VE311
Electronic Circuits
RC Final

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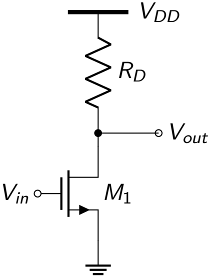
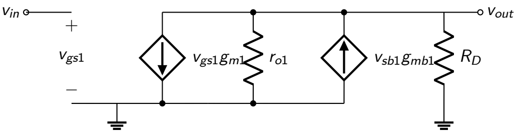
CS with Resistive Load





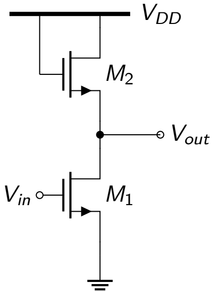
If no channel-length and body effect:

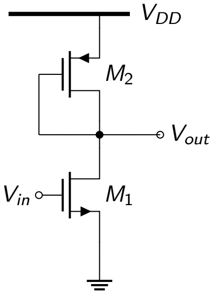
$$A_v = \frac{v_{out}}{v_{in}} = -g_{m1}R_D \tag{1}$$

No body effect:

$$A_v = -g_{m1}(R_D \parallel r_{o1}) \tag{2}$$

CS with Diode-connected Load





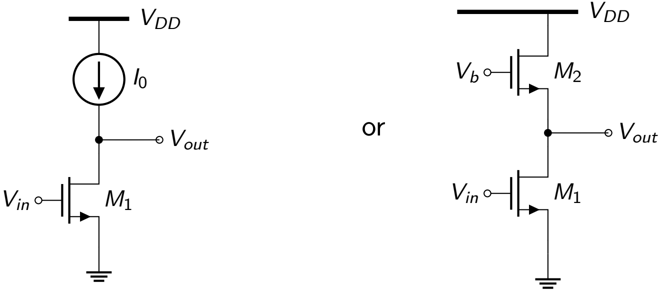
NMOS:

$$A_{\rm v} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}\frac{1}{1+\eta} \qquad \eta = g_{\rm mb2}/g_{\rm m2} \tag{3}$$

PMOS:

$$A_{\rm v} = -\sqrt{\frac{\mu_{\rm n}(W/L)_1}{\mu_{\rm p}(W/L)_2}} \tag{4}$$

CS with Current Source Load



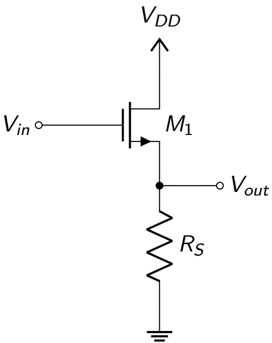
$$A_v = -g_{m1}(r_{o2} \parallel r_{o1}) \tag{5}$$

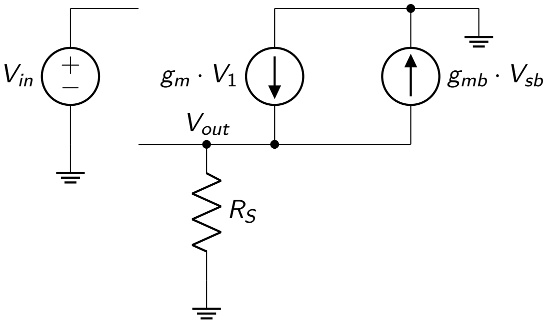
1. MOSFET Single Stage Amplifier
   - Common Source Amplifier
   - Common Drain Amplifier (Source Follower)
   - Common Gate Amplifier
   - Cascode Amplifier

2. MOSFET Differential Pair Amplifier

3. Current Mirror
   - Current Mirror

Source Follower



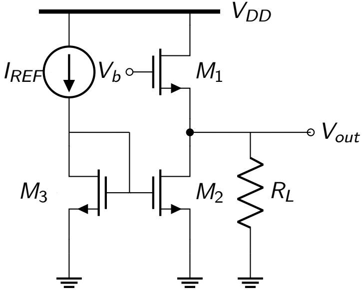


$$A_v = \frac{g_m R_S}{1 + g_m R_S(1+\eta)} = \frac{g_m R_S}{1 + (g_m + g_{mb}) R_S} \approx \frac{1}{1+\eta} \qquad (6)$$

Example 3

In the source follower with current source load, the current source is ideal. Find the output impedance for the amplifier when $I_0 = 0.01$ and $0.1mA$ respectively. (Neglect body effect)
Parameter for NMOS: $V_{THN} = 0.7V$,
$K_n = 110\mu A/V^2, \lambda = 0.04V^{-1}$
Parameter for PMOS: $V_{THP} = -0.7V$,
$K_p = 50\mu A/V^2, \lambda = 0.05V^{-1}$
All the size of transistor is $W = 20\mu m, L = 1\mu m$

Example 1



Example 1

1. MOSFET Single Stage Amplifier
   - Common Source Amplifier
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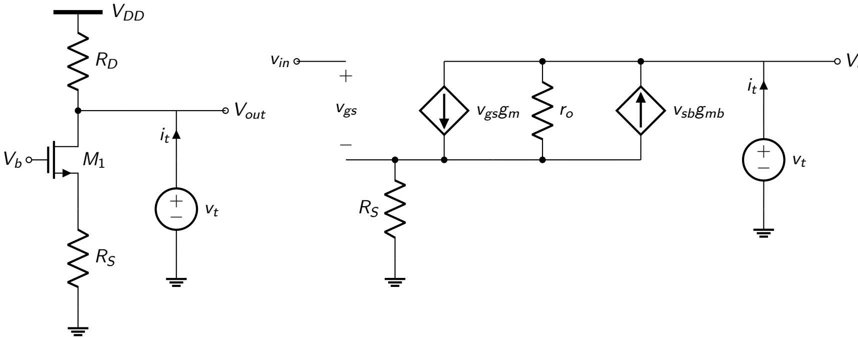
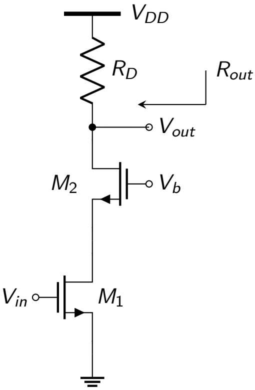
Common Gate



$$R_{in} = \frac{R_D + r_o}{1 + (g_m + g_{mb})r_o} \begin{cases} \text{If } R_D = 0 & R_{in} = r_o \parallel \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \\ \text{If } R_D = \infty & R_{in} = \infty \end{cases} \tag{7}$$

$$R_{out} = [R_S + r_{o1} + (g_{m1} + g_{mb1})r_{o1}R_S] \parallel R_D \tag{8}$$

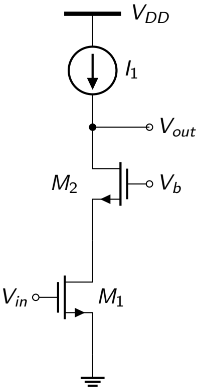
Cascode



$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + \left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}} \right)} \quad (9)$$

$$R_{out} = [r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1}] \parallel R_D \quad (10)$$

Cascode

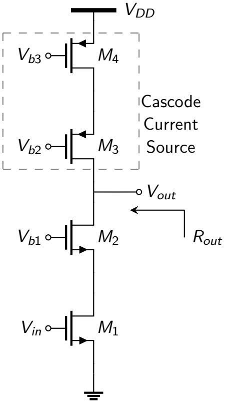


$$G_m = -g_{m1}\frac{r_{o1}}{r_{o1} + \left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}}\right)} \tag{11}$$

$$R_{out} = r_{o1} + r_{o2} + (g_{m2} + g_{mb2})r_{o2}r_{o1} \tag{12}$$

$$A_v = G_m R_{out} \tag{13}$$

Cascode



$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + (r_{o2} \parallel \frac{1}{g_{m2} g_{mb2}})} \tag{14}$$

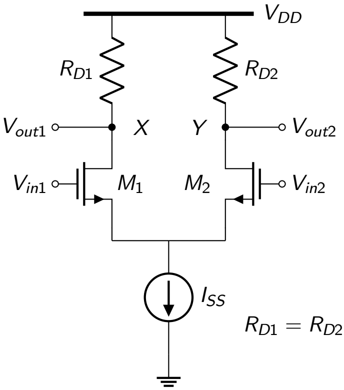
$$R_{out} = [r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1}] \parallel [r_{o3} + r_{o4} + (g_{m3} + g_{mb3}) r_{o3} r_{o4}] \tag{15}$$

$$A_v = G_m R_{out} \tag{16}$$

Example 5

In the cascode amplifier , what is the gain when $I_{REF} = 0.01mA$ and $0.1mA$ respectively? (Neglect body effect)
Parameter for NMOS: $V_{THN} = 0.7V$,
$K_n = 110\mu A/V^2, \lambda = 0.04V^{-1}$
Parameter for PMOS: $V_{THP} = -0.7V$,
$K_p = 50\mu A/V^2, \lambda = 0.05V^{-1}$
All the size of transistor is $W = 20\mu m, L = 1\mu m$

Differential Pair



$R_{D1} = R_{D2} = R_D$

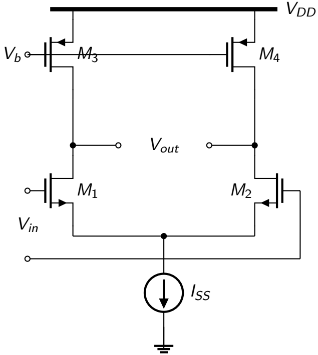
$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} = -g_m(R_D \parallel r_o) \tag{17}$$

If the circuit is fully symmetric,

$$A_{CM-DM} = \frac{V_{out1} - V_{out2}}{v_{in,CM}} = 0 \tag{18}$$

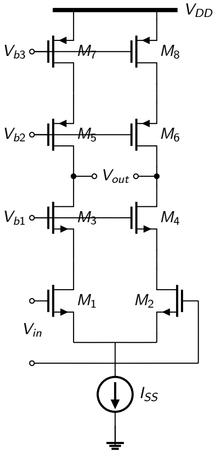
$$CMRR = \left| \frac{A_{DM}}{A_{CM-DM}} \right| = \infty \tag{19}$$

Differential Pair with MOS Loads



$$A_{DM} = -g_{m1,2}(r_{o1,2} \parallel r_{o3,4}) \tag{20}$$

Differential Pair with Cascode Loads

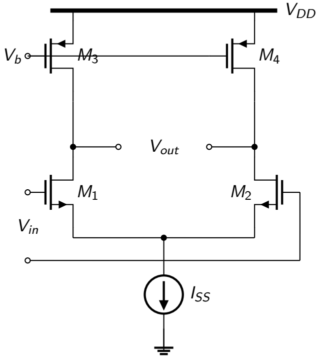


$$A_{DM} \cong -g_{m1,2}[(g_{m3,4} + gmb_{3,4})r_{o3,4}r_{o1,2} \parallel (g_{m5,6} + g_{mb5,6})r_{o5,6}r_{o7,8}] \tag{21}$$

Example 2

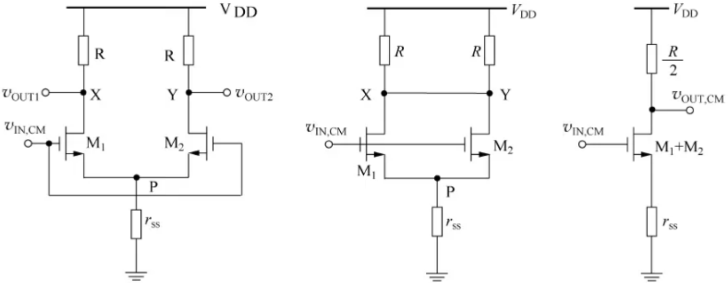
In the differential pair , what is the gain when $I_{SS} = 0.02mA$ and $0.2mA$ respectively? (Neglect body effect)
Parameter for NMOS: $V_{THN} = 0.7V$,
$K_n = 110\mu A/V^2, \lambda = 0.04V^{-1}$
Parameter for PMOS: $V_{THP} = -0.7V$,
$K_p = 50\mu A/V^2, \lambda = 0.05V^{-1}$
All the size of transistor is $W = 20\mu m, L = 1\mu m$

Example 2



Example 2

Common Mode Response



$$v_{\text{in},\mathrm{cm}} = v_{\mathrm{gs}} + 2g_{\mathrm{m}} v_{\mathrm{gs}} \cdot r_{\mathrm{ss}}$$

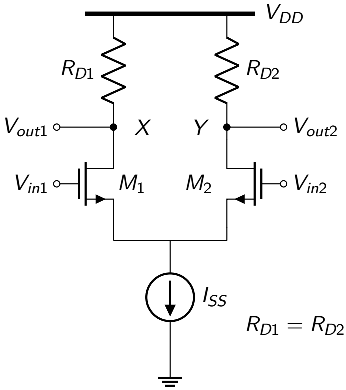
$$2g_{\mathrm{m}} v_{\mathrm{gs}} + \frac{v_{\text{out},\mathrm{cm}}}{R/2} = 0$$

$$\mathrm{CMRR} = \frac{|A_{\mathrm{vd}}|}{|A_{\mathrm{vc}}|} = 1 + 2g_{\mathrm{m}} r_{\mathrm{ss}}$$

Example 3

In the differential pair , what is the common gain and differential gain and CMRR when $I_{SS} = 0.2mA$? (Neglect body effect, $R = 10k\Omega$, $V_{DD} = 5V$)
Parameter for NMOS: $V_{THN} = 0.7V$,
$K_n = 110\mu A/V^2, \lambda = 0.04V^{-1}$
Parameter for PMOS: $V_{THP} = -0.7V$,
$K_p = 50\mu A/V^2, \lambda = 0.05V^{-1}$
All the size of transistor is $W = 20\mu m, L = 1\mu m$

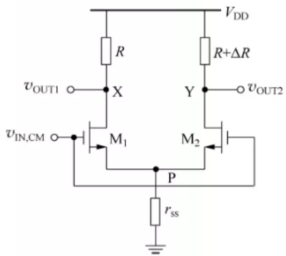
Example 3

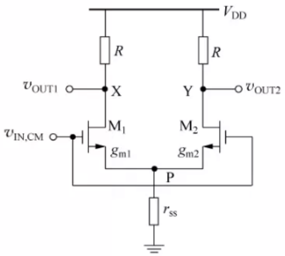


$R_{D1} = R_{D2} = R_D$

Example 3

Mismatch





$$A_{\mathrm{cm-dm}} = -\left(\frac{g_{\mathrm{m}}\Delta R + \Delta g_{\mathrm{m}} R}{2g_{\mathrm{m}} r_{\mathrm{ss}} + 1}\right)$$

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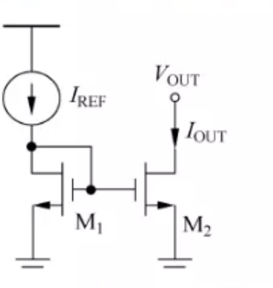
   - Current Mirror

Current Mirror

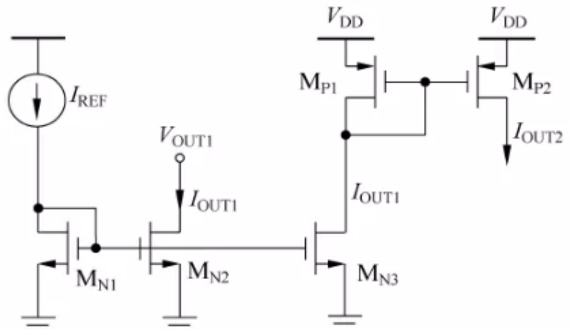


$$I_{\mathrm{REF}} = \frac{1}{2}\mu_{\mathrm{n}} C_{\mathrm{ox}} \left(\frac{W}{L}\right)_1 (V_{\mathrm{GS}} - V_{\mathrm{THN1}})^2$$

$$I_{\mathrm{OUT}} = \frac{1}{2}\mu_{\mathrm{n}} C_{\mathrm{ox}} \left(\frac{W}{L}\right)_2 (V_{\mathrm{GS}} - V_{\mathrm{THN2}})^2$$

$$I_{\mathrm{OUT}} = \frac{(W/L)_2}{(W/L)_1} I_{\mathrm{REF}}$$

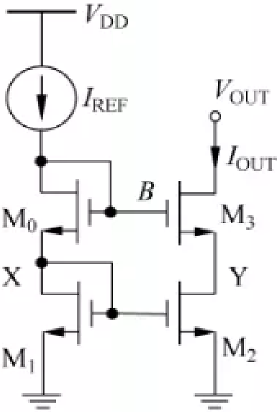
Current Mirror



$$I_{\text{OUT1}} = \frac{(W/L)_{\text{N2}}}{(W/L)_{\text{N1}}} I_{\text{REF}}$$

$$I_{\text{OUT2}} = \frac{(W/L)_{\text{N3}}}{(W/L)_{\text{N1}}} \frac{(W/L)_{\text{P2}}}{(W/L)_{\text{P1}}} I_{\text{REF}}$$

Cascode Current Mirror

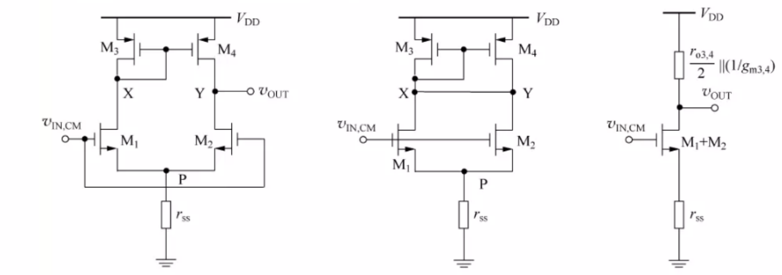


Example 4

In the cascode current mirror , what is the range of output voltage when $I_{REF} = 0.1mA$? (Neglect body effect, channel-length effect)
Parameter for NMOS: $V_{THN} = 0.7V$,
$K_n = 110\mu A/V^2, \lambda = 0.04V^{-1}$
Parameter for PMOS: $V_{THP} = -0.7V$,
$K_p = 50\mu A/V^2, \lambda = 0.05V^{-1}$
All the size of transistor is $W = 20\mu m, L = 1\mu m$

Example 4

Differential Pair with Current Mirror Load



Differential Pair with Current Mirror Load

$$A_{\mathrm{vd}} = \frac{v_{\mathsf{out}}}{v_{\mathrm{d}}} = g_{\mathrm{m}} r_{\mathsf{out}} = g_{\mathrm{m}} \left(r_{\mathrm{o}2} \| r_{\mathsf{of}} \right)$$

$$A_{\mathrm{vc}} \approx -\frac{\frac{1}{2g_{\mathrm{m}3,4}} \| \frac{r_{\mathrm{o}3,4}}{2}}{\frac{1}{2g_{\mathrm{m}1,2}} + r_{\mathrm{ss}}} \approx -\frac{1}{1 + 2g_{\mathrm{m}1,2} r_{\mathrm{ss}}} \frac{g_{\mathrm{m}1,2}}{g_{\mathrm{m}3,4}}$$

$$\mathrm{CMRR} = \frac{|A_{\mathrm{vd}}|}{|A_{\mathrm{vc}}|} = \left(1 + 2g_{\mathrm{m}1,2} r_{\mathrm{ss}}\right) g_{\mathrm{m}3,4} \left(r_{\mathrm{o}2} \| r_{\mathrm{o}4} \right)$$

END

Thanks