Operational Amplifiers

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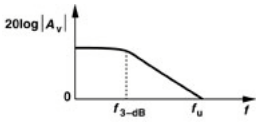
References

- **B. Razavi, "Design of Analog CMOS Integrated Circuits", McGraw-Hill, 2001.**

Operational Amplifier: Performance Parameters

Gain: the open loop gain of an op-amp determines the precision of the feedback system employing the op-amp

Small Signal Bandwith:
Unity-Gain freq., f_u, and the 3dB freq., $f_{3\text{-}dB}$.



Large Signal Bandwidth (slew rate):
Op-Amp response to large transient signals.

Output Swing:

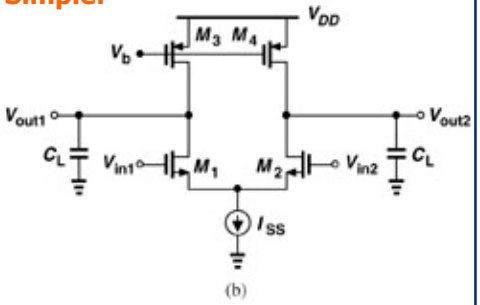
Linearity: non-linearity can be reduced by using a differential circuit and by increasing the open-loop gain in a feedback system

Noise and Offset: input noise and offset determine the minimum signal level that can be processed with reasonable quality.

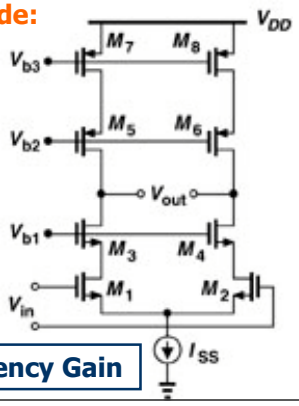
Supply Rejection:

Single stage Op-Amps

Simple:



Cascode:



Small Signal Low Frequency Gain

$$A_0 = g_{mN}(r_{ON} \,//\, r_{OP}) \qquad A_0 \le 20$$

$$A_0 = g_{mN}[(g_{mN} r_{ON}^2 \,//\, g_{mP} r_{OP}^2)]$$

Output Voltage Swing

$$2[V_{DD} - (V_{EG1} + V_{EG2} + V_{EGSS})]$$

$$2[V_{DD} - (V_{EG1} + V_{EG3} + V_{EG5} + V_{EG7} + V_{EGSS})]$$

Single stage Op-Amps

Example:

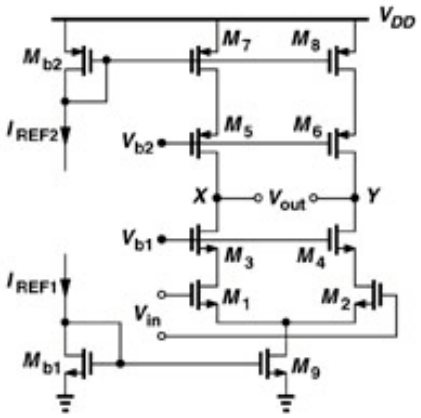
Design this amplifier (find all W/L as well as Vb1, Vb2 and Iref) with the following specifications:

$V_{DD} = 3V$

Differential Output Swing $= 3V$

Power Dissipation $= 10mW$

$A_0 = 2000$



Assume:

$\mu_n C_{ox} = 60\mu A/V^2$

$\mu_p C_{ox} = 30\mu A/V^2$

$\lambda_n = 0.1\,V^{-1}$, $\lambda_p = 0.2\,V^{-1}$

$L_{eff} = 0.5\mu m$

$\gamma = 0$, $V_{THN} = |V_{THP}| = 0.7V$

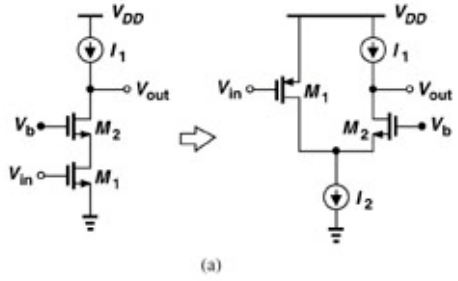
Folded Cascode Circuits

The Idea:

The input device is replaced by the opposite type.

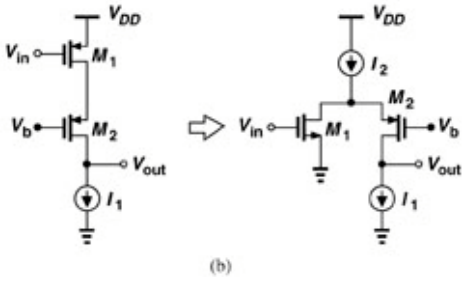
Same Gain:

$$V_{out} = g_{m1} R_{out} V_{in}$$



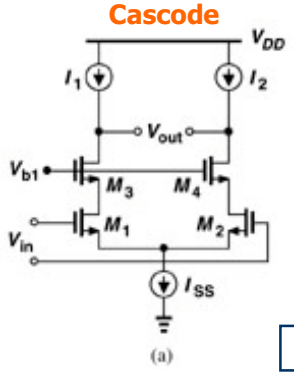
Advantage:

More room to choose the different voltage levels.

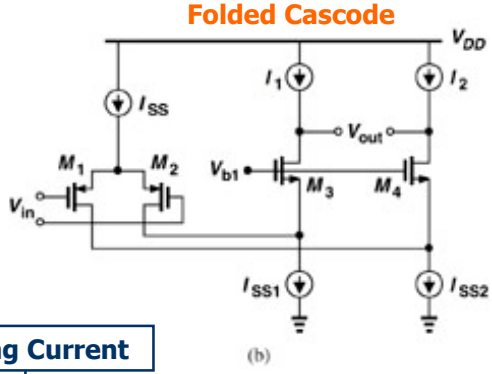


Folded Cascode Amplifier

Cascode



Folded Cascode



Biasing Current

$$I_{SS}$$

$$I_{SS1} = \frac{I_{SS}}{2} + I_1$$

Input Common-Mode

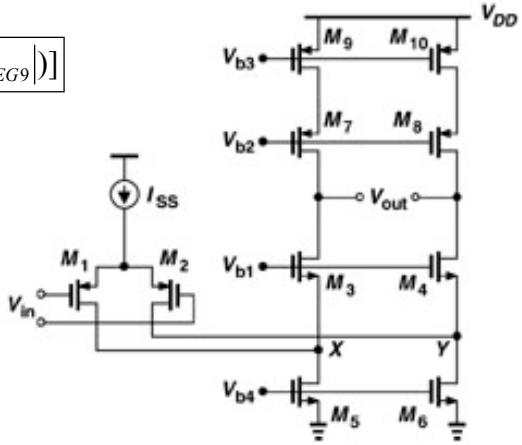
$$V_{in,CM} < V_{b1} - V_{GS3} + V_{TH1}$$

$$V_{in,CM} > V_{b1} - V_{GS3} + |V_{TH1}|$$

Folded Cascode Amplifier

Output Voltage Swing

$$2[V_{DD} - (V_{EG3} + V_{EG5} + |V_{EG7}| + |V_{EG9}|)]$$

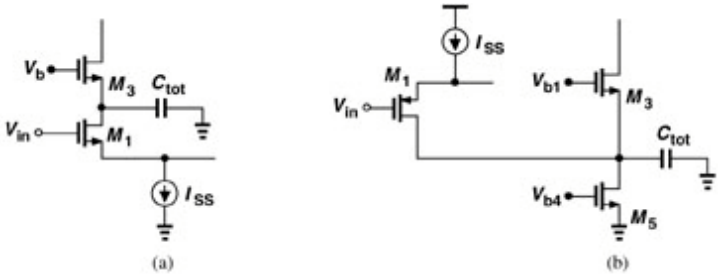


Small Signal Gain

$$A_0 \approx g_{m1}[g_{m3} r_{O3} (r_{O1} // r_{O5}) // g_{m7} r_{O7} r_{O9}]$$

Folded Cascode Amplifier

Telescopic **Folded Cascode**

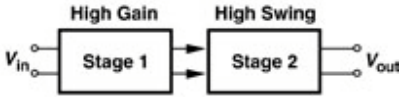


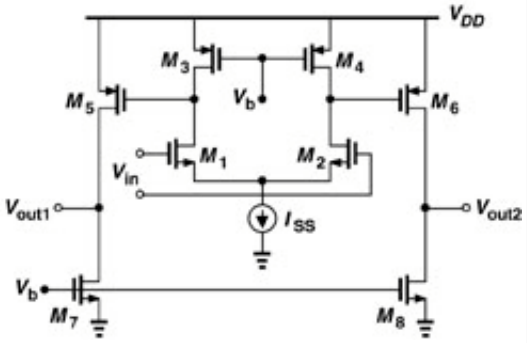
Effect of Device capacitance on the nondominant pole in telescopic and folded cascode

$$C_{tot} = C_{GS3} + C_{SB3} + C_{DB1} + C_{GD1}$$

$$C_{tot} = C_{GS3} + C_{SB3} + C_{DB1} + C_{GD1} + C_{GD5} + C_{DB5}$$

Two-Stage OpAmp





Output Voltage Swing

$$2[V_{DD} - (|V_{EG5}| + V_{EG7})]$$

Small Signal Gain

$$A_0 \approx g_{m1}(r_{O1} // r_{O3}) \times g_{m5}(r_{O5} // r_{O7})$$