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?

Current Mirror

• Better approach: current mirror
Noise

\[ i_{\text{on}}^2 = i_{d1}^2 + M^2 i_{d2}^2 \]
\[ = 4k_B T g_m (g_m + M^2 g_m) |f \Delta f| \]
\[ = 4k_B T g_m (1 + M) |f \Delta f| \]
\[ = 4k_B T |f \Delta f| \]

\[ R_N = \frac{1}{g_m} \frac{1}{1 + M} \]
\[ = \frac{r_o}{a_{\text{no}}} \frac{1}{1 + M} \ll R_o = r_o \]

• 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

• \( I_o^2 \) 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 $r_o$ ("saturation"): $V_{\text{min}} \sim V^*$

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

- Eats into signal swing

\[
V_{\text{min}} = k \times V^* \quad \text{typ.} \quad k = 1\ldots2
\]

\[
R_N = \frac{1}{\gamma g_m} \left( 1 + M \right) = \frac{V_{\text{min}}}{2\gamma kI_D} \left( 1 + M \right)
\]

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**Bipolar’s, GaAs, ...**

\[
\begin{align*}
\overline{I_m} &= \overline{I_e} \left( \frac{1}{1 + g_m R_e} \right) + \frac{g_m R_e}{1 + g_m R_e} \Delta f \quad \overline{V_e} = 0 \\
\text{a) } g_m R_e &= 0 & \overline{I_m} &= 2kT g_m \Delta f \\
R_N &= \frac{2V_f}{I_c} \quad \text{set by } I_c \\
\text{b) } g_m R_e &>> 1 & \overline{I_m} &= 4kT \frac{1}{R_e} \Delta f \\
R_N &= R_e = \frac{V_{\text{min}}}{I_c} \left( \frac{V_{\text{sat}} - V_{\text{min}}}{V_{\text{min}}} \right) \quad \text{compare } R_{N,\text{MOS}} = \frac{V_{\text{min}}}{I_D} \frac{1}{2\gamma k}
\end{align*}
\]

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

\[ V_{DS1} = kV^*_1 \]

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

High-Swing Cascode Biasing
- Need circuit for generating \( V_{bias2} \)
- Accuracy important for high \( V_{ds}/\text{high } R_o \)
  - 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

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 $g_{m}r_o$ is small, we can use nested gain boosting for higher output impedance.
- Watch out for pole-zero doublets!
Noise Analysis

Noise Summary