Bias Current Sources

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

- Other important properties:
  - Voltage range ($V_{\text{max}}$)
  - Noise
  - Accuracy

- Techniques: cascoding, gain boosting

Noise

- $I_{\text{mB}} = I_{\text{m1}} + M^2 I_{\text{m1}}$
- $= 4kT g_m (g_{m1} + M^2 g_{m1}) A f$
- $= 4kT g_m (1 + M^2) A f$
- $= 4kT \frac{1}{R_o} A f$

- $R_o = \frac{1}{g_m} \frac{1}{1 + M}$
- $= \frac{r_o}{g_{m1} (1 + M)} << \frac{r_o}{g_m}$

- 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

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

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

- Voltage required for large \( r_e \) ("saturation"): \( V_{\text{min}} \approx V^* \)
- Minimum noise (for given \( I_D \)):
  - \( \rightarrow \) large \( R_n \)
  - \( \rightarrow \) large \( V^* \) (and, hence, \( V_{\text{min}} \))
- Eats into signal swing...

\[
\begin{align*}
V_{\text{sat}} & = k \times V^* \quad \text{typ. } k = 1...2 \\
R_n & = \frac{1}{\gamma g_m} \frac{1}{1 + M} \\
& = \frac{V_{\text{sat}}}{2 g_m} \frac{1}{1 + M}
\end{align*}
\]

Output Resistance

- \( R_{\text{out}} = f(k) \)

**High-Swing Cascode Biasing**

- Need circuit for generating \( V_{\text{bias2}} \)
- Accuracy important for high \( V_{\text{sat}}/\text{high } R_0 \)
  - 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 $R_{\text{out}}$
  • No increase of $V_{\text{min}}$
    (unlike double cascode)

Local Feedback and Stability

Gain-Boosted $Z_{\text{out}}$

Pole-Zero Doublets

If it works, do it again!
• Since in advanced scaled CMOS $g_{m,\text{in}}$ is small, we can use nested gain boosting for higher output impedance.
• Watch out for pole-zero doublets!
Noise Analysis

Noise Summary

Cascode Sizing