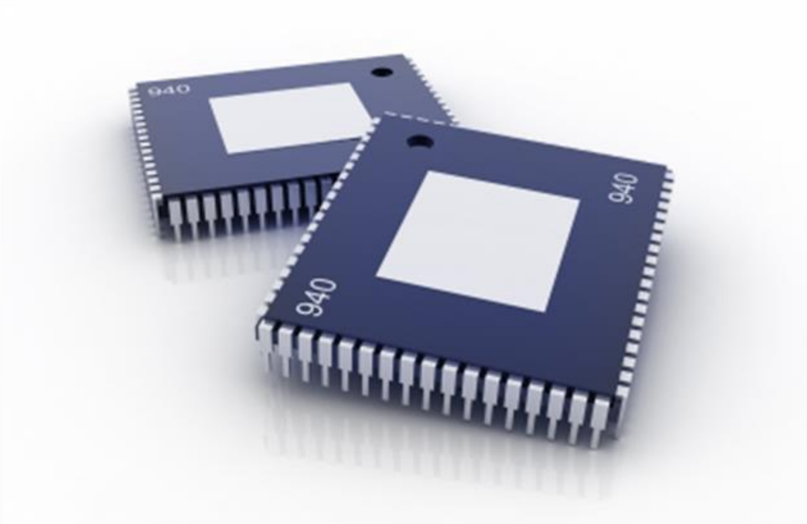

LECTURE 6

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6. Basic Opamp Design and Compensation

Gain Boosting

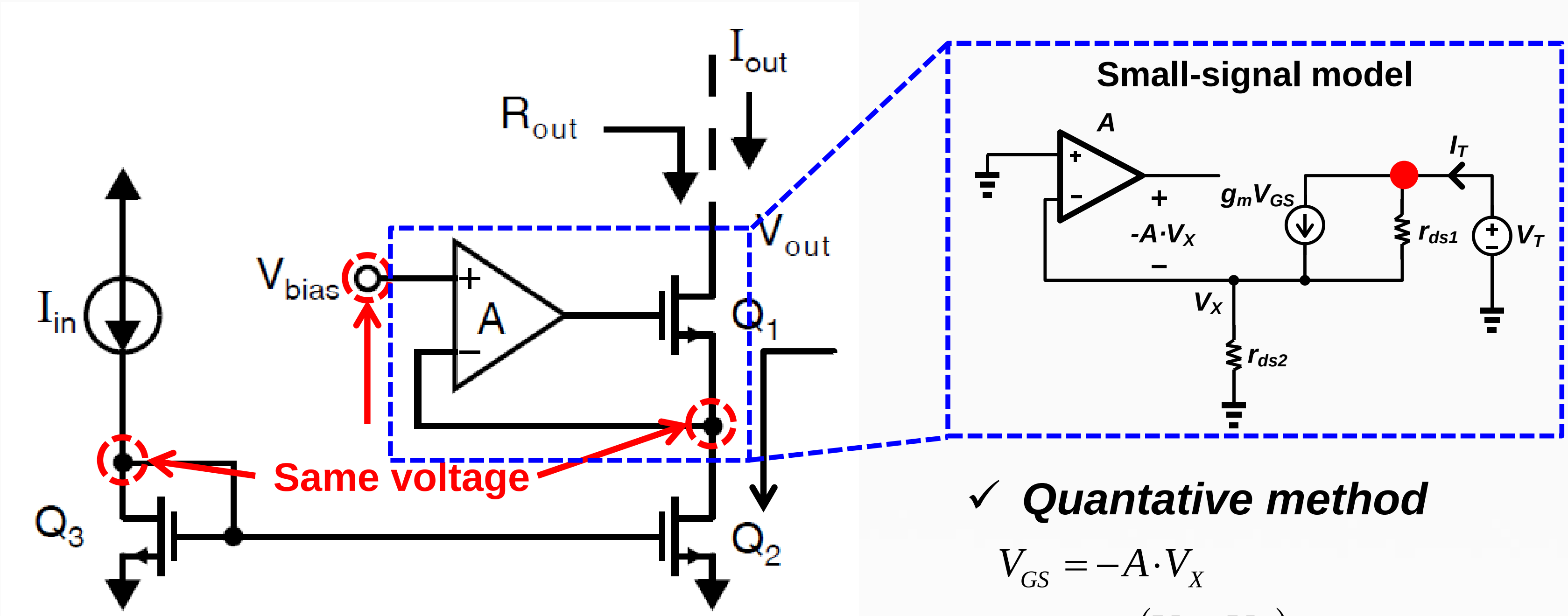


Fig. 6.13 The enhanced output-impedance current mirror.

✓ ***Quantative method***

$$V_{GS} = -A \cdot V_X$$

KCL : $$g_m V_{GS} + \frac{(V_T - V_X)}{r_{ds1}} = I_T$$

$$V_X = I_T \cdot r_{ds2}$$

$$R_{out} = \frac{V_T}{I_T} = (A_1 + 1) g_{m1} r_{ds2} r_{ds1} + r_{ds2} r_{ds1}$$

$$R_{out} \cong g_{m1} r_{ds1} r_{ds2} (1 + A)$$

✓ ***Intuitive method***

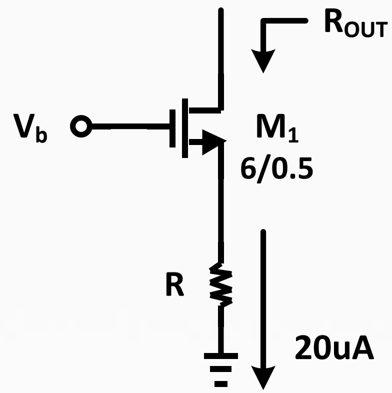
Keep the V_{DS2}

→ **Increase the output impedance**

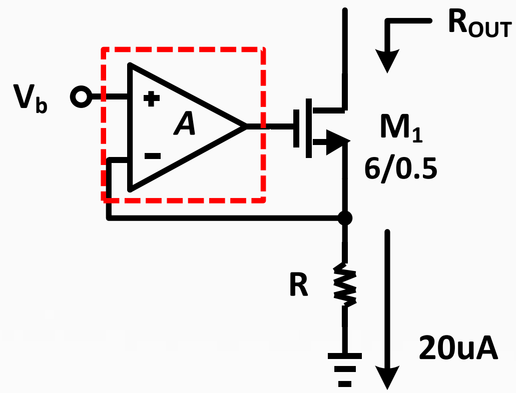
Example

두 회로의 Output Impedance를 비교하라.

$$R = 10k\Omega,\ \ \mu_n C_{OX} = 270\mu A/V^2,\ \ I_D = 20\mu A,\ \ \lambda = 0.1,\ \ A = 100$$



(a) NMOS with source resistance



(b) Gain boosting applied

$$g_{m1} = \sqrt{\mu_n C_{OX} (W/L) 2I_D} = 2.54\times10^{-4} S$$

$$r_{o1} = \frac{1}{\lambda I_D} = 500k\Omega$$

$$R_{OUT} = g_{m1} r_{o1} R + r_{o1} + R = g_{m1} r_{o1} R = 1.27M\Omega$$

$$R_{OUT} = (A+1) g_{m1} r_{o1} R + r_{o1} R = A g_{m1} r_{o1} R = 127M\Omega$$

Output impedance increased 100 times

Enhanced Output-Impedance Current Mirror

- Bedrich J,Hosticka, Swiss Federal Institute of Technology (1979년)

- Current mirror using gain boosting technique

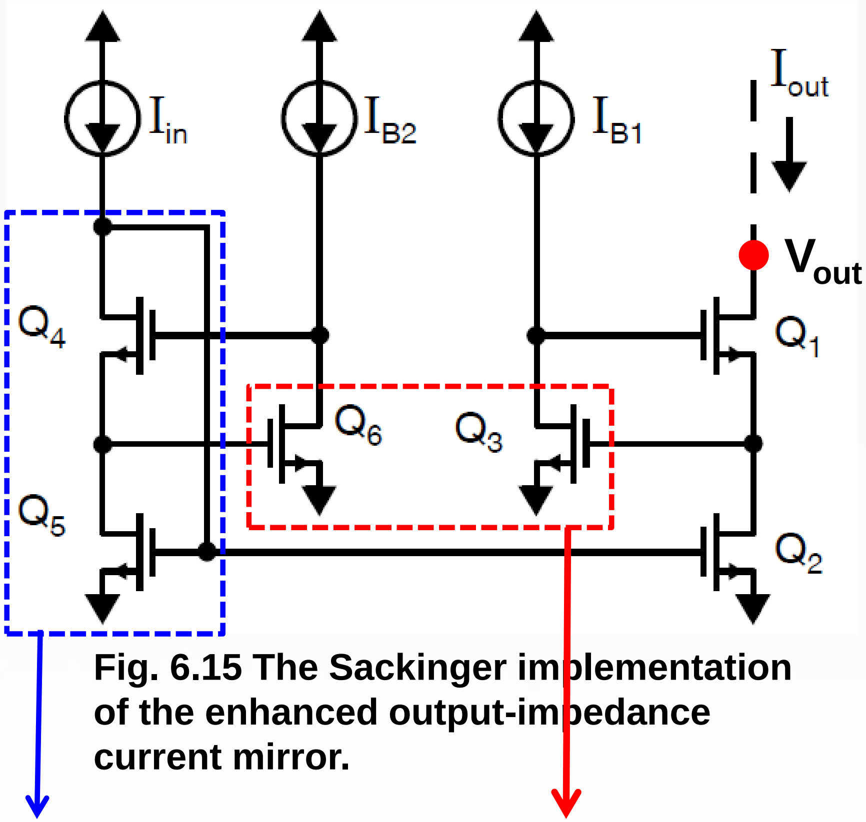


Fig. 6.15 The Sackinger implementation of the enhanced output-impedance current mirror.

Wide-range current mirror

Gain boosting

$$I_{in} = I_{out}$$

$$R_{out} \cong \frac{g_{m1} g_{m3} r_{ds1} r_{ds2} r_{ds3}}{2}$$

High output impedance
Equal current

Output swing limited by Q_3

$$V_{out} > V_{DS1} + V_{DS2}$$

$$V_{out} > V_{DS1} + V_{GS3} = V_{DS1} + V_{DS3} + V_{TH}$$

Wide-Swing Current Mirror

- Umberto Gatti, University of Pavia (1990년)

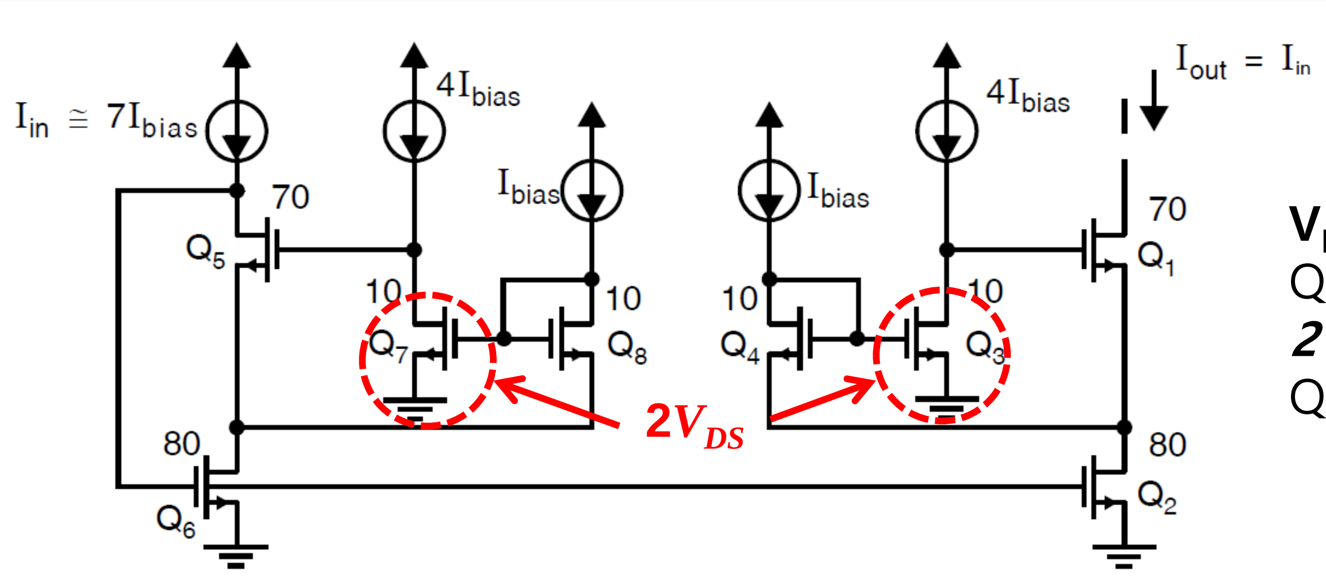


Fig. 6.16 A wide-swing current mirror with enhanced output impedance..

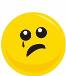
$V_{DS}(=V_{GS}-V_{TH}=V_{eff})$
$Q_1, Q_2, Q_4, Q_5, Q_6, Q_8$
$2V_{DS}$
Q_3, Q_7

$$V_{G3} = V_{DS2} + V_{GS4} = 2 \cdot V_{DS} + V_{TH}$$

$$V_{DS2} = V_{S4} = V_{G3} - V_{GS4}$$
$$= (2V_{DS} + V_{TH}) - (V_{DS} + V_{TH}) = V_{DS}$$

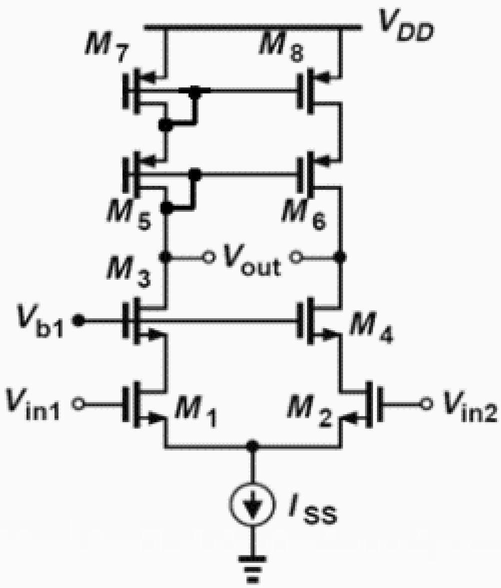
$$V_{out} > V_{DS2} + V_{DS1} = \underline{2V_{DS}}$$

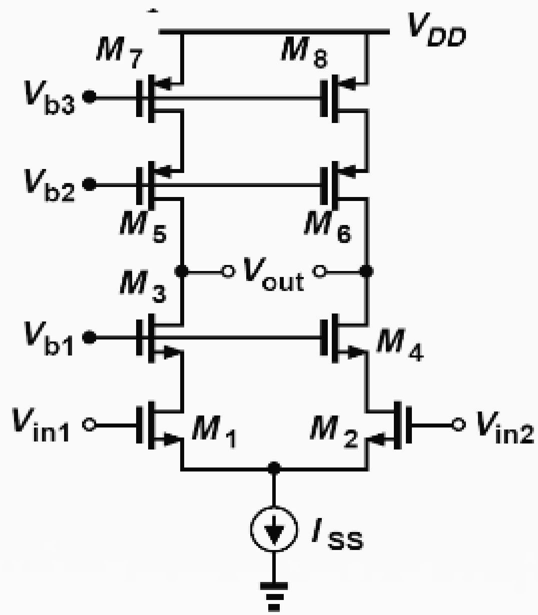
High output impedance
Equal current
Wide-Swing



Power dissipation(x2)
Additional poles

Folded Cascode Op amp



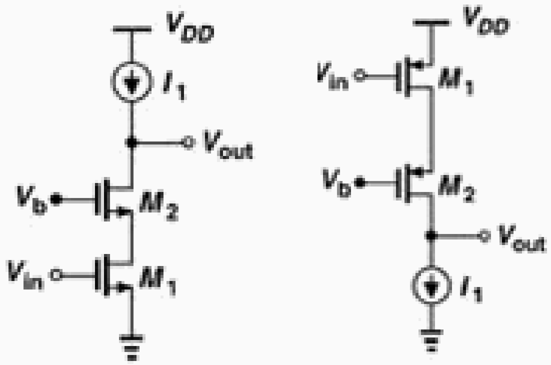


High gain

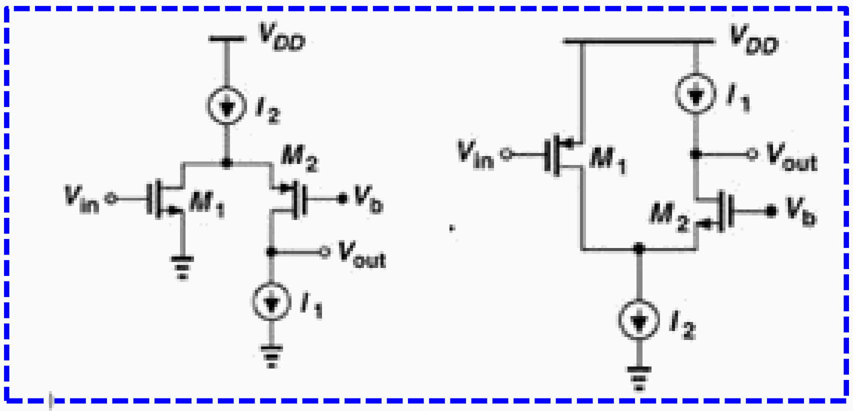
$$|A_v| \approx g_{m1,2}\left(g_{m4} r_{ds4} r_{ds2} \,||\, g_{m6} r_{ds6} r_{ds8}\right)$$

Output Swing

Folded Cascode Op amp



Cascode circuits



Folded cascade circuits

	Cascode	Folded Cascode
Swing	$V_{in}-V_{th}+V_{DS} \le V_{out} \le V_{DD}-V_{I1}$	$V_{I2}+V_{DS} \le V_{out} \le V_{DD}-V_{I1}$
Power	$P=V_{DD} \cdot I_1$	$P=V_{DD} \cdot I_2=V_{DD} \cdot 2I_1$

V_{out} is independent of V_{in}.(Swing)

Power dissipation

Folded Cascode Op amp

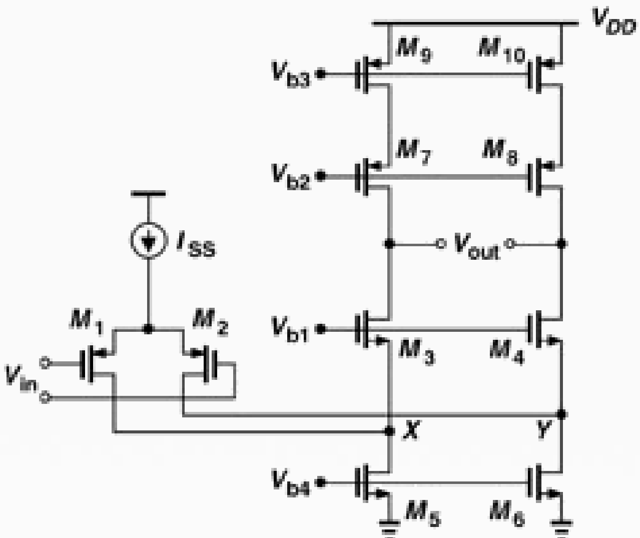


Fig. Folded-cascode op amp topology

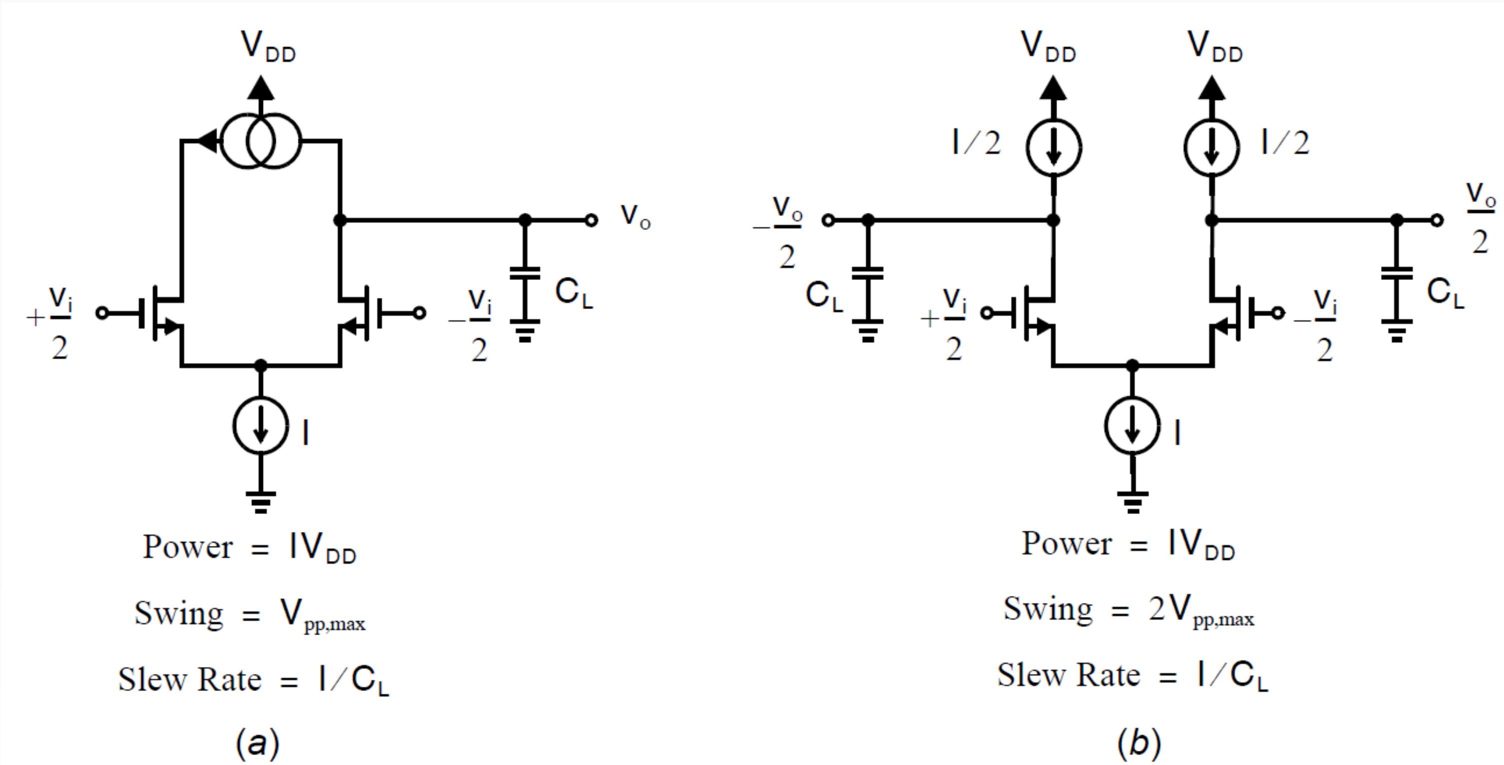
$$|A_v| \approx g_{m1}\left[g_{m3}r_{o3}\left(r_{o1} \| r_{o5}\right) \| g_{m7}r_{o7}r_{o9}\right]$$

$$P_{dominant} \approx \frac{1}{C_L \cdot \left[g_{m3}r_{o3}\left(r_{o1} \| r_{o5}\right) \| g_{m7}r_{o7}r_{o9}\right]}$$

Single pole, High speed, Good phase margin

Power dissipation

Single & Differential



Same

Power
Slew-rate
Gain

Different

Swing(x2)

Advantage of Fully differential opamp

1. Twice the available swing
2. Canceling unwanted common-mode noise

Example

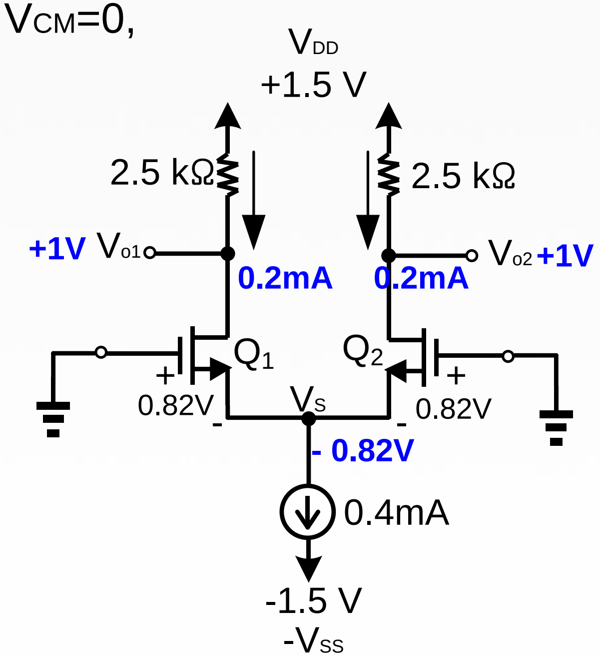
V_{DD}=V_{SS}=1.5V, V_{GS}=0.82V, V_t=0.5V, I=0.4mA, R_D=2.5KΩ, Current source minimum voltage(V_{CS})=0.4V.

(a)For V_{CM}=0, find V_s and V_{out1} and V_{out2}.

(b)Repeat (a) for V_{CM}= +1V

(c)Repeat (a) for V_{CM}= -0.2V

(a) For V_{CM}=0,



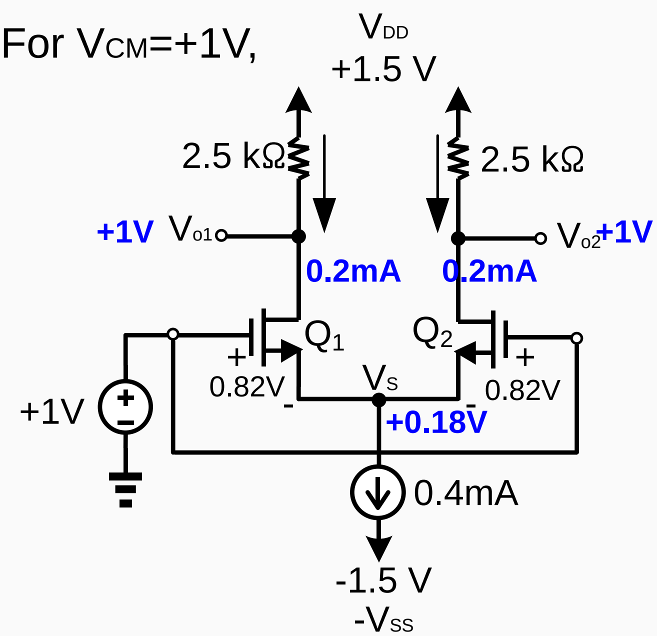
$V_S = V_{CM} - V_{GS} = 0 - 0.82V = -0.82V$

$V_{O1} = V_{O2} = V_{DD} - \frac{1}{2} I_D$

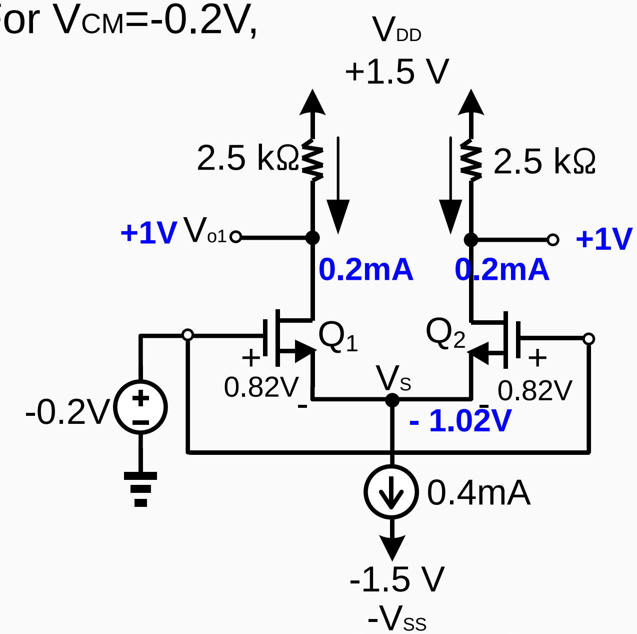
$= 1.5 - 0.2 \times 2.5 = 1V$

Example

(b) For V_{CM}=+1V,



(c) For V_{CM}=-0.2V,



$V_S = V_{CM} - V_{GS} = 1 - 0.82V = +0.18V$

$V_{O1} = V_{O2} = V_{DD} - \frac{1}{2} I_D$

$= 1.5 - 0.2 \times 2.5 = 1V$

$V_S = V_{CM} - V_{GS} = -0.2 - 0.82V = -1.02V$

$V_{CS} = -V_S - (-V_{SS}) = -1.02 + 1.5V = 0.48V \geq 0.4V$

$V_{O1} = V_{O2} = V_{DD} - \frac{1}{2} I_D = 1.5 - 0.2 \times 2.5 = 1V$

$V_{CM\,max} = V_t + (V_{DD} - \frac{1}{2} I_D) = 0.5 + 1 = 1.5V$

$V_{CM\,min} = -V_{SS} + V_{CS} + V_{GS} = -1.5 + 0.4 + 0.82 = -0.28V$

$\Rightarrow -0.28V \leq V_{CM} \leq +1.5V$

Common-mode Output voltage

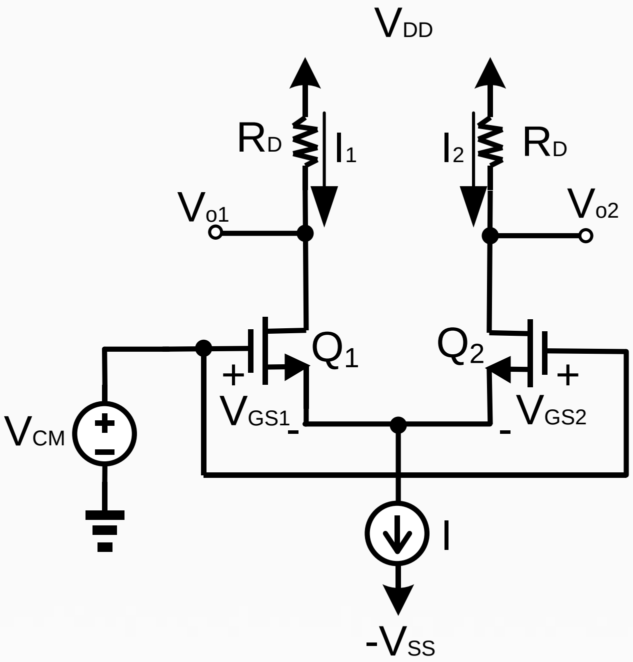
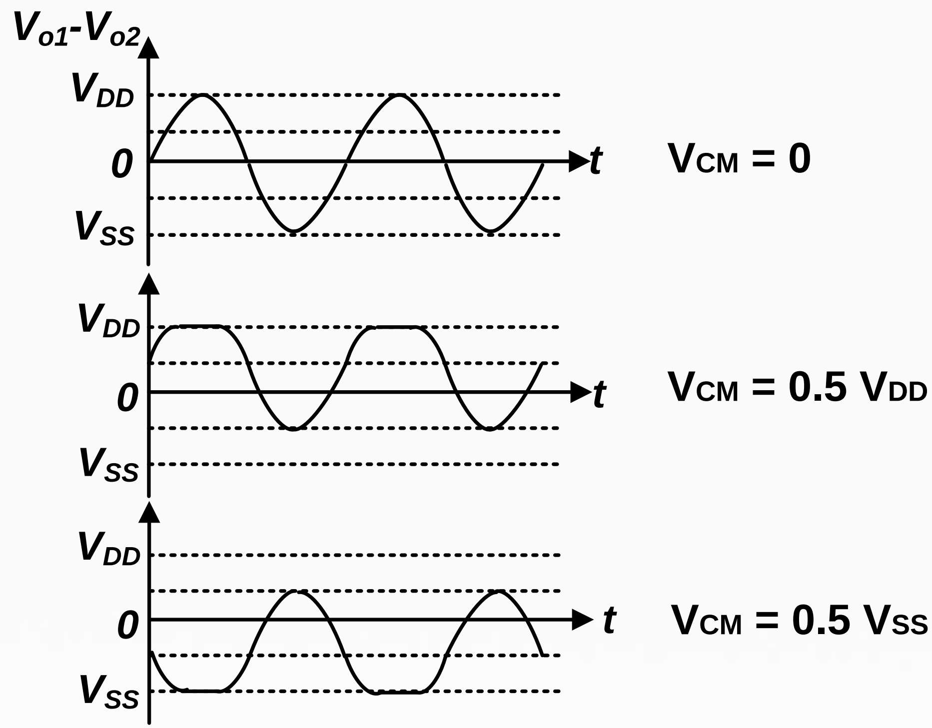


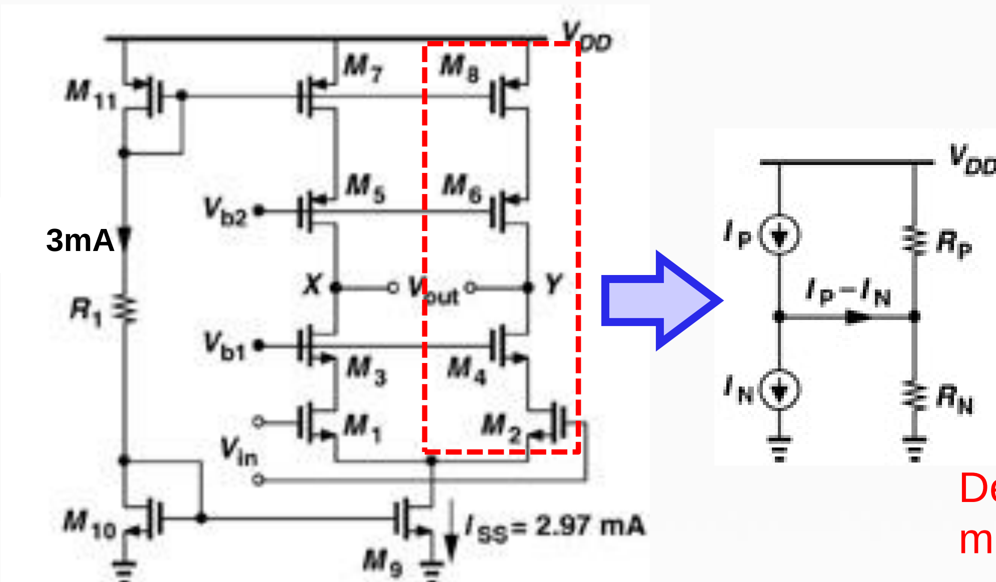
Fig. fully differential amp



Influence of the output CM signal on differential amp

CM level is influenced by the mismatches and loads and can be at any value.

Why we need the CMFB?



Ideally $I_P = I_N$

In practice $I_P \neq I_N$ (mismatches)

$$(I_P - I_N)(R_P \parallel R_N) \rightarrow 0 \;\; or \;\; V_{DD}$$

Depends on mismatches

Quite high

Simplified model of high-gain amplifier

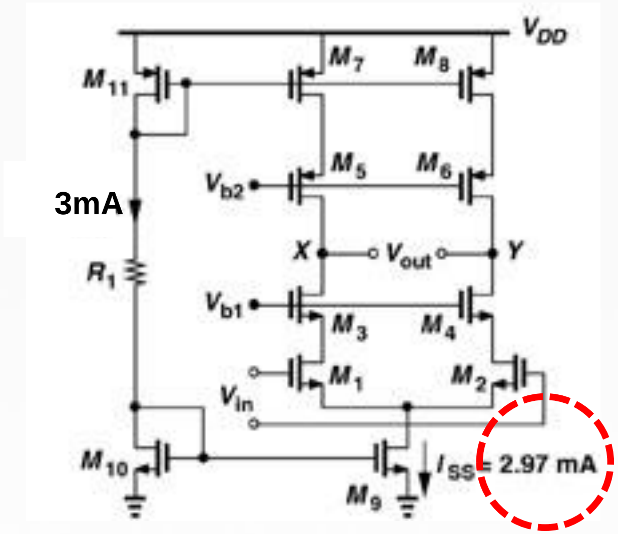
1) $I_{D5,6} > I_{SS}/2 \rightarrow$ both M_5 and $M_6 \rightarrow$ triode region

2) $I_{D3.4} < I_{SS}/2 \rightarrow$ both V_X and $V_Y \downarrow$, $M_5 \rightarrow$ triode region

CM level poorly defined!!

Example

Suppose M_9 suffers from a **1% current mismatch** with respect to M_{10}, producing I_{SS}=2.97mA rather than 3mA.



Current mismatch

Output impedance $\left(g_{m6}r_{o6}r_{o8}\right) \| \left(g_{m4}r_{o4}r_{o2}\right) = 266k\Omega$

Current mismatch $I_6 - I_4 = 15uA$

Output voltage error $V_{err} = 266k\Omega \cdot 15uA = 3.99V$

Too large to produce!

1. V_X and V_Y must rise
2. M_5-M_6 and M_7-M_8 enter the triode region
3. $I_{D7,8}$ = 1.485mA.

CM level poorly defined!!

Concept of CMFB

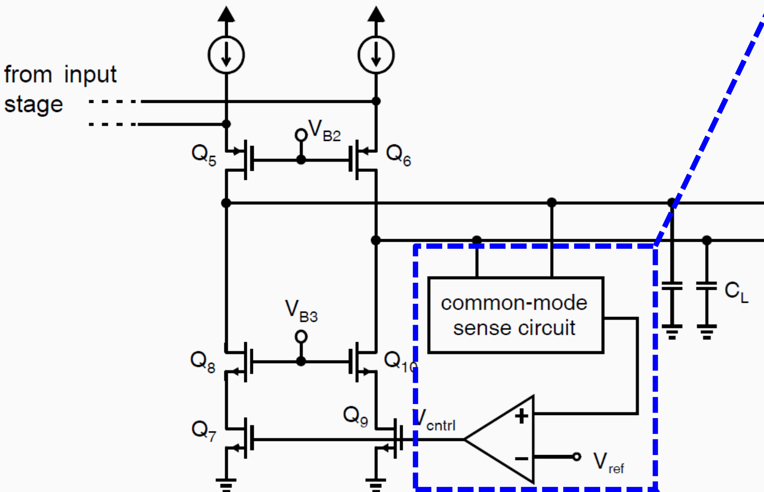


Fig. 6.37 The common-mode feedback loop in a fully differential folded-cascode opamp

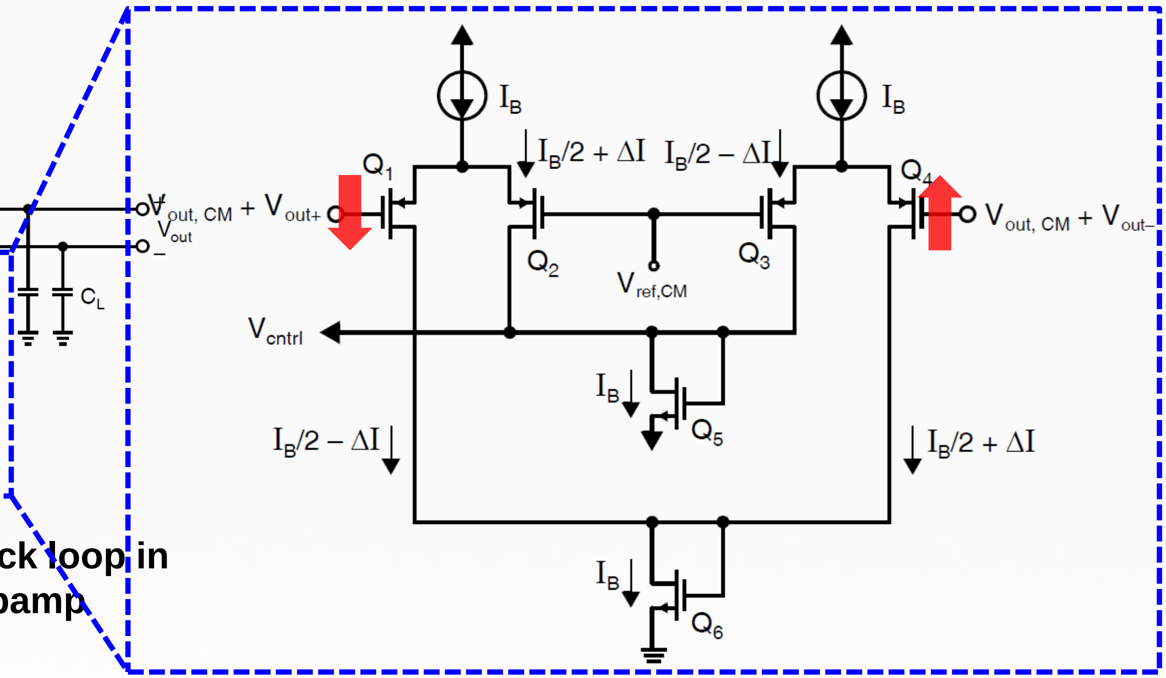


Fig. 6.34 An example of a continuous-time CMFB circuit

Three operations of CMFB

1. Sensing the output CM level
2. Comparison with a reference
3. Returning the error to the amplifier’s bias network

Concept of CMFB

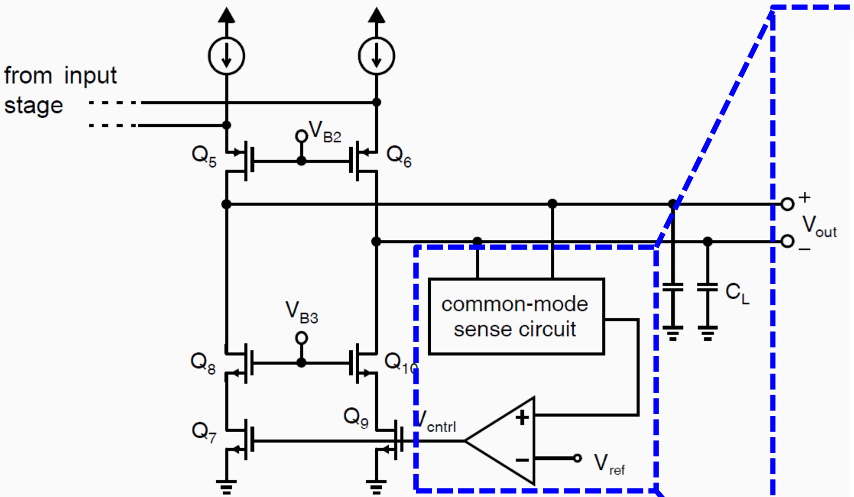
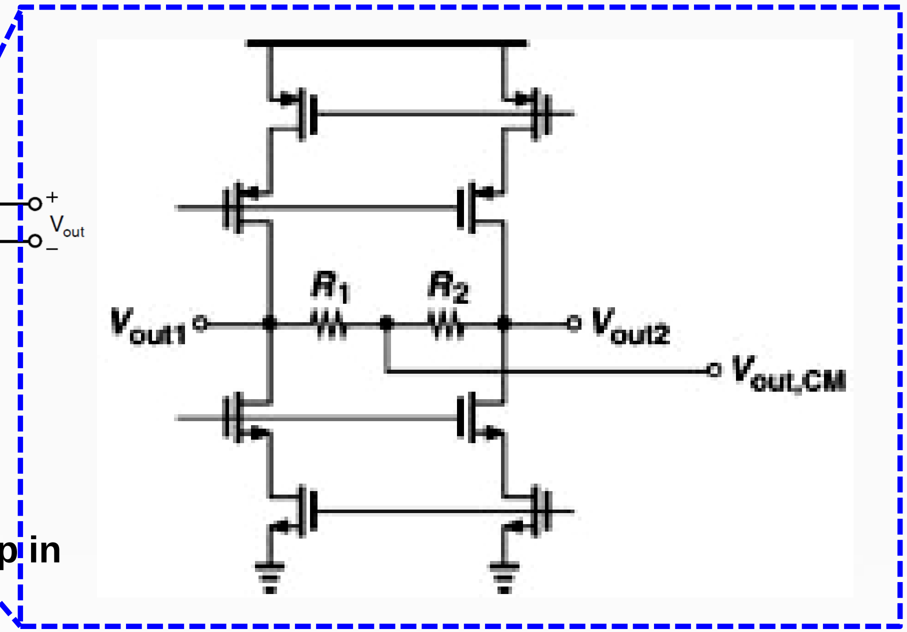


Fig. 6.37 The common-mode feedback loop in a fully differential folded-cascode opamp



Resistive sensing CMFB

Set CM level easily

(if R_1=R_2)

Large area and suffer from parasitic capacitance.

R_1 , R_2 >> R_{out}

(To avoid lowering the open loop gain.)