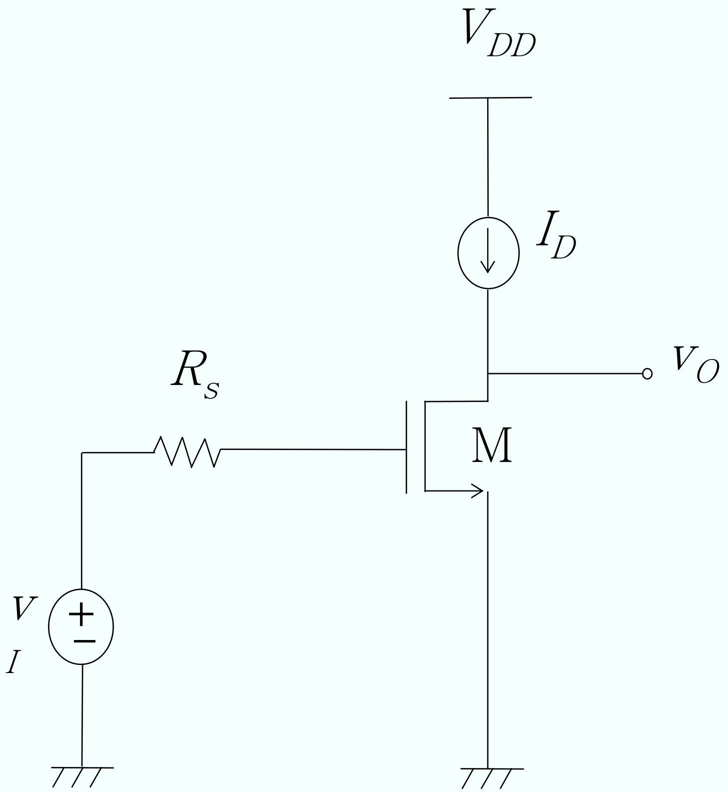
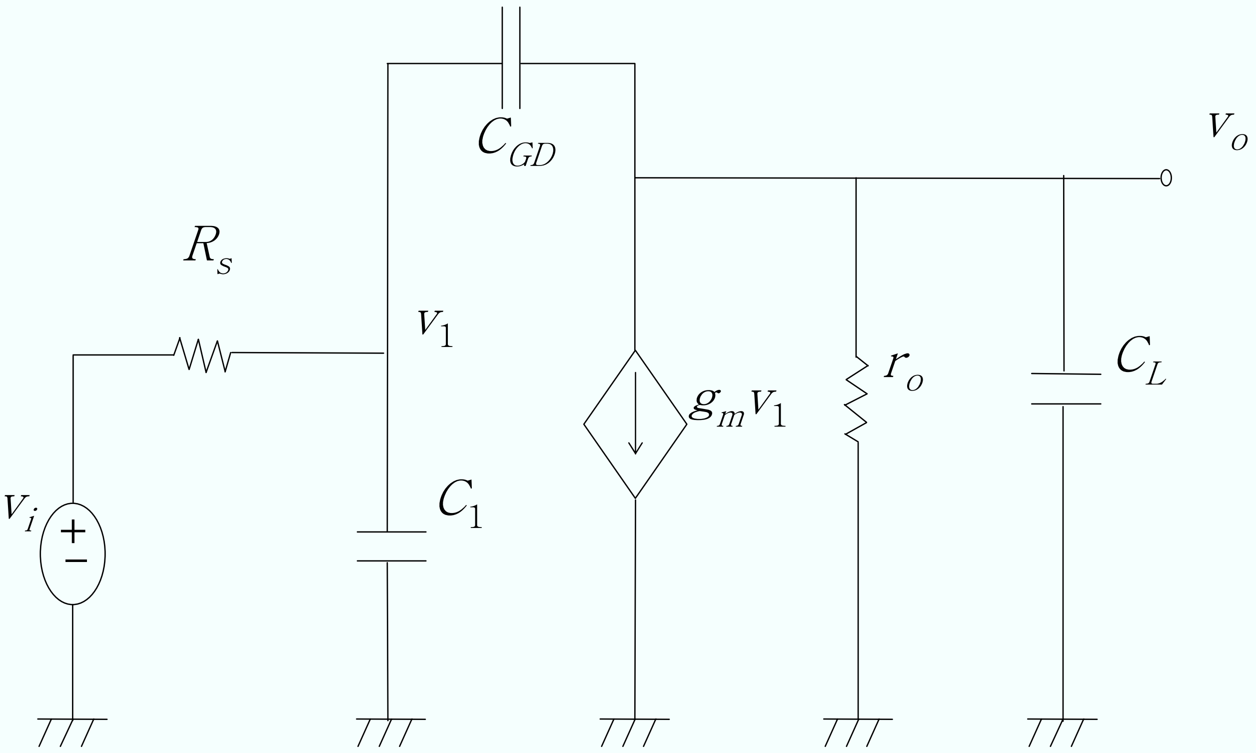
frequency response of CS amp



(a)



(b)

$$\omega_{p1} = \frac{1}{(g_m r_o)\cdot(R_s C_{GD}) + R_s(C_1 + C_{GD}) + r_o(C_L + C_{GD})}$$

$$\omega_{p1} \approx \frac{1}{R_s\ C_{GD}\ g_m r_o}$$

How to improve the frequency response of CS amp

$$\omega_{-3dB} = \frac{1}{R_s \cdot \left[C_{GD} \cdot \left\{1 + g_m \cdot (r_o \| R_L)\right\} + C_{GS} + C_{GB}\right]}$$

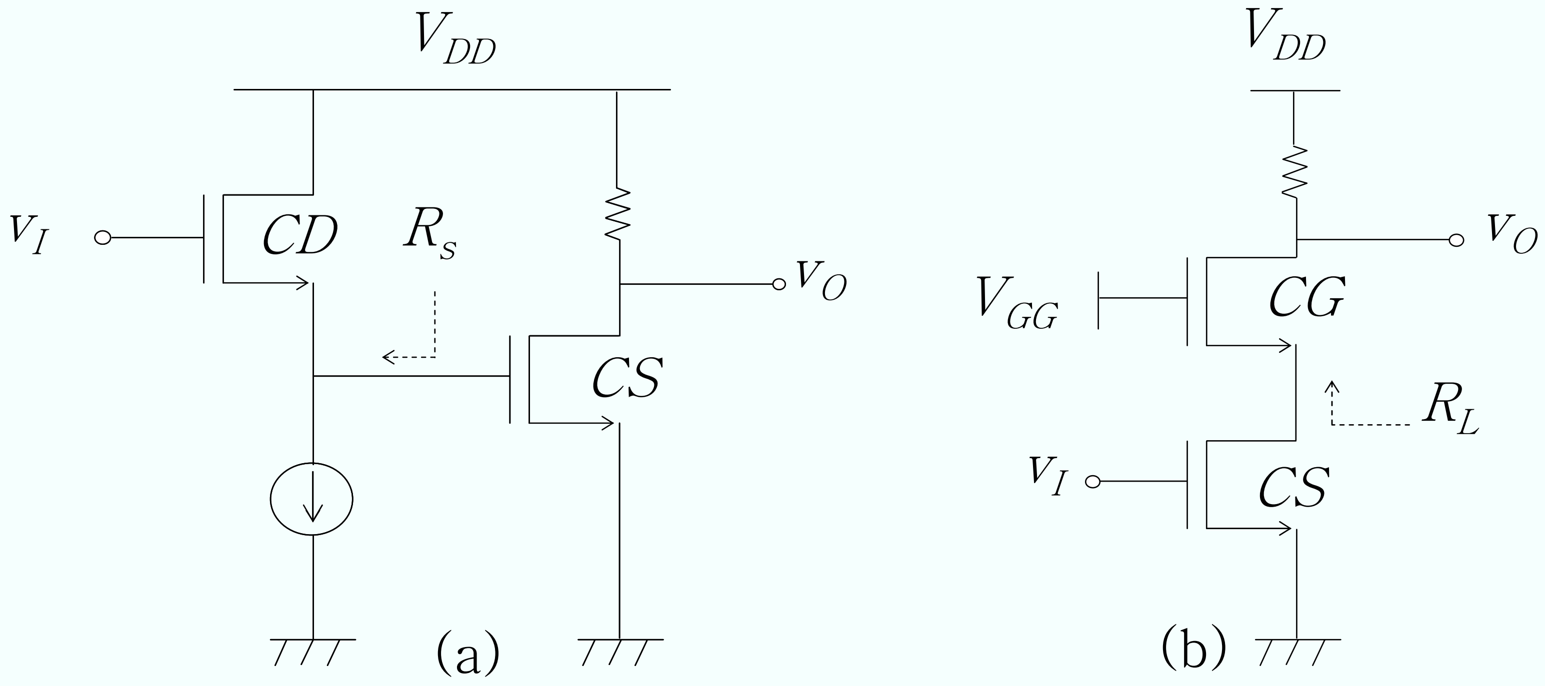


Fig 4.5.2 Circuits to improve the frequency response of CS amp

(a) CD-CS series connection (cascade) => reduce Rs

(b) CS-CG series connection (cascode) => reduce voltage gain by decreasing RL

Gm Ro analysis method

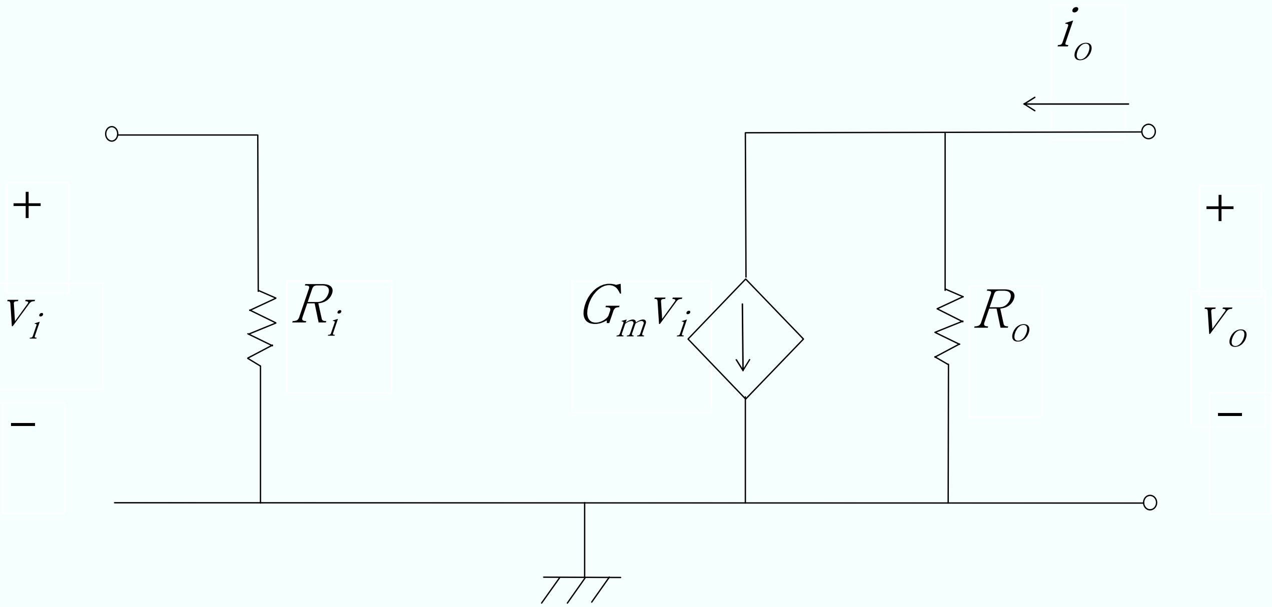


Fig 4.6.1 Low frequency small-signal equivalent circuit of general amplifier

$$G_m \triangleq \left.\frac{i_o}{v_i}\right|_{v_o=0}$$

$$R_o \triangleq \left.\frac{v_o}{i_o}\right|_{v_i=0}$$

Gm Ro analysis method

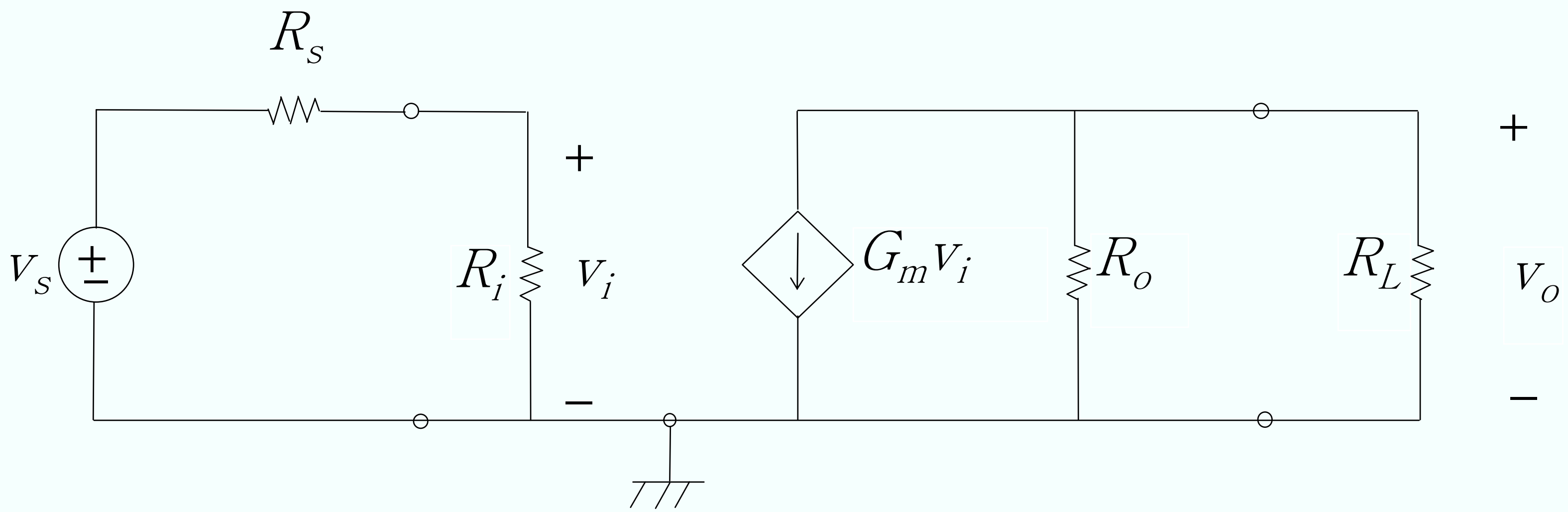
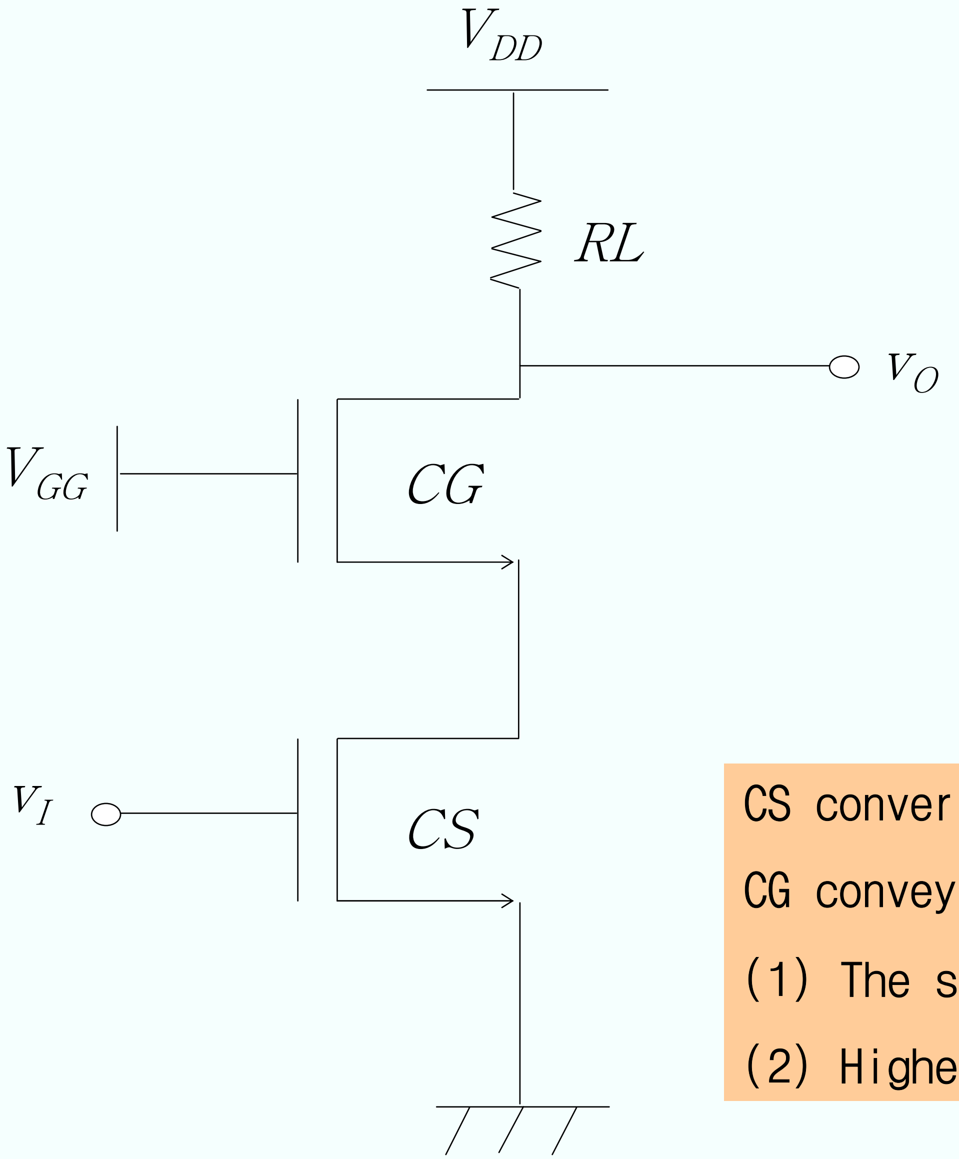


Fig 4.6.2 General amp with a voltage source input and a resistor load

$$A_v = \frac{v_o}{v_s} = -G_m \cdot (R_o \parallel R_L) \cdot \frac{R_i}{R_s + R_i}$$

Cascode amp (small RL)



CS converts voltage to current (V➔I),

CG conveys current to load (I➔I)

(1) The same voltage gain as a single CS amp

(2) Higher bandwidth than a single CS amp

Cascode amp (small RL)

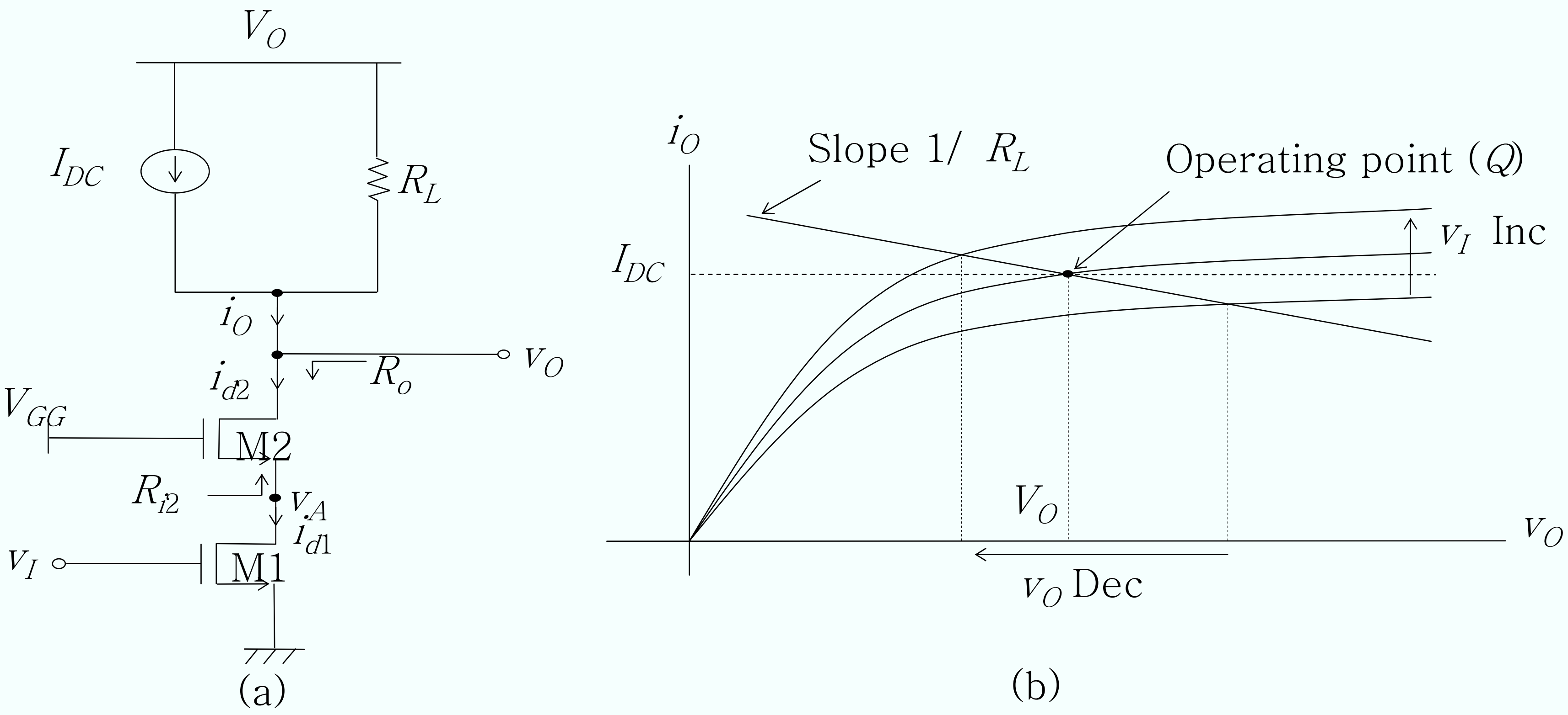
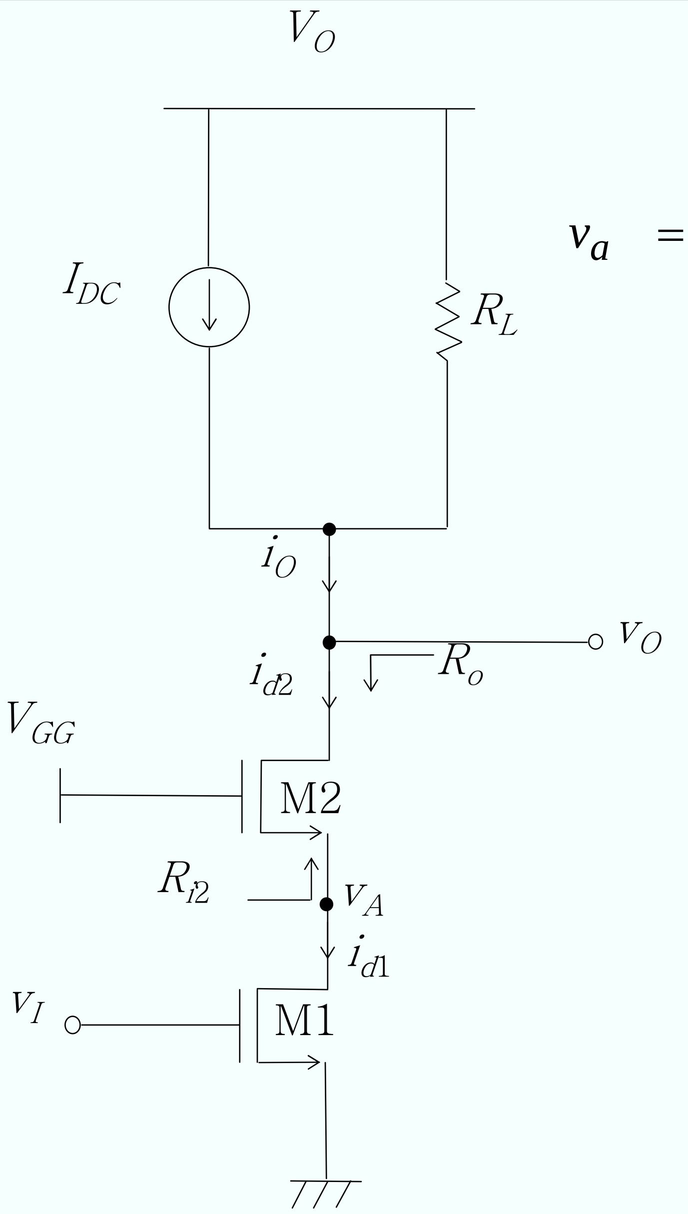


Fig 4.6.3 Cascode amplifier (a) circuit (b) operating point computation

$$v_A = V_{GG} - v_{GS2} \approx V_{GG} - V_{GS2} = V_{GG} - V_{DSAT2} - V_{TH2} = V_{GG} - \sqrt{\frac{2 \cdot I_{DC}}{\mu_n C_{ox} \cdot \left(\frac{W}{L}\right)_2}} - V_{TH2}$$

For max VO headroom, set VGG = 2 VDSAT+VTH, VA=VDSAT(=VI-VTH) => VO > 2 VDSAT, but little headroom for VA (problem) ➔ Set VGG = 2 VDSAT + VTH + Vmargin

Cascode amp (small RL)



$$i_{d1} = g_{m1} v_i$$

$$v_a = -i_{d1}\cdot(r_{o1}\|R_{i2}) = -i_{d1}\cdot(r_{o1}\|r_{s2}) \approx -i_{d1}\, r_{s2} = -\frac{g_{m1}}{g_{m2}}\cdot v_i$$

$$v_a = -\frac{g_{m1}}{g_{m2}}\cdot v_i = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}\cdot v_i$$

if $(W/L)_1 = (W/L)_2$ $\quad v_a/v_i \approx -1$

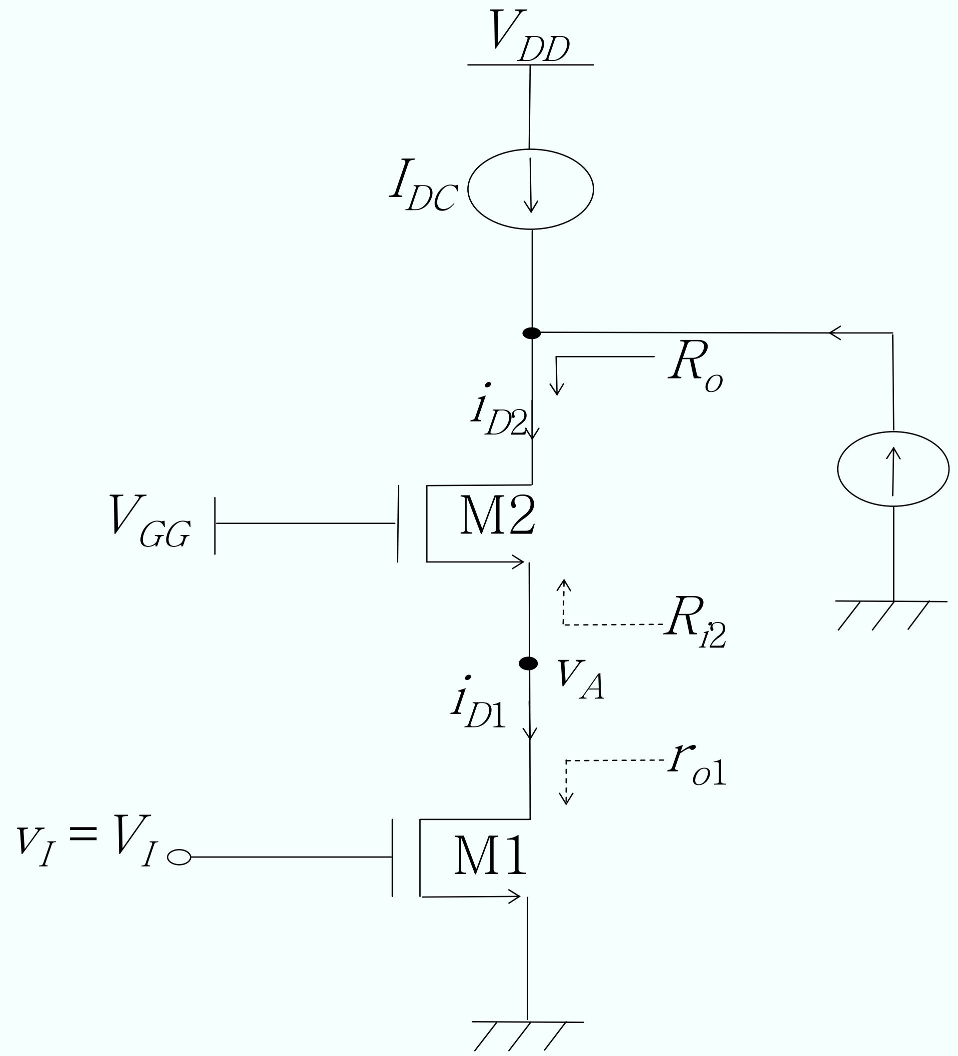
$2C_{GD1}$ Due to Miller effect

Cascode amp (infinite RL)

$$v_a = -i_{d1} \cdot (r_{o1} \parallel R_{i2}) = -i_{d1} \cdot r_{o1} = -g_{m1} r_{o1} \cdot v_i$$

$$\boxed{v_o = -G_m R_o \cdot v_i}$$

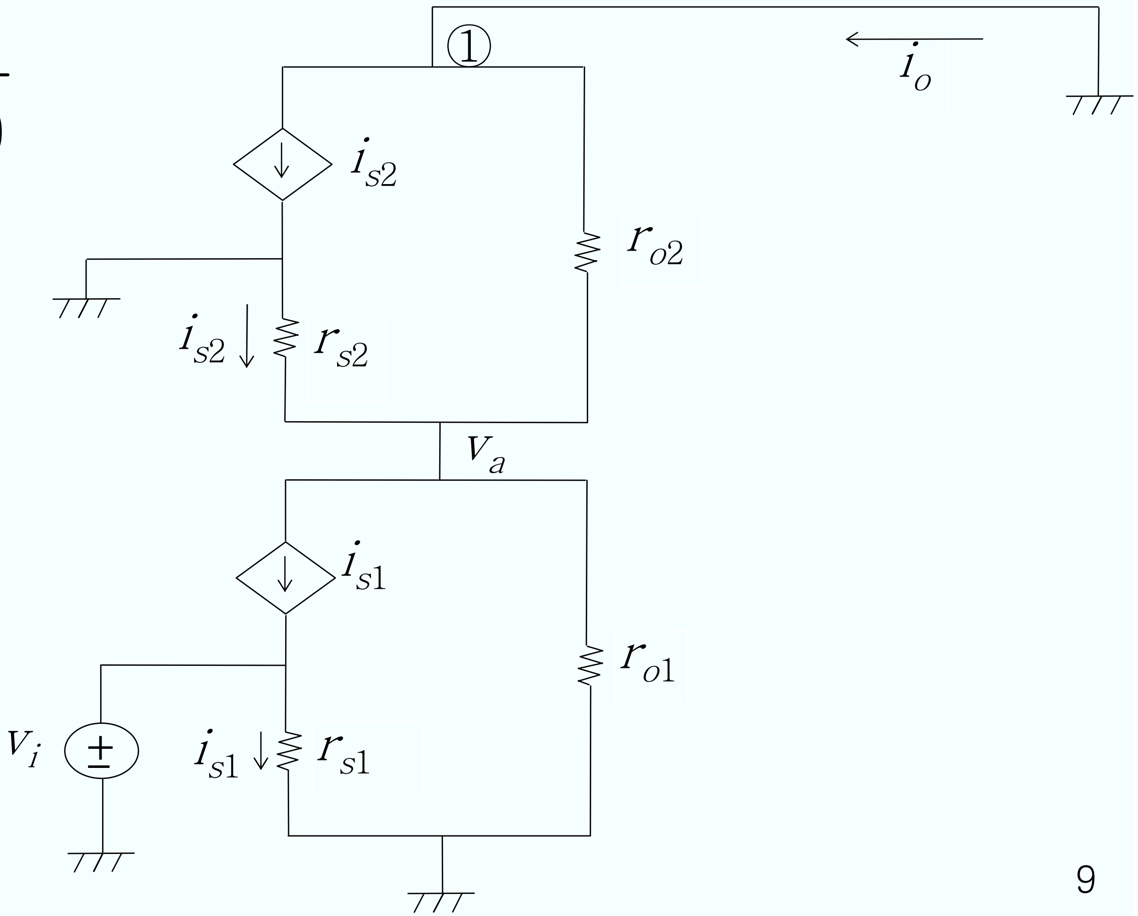
$$\boxed{G_m \approx g_{m1}}$$



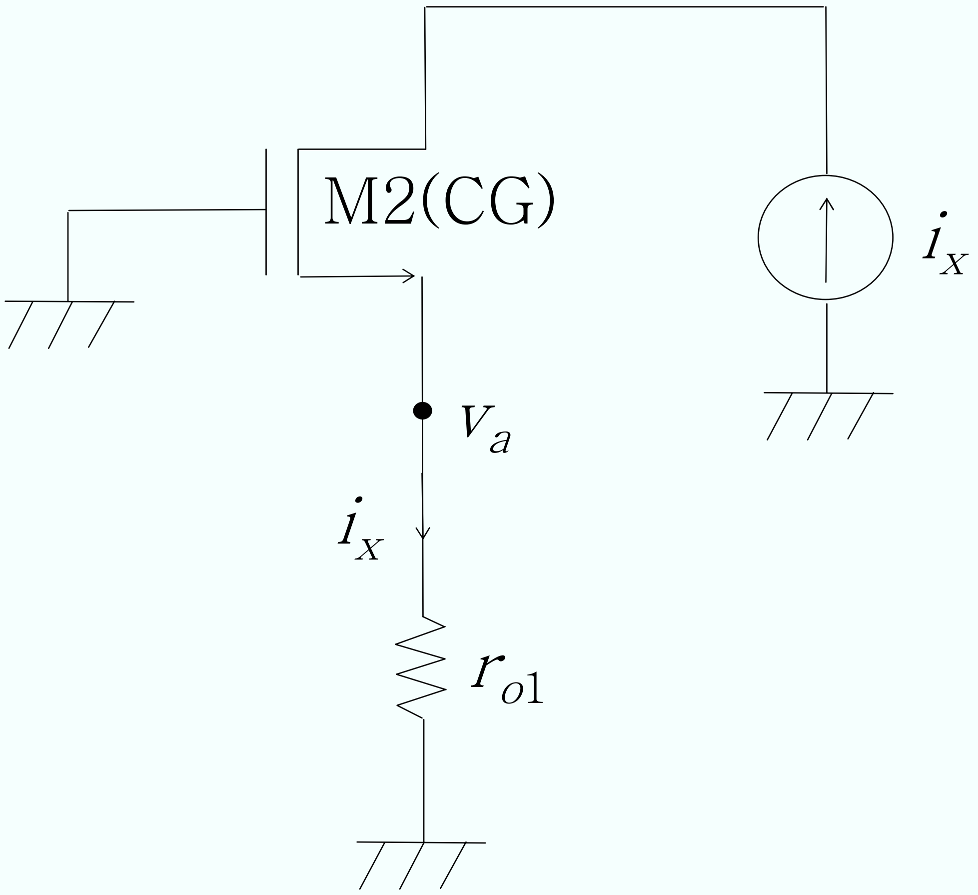
Cascode amp (Small signal analysis: Gm)

$$G_m = \frac{i_o}{v_i} = g_{m1} \cdot \frac{r_{o1}}{r_{o1} + R_{i2}} \approx g_{m1}$$

$$R_{i2} = \frac{1+(R_L / r_{o2})}{g_{m2} + g_{mb2} + (1/ r_{o2})}$$



Cascode amp (calculate RO: qualitative)



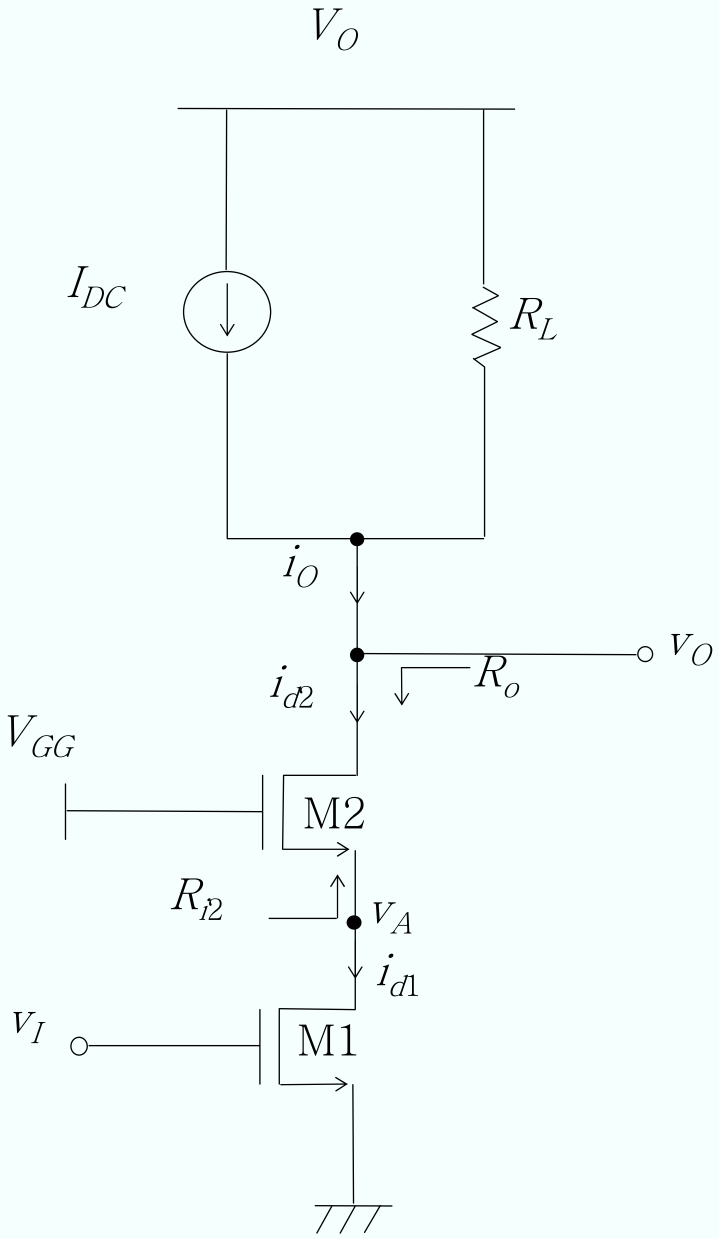
$$v_a = v_{ds1} = i_x \cdot r_{o1}$$

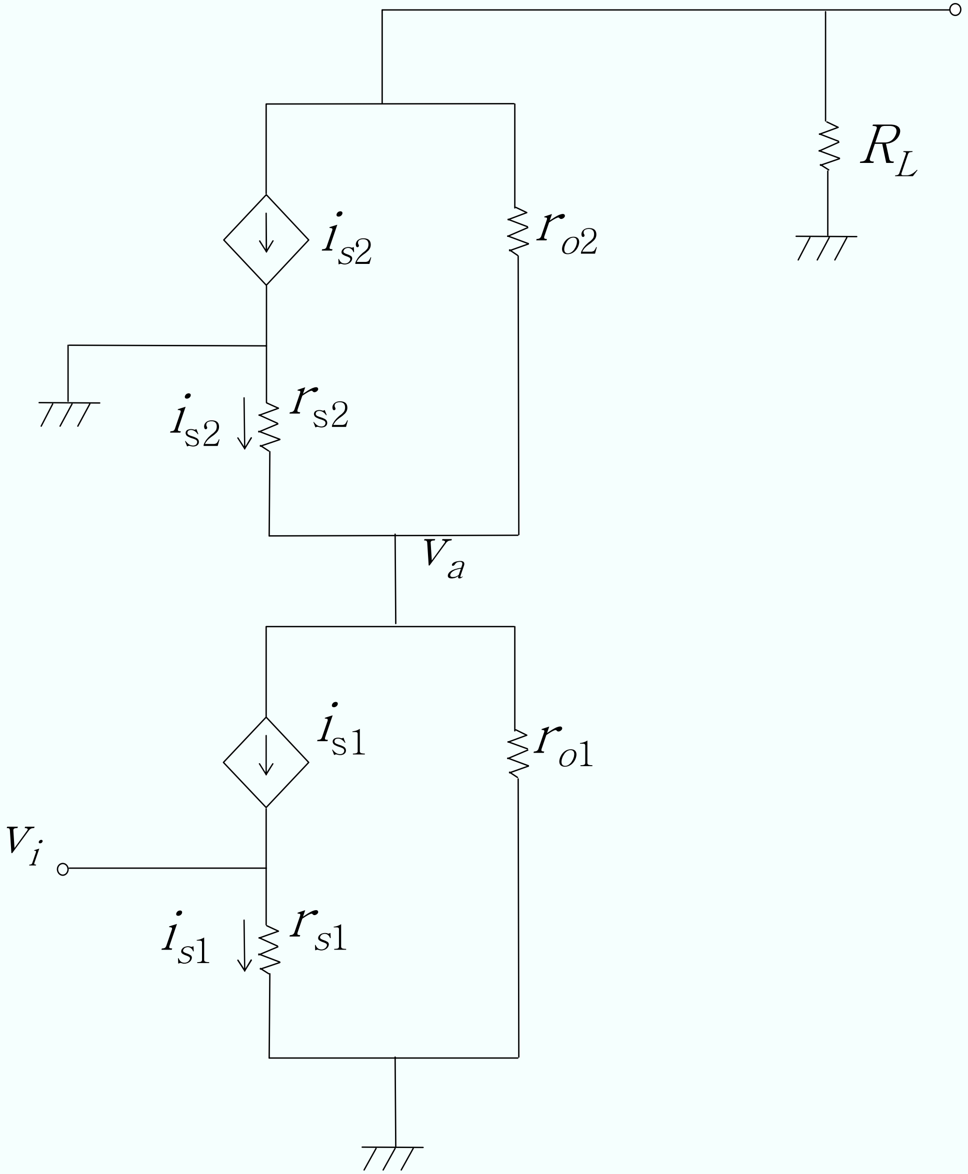
$$v_o \approx (g_{m2} + g_{mb2}) r_{o2} \cdot v_a = (g_{m2} + g_{mb2}) r_{o2} \cdot r_{o1} \cdot i_x$$

$$R_o = \frac{v_o}{i_x}$$

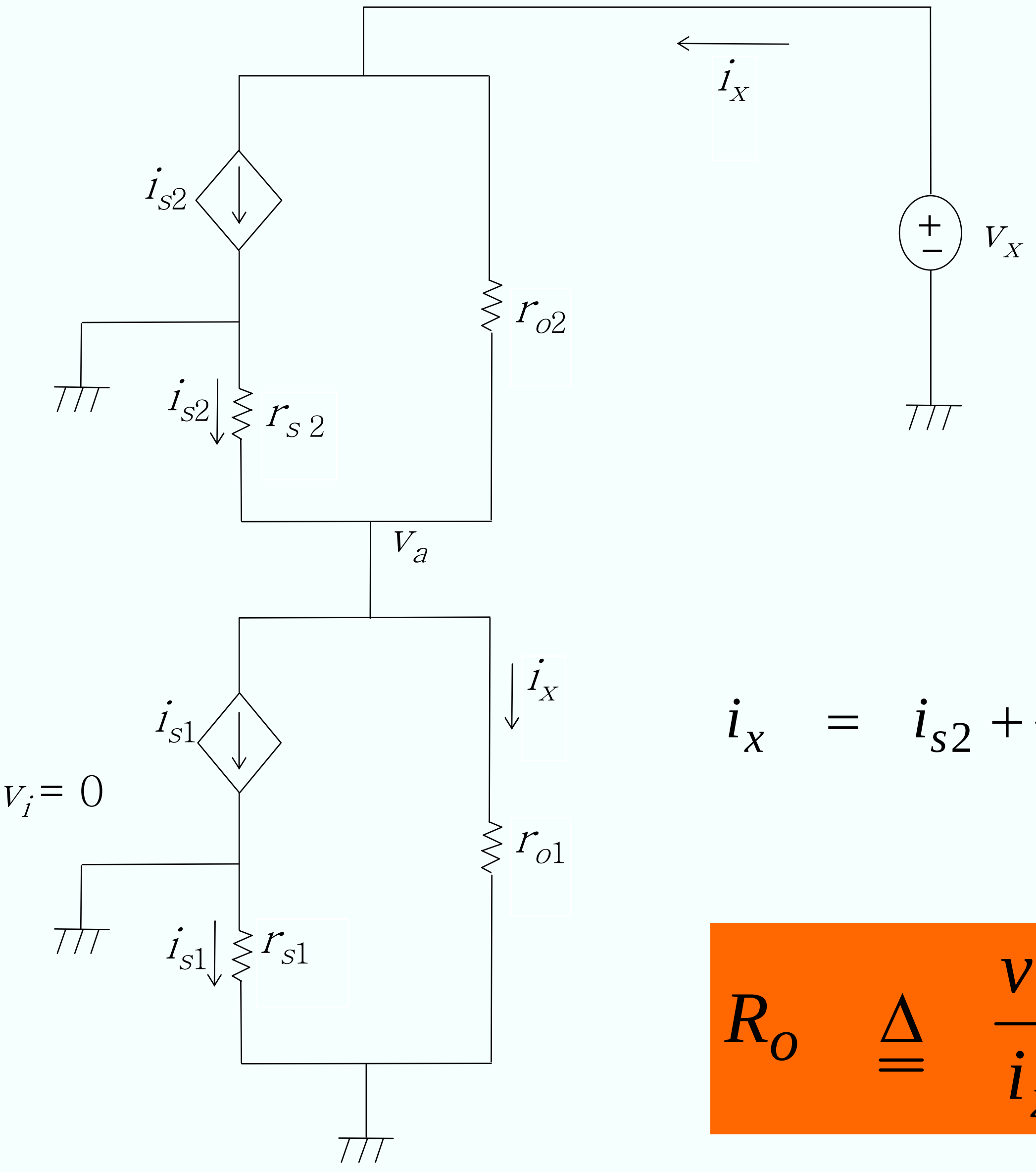
$$R_o \approx g_{m2} r_{o2} \cdot r_{o1}$$

Cascode amp (Small signal analysis)





Cascode amp (Small signal analysis: Ro)



$$i_x = i_{s2} + \frac{v_x - v_a}{r_{o2}} = -g_{m2} r_{o1} \cdot i_x + \frac{v_x - i_x r_{o1}}{r_{o2}}$$

$$R_o \triangleq \frac{v_x}{i_x} = g_{m2} r_{o2} \cdot r_{o1} + r_{o1} + r_{o2}$$

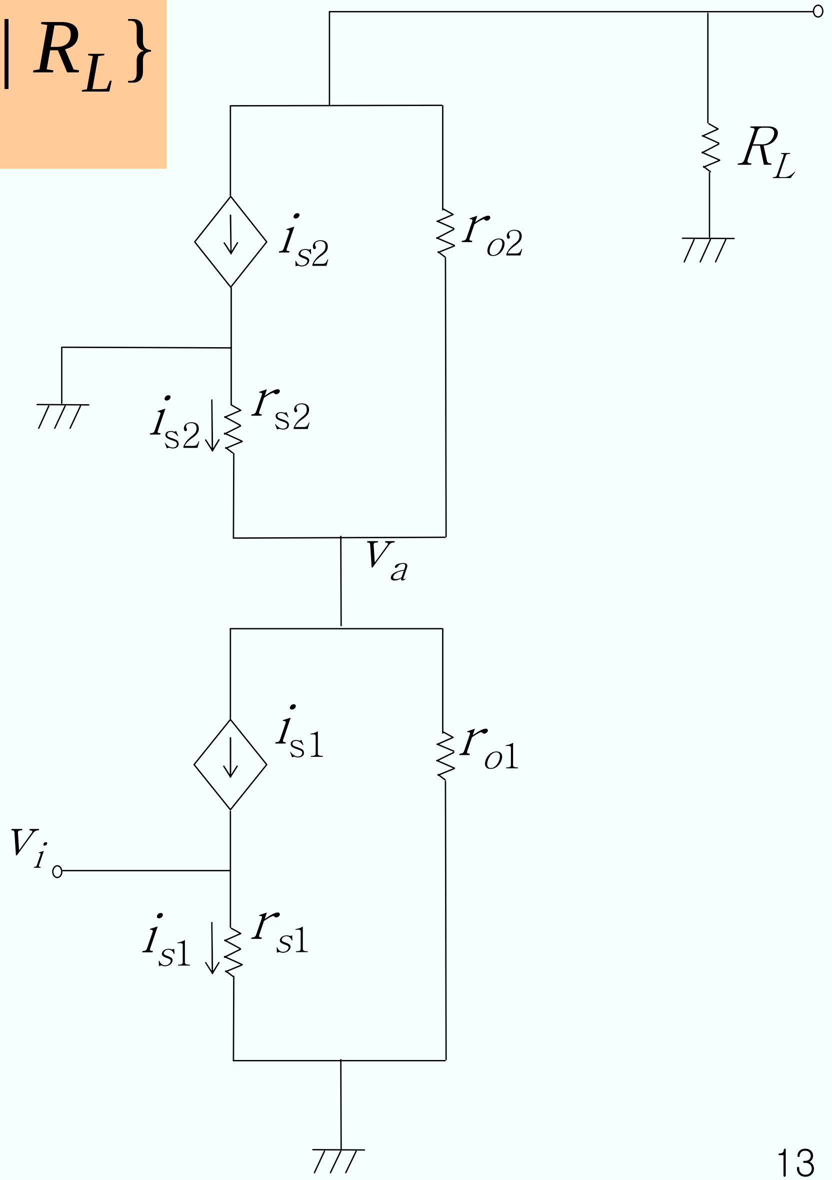
Cascode amp (Small signal analysis)

$$A_v = \frac{v_o}{v_i} \approx -g_{m1}\cdot\{(r_{o1}g_{m2}r_{o2})\,\|\,R_L\}$$

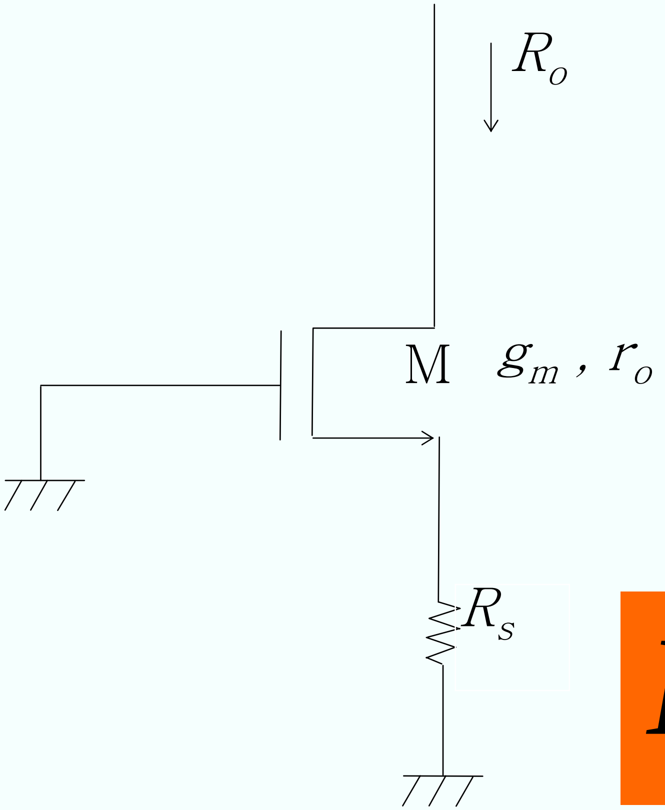
$$v_a = (R_{i2}\,\|\,r_{o1})\cdot g_{m1}v_i \approx \frac{R_{i2}\,\|\,r_{o1}}{(g_{m2}r_{o2}r_{o1})\,\|\,R_L}\cdot v_o$$

$$R_{i2} = \frac{1+(R_L/r_{o2})}{g_{m2}+g_{mb2}+(1/r_{o2})}$$

$$v_a \approx \frac{v_o}{g_{m2}r_{o2}} \qquad if \quad R_L = \infty$$



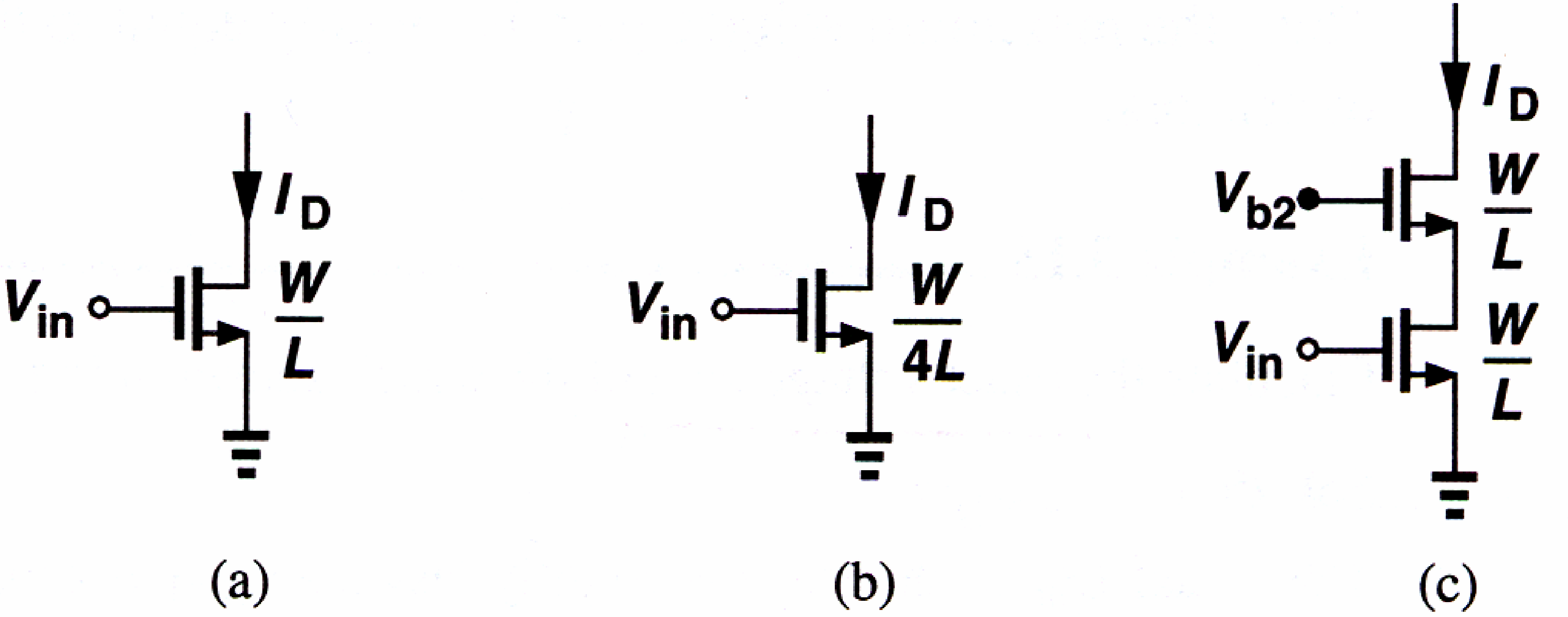
Ro of CS amp with Rs



$$R_o = g_m r_o \cdot R_s + R_s + r_o$$

$$R_o = (g_m + g_{mb})\, r_o \cdot R_s + R_s + r_o$$

Effectiveness of casocde to increase Ro



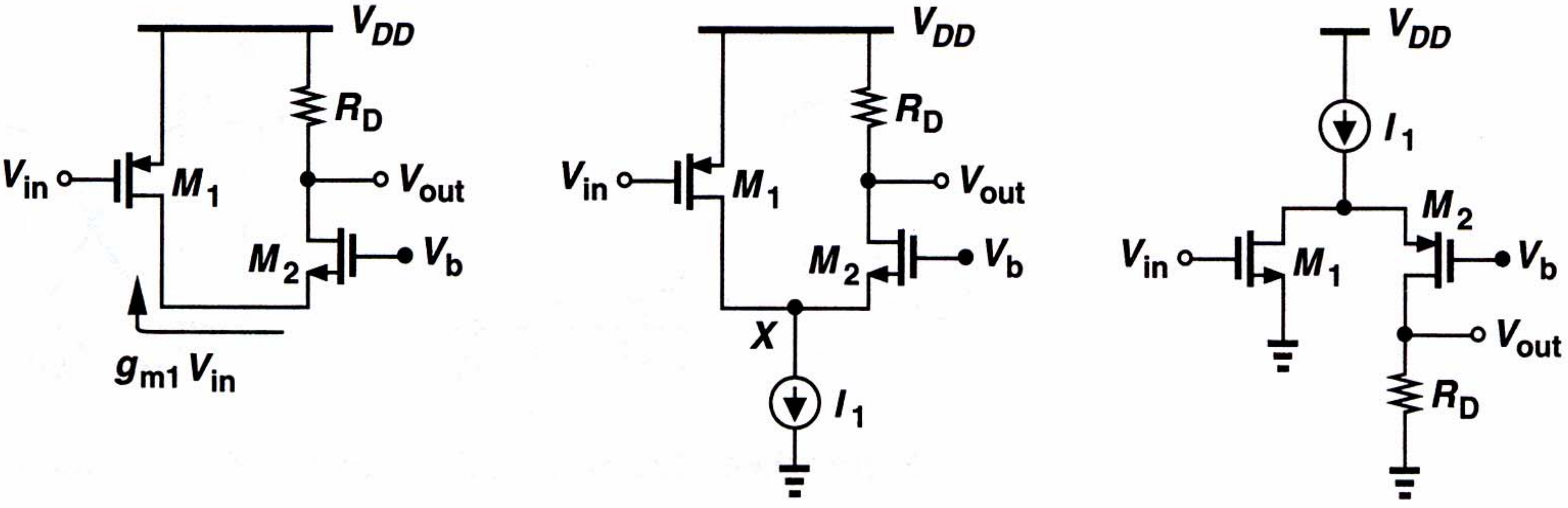
	(a)	(b)	(c)
Linear VOUT	> VDSAT	> 2 VDSAT	> 2 VDSAT
Gm	1	0.5	1
Ro	1	4	gm x ro
Av (Gm x Ro)	1	2	gm x ro

Razavi

Folded cascode:

(1)relaxes voltage headroom problem

(2)Larger current than the regular cascode



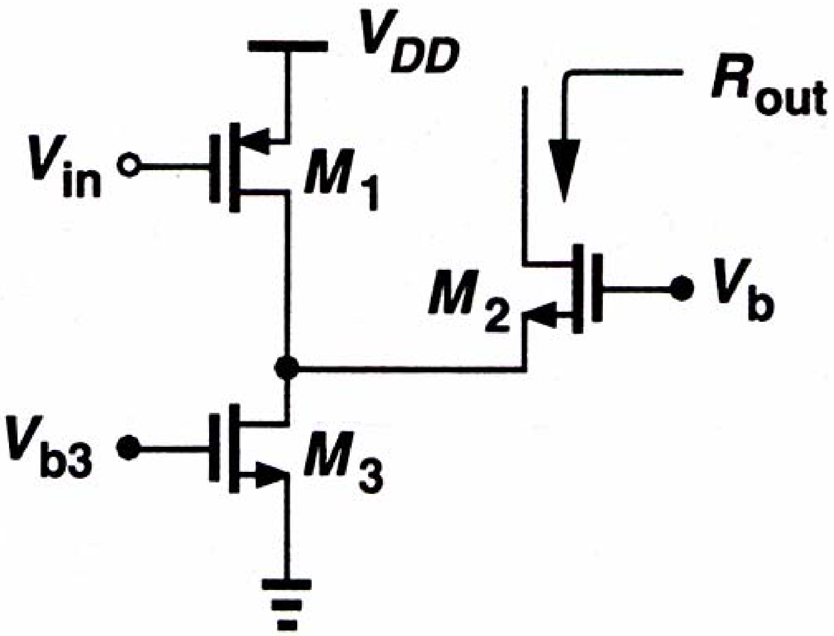
(a) (b) (c)

PMOS + NMOS

NMOS + PMOS

Razavi

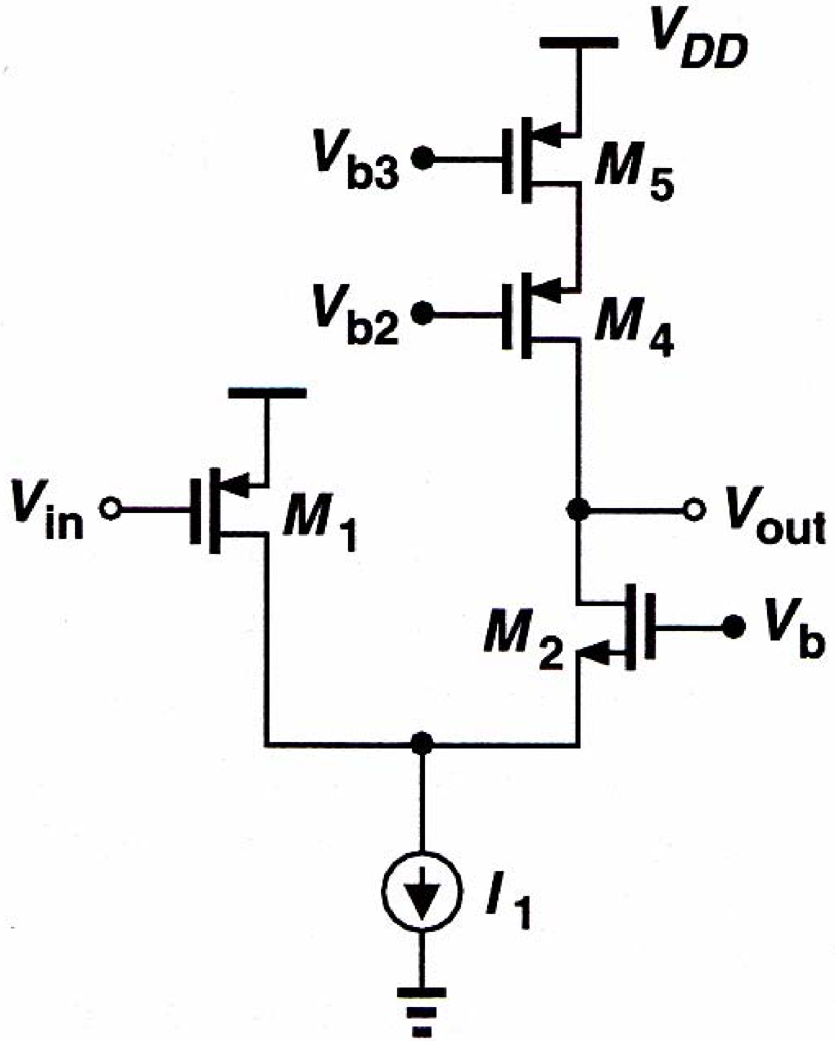
Folded cascode



$$R_{out} = [1 + (g_{m2} + g_{mb2})r_{O2}](r_{O1} \| r_{O3}) + r_{O2}.$$

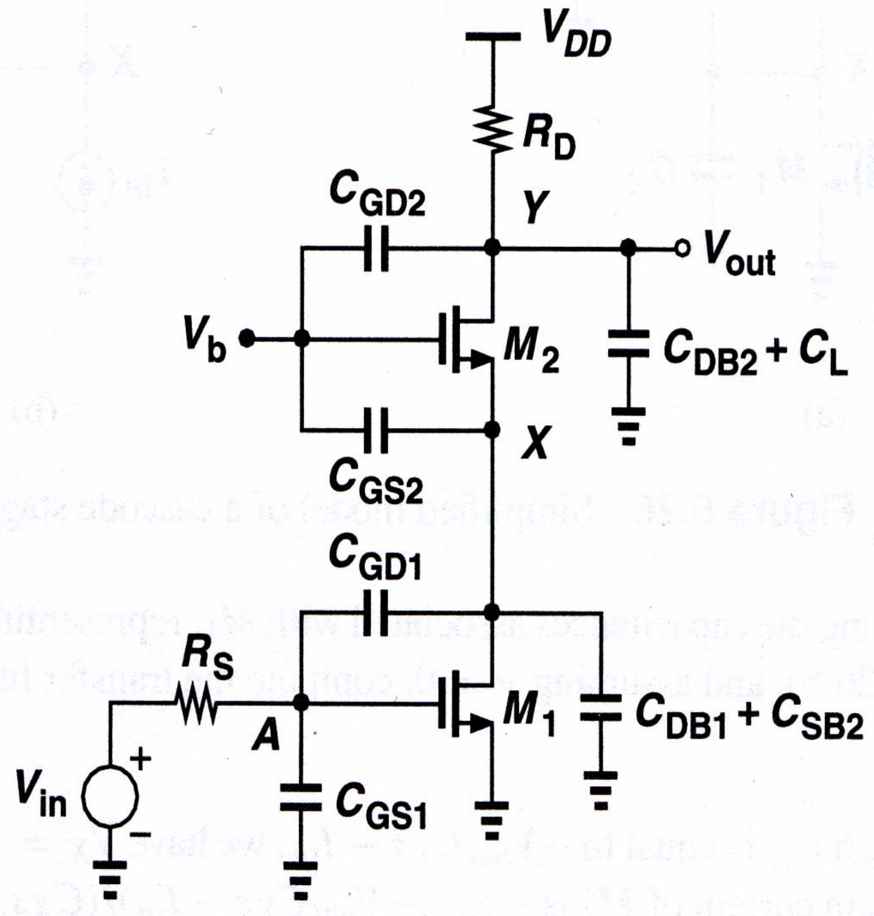
Razavi

Folded cascode for HIGH Av



Razavi

Frequency response: Cascode amp with R load



$$\omega_{p,A} = \frac{1}{R_S\left[C_{GS1} + \left(1 + \frac{g_{m1}}{g_{m2}+g_{mb2}}\right)C_{GD1}\right]}$$

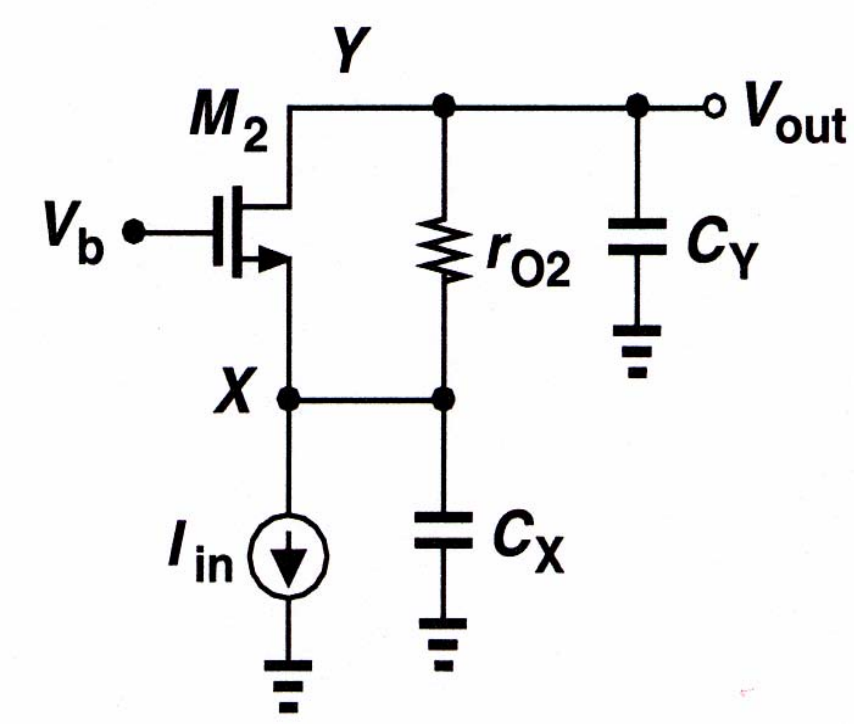
$$\omega_{p,X} = \frac{g_{m2}+g_{mb2}}{2C_{GD1}+C_{DB1}+C_{SB2}+C_{GS2}}$$

Not much affected by RD increase

$$\omega_{p,Y} = \frac{1}{R_D(C_{DB2}+C_L+C_{GD2})}$$

Razavi

Freq. response: Cascode amp(current source load)



$$Z_X = r_{o1} \parallel \frac{1}{sC_X} = \frac{r_{o1}}{1 + s\, r_{o1}\, C_X}$$

$$Z_{out} = (1 + g_{m2} r_{O2}) Z_X + r_{O2}$$

Zout: capacitive, pole at 1/(ro1*Cx)

Razavi