Bias Current Sources

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

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

- Techniques: cascoding, gain boosting

Bias Current Source

- Is this a “good” bias current source?

Noise

\[
\begin{align*}
\bar{I}_c &= I_c^0 + M \bar{I}_m^0 \\
&= kT (g_m^0 + M^2 g_m^0) A_f \\
&= kT g_m^0 \left( 1 + M^2 \right) A_f \\
&= kT g_m^0 \frac{1}{R_n} A_f
\end{align*}
\]

- $M^2$ 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

- $I_c^2$ 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 $r_e$ ("saturation"): $V_{sat} \sim V^*$
- Minimum noise (for given $I_D$):
  - $R_g \to$ large $R_g$
  - $V^* \to$ large $V^*$ (and, hence, $V_{min}$)
- Eats into signal swing...

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

\[ R_g = \frac{1}{g_{m}^2} \frac{1}{1 + M} \]

\[ V_{sat} = V_{GS} - V_{th} \]

**Output Resistance**

- Bipolar’s, GaAs, …

\[ \frac{V_{sat}}{I_d} = \frac{1}{g_{m}} \frac{g_{m}}{g_{m}} \]

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

**R_{out} = f(k)**

- $V_{DR} = kV^*$
- How to choose $k$?
  - Large $k$ useful only for large $V_{out}$
  - But, little penalty for large $k$ and small $V_{sat}$
  - Typically choose $k > 1$
  - Get benefit if $V_{sat}$ is big

**Cascoding**

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

- $M_2$ sets $V_{DS2} = V_{DS1}$: improves matching
- $M_4$ quarter size or less
  - $M = 1/5$ for high $R_{out}$
  - Note: $M \neq k$

Gain-Boosted $Z_{out}$

Gain Boosting

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

Pole-Zero Doublets

Local Feedback and Stability

If it works, do it again!

- Since in advanced scaled CMOS $g_{mro}$ is small, we can use nested gain boosting for higher output impedance.
- Watch out for pole-zero doublets!
Noise Analysis

Noise Summary

Cascode Sizing