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
Bias Current Source

- Is this a “good” bias current source?

Current Mirror

- Better approach: current mirror
Noise

\[ \overline{i_{in}} = \overline{i_{d1}} + M^2 \overline{i_{d2}} \]
\[ = 4k_B T f \left( g_{m1} + M^2 g_{m2} \right) \Delta f \]
\[ = 4k_B T g_{m1} \Delta f \]
\[ = 4k_B T \frac{1}{R_N} \Delta f \]

\[ R_N = \frac{1}{\gamma} \frac{g_{m1}}{1 + M} \]
\[ = \frac{r_o \gamma}{a_{o0} (1 + M) } \ll R_o = r_o \]

- 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 \( R_N \)

Noise cont’d

- \( I_i^2 \) from transistor current source much larger than real R with same output impedance

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

- Voltage required for large $r_o$ ("saturation"): $V_{min} \sim V^*$

- Minimum noise (for given $I_D$):
  - Large $R_N$
  - Large $V^*$ (and, hence, $V_{min}$)

- Eats into signal swing…

\[ R_N = \frac{1}{\frac{1}{\gamma g_m} + \frac{1}{1 + M}} = \frac{V_{min}}{2 \gamma k I_D} \]

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**Bipolar’s, GaAs, …**

- Increasing $R_E$ lowers noise
- Same in MOS, BJT, etc.
- $V_{min}$ always trades with noise

- Lowest possible noise: resistor (large $V_{min}$)

\[ V_{min} = k \times V^* \quad \text{typ.} \quad k = 1...2 \]
Cascoding

Output Resistance
\[ R_{\text{out}} = f(k) \]

\[ V_{DS1} = kV_1^* \]

**How to choose k?**

- Large \( k \) useful only for large \( V_{\text{min}} \)
- But, little penalty for large \( k \) and small \( V_{\text{min}} \)
  - Typically choose \( k > 1 \)
  - Get benefit if \( V_{ds} \) is big

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**High-Swing Cascode Biasing**

- Need circuit for generating \( V_{bias2} \)
- Accuracy important for high \( V_{ds}/\text{high} \) \( Ro \)
  - In practice, not quite as critical (\( V_{ds} \) often low)
- Assume you’ve seen these before
  - Review G & M if not
High-Swing Bias Example

- $M_5$ sets $V_{DS3} = V_{DS1}$: improves matching
- $M_4$ quarter size or less
  - $M=1/5$ for high $R_{out}$
  - Note: $M \neq k$

Gain Boosting

- Use feedback to further increase $R_{out}$
  - No increase of $V_{min}$
    (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 \( g_{m}r_{o} \) is small, we can use nested gain boosting for higher output impedance.
• Watch out for pole-zero doublets!
Cascode Sizing