EE 330
Lecture 41

- High-Gain Amplifiers
- Current Sources and Mirrors
- Current Source Biasing
High-gain BJT amplifier

\[ A_V = \frac{-g_m}{g_0 + G_C} \approx -g_m R_C \]

To make the gain large, it appears that all one needs to do is make \( R_C \) large!

\[ A_V \approx -g_m R_C = \frac{-I_{CQ} R_C}{V_t} \]

But \( V_t \) is fixed at approx 25mV and for good signal swing, \( I_{CQ} R_C < (V_{DD} - V_{EE})/2 \)

\[ |A_V| < \frac{V_{DD} - V_{EE}}{2V_t} \]

If \( V_{DD} - V_{EE} = 5V \),

\[ |A_V| < \frac{5V}{2 \cdot 25mV} = 100 \]

Gain is practically limited with this supply voltage to around 100
High-gain MOS amplifier

$$A_V = \frac{-g_m}{g_0 + G_D} \approx -g_m R_D$$

To make the gain large, it appears that all one needs to do is make $R_D$ large!

$$A_V \approx -g_m R_D = \frac{-2I_{DQ}R_D}{V_{EB}}$$

But $V_{EB}$ is practically limited to around 100mV and for good signal swing, $I_{DQ}R_D < (V_{DD} - V_{SS})/2$

$$|A_V| < \frac{V_{DD} - V_{SS}}{V_{EB}}$$

If $V_{DD} - V_{SS} = 5V$ and $V_{EB} = 100mV$,

$$|A_V| < \frac{5V}{100mV} = 50$$

Gain is practically limited with this supply voltage to around 100

Are these fundamental limits on the gain of the BJT and MOS Amplifiers?
This gain is very large!

Too good to be true!

Need better model of the BJT device!
High-gain amplifier

This gain is very large (but realistic)!

But how can we make a current source?
High-gain amplifier

\[ A_V \approx -8000 \]

How can we build the ideal current source?

What is the small-signal model of an actual current source?
High-gain amplifier

$$A_V \approx -8000$$

How can we build the ideal current source?

What is the small-signal model of an actual current source?
Model of Current Source

As a 1-port network

\[ I_1 = f(V_1) \]

"Reasonable Current Source"

\[ I_{xx} \] independent of \( V_1 \) and \( R_S \) large

Small-signal model of current source

\[ g_{in} = \frac{\partial I_1}{\partial V_1} = R_{in}^{-1} \]

want \( R_{in} \) large
Model of Current Source

“Reasonable Current Source”

$I_1$

$+\quad V_1$

$\_\_\_\_\_\_\_

$R_S$

$LARGE\ SIGNAL$

$I_{xx}$

Current Source

$I_{xx}$ independent of $V_1$ and $R_S$ large

Small-signal model of current source

$i_1$

$+\quad v_1$

$\_\_\_\_\_\_

$R_{IN}$

$SMALL\ SIGNAL$

want $R_{IN}$ large

Ideal Current Source

$I_1$

$+\quad V_1$

$\_\_\_\_\_\_

$I_{xx}$

Current Source

$LARGE\ SIGNAL$

$I_{xx}$ independent of $V_1$

$R_{IN}=\infty$
Current Sources/Mirrors
Current Sources/Mirrors

If the base currents are neglected

\[ I_0 \approx \frac{(V_{CC} - 0.6V)}{R} \]
Current Sources/Mirrors

\[ I_0 = \left( \frac{V_{CC}-0.6V}{R} \right) \]

If the base currents are neglected

\[ I_0 = J_S A_{E0} e^{\frac{V_{BE0}}{V_1}} \]

\[ I_1 = J_S A_{E1} e^{\frac{V_{BE1}}{V_1}} \]

since \( V_{BE1} = V_{BE2} \)

\[ I_1 \approx \left( \frac{A_{E1}}{A_{E0}} \right) I_0 = \left( \frac{A_{E1}}{A_{E0}} \right) \frac{V_{CC} - 0.6V}{R} \]

Behaves as a current source!

Note \( I_1 \) is not a function of \( V_1 \) (defined on previous slide) So is ideal with this model!!

Actually termed a “sink” current since coming out of load
Current Sources/Mirrors

- Multiple Outputs Possible
- Can be built at sourcing or sinking currents
- Also useful as a current amplifier
- MOS counterparts work very well and are not plagued by base current

Current Sink
Current Sources/Mirrors

Multiple-Output Bipolar Current Sink

\[ I_k = \begin{bmatrix} \frac{A_{Ek}}{A_{E0}} \end{bmatrix} I_0 \]
Current Sources/Mirrors

Multiple-Output Bipolar Current Source

\[ I_k = \frac{A_{E_k}}{A_{E_0}} I_0 \]
Current Sources/Mirrors

Multiple-Output Bipolar Current Source and Sink

\[ I_{nk} = ? \quad I_{pk} = ? \]
Current Sources/Mirrors

Multiple-Output Bipolar Current Source and Sink

\[ I_{nk} = \left( \frac{A_{Enk}}{A_{E0}} \right)_0 I_0 \]

\[ I_{pk} = \left( \frac{A_{En1}}{A_{E0}} \right) \left( \frac{A_{Epk}}{A_{Ep0}} \right)_0 I_0 \]
Current Sources/Mirrors

- Termed a “current mirror”
- Output current linearly dependent on $I_{in}$
- Serves as a current amplifier
- Widely used circuit

$$I_{out} = \left[ \frac{A_{E1}}{A_{E0}} \right] I_{in}$$
Current Sources/Mirrors

\[ i_{\text{out}} = ? \]

npn current mirror amplifier

\[ M = \frac{A_{E1}}{A_{E0}} \]
Current Sources/Mirrors

npn current mirror amplifier

\[ i_{out} = \left[ \frac{A_{E1}}{A_{E0}} \right] i_{in} \]

Amplifiers both positive and negative currents
Current Sources/Mirrors

n-channel Current Mirror

\[ I_{\text{out}} =? \]
Current Sources/Mirrors

If process parameters are matched, it follows that

\[
\begin{align*}
I_{in} &= \frac{\mu C_{OX}W_0}{2L_0} (V_{GS0} - V_{T0})^2 \\
I_{out} &= \frac{\mu C_{OX}W_1}{2L_1} (V_{GS1} - V_{T1})^2
\end{align*}
\]

Current mirror gain can be accurately controlled
Layout is important to get accurate gain (for both MOS and BJT)
Layout of Current Mirrors

Example with $M = 2$

\[
\begin{bmatrix}
W_2/L_1 \\
W_1/L_2
\end{bmatrix}
\]

Standard layout

\[
M = \begin{bmatrix}
\frac{W_2 + 2\Delta W}{W_1 + 2\Delta W} \cdot \frac{L_1 + 2\Delta L}{L_2 + 2\Delta L}
\end{bmatrix}
\neq 2
\]

Gate area after fabrication depicted
Layout of Current Mirrors

Example with \( M = 2 \)

Standard layout

\[
M = \begin{bmatrix}
W_2 & L_1 \\
\frac{W_1}{W_1} & L_2
\end{bmatrix}
\]

Better Layout

\[
M = \frac{2W_1 + 4\Delta W}{W_1 + 2\Delta W} \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} = 2
\]
Layout of Current Mirrors

Example with $M = 2$

Standard layout

Better Layout

Even Better Layout

This is termed a common-centroid layout
Current Sources/Mirrors

\[ M = \frac{W_2 \cdot L_1}{W_1 \cdot L_2} \]

n-channel current mirror current amplifier

\[ \mathbf{i}_{\text{out}} = \begin{bmatrix} \frac{W_2}{W_1} & \frac{L_1}{L_2} \end{bmatrix} \mathbf{i}_{\text{in}} \]

Amplifiers both positive and negative currents
Current Sources/Mirrors

\[ I_k = \begin{bmatrix} W_k & L_0 \\ W_0 & L_k \end{bmatrix} I_0 \]

multiple output n-channel current sink array

multiple output p-channel current source array