### EE 330 Class Seating

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Zechariah Pettit</td>
<td>Daniel Borgerding</td>
<td>Liuchang Li</td>
<td>Andrew Mun</td>
<td>Brian Crist</td>
<td>Difeng Liu</td>
<td>Aimee Salt</td>
<td>Julien Di Tria</td>
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<td>2</td>
<td>Erik Lee</td>
<td>Nick Robbins</td>
<td>Bijan Choobineh</td>
<td>Wing Yi Lwe</td>
<td>Pangzhou Li</td>
<td>Travis Cook</td>
<td>Wentai Wang</td>
<td>Hisham Abbas</td>
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<td>3</td>
<td>Ryan Wade</td>
<td>Jiayu Hong</td>
<td>Jean-Francois Burnier</td>
<td>Morgan Hardy</td>
<td>Bodhisatta Pramanik</td>
<td>Nagulapally Spurthi</td>
<td>Alfonso Raymundo</td>
<td>Corey Wright</td>
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<td>4</td>
<td>Mohamad Samusdin</td>
<td>Aqila-Sarah Zulkifli</td>
<td>Honghao Liu</td>
<td>Clayton Hawken</td>
<td>Christopher Little</td>
<td>Antonio Montoya</td>
<td>Jaehyuk Han</td>
<td>Logan Heinen</td>
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<td>5</td>
<td>Nicholas Riesen</td>
<td>Satvik Shah</td>
<td>Alex McCullough</td>
<td>Wei Shen Theh</td>
<td>Minh Nguyen</td>
<td>Trevor Brown</td>
<td>Zhong Zhang</td>
<td>Mingda Yang</td>
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<td>6</td>
<td>Abdussamad Hisham</td>
<td>Brenda Lopez</td>
<td>Benjamin Engh</td>
<td>Blake Burns</td>
<td>Mark Rusciano</td>
<td>Daniel Mallek</td>
<td>Ilya Simirov</td>
<td>Bryce Rooney</td>
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**Exam 3**  **Friday**  **November 20**
EE 330
Lecture 33

• High Gain Amplifiers
• Current Sources and Mirrors
• The Cascode Configuration
• The Differential Amplifier
High-gain amplifier

Review from Last Lecture

This gain is very large (but realistic)!
And no design parameters affect the gain
But how can we make a current source?

$$A_V = \frac{-g_m}{g_0}$$

$$A_V = \frac{-I_{CQ}}{V_t I_{CQ}/V_{AF}} = -\frac{V_{AF}}{V_t}$$

$$A_V = -\frac{V_{AF}}{V_t} \approx \frac{200V}{25mV} = -8000$$
How can we build the dc current source?

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

“Reasonable Current Source”

\[ I_x \text{ independent of } V_1 \text{ and } R_S \text{ large} \]

Small-signal model of current source

want \( R_{IN} \) large

Ideal Current Source

\[ I_x \text{ independent of } V_1 \]

\[ R_{IN}=\infty \]
Current Sources/Mirrors

Will show circuit in red behaves as a current source
If the base currents are neglected
Current Sources/Mirrors

Behaves as a current source! So is ideal with this model!!
Actually termed a “sink” current since coming out of load
And does not require an additional dc voltage source!!!
Current Sources/Mirrors

- Multiple Outputs Possible
- Can be built for 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

Biasing Circuit

Key Block

Current Sink
Current Sources/Mirrors

Multiple-Output Bipolar Current Sink

\[ I_k = \left[ \frac{A_{E_k}}{A_{E0}} \right] I_0 \]
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

\[ I_{nk} = ? \quad I_{pk} = ? \]
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

But $I_{in}$ and $I_{out}$ must be positive!
Current Sources/Mirrors

npn current mirror amplifier

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

\[
\begin{align*}
Q_0 & \quad A_{E0} \\
Q_1 & \quad A_{E1} \\
M & = \frac{A_{E1}}{A_{E0}} \\
i_{\text{out}} & = \left[ \frac{A_{E1}}{A_{E0}} \right] i_{\text{in}}
\end{align*}
\]

n npn current mirror amplifier

Amplifiers both positive and negative currents (provided \( i_{\text{in}} > -I_{BS} \))
Current Sources/Mirrors

npn Current Mirror

n-channel Current Mirror

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

If process parameters are matched, it follows that

\[
I_{\text{out}} = \left[ \frac{W_1}{W_0} \frac{L_0}{L_1} \right] I_{\text{in}}
\]

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

n-p-n Current Mirror

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

n-channel Current Mirror

\[ I_{\text{out}} = \left[ \frac{W_1}{W_0} \frac{L_0}{L_1} \right] I_{\text{in}} \]
Layout of Current Mirrors

Example with $M = 2$

Standard layout

Gate area after fabrication depicted

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

$M = \begin{bmatrix} \frac{W_2 + 2\Delta W}{W_1 + 2\Delta W} & \frac{L_1 + 2\Delta L}{L_2 + 2\Delta L} \\ \frac{L_1 + 2\Delta L}{W_1 + 2\Delta W} & \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L} \end{bmatrix}$
Layout of Current Mirrors

Example with $M = 2$

Standard layout

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

$M \neq \begin{bmatrix}
\frac{2W_1 + 2\Delta W}{W_1 + 2\Delta W} & \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L}
\end{bmatrix} \neq 2$

Better Layout

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

Example with $M = 2$

Standard layout

Better Layout

Even Better Layout

This is termed a common-centroid layout

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

\[
M = \begin{bmatrix}
  \frac{2W_1 + 4\Delta W}{W_1 + 2\Delta W} & \cdot \frac{L_1 + 2\Delta L}{L_1 + 2\Delta L}
\end{bmatrix} = 2
\]
n-channel current mirror current amplifier

Amplifies both positive and negative currents

\[ i_{\text{out}} = \begin{bmatrix} W_2 & L_1 \\ W_1 & L_2 \end{bmatrix} i_{\text{in}} \]
Current Sources/Mirrors

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

multiple output p-channel current source array

multiple output n-channel current sink array
Current Sources/Mirrors

multiple sourcing and sinking current outputs

\[ I_{p0} = \frac{W_{p0}}{L_{p0}} I_0 \]

\[ M = \frac{W_{n0}}{L_{n0}} \frac{L_0}{W_0} \]

\[ I_{nj} = \frac{W_{nj}}{L_{nj}} \frac{L_0}{W_0} I_0 \]

m and k may be different
Often M=1
High-gain amplifier

How can we build the current source?

What is the small-signal model of an actual current source?
Basic Current Sources and Sinks

Bipolar Mirror-Based Current Sink

Bipolar Mirror-Based Current Source

Biasing circuit uses same $V_{CC}$ as amplifier and no other independent sources
High-gain amplifier

• Bias circuitry requires only a single independent dc voltage source!
• Incremental overhead is only one transistor, $Q_B$
Basic Current Sources and Sinks

Basic Bipolar Current Sinks

\[ I_X = J_S A e^\frac{V_{XX}}{V_t} \]

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

Basic Bipolar Current Sources

\[ I_X \]

\[ V_{CC} \]

- Very practical methods for biasing the BJTs (or MOSFETs) can be used
- Current Mirrors often used for generating sourcing and sinking currents
- Can think of biasing transistors with \( V_{XX} \) and \( V_{YY} \) in these current sources
How can we build the current source?

What is the small-signal model of an actual current source?
Basic Current Sources and Sinks

Small-signal Model of BJT Current Sinks and Sources

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

Small-signal Model of MOS Current Sinks and Sources

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

$$A_V = \frac{-g_m}{g_0}$$

$$A_V = \frac{-g_{m1}}{g_{01} + g_{02}} \approx \frac{-g_{m1}}{2g_{01}}$$
High-gain amplifier

\[ g_m \frac{V_{AF}}{g_0 V_t} \approx 8000 \]

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

- Nonideal current source decreased the gain by a factor of 2
- But the voltage gain is still quite large (-4000)

Can the gain be made even larger?
High-gain amplifier

Can the gain be made even larger?

The Cascode Configuration

Discuss
The Cascode Amplifier (consider npn BJT version)

- Actually a cascade of a CE stage followed by a CB stage but usually viewed as a “single-stage” structure
- Cascode structure is widely used
End of Lecture 33