EE 330
Lecture 31

• Current Source Biasing
• Current Sources and Mirrors
## Basic Amplifier Gain Table

<table>
<thead>
<tr>
<th>Circuit</th>
<th>MOS</th>
<th>BJT</th>
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<th>BJT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE/CS</td>
<td>(-\frac{g_m R_C}{g_m + g_E})</td>
<td>(-\frac{2 I_{DQ} R_C}{V_{EB}})</td>
<td>(-\frac{I_{CQ} R_C}{V_t})</td>
<td>(-\frac{R_C}{R_E})</td>
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<td>CC/CD</td>
<td>(\frac{g_m}{g_m + g_E})</td>
<td>(\frac{2 I_{DQ} R_E}{2 I_{DQ} R_E + V_{EB}})</td>
<td>(\frac{I_{CQ} R_E}{I_{CQ} R_E + V_t})</td>
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</tbody>
</table>

### Equations

- **Input Resistance**: \(r_{\pi} = \infty\) for MOS, \(r_{\pi} + \beta R_E\) for BJT
- **Output Resistance**: \(R_C\)
- **Gain**: \(-\frac{g_m R_C}{g_m + g_E}\) for MOS, \(-\frac{2 I_{DQ} R_C}{V_{EB}}\) for BJT

Can use these equations only when circuit is EXACTLY like that shown above!!
Review from Last Lecture

Basic Amplifier Characteristics Summary

CE/CS

- Large noninverting gain
- Low input impedance
- Moderate (or high) output impedance
- Used more as current amplifier or, in conjunction with CD/CS to form two-stage cascode

CC/CD

- Gain very close to +1 (little less)
- High input impedance for BJT (high for MOS)
- Low output impedance
- Widely used as a buffer

CB/CG

- Large noninverting gain
- Low input impedance
- Moderate (or high) output impedance
- Used more as current amplifier or, in conjunction with CD/CS to form two-stage cascode

CEwRE/CSwRS

- Reasonably accurate but somewhat small gain (resistor ratio)
- High input impedance
- Moderate output impedance
- Used when more accurate gain is required
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 MOS device!
Review from Last Lecture

**High-gain amplifier**

This gain is very large (but realistic)!

But how can we make a current source?

\[
A_V = \frac{-g_m}{g_0} \\
A_V = \frac{-I_{CQ}}{V_t I_{CQ}/V_{AF}} = -\frac{V_{AF}}{V_t} \\
A_V = -\frac{V_{AF}}{V_t} \approx \frac{200V}{25mV} = -8000
\]
High-gain amplifier

How can we build the ideal current source?

What is the small-signal model of an actual current source?
Current Sources/Mirrors

\[ I_0 \approx \frac{V_{CC} - 0.6V}{R} \]

If the base currents are neglected
Current Sources/Mirrors

If the base currents are neglected

\[ I_0 = J_S A_{E_0} e^{\frac{V_{BE_0}}{V_t}} \]

\[ I_1 = J_S A_{E_1} e^{\frac{V_{BE_1}}{V_t}} \]

since \( V_{BE_1} = V_{BE_2} \)

\[ I_1 \approx \left( \frac{A_{E_1}}{A_{E_0}} \right) I_0 \]

Behaves as a current source!

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 Sources/Mirrors

Multiple-Output Bipolar Current Sink

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

Multiple-Output Bipolar Current Source

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

Multiple-Output Bipolar Current Source and Sink

$I_{nk} = ?$  
$I_{pk} = ?$

\[ V_{DD} \]

$Q_0$  
$A_{E0}$  

$I_0$  

$Q_{n1}$  
$A_{En1}$  

$I_{n0}$  

$Q_{n2}$  
$A_{En2}$  

$\ldots$  

$Q_{nn}$  
$A_{Enn}$  

$Q_{p0}$  
$A_{Ep0}$  

$\downarrow I_{p1}$  

$Q_{p1}$  
$A_{Ep1}$  

$\downarrow I_{p2}$  

$Q_{p2}$  
$A_{Ep2}$  

$\downarrow \ldots$  

$Q_{pn}$  
$A_{Epn}$  

$\downarrow I_{pn}$
Current Sources/Mirrors

Multiple-Output Bipolar Current Source and Sink

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

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

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

\[
I_{out} = \begin{bmatrix} A_{E1} \\ A_{E0} \end{bmatrix} I_{in}
\]
Current Sources/Mirrors

npn current mirror amplifier

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

npn current mirror amplifier

\[ i_{\text{out}} = \begin{bmatrix} \frac{A_{E1}}{A_{E0}} \end{bmatrix} i_{\text{in}} \]

Amplifiers both positive and negative currents
Current Sources/Mirrors

n-p-n Current Mirror

n-channel Current Mirror

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

If process parameters are matched, it follows that

$$I_{\text{out}} = \begin{bmatrix} \frac{W_2}{W_1} & \frac{L_1}{L_2} \end{bmatrix} I_{\text{in}}$$

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 $M = 2$

Standard layout

Gate area after fabrication depicted
Layout of Current Mirrors

Example with $M = 2$

Standard layout

$$M = \begin{bmatrix} W_2 & L_1 \\ W_1 & L_2 \end{bmatrix}$$

$$\frac{2W_1 + 2\Delta W}{W_1 + 2\Delta W} \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} \neq 2$$

Better Layout

$$M = \begin{bmatrix} 2W_1 + 4\Delta W \\ W_1 + 2\Delta W \end{bmatrix} \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} = 2$$
Layout of Current Mirrors

Example with $M = 2$

Standard layout

Better Layout

Even Better Layout

This is termed a common-centroid layout

$$M = \begin{bmatrix} W_2 & L_1 \\ W_1 & L_2 \end{bmatrix}$$

$$M = \begin{bmatrix} 2W_1 + 4\Delta W \\ W_1 + 2\Delta W \end{bmatrix} \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} = 2$$

$$M = \begin{bmatrix} 2W_1 + 4\Delta W \\ W_1 + 2\Delta W \end{bmatrix} \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} = 2$$
Current Sources/Mirrors

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

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
High-gain amplifier

\[ A_V \approx -8000 \]

How can we build the current source?

What is the small-signal model of an actual current source?
Very practical methods for biasing the BJTs can be used.

Current Mirrors often used for generating sourcing and sinking currents.
Basic Current Sources and Sinks

Small-signal Model of BJT Current Sinks and Sources

Small-signal model of all other BJT Sinks and Sources are the same
Basic Current Sources and Sinks

Small-signal Model of BJT Current Sinks and Sources

Small-signal model of all other BJT Sinks and Sources are the same.
Basic Current Sources and Sinks

Small-signal Model of BJT Current Sinks and Sources

Small-signal model of all other MOS Sinks and Sources are the same
High-gain amplifier

\[
A_V = \frac{-g_m}{g_0}
\]

\[
A_V = \frac{-g_{m1}}{g_{01} + g_{02}} \approx \frac{-g_{m1}}{2g_{01}}
\]
Nonideal current source decreased the gain by a factor of 2

But the voltage gain is still quite large

Can the gain be made even larger?