB stage with source resistance
    – Impact of base resistance

Reading: Chapter 5.3.2
Common Base (CB) Amplifier

- The base terminal is biased at a fixed voltage; the input signal is applied to the emitter, and the output signal sensed at the collector.
Small-Signal Analysis of CB Core

- The voltage gain of a CB stage is $g_m R_C$, which is identical to that of a CE stage in magnitude and opposite in phase.

\[
A_v = g_m R_C
\]
Tradeoff between Gain and Headroom

- To ensure that the BJT operates in active mode, the voltage drop across $R_C$ cannot exceed $V_{CC} - V_{BE}$.

\[ V_{CC} - I_C R_C > V_b \]
\[ I_C R_C < V_{CC} - V_b \]

\[ A_v = \frac{I_C}{V_T} R_C \leq \frac{V_{CC} - V_{BE}}{V_T} \]
Simple CB Stage Example

\[ V_{cc} = 1.8V \]
\[ I_c = 0.2mA \]
\[ I_s = 5 \times 10^{-17} A \]
\[ \beta = 100 \]

\[ g_m = \frac{I_c}{V_T} > \frac{1}{130 \Omega} \]
\[ V_{in} = 600 \text{ mV} \]

\[ V_b = 1.354V \approx \frac{R_2}{R_1 + R_2} V_{cc} \text{ if } I_1 \gg I_B \]

Choose \[ I_1 \approx 10I_B = 20 \mu A \approx \frac{V_{cc}}{R_1 + R_2} \]

\[ \Rightarrow R_1 = 22.3k\Omega, R_2 = 67.7k\Omega \]
Input Impedance of a CB Stage

- The input impedance of a CB stage is much smaller than that of a CE stage.

\[ R_{in} = \frac{1}{g_m} \text{ if } V_A = \infty \]
CB Stage with Source Resistance

• With the inclusion of a source resistance, the input signal is attenuated before it reaches the emitter of the amplifier; therefore, the voltage gain is lowered.
  – This effect is similar to CE stage emitter degeneration.
Practical Example of a CB Stage

- An antenna usually has low output impedance; therefore, a correspondingly low input impedance is required for the following stage.

\[ g_m = \frac{I_c}{V_T} = \frac{1}{50\Omega} \]

\[ \Rightarrow I_c = 0.02 \text{mA} \]

\[ \Rightarrow g_m = 60\Omega \]
Output Impedance of a CB Stage

- The output impedance of a CB stage is equal to $R_C$ in parallel with the impedance looking into the collector.

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

\[
R_{out 2} = R_C \parallel R_{out 1}
\]
Output Impedance: CE vs. CB Stages

- The output impedances of emitter-degenerated CE and CB stages are the same. This is because the circuits for small-signal analysis are the same when the input port is grounded.
$A_v$ of CB Stage with Base Resistance

$(V_A = \infty)$

- With base resistance, the voltage gain degrades.

\[ v_{out} = -g_m v_\pi R_C \Rightarrow v_\pi = -\frac{v_{out}}{g_m R_C} \]

\[ v_P = -\frac{v_\pi (r_\pi + R_B)}{r_\pi} = \frac{v_{out}}{r_\pi g_m R_C} (r_\pi + R_B) \]

\[ v_P = \frac{v_{out}}{\beta R_C} (r_\pi + R_B) \]

KCL at node P:

\[ \frac{v_\pi}{r_\pi} + g_m v_\pi = \frac{v_P - v_{in}}{R_E} \Rightarrow \left( \frac{1}{r_\pi} + g_m \right) \left( -\frac{v_{out}}{g_m R_C} \right) = \frac{v_{out}}{\beta R_C} \frac{(r_\pi + R_B) - v_{in}}{R_E} \]

\[ A_v \approx \frac{v_{out}}{v_{in}} = \frac{\beta R_C}{r_\pi + (\beta + 1) R_E + R_B} \approx \frac{R_C}{\frac{1}{g_m} + R_E + \frac{R_B}{\beta + 1}} \]
 Voltage Gain: CE vs. CB Stages

• The magnitude of the voltage gain of a CB stage with source and base resistances is the same as that of a CE stage with base resistance and emitter degeneration.
$R_{in}$ of CB Stage with Base Resistance

$(V_A = \infty)$

- The input impedance of a CB stage with base resistance is equal to $1/g_m$ plus $R_B$ divided by $(\beta+1)$. This is in contrast to a degenerated CE stage, in which the resistance in series with the emitter is multiplied by $(\beta+1)$ when seen from the base.

\[
KCL \implies \frac{v_\pi}{r_\pi} + g_m v_\pi = -i_x
\]

\[
\left( \frac{1}{r_\pi} + g_m \right) \left( -\frac{r_\pi}{r_\pi + R_B} v_x \right) = -i_x
\]

\[
R_{in} \equiv \frac{v_x}{i_x} = \frac{r_\pi + R_B}{\beta+1} \approx \frac{1}{g_m} + \frac{R_B}{\beta+1}
\]
Input Impedance Seen at Emitter vs. Base

Common Base Stage

\[ \frac{1}{g_m} + \frac{R_B}{\beta+1} \]

Common Emitter Stage

\[ r_\pi + (\beta+1) R_E \]

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Input Impedance Example

- To find $R_X$, we have to first find $R_{eq}$, treat it as the base resistance of $Q_2$ and divide it by $(\beta+1)$.

$$R_{eq} = \frac{1}{g_{m1}} + \frac{R_B}{\beta+1}$$

$$R_X = \frac{1}{g_{m2}} + \frac{1}{\beta+1} \left( \frac{1}{g_{m1}} + \frac{R_B}{\beta+1} \right)$$