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

Bias Current Source

- Is this a “good” bias current source?

Current Mirror

- Better approach: current mirror

Noise

\[
\begin{align*}
I_0 & = I_i + M' I_i \\
& = 4kT (g_{m1} + M' g_{m1}) I_i \\
& = 4kT g_{m1} (1 + M) I_i \\
& = 4kT \frac{V_G}{R} I_i
\end{align*}
\]

- 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

\[
R_o = \frac{1}{g_{m1} (1 + M)}
\]

- \( R_o \) 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 $r_p$ ("saturation"): $V_{\text{min}} \sim V^*$
- Minimum noise (for given $I_p$):
  - large $R_p$
  - large $V^*$ (and, hence, $V_{\text{min}}$)
- Eats into signal swing...

**Bipolar’s, GaAs, …**

\[ R_p = \frac{1}{2g_m(1+M)} \]

\[ V_{\text{min}} = \frac{V_{sat}}{2^M + 1} \]

\[ R_e = \frac{2}{\alpha T} \]

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

**Cascoding**

**Output Resistance**

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

\[ V_{\text{OSS}} = kV^* \]

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 $V_{\text{min}}$ is big

**High-Swing Cascode Biasing**

- Need circuit for generating $V_{\text{bias2}}$
- Accuracy important for high $V_{\text{sat}}$/high $R_o$
  - 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)

Local Feedback and Stability

Gain-Boosted $Z_{out}$

Pole-Zero Doublets

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

\[ V_{th} \rightarrow I_c \rightarrow \text{small } V_{RF} \]

\[ V_{in} \rightarrow I_c \rightarrow \text{larger } V_{RF} \]