Bias Current Sources

- What makes a current source a current source?
  - High output impedance

- Other important properties:
  - Voltage range ($V_{min}$)
  - Noise
  - Accuracy

- Techniques: cascoding, gain boosting

Current Mirror

- Better approach: current mirror

Noise

\[ \frac{I_{in}}{I_{out}} = \frac{1}{1 + M} \]

- M2 adds noise
  - Choose small M (power), or
  - Filter at gate of M1

- Current source FOMs
  - Output resistance $R_o$
  - Noise resistance $R_n$
  - Active sources boost $R_o$, not $R_n$

Bias Current Source

- Is this a “good” bias current source?

Noise cont’d

- $I_{in}^2$ from transistor current source much larger than real R with same output impedance

- So why do we use transistors as current sources?
**V\text{\scriptsize{\text{min}}} \text{ versus Noise}**

- Voltage required for large $r_\text{g}$ ("saturation"): $V_{\text{min}} \sim V^*$
- Minimum noise (for given $I_\text{D}$):
  - $\Rightarrow$ large $R_\text{g}$
  - $\Rightarrow$ large $V^*$ (and, hence, $V_{\text{min}}$)
- Eats into signal swing...

\[ R_\text{g} = \frac{1}{\frac{1}{2}m_{\text{g}} + 1 + M} \]
\[ = \frac{V_{\text{sat}}}{2\text{g}_{\text{m}}} \]

**Output Resistance**

$V_{\text{sat}} = kV^*$

- How to choose $k$?
  - Large $k$ useful only for large $V_{\text{sat}}$
  - But, little penalty for large $k$ and small $V_{\text{sat}}$
  - Typically choose $k > 1$
  - Get benefit if $V_{\text{sat}}$ is big

**Bipolar’s, GaAs, …**

\[ R_\text{g} = \frac{1}{\frac{1}{2}m_{\text{g}} + 1 + M} \]
\[ = \frac{V_{\text{sat}}}{2\text{g}_{\text{m}}} \]

a) $g_m R_\text{g} = 0$

- Increasing $R_\text{g}$ lowers noise
- Same in MOS, BJT, etc.
- $V_{\text{min}}$ always trades with noise
- Lowest possible noise: resistor (large $V_{\text{min}}$)

b) $g_m R_\text{g} \gg 1$

\[ R_\text{g} = \frac{1}{g_m} \frac{1}{R_\text{g}} \]

\[ R_{\text{in}} = \frac{V_{\text{sat}}}{V_{\text{in}}} \frac{1}{2\text{g}_{\text{m}}} \]

**Cascoding**

- Need circuit for generating $V_{\text{bias}}$

- Accuracy important for high $V_{\text{sat}}$/high $R_\text{g}$
  - In practice, not quite as critical ($V_{\text{sat}}$ often low)

- Assume you’ve seen these before
  - Review G & M if not
High-Swing Bias Example

Gain Boosting
- Use feedback to further increase $R_{out}$
  - No increase of $V_{min}$ (unlike double cascode)

Gain-Boosted $Z_{out}$

Pole-Zero Doublets

Local Feedback and Stability

If it works, do it again!
- Since in advanced scaled CMOS $g_m r_f$ is small, we can use nested gain boosting for higher output impedance.
- Watch out for pole-zero doublets!
Noise Analysis

Noise Summary

Cascode Sizing