ECEN474: (Analog) VLSI Circuit Design
Fall 2012

Lecture 13: Three Current Mirror OTA

Sam Palermo

Analog & Mixed-Signal Center

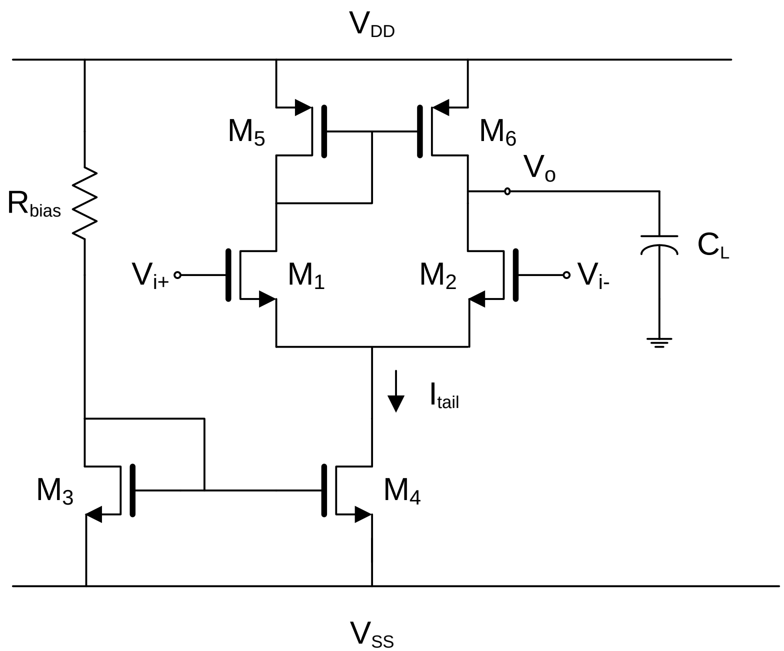
Texas A&M University

Announcements & Agenda

- HW4 due Wednesday 10/31
- Exam 2 Friday 11/2

- Simple OTA Review
- Three Current Mirror OTA Parameters
- Three Current Mirror OTA w/ Cascode Output

Operational Transconductance Amplifier



Transconductance $G_m = g_{m1} = \sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}$

Output Conductance $g_{out} = g_{o2} + g_{o6} = \frac{I_{TAIL}}{2}(\lambda_n + \lambda_p)$

DC Gain $A_v = G_m R_{out} = \frac{g_{m1}}{g_{o2} + g_{o6}} = \frac{2\sqrt{\frac{KP_n}{I_{TAIL}} \frac{W}{L}_1}}{\lambda_n + \lambda_p}$

Dominant Pole $\omega_{\mathbf{p1}} = \frac{g_{o2} + g_{o6}}{C_L}$

Non - Dominant Pole $\omega_{p2} = \frac{g_{m6}}{C_M} \approx \frac{g_{mg}}{2C_{gs6}}$

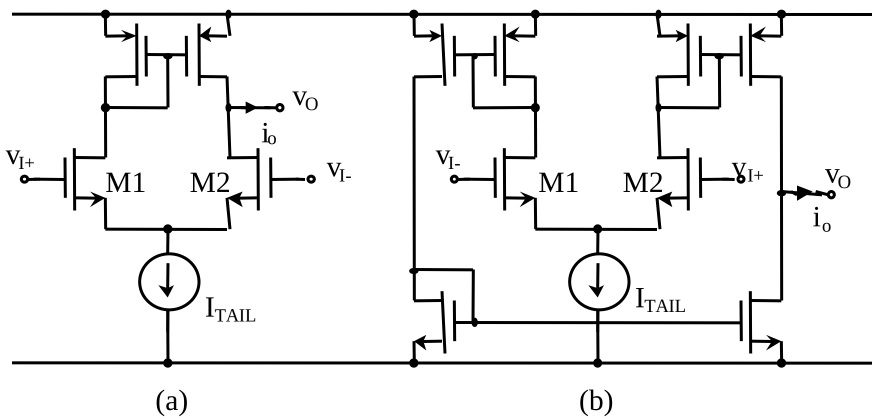
Output Noise Current $i_{on}^2 = 2\left(\frac{8}{3}kT\right)(g_{m1} + g_{m6})$

Input Noise Voltage $v_{in}^2 = 2\left(\frac{8}{3}kT\right)\left(\frac{1}{g_{m1}}\right)\left(1 + \frac{g_{m6}}{g_{m1}}\right)$

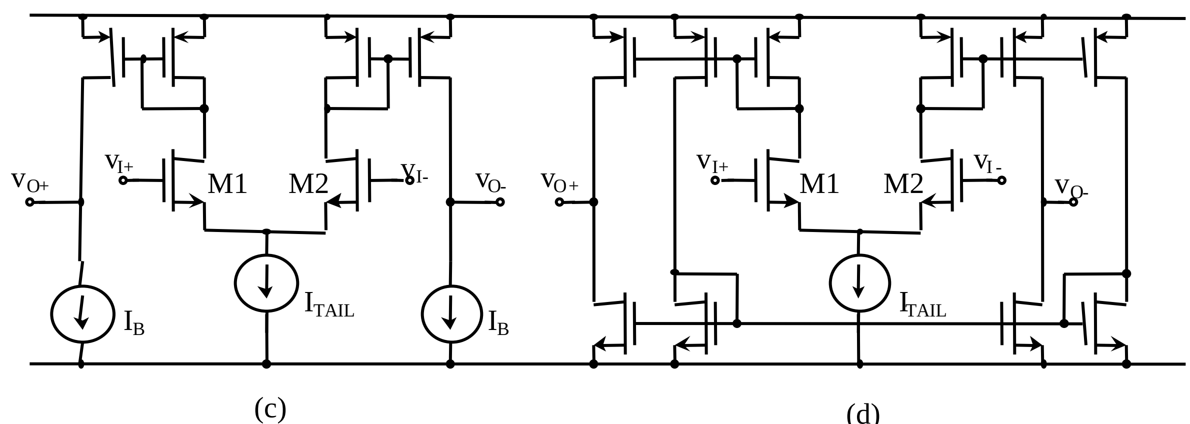
$GBW = \frac{G_m}{C_L} = \frac{\sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}}{C_L}$

Slew Rate $SR = \frac{I_{tail}}{C_L}$

Basic Operational Transconductance Amplifier Topologies

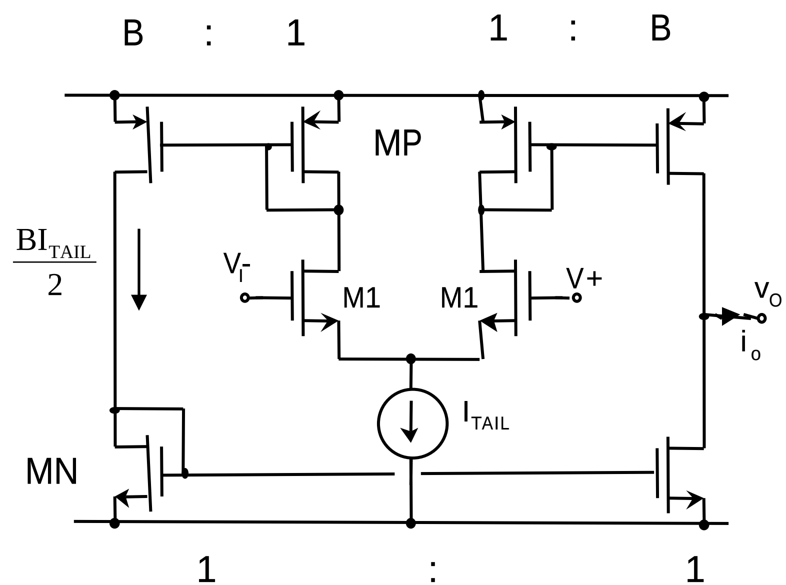


SINGLE-ENDED



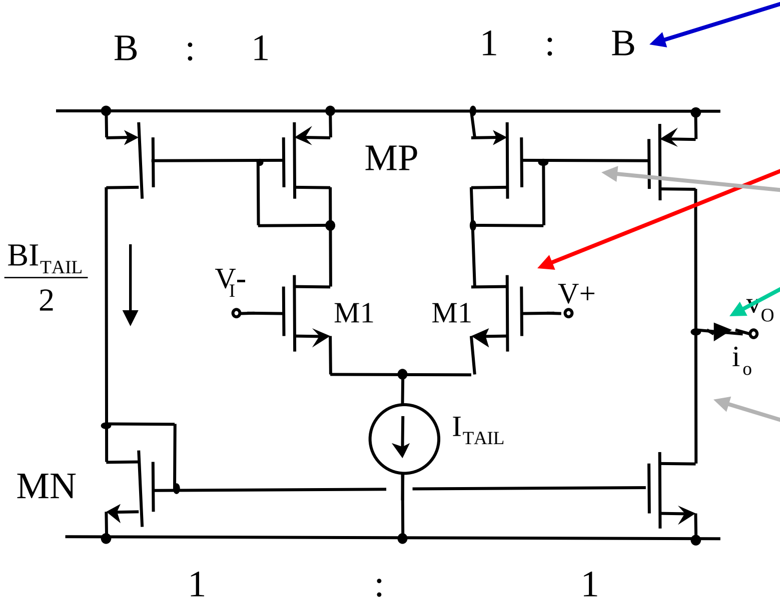
FULLY-DIFFERENTIAL

3 Current Mirror OTA



- Relative to Simple OTA
  - Factor of “B” increase in G_m, GBW, and SR
  - Same A_v
  - Slightly higher noise
  - Lower frequency non-dominant pole and third pole
  - (B+1) times the power

OTA based on 3 current mirrors



Transconductance $G_m = Bg_{m1} = B\sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}$

Output Conductance $g_{out} = g_{on} + g_{op} = \frac{BI_{TAIL}}{2}(\lambda_n + \lambda_p)$

DC Gain $A_v = G_m R_{out} = \frac{Bg_{m1}}{g_{on} + g_{op}} = \frac{2\sqrt{\frac{KP_n}{I_{TAIL}} \frac{W}{L}_1}}{\lambda_n + \lambda_p}$

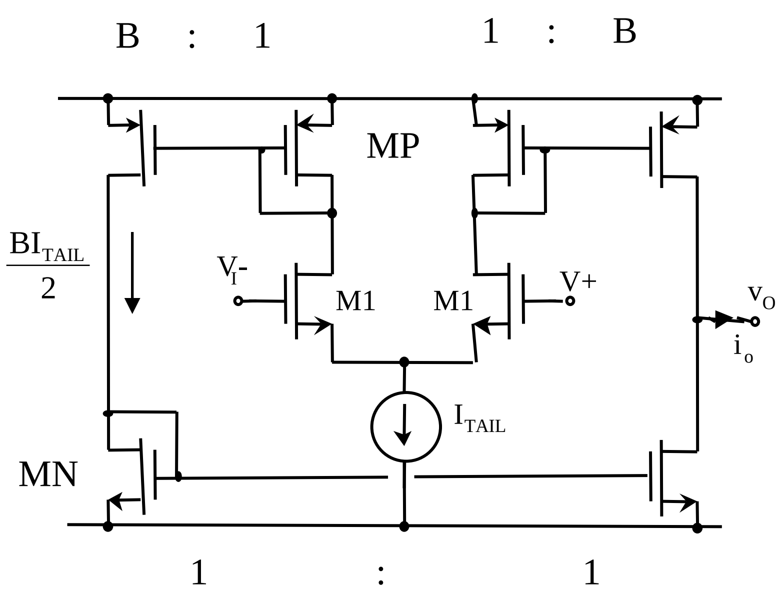
Dominant Pole $\omega_{p1} = \frac{g_{on} + g_{op}}{C_L}$

Non - Dominant Pole $\omega_{p2} = \frac{g_{mp}}{C_{Mp}} \approx \frac{g_{mp}}{(1+B)C_{gsp}}$

Gain - Bandwidth $GBW = \frac{G_m}{C_L} = \frac{B\sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}}{C_L}$

Slew Rate $SR = \frac{BI_{tail}}{C_L}$

OTA based on 3 current mirrors



Transconductance $G_m = Bg_{m1} = B\sqrt{KP_n \frac{W}{L_1} I_{TAIL}}$

Output Conductance $g_{out} = g_{on} + g_{op} = \frac{BI_{TAIL}}{2}(\lambda_n + \lambda_p)$

DC Gain $A_v = G_m R_{out} = \frac{Bg_{m1}}{g_{on} + g_{op}} = \frac{2\sqrt{\frac{KP_n}{I_{TAIL}} \frac{W}{L_1}}}{\lambda_n + \lambda_p}$

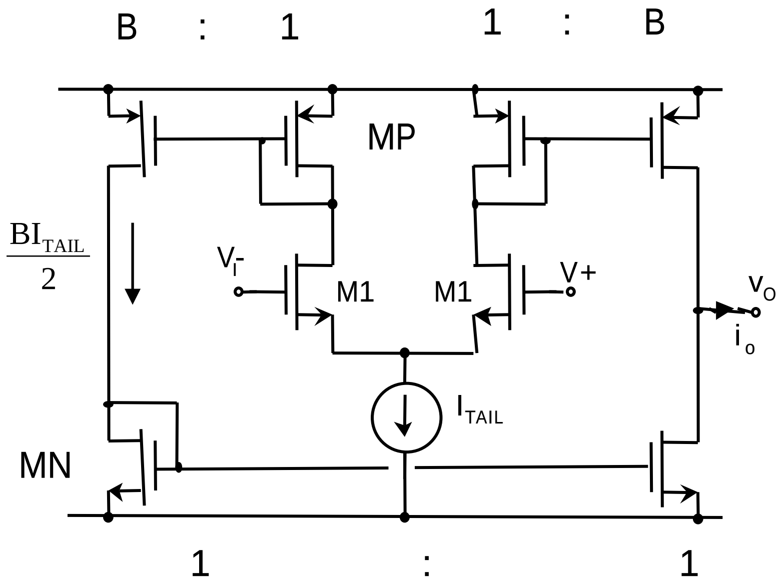
Dominant Pole $\omega_{\mathbf{p1}} = \frac{g_{on} + g_{op}}{C_L}$

Non-Dominant Pole $\omega_{p2} = \frac{g_{mp}}{C_{Mp}} \approx \frac{g_{mp}}{(1+B)C_{gsp}}$

Gain-Bandwidth $GBW = \frac{G_m}{C_L} = \frac{B\sqrt{KP_n \frac{W}{L_1} I_{TAIL}}}{C_L}$

Slew Rate $SR = \frac{BI_{tail}}{C_L}$

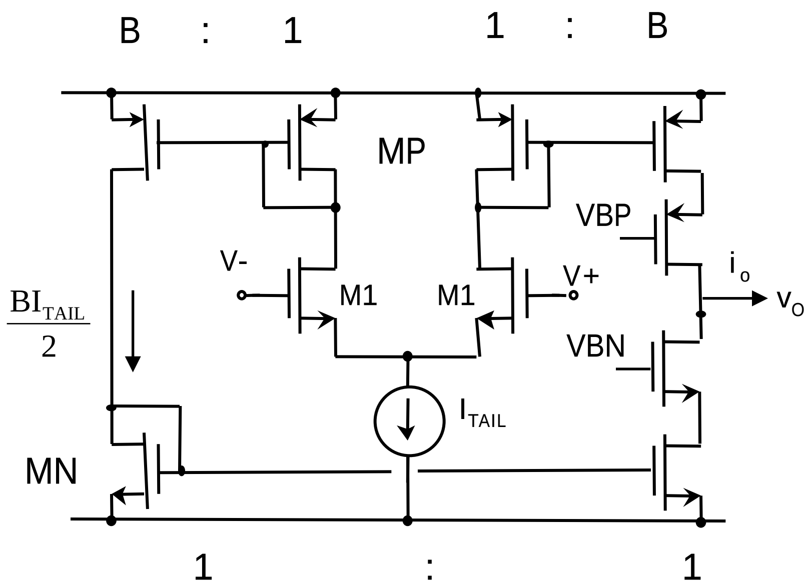
3 Current Mirror OTA Noise



$$\textbf{Output Noise Current}\quad i_{on}^2 = 2\left(\frac{8}{3}kT\right)\left(B^2 g_{m1} + B^2 g_{mp} + B g_{mp} + g_{mn}\right)$$

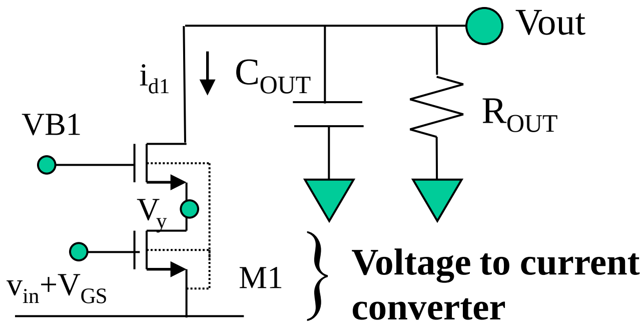
$$\textbf{Input Noise Voltage}\quad v_{in}^2 = 2\left(\frac{8}{3}kT\right)\left(\frac{1}{g_{m1}}\right)\left(1 + \frac{g_{mp}}{g_{m1}}\left(1 + \frac{1}{B}\right) + \frac{g_{mn}}{B^2 g_{m1}}\right)$$

3 Current Mirror OTA w/ Cascode Output



- Relative to 3 Current Mirror OTA
  - Same G_m, GBW, and SR
  - A_v increased by cascode $g_{mc}r_{oc}$ factor
  - Approximately same noise
  - Introduce two additional cascode non-dominant poles
  - Same power

Small Signal Analysis: Common-source Cascode Amplifier



AC analysis:

POLE AT V_Y

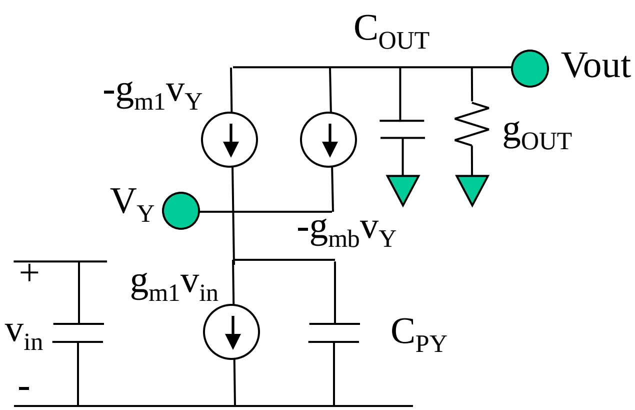
⇨Non-dominant pole: ≅

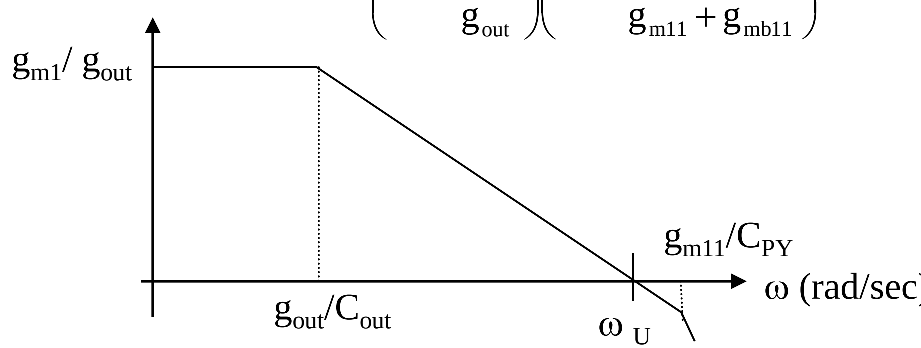
⇨ $\omega_{PND} = (g_{m11}+g_{mb11})/C_{PY}$

⇨Dominant pole at $1/R_{OUT}C_{OUT}$

⇨Transfer function

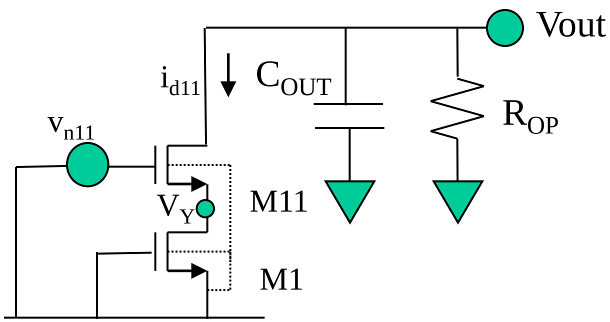
$$\frac{vout}{vin} = \left(-\frac{g_{m1}}{g_{out}}\right)\left(\frac{1}{1+s\frac{C_{out}}{g_{out}}}\right)\left(\frac{1}{1+s\frac{C_{PY}}{g_{m11}+g_{mb11}}}\right)$$

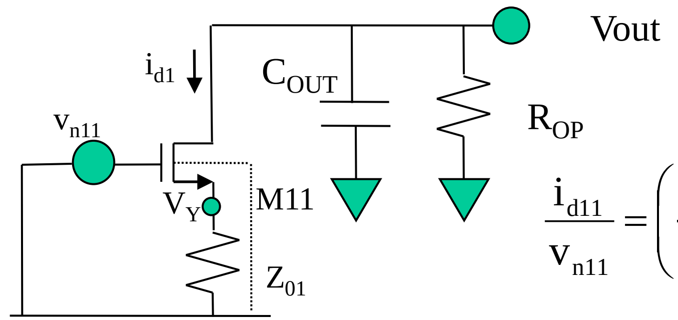




Small signal circuit

Small Signal Analysis: Noise Level



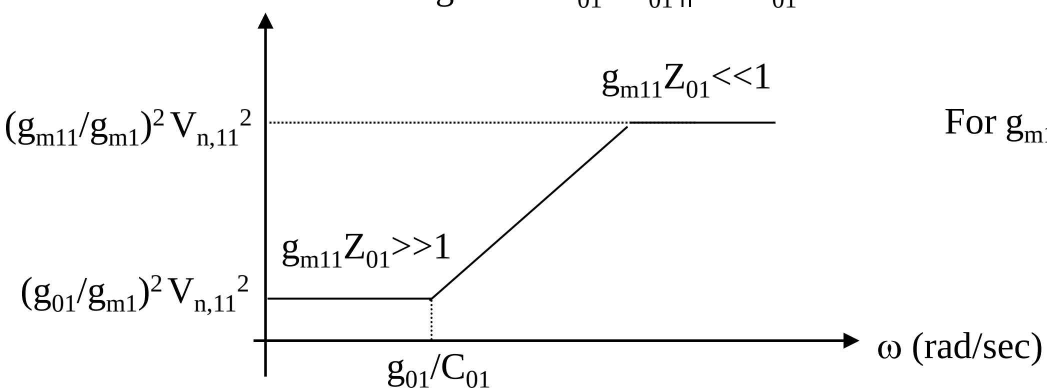


$$\frac{i_{d11}}{v_{n11}} = \left(-\frac{g_{m11}}{1+g_{m11}Z_{01}}\right)$$

Input referred Noise:

$$v_{eqin,11}^{2} = \frac{\left(\frac{g_{m11}}{1+g_{m11}Z_{01}}\right)^2}{g_{m1}^{2}} v_{n,11}^{2}$$

In general $Z_{01}=R_{01} \,||\, 1/sC_{01}$

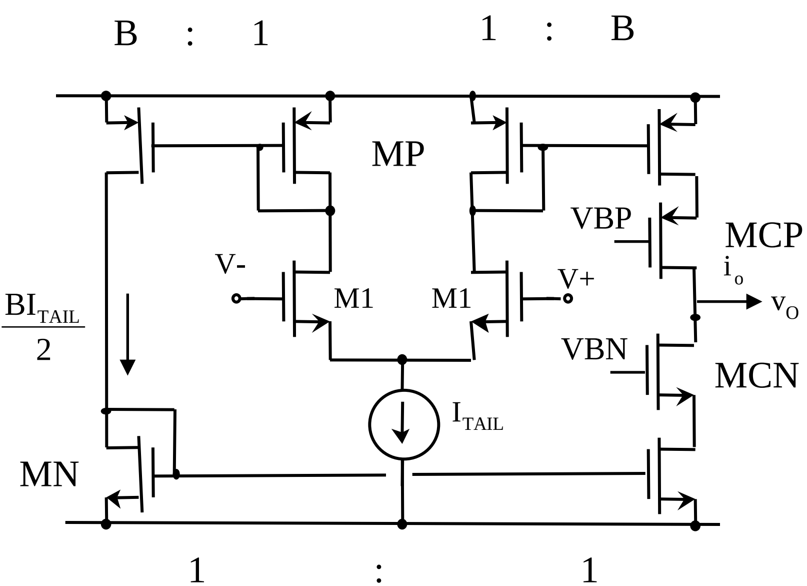


For $g_{m11}Z_{01}>>1$

$$v_{eqin,11}^{2} = \frac{1}{g_{m1}^{2} Z_{01}^{2}} v_{n,11}^{2}$$

- Cascode transistor noise can generally be neglected

OTA based on 3 current mirrors using cascode transistors



Current=(1+B)I $_{TAIL}$

Transconductance $G_m = Bg_{m1} = B\sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}$

Output Conductance $g_{out} = \frac{g_{on}}{g_{mcn} r_{ocn}} + \frac{g_{op}}{g_{mcp} r_{ocp}} \approx \frac{BI_{TAIL}}{2 g_{mc} r_{oc}} (\lambda_n + \lambda_p)$

DC Gain $A_v = G_m R_{out} = \frac{B g_{m1} g_{mc} r_{oc}}{g_{on} + g_{op}} = \frac{2\sqrt{\frac{KP_n}{I_{TAIL}} \frac{W}{L}_1}}{\lambda_n + \lambda_p} (g_{mc} r_{oc})$

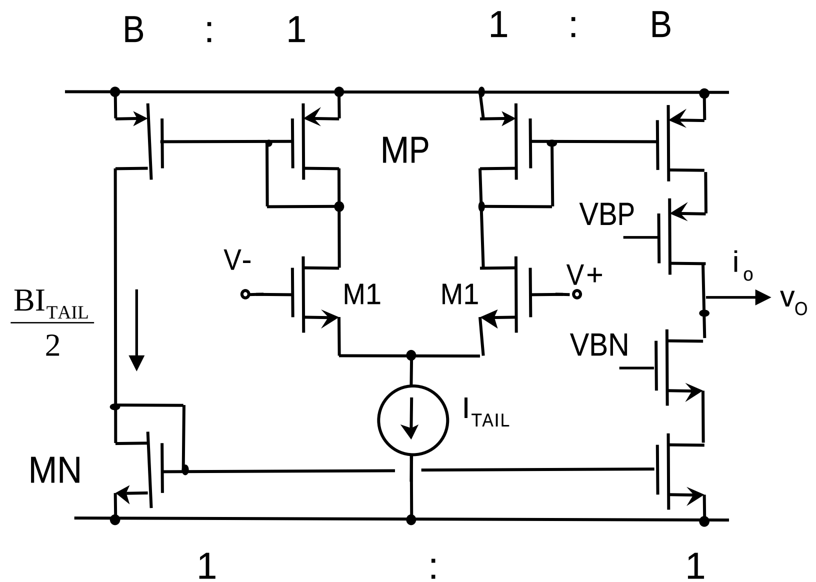
Dominant Pole $\omega_{p1} = \frac{g_{on} + g_{op}}{g_{mc} r_{oc} C_L}$

Non - Dominant Pole $\omega_{p2} = \frac{g_{mp}}{C_{Mp}} \approx \frac{g_{mp}}{(1+B) C_{gsp}}$

Gain - Bandwidth $GBW = \frac{G_m}{C_L} = \frac{B\sqrt{KP_n \frac{W}{L}_1 I_{TAIL}}}{C_L}$

Slew Rate $SR = \frac{BI_{tail}}{C_L}$

3 Current Mirror OTA Noise

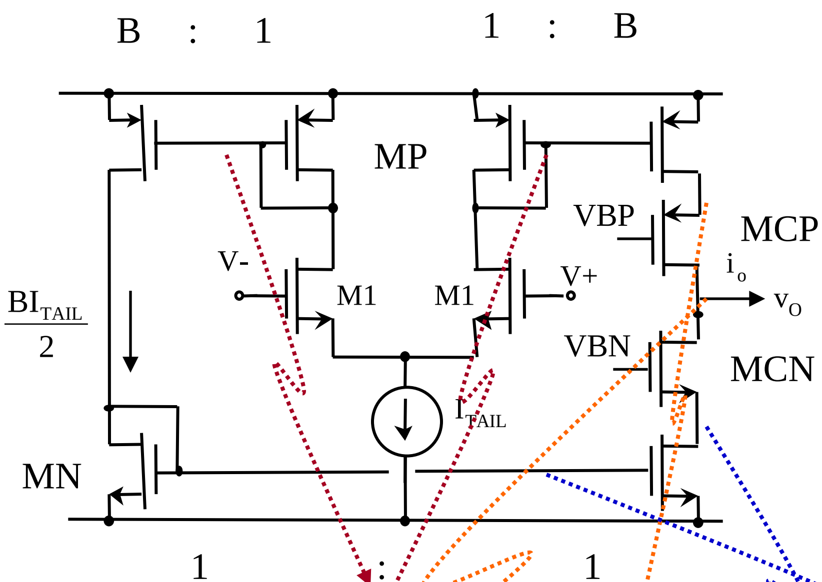


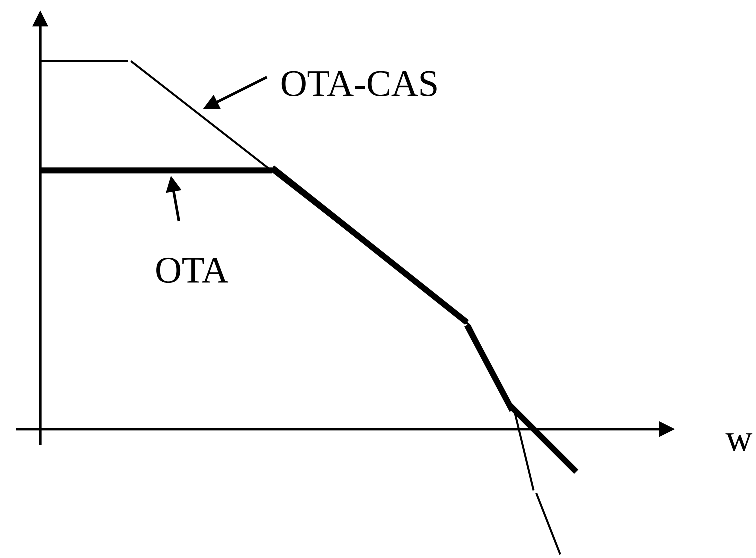
Output Noise Current $\overline{i_{on}^2} = 2\left(\frac{8}{3}kT\right)\left(B^2 g_{m1} + B^2 g_{mp} + Bg_{mp} + g_{mn}\right)$

Input Noise Voltage $\overline{v_{in}^2} = 2\left(\frac{8}{3}kT\right)\left(\frac{1}{g_{m1}}\right)\left(1 + \frac{g_{mp}}{g_{m1}}\left(1 + \frac{1}{B}\right) + \frac{g_{mn}}{B^2 g_{m1}}\right)$

- Cascode transistor contribution can be neglected
- Approximately equal to 3 current mirror OTA noise

OTA based on 3 current mirrors using cascode transistors





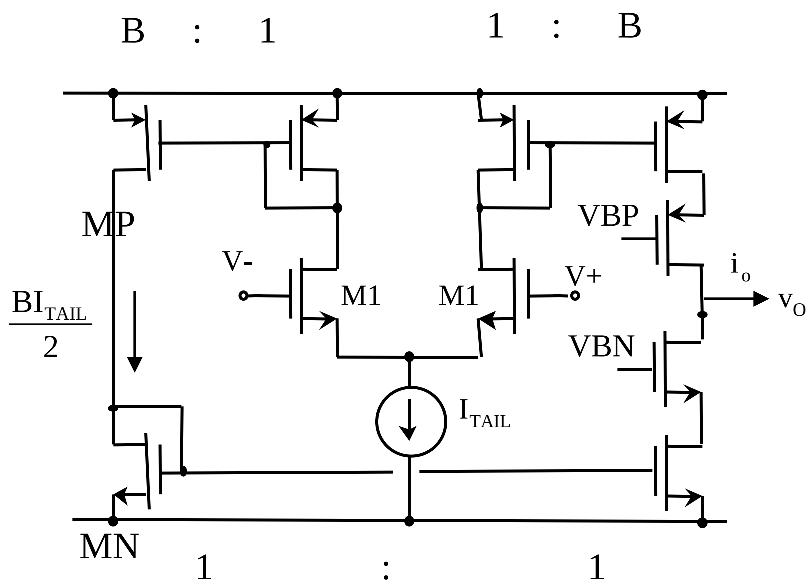
P-type current mirror P-type cascode N-type cascode N-type current mirror

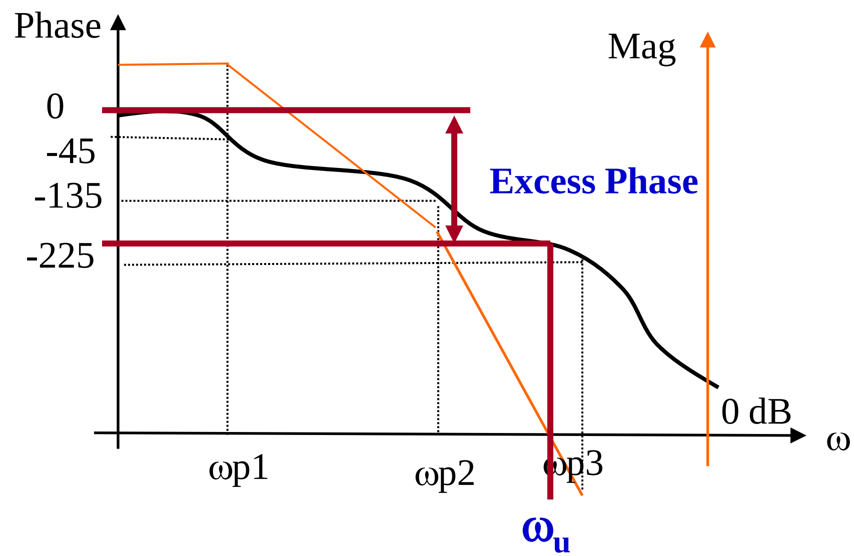
$$A_V \cong \frac{\frac{Bg_{m1}R_{out}}{2}}{1+sR_{out}C_{out}}\left[\frac{1}{1+s\frac{(1+B)C_{GSP}}{g_{mP}}}\right]\left[\left[\frac{1}{1+s\frac{(1+\Delta)C_{GSCP}}{g_{mcp}}}+\left(\frac{1}{1+s\frac{(1+\Delta)C_{GSCN}}{g_{mcn}}}\right)\right]\left(\frac{1}{1+s\frac{2C_{GSN}}{g_{mN}}}\right)\right]$$

Phase Margin is limited

OTA-output

OTA based on 3 current mirrors using cascode transistors





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Excess Phase is defined as (phase at 0 - phase at ω_u)

Phase Margin = (180 – excess phase)

Gain margin = Gain measured at 180° excess phase

Next Time

- Folded Cascode OTA
- Two Stage Miller OTA