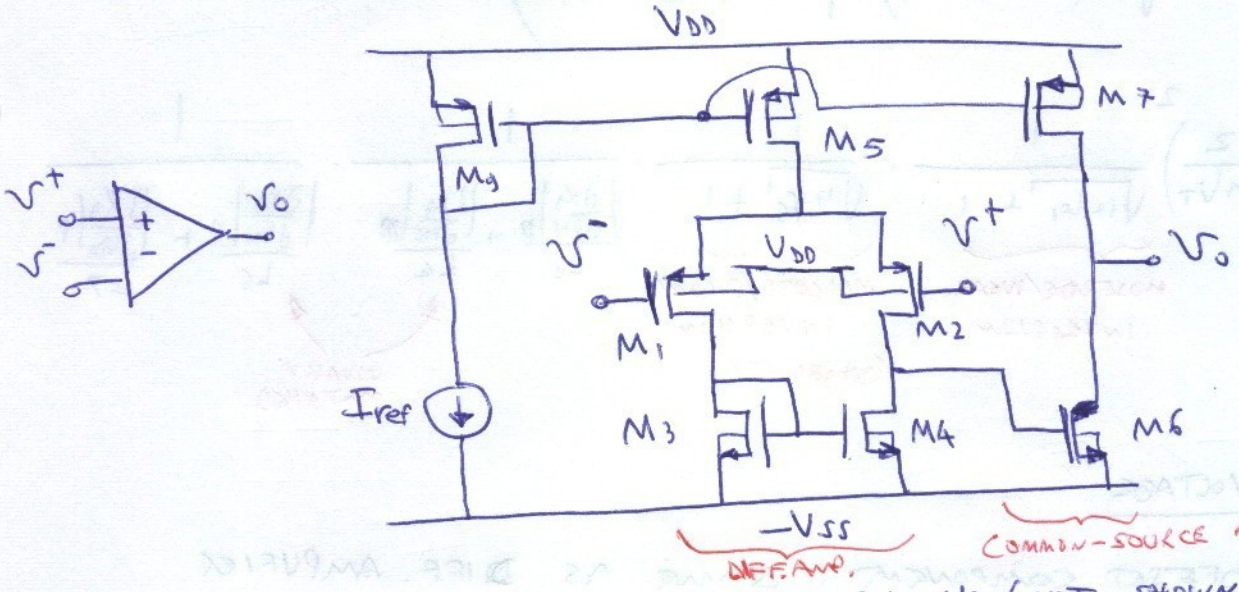
OPERATIONAL AMPLIFIERS



- USUALLY NEEDS A COMPENSATION NETWORK (NOT SHOWN)
- CAN ONLY DRIVE CAPACITIVE LOADS. IF A RESISTNE LOAD MUST BE DRIVEN (INCLUDING FEEDBACK NETWORK), AN ADDITIONAL STAGE MUST BE ADDED TO THE OUTPUT.
- MOST ON-CHIP OP-AMPS ONLY DRIVE CAPACITIVE LOADS SO THIS DESIGN IS OK.

DC CHARACTERISTICS

- INPUT-COMMON-MODE RANGE: SAME AS DIFFERENTIAL AMPLIFIER
- OUTPUT VOLTAGE RANGE:

$$-V_{SS} + |V_{DS6SAT}| \leq v_o \leq V_{DD} - |V_{DS7SAT}|$$

COMMON-MODE AND DIFFERENTIAL GAIN

- GAINS ARE EQUAL TO THE PRODUCT OF DIFF. AMP. GAIN TIMES COMMON-SOURCE STAGE GAIN.
- CMRR EQUAL TO CMRR OF DIFFERENTIAL AMPLIFIER (SINCE THE C.S. GAIN IS CANCELLED IN $\frac{a_{dm}}{a_{cm}}$).

$$a_{dm} \simeq g_{m1}(r_{o2} \parallel r_{o4})\, g_{m6}(r_{o6} \parallel r_{o7})$$

$$a_{dm} \simeq \left(\frac{2}{nV_T}\right)^2 \frac{1}{\sqrt{1+i_{f1}}+1} \cdot \frac{1}{\sqrt{1+i_{f6}}+1} \cdot \frac{1}{\left|\frac{\partial X_D}{\partial V_{DS}}\right|_n + \left|\frac{\partial X_D}{\partial V_{DS}}\right|_p} \cdot \frac{1}{\left|\frac{\partial X_D}{\partial V_{DS}}\right|_n + \left|\frac{\partial X_D}{\partial V_{DS}}\right|_p}$$

L_2 L_4 L_6 L_7

MODERATE/WEAK INVERSION

MODERATE/STRONG INVERSION (STABILITY)

USUALLY MATCHED

OFFSET VOLTAGE

- RANDOM OFFSET COMPONENT: SAME AS DIFF. AMPLIFIER
- SYSTEMATIC OFFSET:

$V_{DS6} = V_{DS4} = V_{DS3}$ → IF M_3, M_4 AND M_6 DESIGNED TO HAVE SAME INVERSION LEVEL $(i_{f3} = i_{f4} = i_{f6})$

∴ SYSTEMATIC OFFSET:

$$V_{os} = \frac{\overbrace{(V_{GS3} - V_{SS})}^{\text{ACTUAL OUTPUT}} - \overbrace{\frac{(V_{DD} - V_{SS})}{2}}^{\text{IDEAL OUTPUT WITH } V_{ID}=0}}{a_{dm}}$$

$$i_{f3} = i_{f4} = i_{f6}$$

$$\frac{I_T}{I_{Sq}^2 \left(\frac{W}{L}\right)_3} = \frac{I_T}{I_{Sq}^2 \left(\frac{W}{L}\right)_4} = \frac{I_{D6}}{I_{Sq}\left(\frac{W}{L}\right)_6}$$

$$I_{D6} = I_{D7} = \frac{I_{D5}}{\left(\frac{W}{L}\right)_5}\left(\frac{W}{L}\right)_7 = I_T \frac{\left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_5}$$

$$2\frac{I_T}{\left(\frac{W}{L}\right)_3} = \frac{I_T \left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_6 \left(\frac{W}{L}\right)_5} \Rightarrow \boxed{\frac{1}{2}\frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_3} = \frac{\left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_5}}$$

FOR SAME CURRENT DENSITY

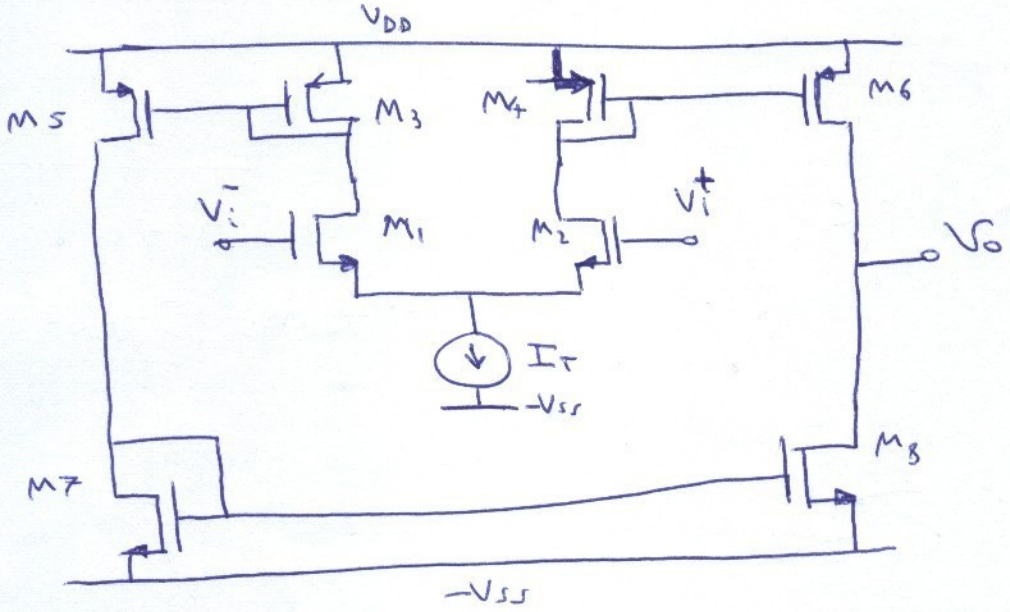
OTHER OPERATIONAL AMPLIFIER TOPOLOGIES

1) DIFFERENTIAL AMPLIFIER STAGE → HAS REDUCED OUTPUT VOLTAGE RANGE

2) RANGE CAN BE INCREASED USING A FOLDED CASCODE CONFIGURATION

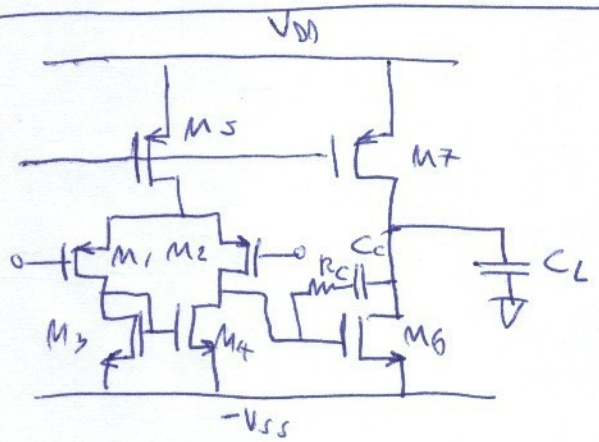
OR:

3) SYMMETRIC OPERATIONAL AMPLIFIER



- MORE OUTPUT VOLTAGE RANGE
- BETTER FREQUENCY RESPONSE IF SOURCE HAS HIGH IMPEDANCE.
- NORMALLY $M_5 = M_3 = M_4 = M_6$, $M_1 = M_2$, $M_7 = M_8$

COMPENSATION NETWORK FOR 2-STAGE OP. AMP. SUMMARY



$$C_c = \frac{g_{m1}}{g_{m6}} C_L$$

(MAKE $g_{m6} > g_{m1}$)

$$R_c \simeq \frac{1}{g_{m6}}$$

THIS GIVES $PM \simeq 45°$