EECS240 – Spring 2010

Lecture 8: Current Sources

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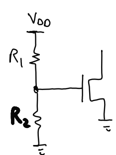
Bias Current Sources

- What makes a current source a current source?
  - High output impedance
- Other important properties:
  - Voltage range (V_{min})
  - Noise
  - Accuracy
- Techniques: cascoding, gain boosting

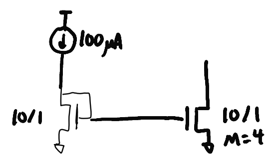
Bias Current Source

- Is this a "good" bias current source?



Current Mirror

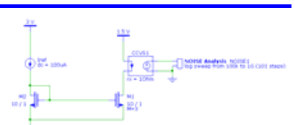
- Better approach: current mirror



Noise

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

$$R_N = \frac{1}{g_{m1}}\frac{\gamma^{-1}}{1+M}$$
$$= \frac{r_o}{a_{v0}}\frac{\gamma^{-1}}{1+M} << R_o = r_o$$



- 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_n^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} ~ V*

$$V_{\min} = k \times V^* \qquad \text{typ.} \quad k = 1 \ldots 2$$

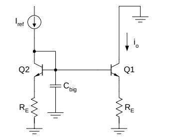
- Minimum noise (for given I_D):
  → large R_N
  → large V* (and, hence, V_{min})

$$R_N = \frac{1}{\gamma g_{m1}} \frac{1}{1+M} = \frac{V_{\min}}{2\gamma k I_D} \frac{1}{1+M}$$

- Eats into signal swing…

Bipolar's, GaAs, …

$$\overline{i_{on}^2} = \underbrace{\overline{i_{cn}^2} \left| \frac{1}{1+g_m R_E} \right|^2}_{\text{BJT}} + \underbrace{\overline{i_{Rn}^2} \left| \frac{g_m R_E}{1+g_m R_E} \right|^2}_{\text{R}_E} \Delta f \qquad \left(\overline{i_b^2} = 0\right)$$



a) $g_m R_E = 0$ $\quad \overline{i_{on}^2} = 2k_B T g_m \Delta f$

$$R_N = \frac{2}{g_m} = \frac{2V_t}{I_C} \qquad \text{set by } I_C$$

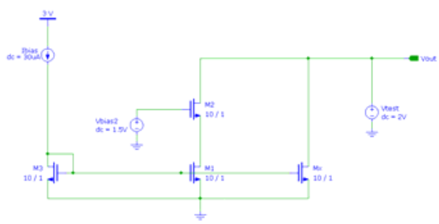
b) $g_m R_E >> 1$ $\quad \overline{i_{on}^2} = 4k_B T \frac{1}{R_E} \Delta f$

$$R_N = R_E = \frac{V_{\min}}{I_C} \frac{V_{\min} - V_{ce}^{sat}}{V_{\min}}$$

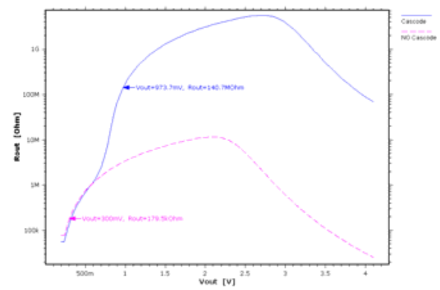
compare $\quad R_{N,MOS} = \frac{V_{\min}}{I_D} \frac{1}{2\gamma k}$

- Increasing R_E <u>lowers</u> noise
  - Same in MOS, BJT, etc.
  - V_{min} always trades with noise
- Lowest possible noise: resistor (large V_{min})

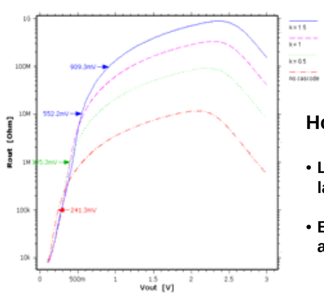
Cascoding



Output Resistance



R_{out} = f(k)



$$V_{DS1} = kV_1^*$$

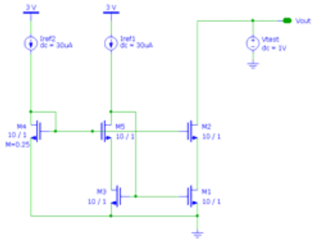
How to choose k?

- 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

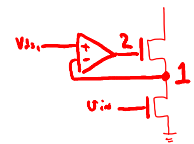
- Need circuit for generating V_{bias2}
- Accuracy important for high V_{ds}/high Ro
  - In practice, not quite as critical (V_{ds} often low)
- Assume you've seen these before
  - Review G & M if not

High-Swing Bias Example



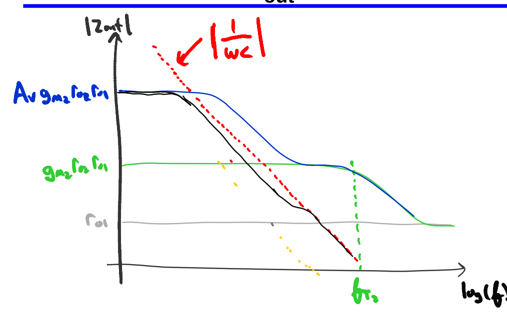
Gain Boosting

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

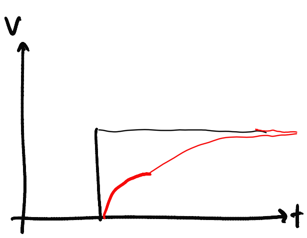


Local Feedback and Stability

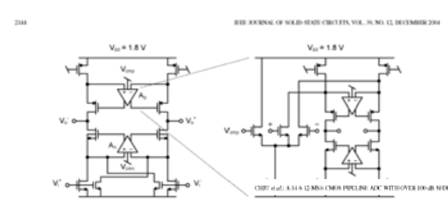
Gain-Boosted Z_{out}



Pole-Zero Doublets

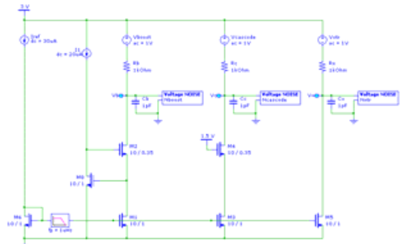


If it works, do it again!

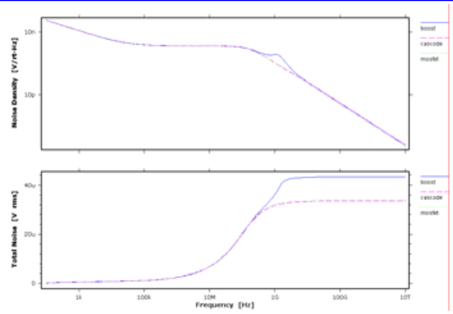


- Since in advanced scaled CMOS $g_m r_o$ is small, we can use nested gain boosting for higher output impedance.
- Watch out for pole-zero doublets!

Noise Analysis



Noise Summary



Cascode Sizing