6장 SINGLE-STAGE INTEGRATED-CIRCUIT AMPLIFIERS,
전자회로

4차시

능동부하 CS/CE 증폭기

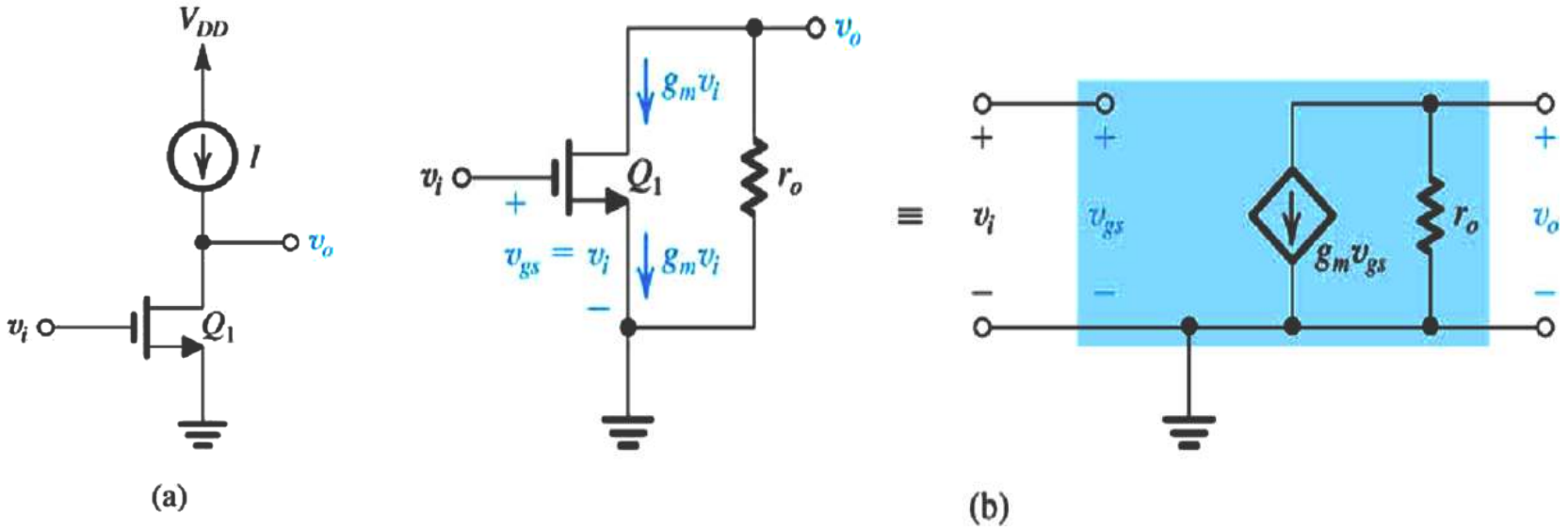
능동부하 CS/CE 증폭기

공통 소스 회로

- drain 저항 R_D를 전류전원 I(PMOS)로 대체한 능동부하 증폭기

$$R_i = \infty \qquad A_{vo} = -g_m r_o$$

$$R_o = r_o \qquad A_0 = g_m r_o$$



능동부하 CS/CE 증폭기

공통 소스 회로

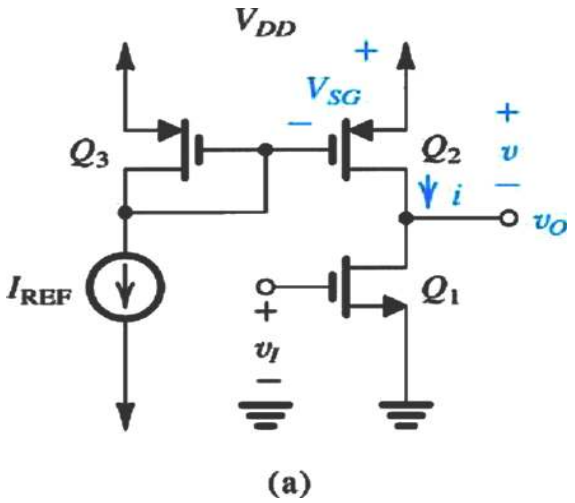
- Q2, Q3를 이용한 current mirror 능동부하

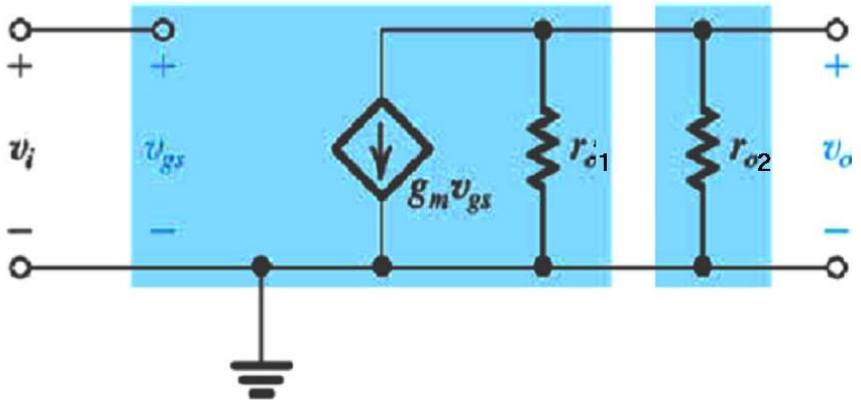
  - Q2의 증분저항

$$r_{o2} = \frac{|V_{A2}|}{I_{REF}}$$

$$A_v \equiv \frac{v_o}{v_i} = A_{vo}\frac{R_L}{R_L + R_o}$$

$$A_v = -(g_{m1}r_{o1})\frac{r_{o2}}{r_{o2} + r_{o1}} = -g_{m1}(r_{o1} \parallel r_{o2})$$





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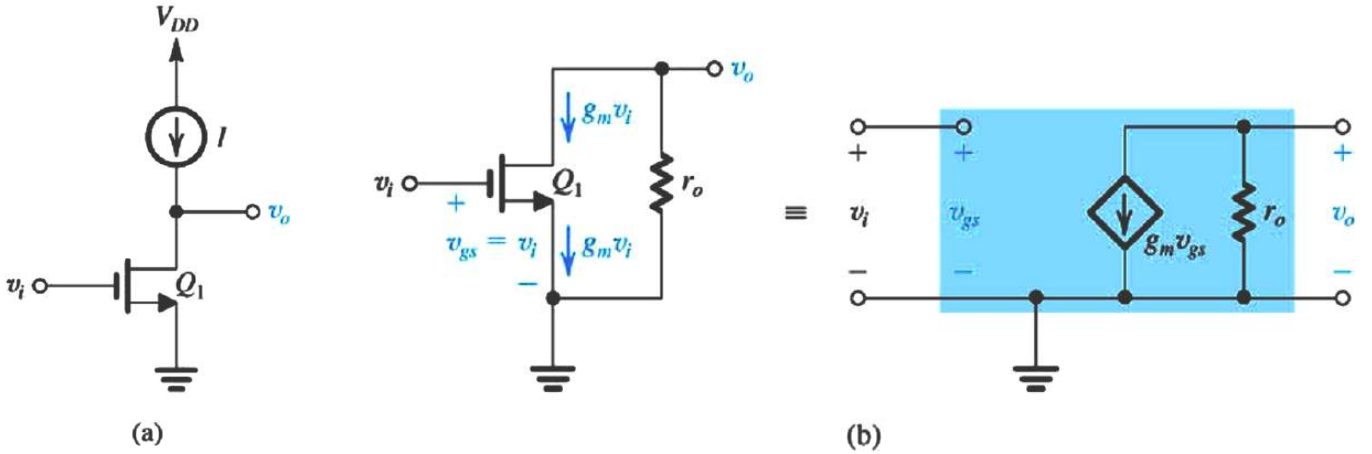

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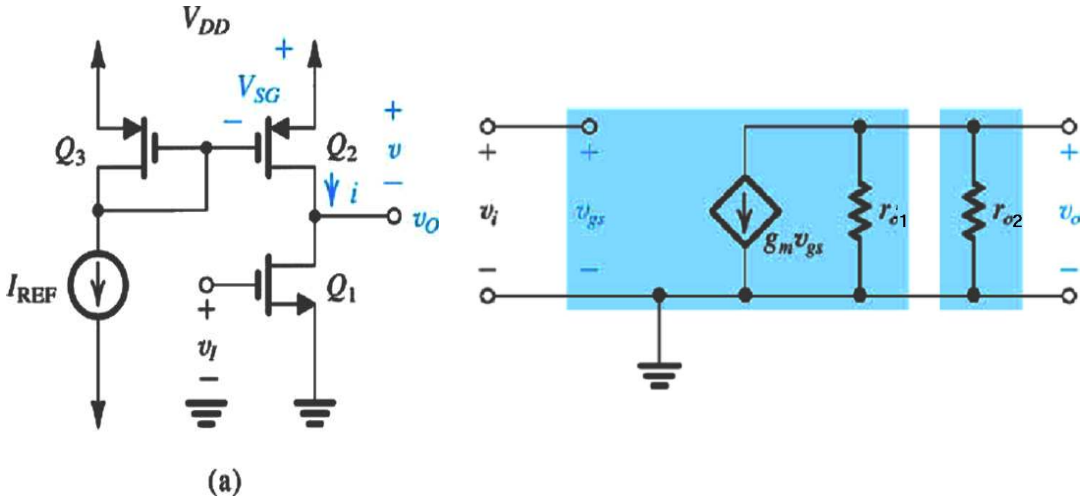
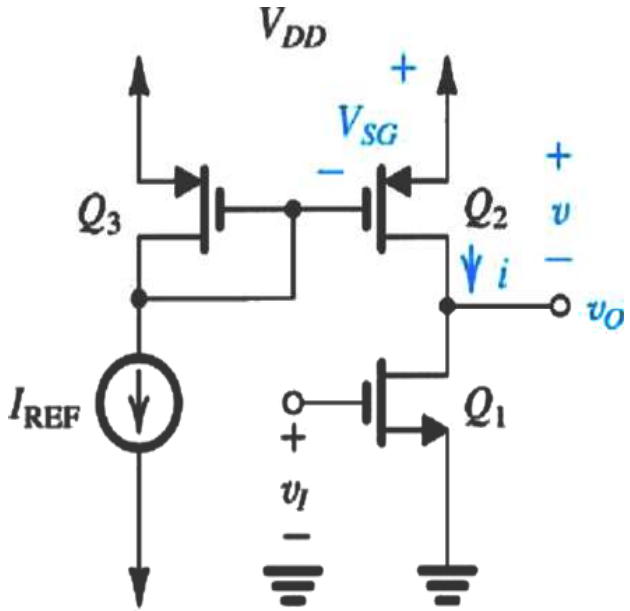
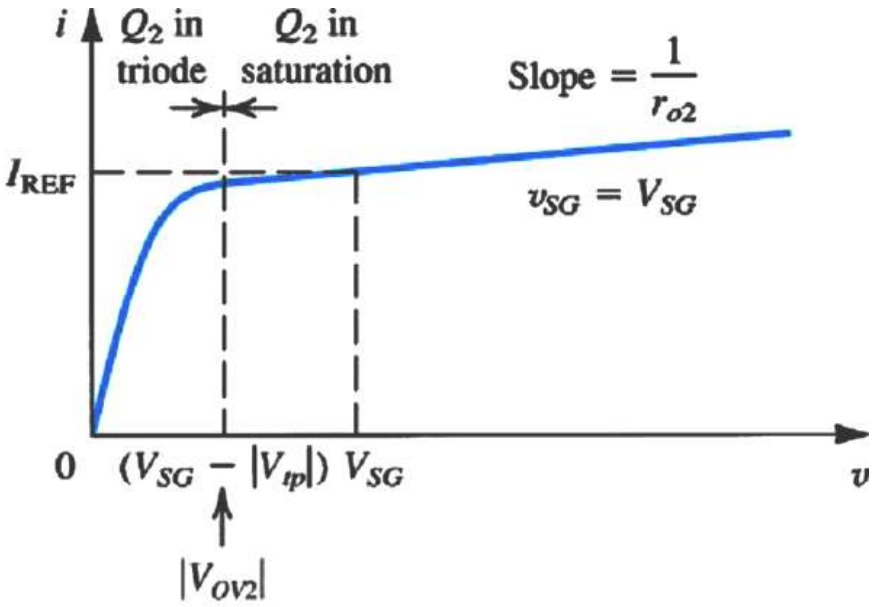


능동부하 CS/CE 증폭기

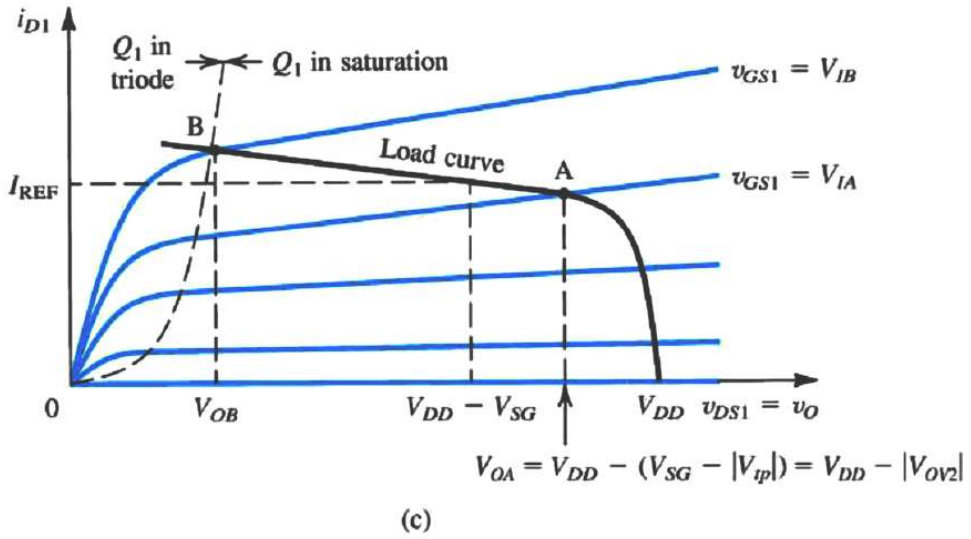


(a)

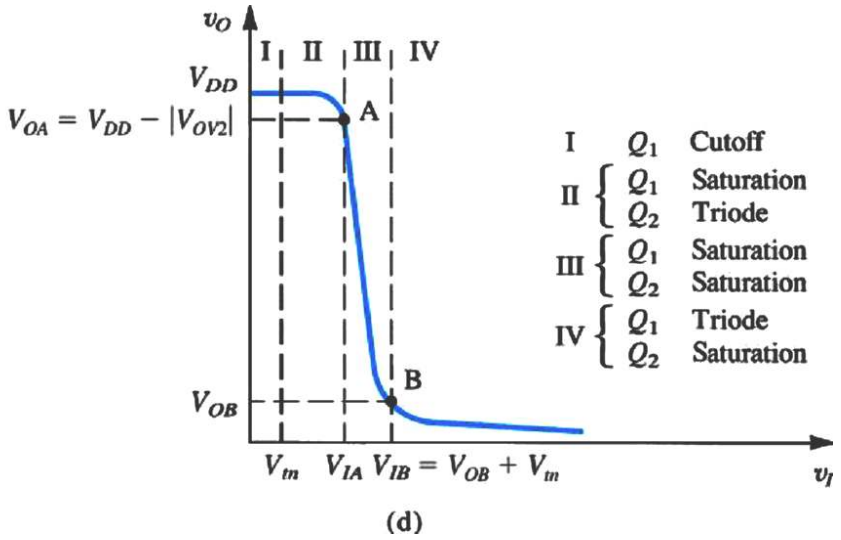


(b)

능동부하 CS/CE 증폭기

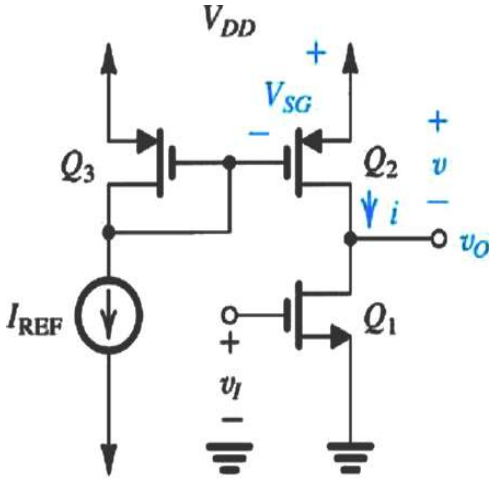


(c)



(d)

능동부하 CS/CE 증폭기



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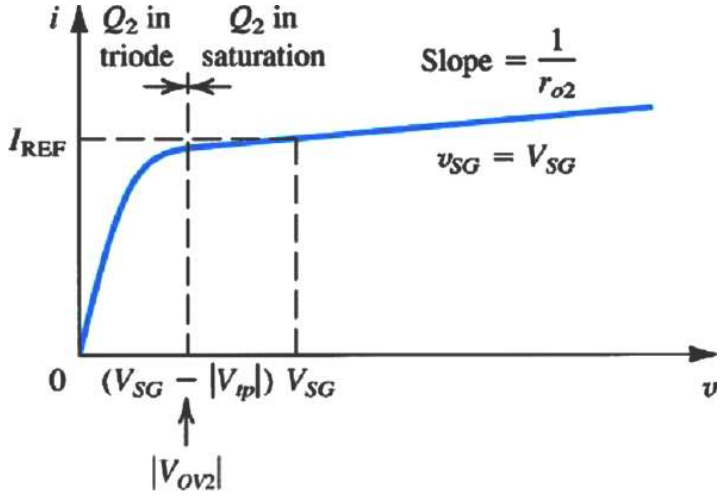
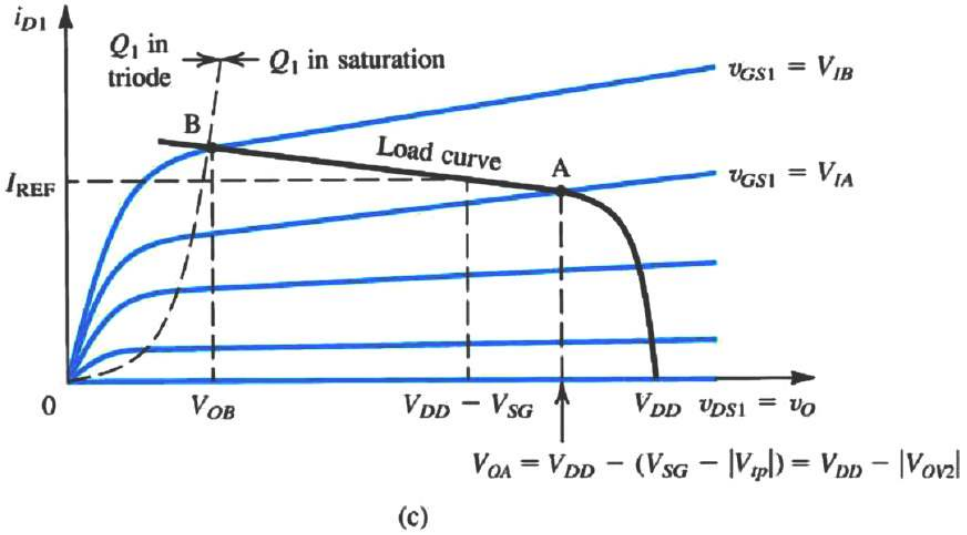
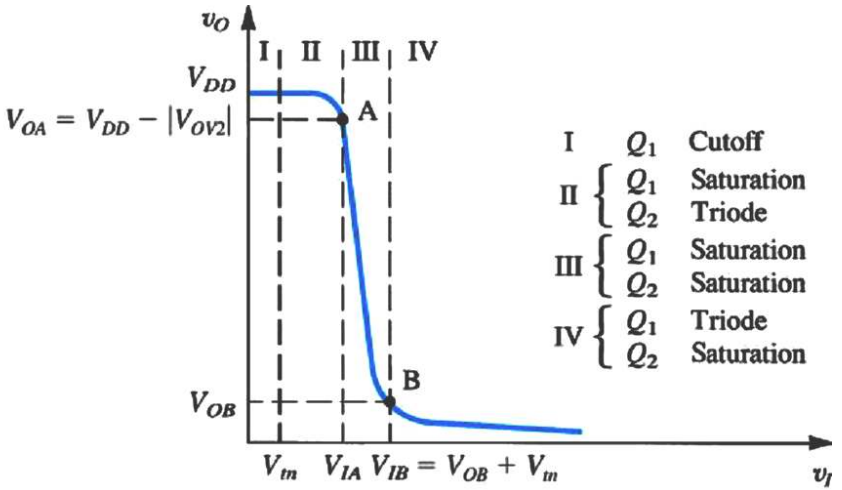


(b)



(c)



(d)

능동부하 CS/CE 증폭기

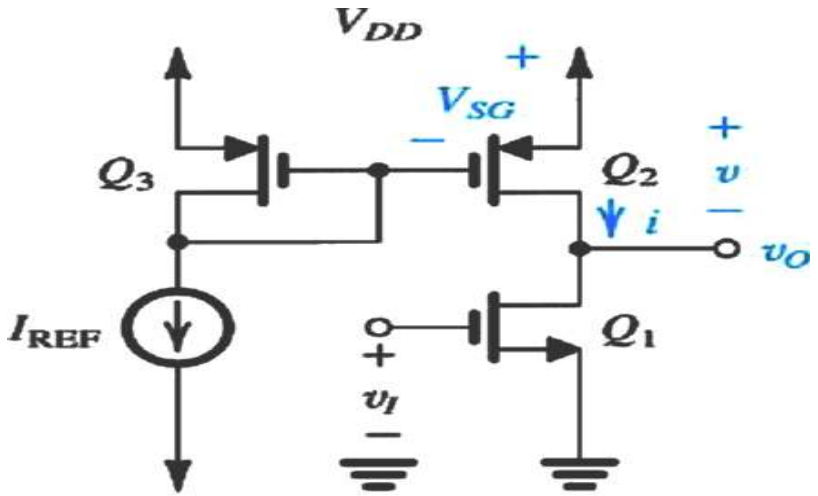
EX 6.8 V_{DD}=3V, V_{tn}=|V_{tp}|=0.6V, k_n'=200μA/V², k_p'=65μA/V². L=0.4μm, W=4μm, V_{An}=20V, |V_{ap}|=10V, I_{REF}=100μA . A_v=?

$$g_{m1} = \sqrt{2k_n'\left(\frac{W}{L}\right)_1 I_{REF}} = \sqrt{2\times 200\times\frac{4}{0.4}\times 100} = 0.63\,\text{mA/V}$$

$$r_{o1} = \frac{V_{An}}{I_{D1}} = \frac{20\text{V}}{0.1\text{mA}} = 200\text{k}\Omega$$

$$r_{o2} = \frac{V_{Ap}}{I_{D2}} = \frac{10\text{V}}{0.1\text{mA}} = 100\text{k}\Omega$$

$$A_v = -g_{m1}(r_{o1} \square r_{o2}) = -0.63(\text{mA/V}) + (200 \square 100)(\text{k}\Omega) = -42\,\text{V/V}$$



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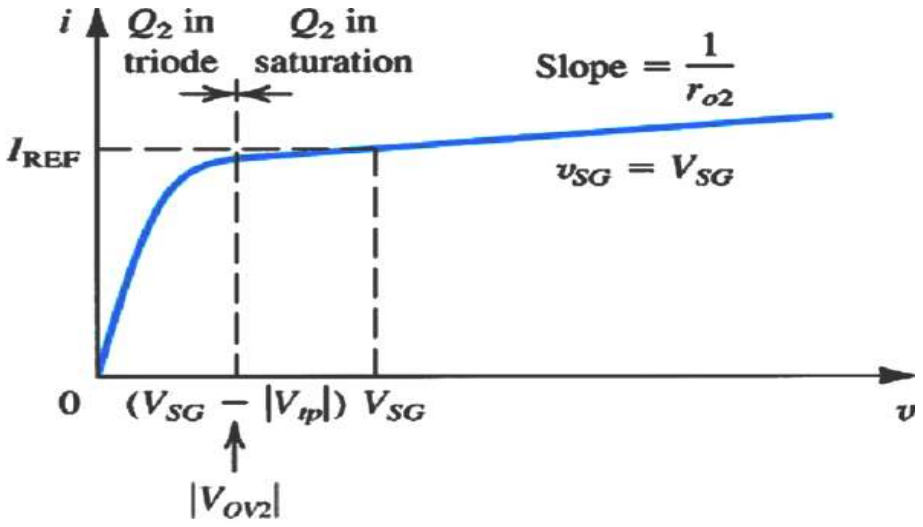
- I_D=I_{REF}=100μA 가 되는 Q2, Q3의 V_{SG}

$$I_D = \frac{1}{2}k_p'\left(\frac{W}{L}\right)_3\left(V_{SG}-|V_{tp}|\right)^2\left(1+\frac{V_{SD}}{|V_{Ap}|}\right)$$

$$100 = \frac{1}{2}\times 65\left(\frac{4}{0.4}\right)|V_{OV3}|^2\left(1+\frac{0.6+|V_{OV3}|}{10}\right)$$

$$0.29 = |V_{OV3}|^2\left(1+0.09|V_{OV3}|\right) \qquad |V_{OV3}| = 0.53\,\text{V}$$

$$V_{SG} = 0.6+0.53 = 1.13\,\text{V}$$



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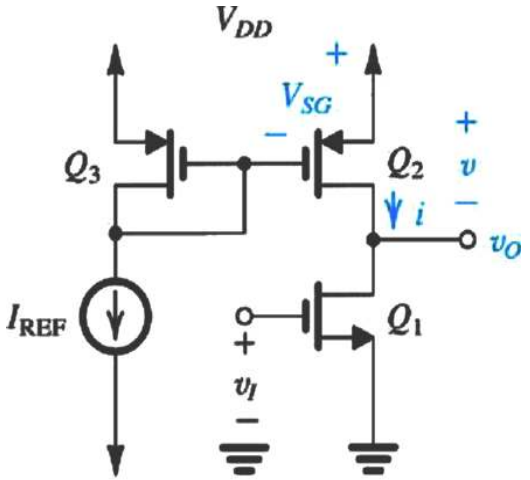
$$A_v=-g_{m1}(r_{o1}\,\square\, r_{o2})=-0.63(\text{mA/V})+(200\,\square\,100)(\text{k}\Omega)=-42\,\text{V/V}$$



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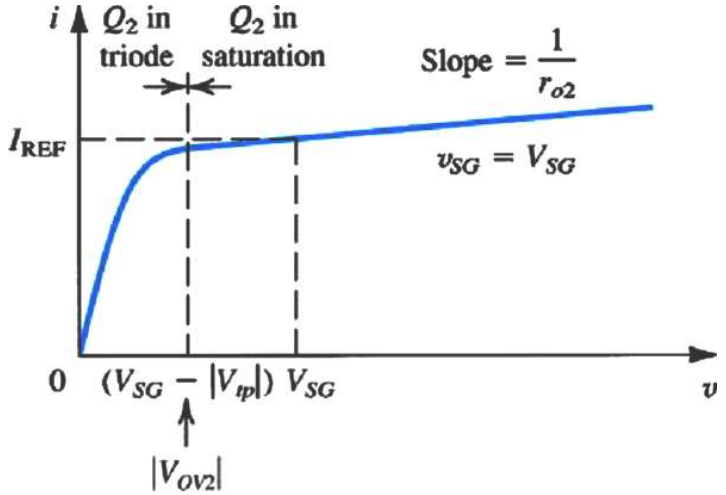


(b)

능동부하 CS/CE 증폭기

$$V_{OA} = V_{DD} - V_{OV3} = 2.47\,\text{V}$$

- 점 A, B사이에서 Q1, Q2는 포화, 같은 전류.

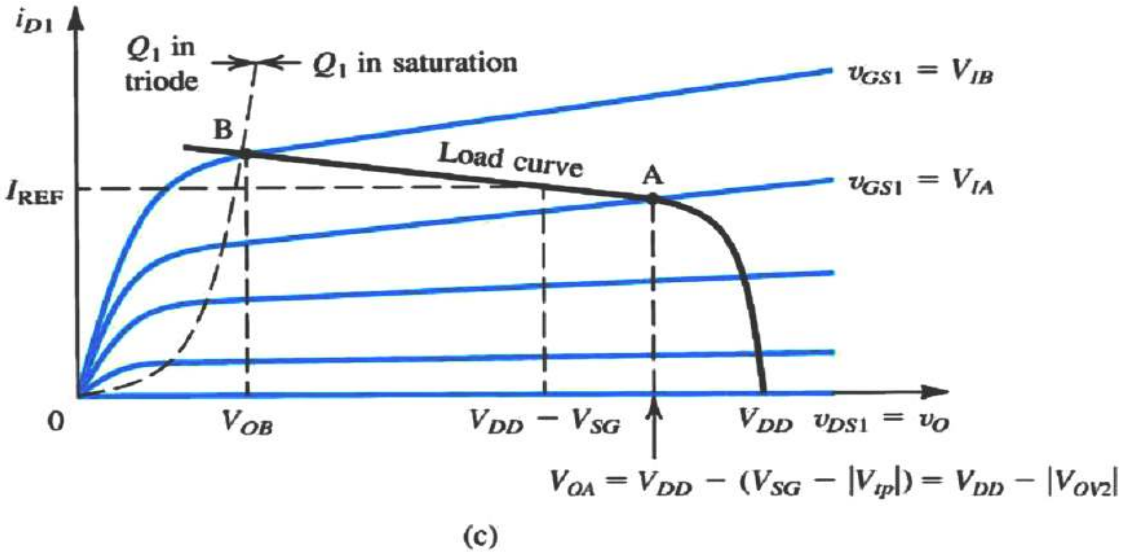
$$i_{D1} = i_{D2}$$

$$\frac{1}{2}k_n'\left(\frac{W}{L}\right)_1\left(\upsilon_I - V_{tn}\right)^2\left(1+\frac{\upsilon_O}{|V_{An}|}\right)$$

$$=\frac{1}{2}k_p'\left(\frac{W}{L}\right)_2\left(V_{SG}-|V_{tp}|\right)^2\left(1+\frac{V_{DD}-\upsilon_O}{|V_{Ap}|}\right)$$

$$8.55\left(\upsilon_I - 0.6\right)^2 = \frac{1-0.08\upsilon_O}{1+0.05\upsilon_O} \cong 1-0.13\upsilon_O$$

$$\upsilon_O = 7.69 - 65.77\left(\upsilon_I - 0.6\right)^2$$



(c)

능동부하 CS/CE 증폭기

- $v_O = V_{OA} = 2.47V$ 에서 $V_{IA} = 0.88V$.

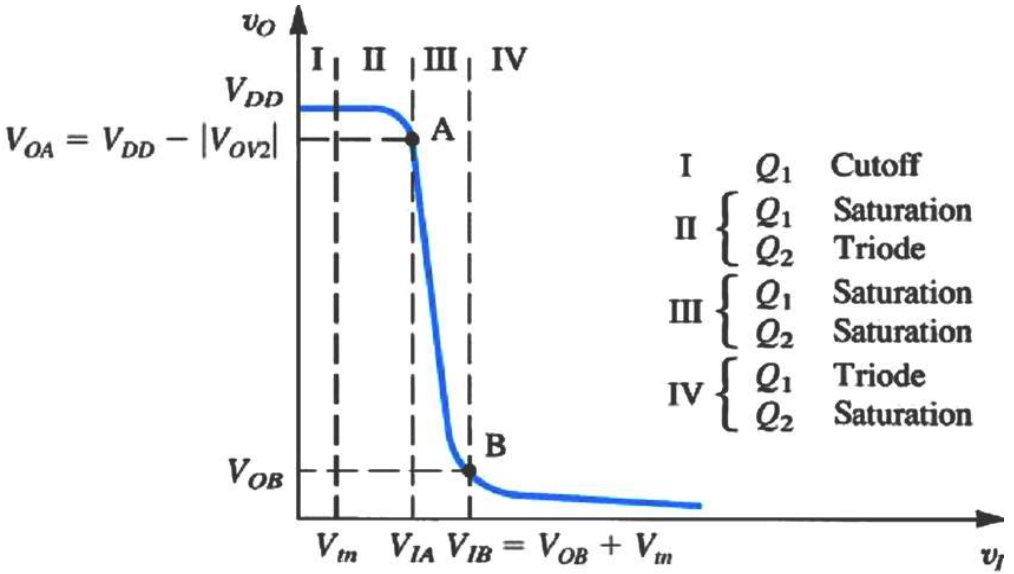
$V_{OB} = V_{IB} - V_{tn}$ 이므로, $V_{IB} = 0.93V$, $V_{OB} = 0.33V$

$$\Delta v_I = V_{IB} - V_{IA} = 0.05\,\text{V}$$

$$\Delta v_O = V_{OB} - V_{OA} = -2.14\,\text{V}$$

$$\frac{\Delta v_O}{\Delta v_I} = -\frac{2.14}{0.05} = -42.8\,\text{V/V}$$

- 소신호 전압이득 $A_v = -42$에 근접.(III영역의 전달특성 → 선형적)



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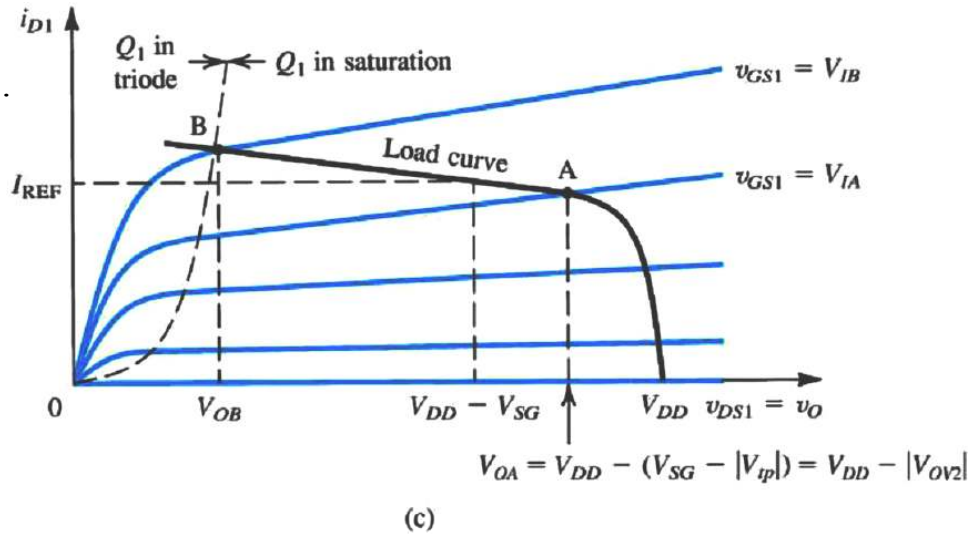

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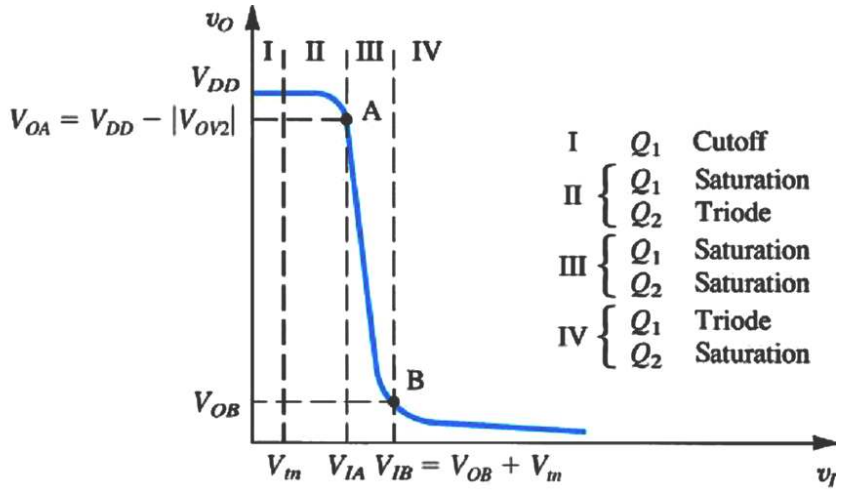

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능동부하 CS/CE 증폭기

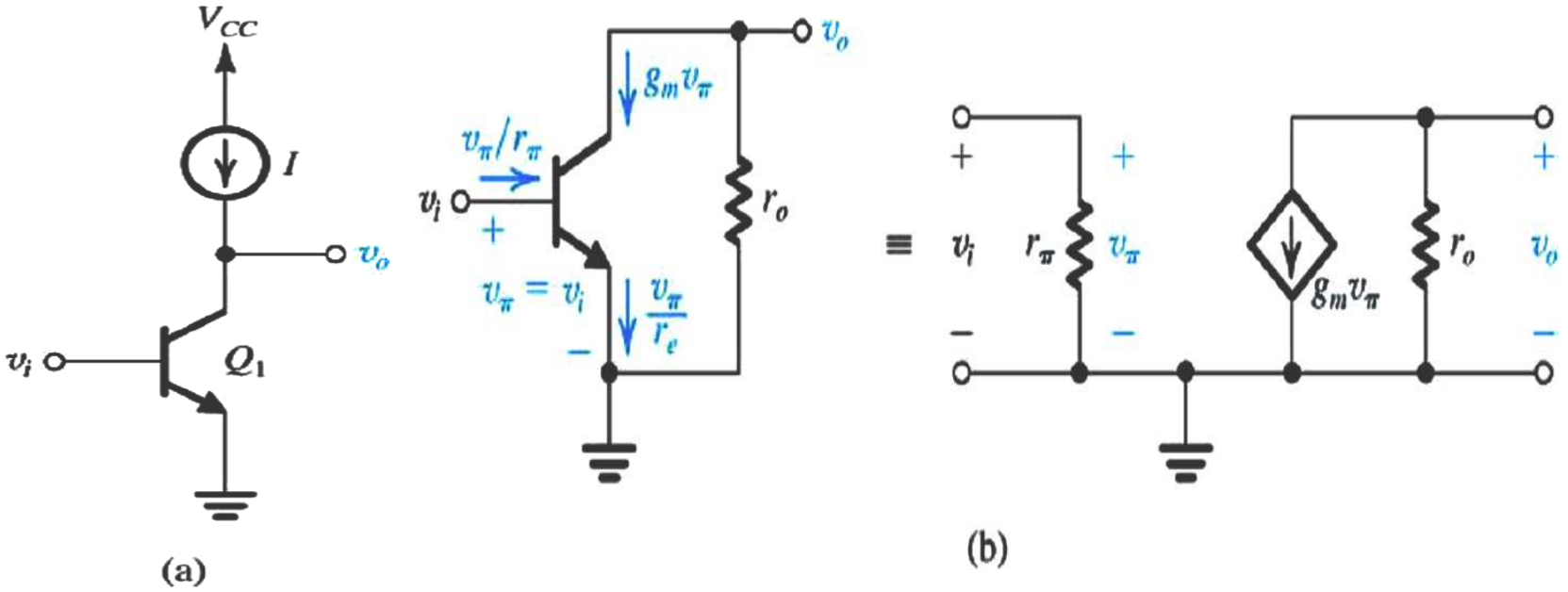
공통 이미터 회로

$$R_i = r_\pi$$

$$A_{vo} = -g_m r_o$$

$$R_o = r_o$$

▪ 공통소스 증폭기와 비교하여, 낮은 입력저항, r_π, 매우 큰 고유이득 $g_m r_o$. (공통소스 증폭기의 무한 입력저항에 의해 평형)



능동부하 CG/CB 증폭기

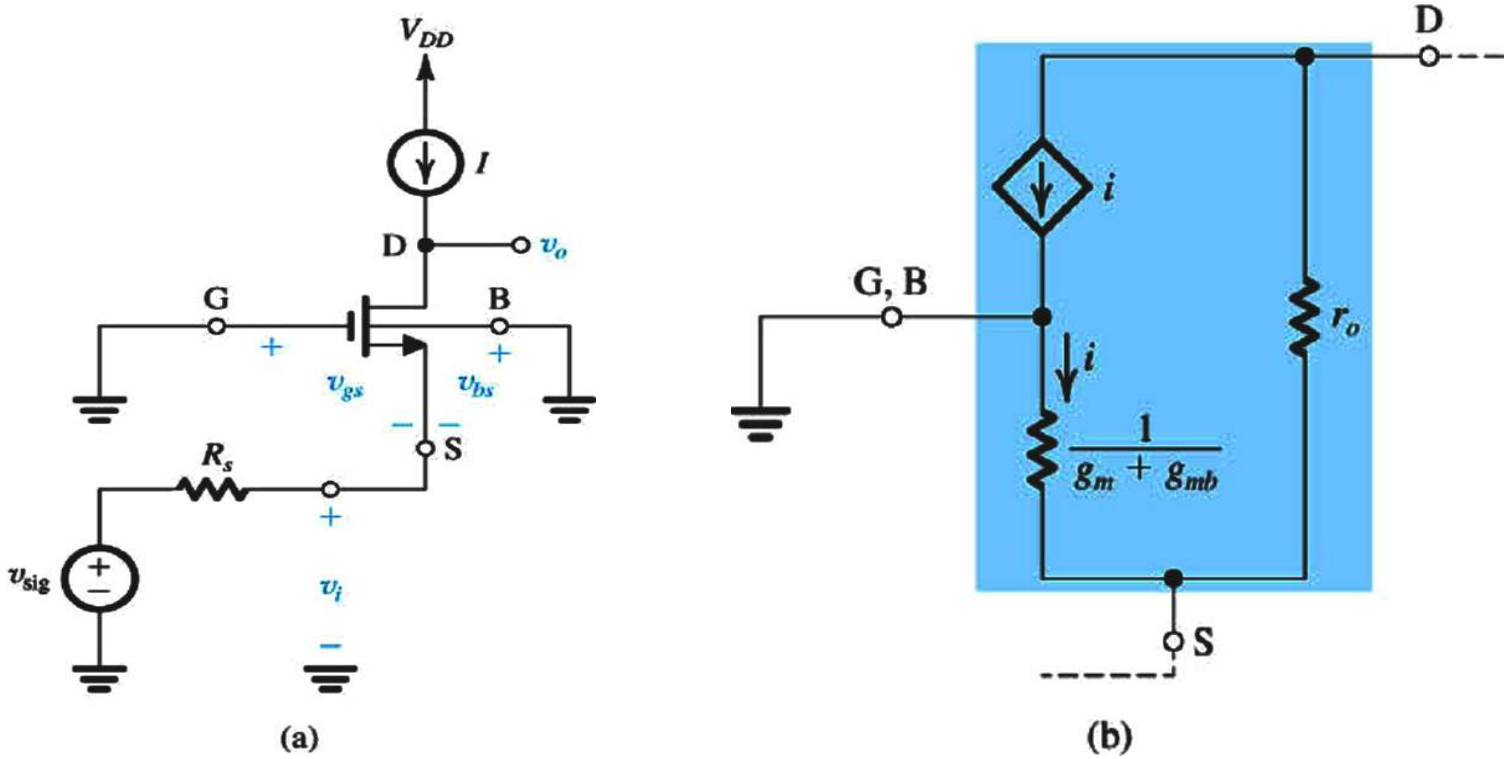
공통 게이트 증폭기

- Body effect

$$i_d = g_m v_{gs} + g_{mb} v_{bs}$$

CG회로에서 $v_{gs} = v_{bs}$ 이므로

$$i_d = (g_m + g_{mb}) v_{gs}$$



능동부하 CG/CB 증폭기

공통 게이트 증폭기

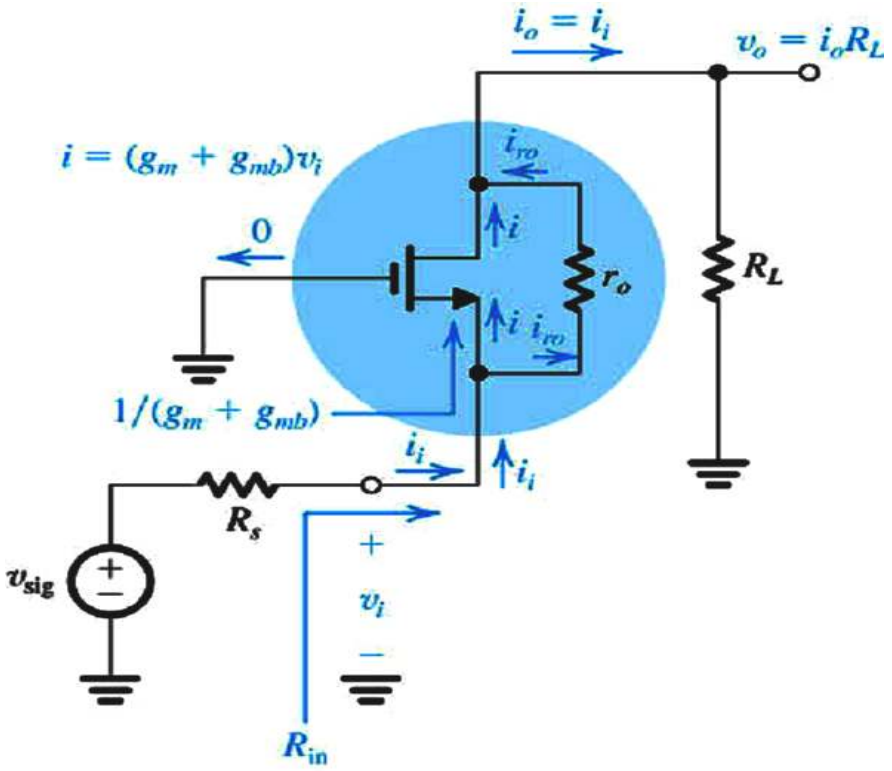
▪ 입력 저항

$$i_i = (g_m + g_{mb})v_i + i_{ro}$$

$$i_{ro} = \frac{v_i - v_o}{r_o} = \frac{v_i - i_i R_L}{r_o}$$

$$i_i = \left(g_m + g_{mb} + \frac{1}{r_o}\right)v_i \Big/ \left(1 + \frac{R_L}{r_o}\right)$$

$$R_{in} \equiv \frac{v_i}{i_i} = \frac{r_o + R_L}{1 + (g_m + g_{mb})r_o}$$



(c)

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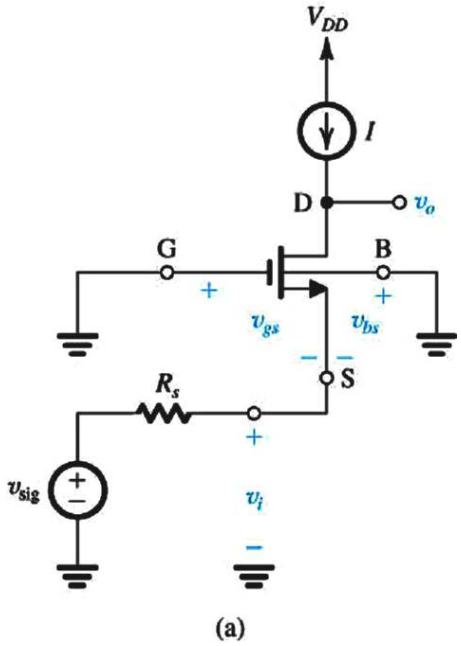
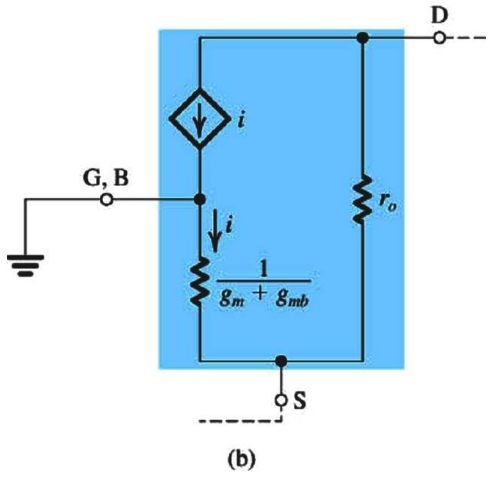
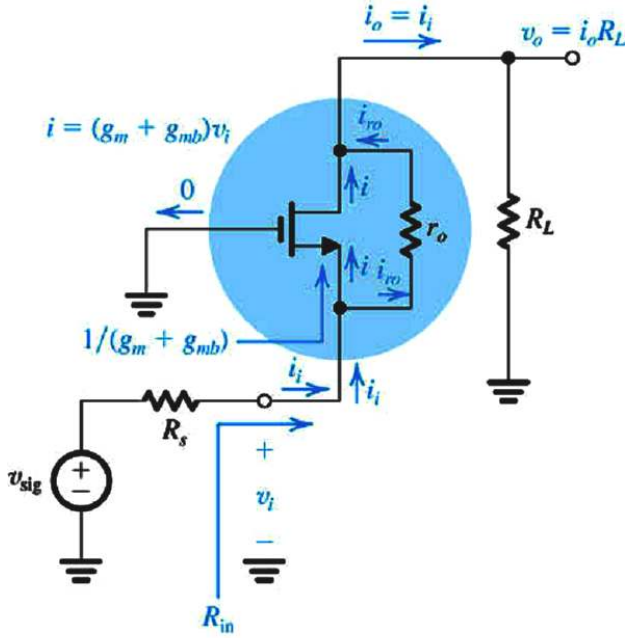


(a)



(b)



(c)

능동부하 CG/CB 증폭기

▪ $R_L=\infty$ 일 때의 동작

$$R_i = \infty$$

$$v_o = ir_o + v_i = (g_m + g_{mb}) r_o v_i + v_i$$

- Open-circuit voltage gain

$$A_{vo} = 1 + (g_m + g_{mb}) r_o$$

- 입력 저항

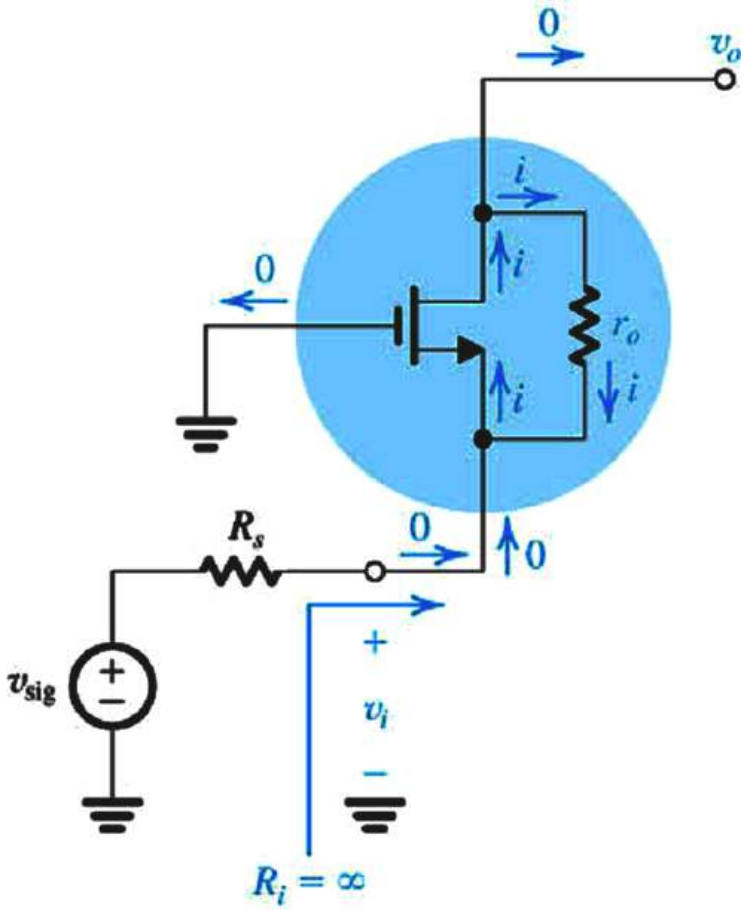
$$R_{in} = \frac{r_o + R_L}{A_{vo}}$$

$A_{vo} \approx (g_m + g_{mb}) r_o \approx A_0$ 이므로

$$R_{in} \cong \frac{1}{g_m + g_{mb}} + \frac{R_L}{A_0}$$

- Open-circuit overall voltage gain

$$G_{vo} = \frac{v_o}{v_{sig}} = A_{vo} = 1 + (g_m + g_{mb}) r_o$$



(d)

능동부하 CG/CB 증폭기

- 전압이득

$$\upsilon_o = i_o R_L = i_i R_L$$

$$\upsilon_i = i_i R_{in}$$

$$A_\upsilon = \frac{\upsilon_o}{\upsilon_i} = \frac{R_L}{R_{in}}$$

$$A_\upsilon = A_{\upsilon o}\frac{R_L}{R_L + r_o}$$

- 전체 전압이득

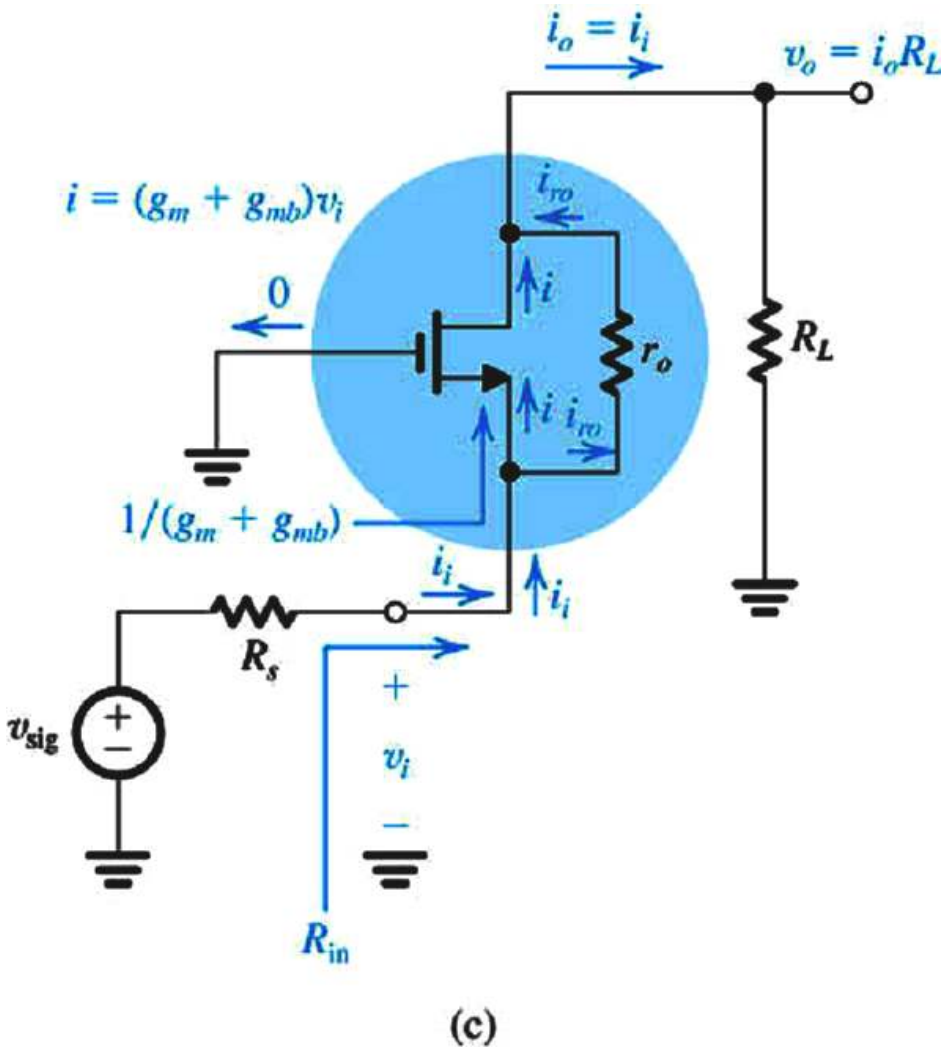
$$\upsilon_o = i_o R_L = i_i R_L$$

$$\upsilon_{sig} = i_i\left(R_s + R_{in}\right)$$

$$G_\upsilon = \frac{R_L}{R_s + R_{in}}$$

$$G_\upsilon = A_{\upsilon o}\frac{R_L}{R_L + r_o + A_{\upsilon o}R_s}$$

$$G_\upsilon = G_{\upsilon o}\frac{R_L}{R_L + r_o + A_{\upsilon o}R_s}$$



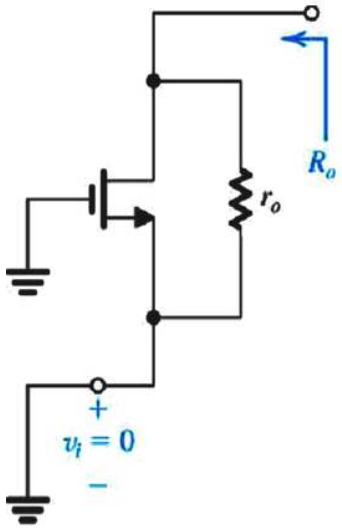
능동부하 CG/CB 증폭기

- 출력저항

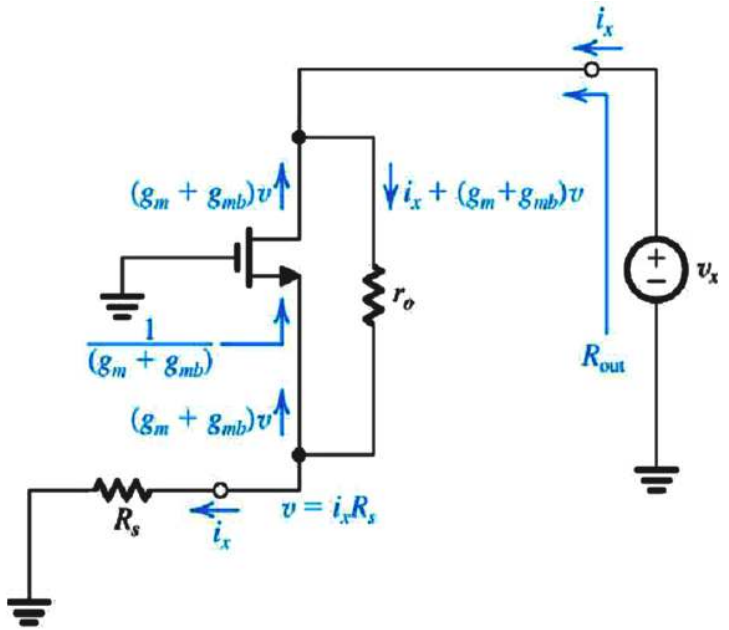
$$R_o = r_o \qquad \upsilon = i_x R_s$$

$$\upsilon_x = \left[i_x + \left(g_m + g_{mb} \right) \upsilon \right] r_o + \upsilon$$

$$R_{out} = r_o + \left[1 + \left(g_m + g_{mb} \right) r_o \right] R_s \qquad R_{out} = r_o + A_{vo} R_s$$



(a)



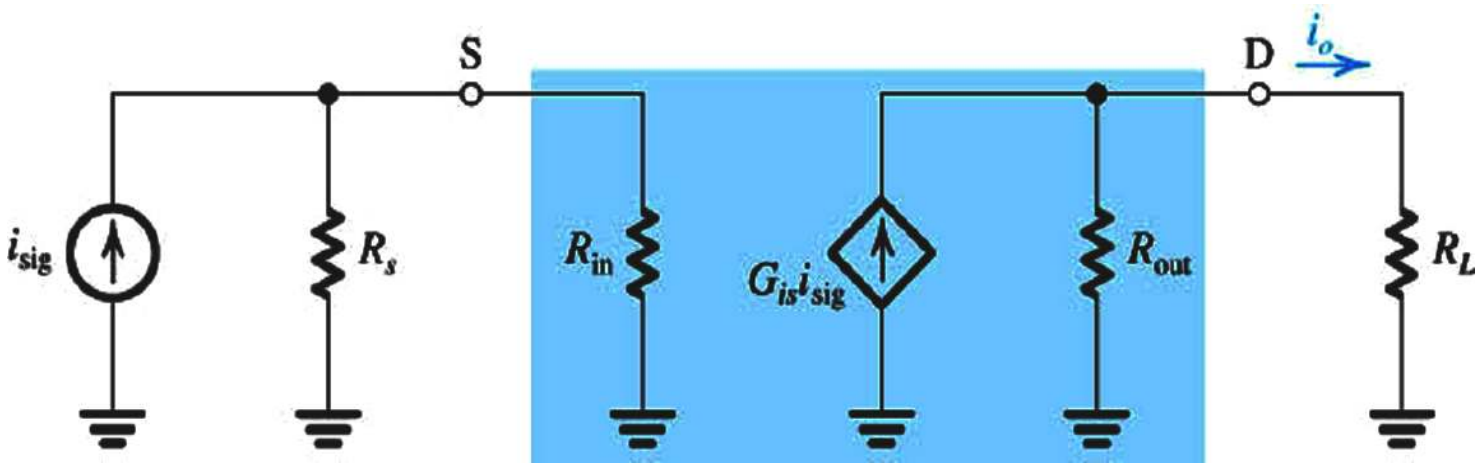
(b)

능동부하 CG/CB 증폭기

▪ 총 단락회로 전류이득

$$G_{is} = G_{vo}\frac{R_s}{R_{out}} \cong 1$$

→ current buffer (낮은 입력저항, 높은 출력저항)



능동부하 CG/CB 증폭기

- 출력저항

$$R_o = r_o$$

$$\upsilon = i_x R_s$$

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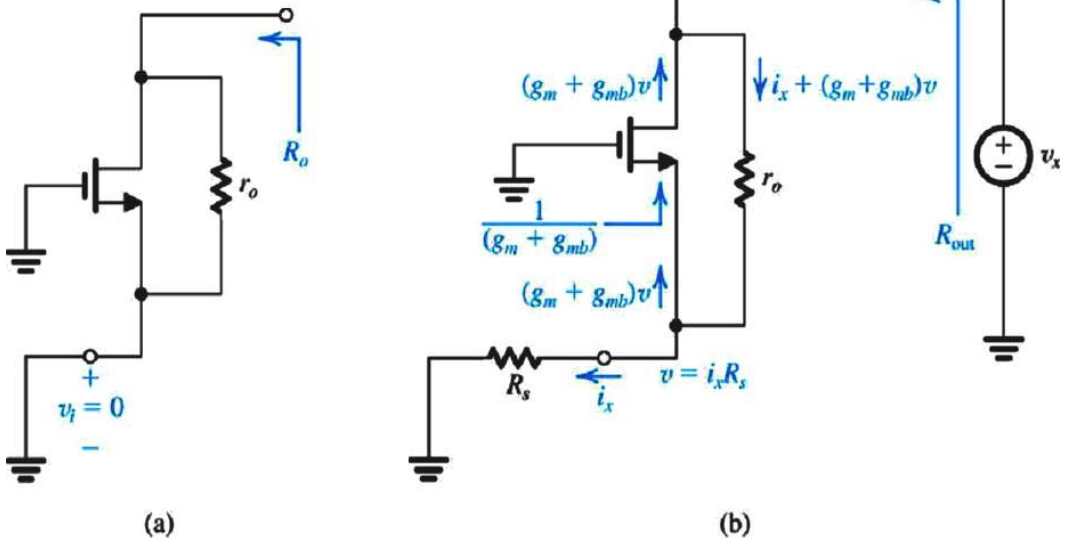
$$R_{out} = r_o + \left[1 + \left(g_m + g_{mb} \right) r_o \right] R_s$$

$$R_{out} = r_o + A_{\upsilon o} R_s$$



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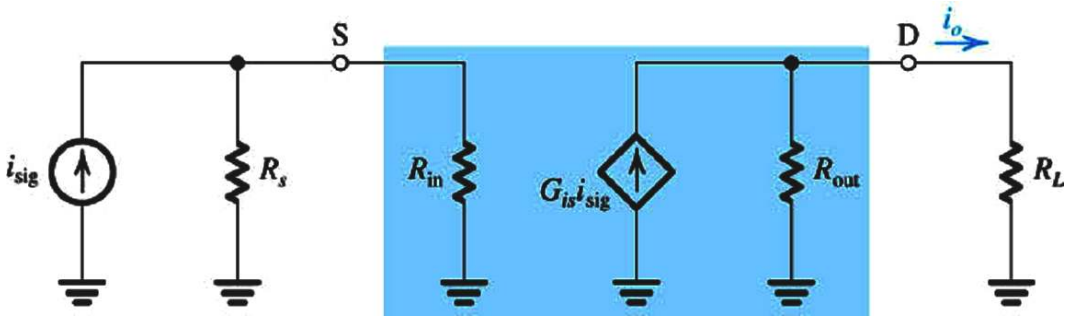


능동부하 CG/CB 증폭기

고주파 응답

- r_o를 무시하면

$$f_{P1} = \frac{1}{2\pi C_{gs} R_s \square 1/(g_m + g_{mb})}$$

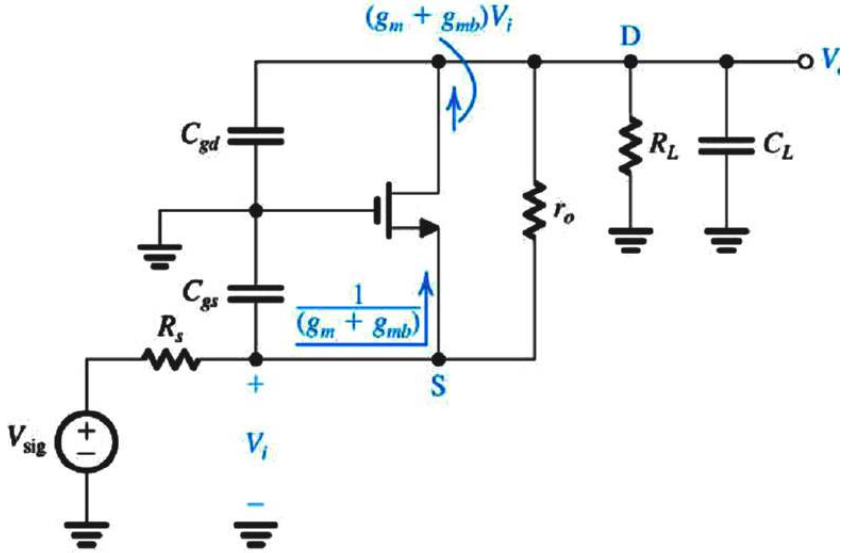
$$f_{P2} = \frac{1}{2\pi \left(C_{gd} + C_L\right) R_L}$$

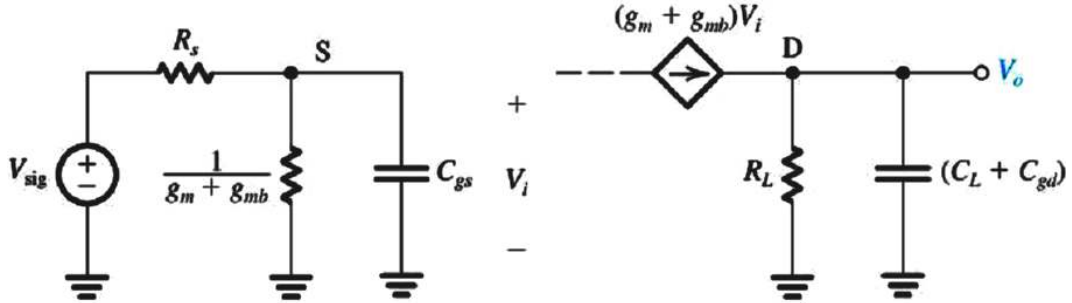
- r_o를 고려하면, 개방회로 시정수를 이용하여

$$R_{gs} = R_s \square R_{in}$$

$$R_{gd} = R_L \square R_{out}$$

$$f_H = \frac{1}{2\pi \left[C_{gs} R_{gs} + \left(C_{gd} + C_L\right) R_{gd}\right]}$$





(b)

능동부하 CG/CB 증폭기

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$$R_{gs} = R_s \,\square\, R_{in}$$

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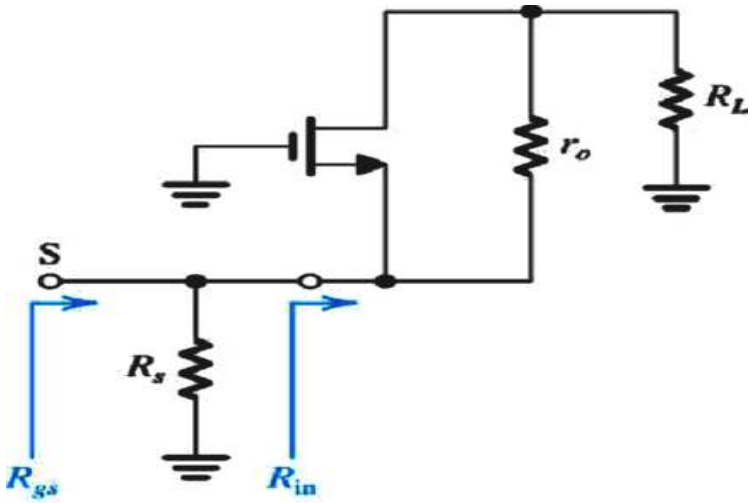
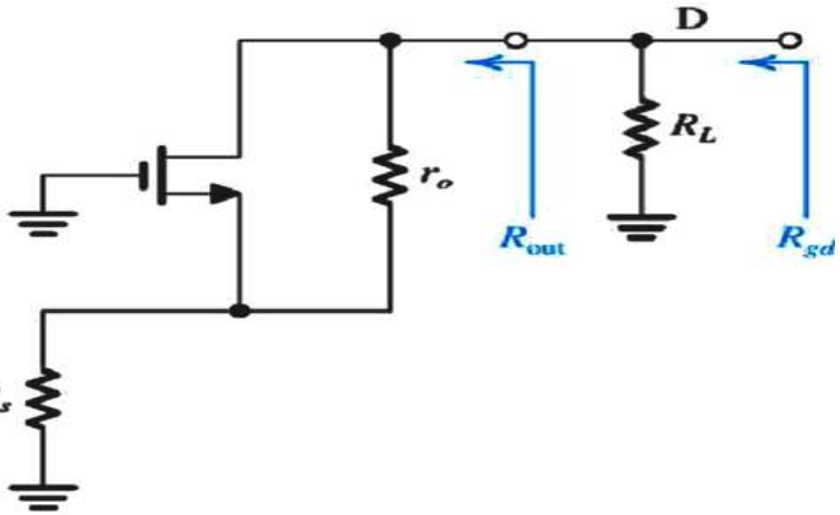
$$f_H = \frac{1}{2\pi\left[C_{gs}R_{gs} + \left(C_{gd} + C_L\right)R_{gd}\right]}$$





능동부하 CG/CB 증폭기

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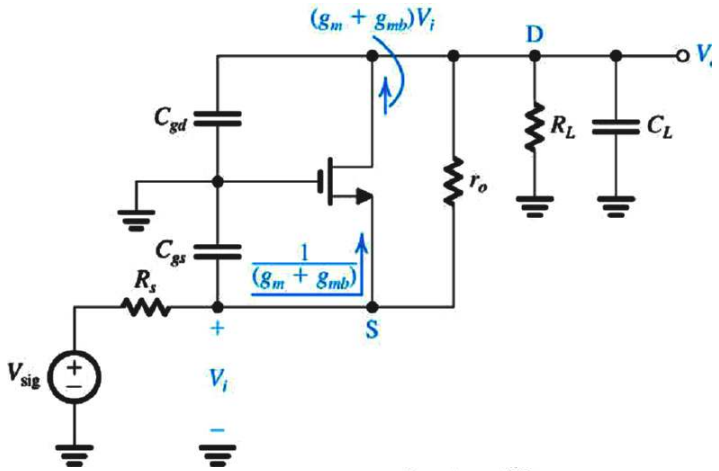
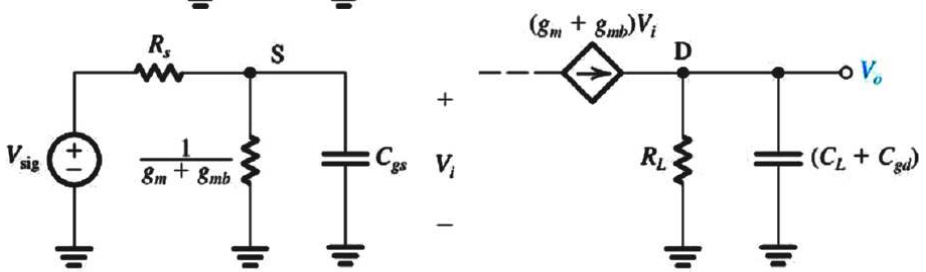
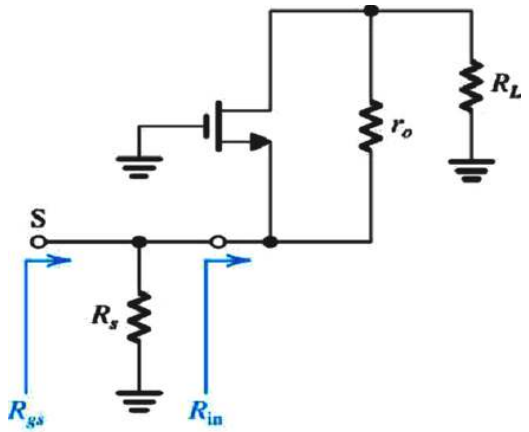
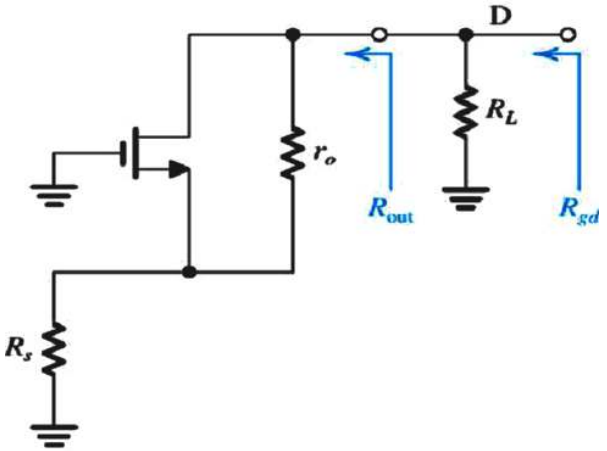








능동부하 CG/CB 증폭기

Ex 6.11 W/L=7.2μm/0.36μm, k_n'=387μA/V^2, r_o=18kΩ, I_D=100μA, g_m=1.25mA/V, χ=0.2, R_s=10kΩ, R_L=100kΩ, C_{gs}=20fF, C_{gd}=5fF, C_L=0. A_{vo}, R_{in}, R_{out}, G_v, G_{is}, G_i, f_H=?

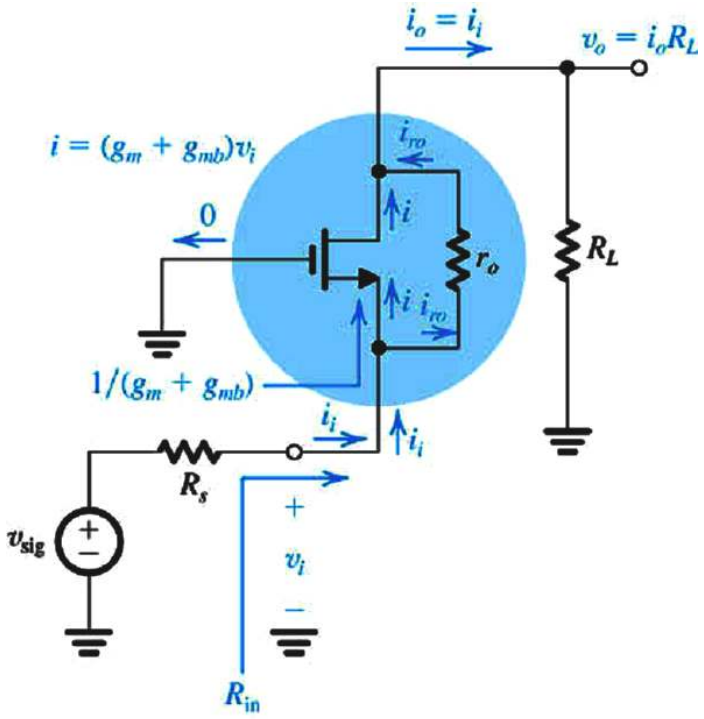
$$g_m + g_{mb} = 1.25 + 0.2 \times 1.25 = 1.5\,\text{mA/V}$$

$$A_{vo} = 1 + (g_m + g_{mb}) r_o = 1 + 1.5 \times 18 = 28\,\text{V/V}$$

$$R_{in} = \frac{r_o + R_L}{A_{vo}} = \frac{18 + 100}{28} = 4.2\,\text{k}\Omega$$

$$R_{out} = r_o + A_{vo} R_s = 18 + 28 \times 10 = 298\,\text{k}\Omega$$

$$G_v = G_{vo} \frac{R_L}{R_L + R_{out}} = A_{vo} \frac{R_L}{R_L + R_{out}} = 28 \frac{100}{100 + 298} = 7\,\text{V/V}$$



(c)

능동부하 CG/CB 증폭기

Ex 6.11 W/L=7.2μm/0.36μm, k_n'=387μA/V^2, r_o=18kΩ, I_D=100μA, g_m=1.25mA/V, χ=0.2, R_s=10kΩ, R_L=100kΩ, C_{gs}=20fF, C_{gd}=5fF, C_L=0. A_{vo}, R_{in}, R_{out}, G_v, G_{is}, G_i, f_H=?

$$G_{is} = \frac{A_{vo} R_s}{R_{out}} = \frac{28 \times 10}{298} = 0.94 \text{ A/A}$$

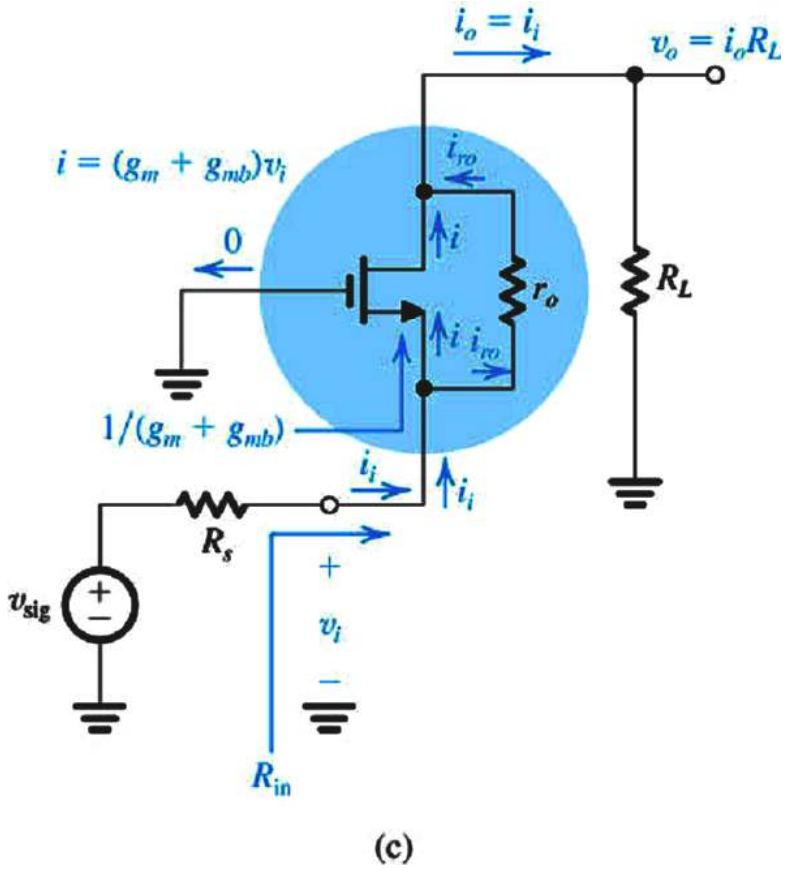
$$G_i = G_{is} \frac{R_{out}}{R_{out} + R_L} = 0.94 \frac{298}{298 + 100} = 0.7 \text{ A/A}$$

$$R_{gs} = R_s \,\square\, R_{in} = 10 \,\square\, 4.2 = 3 \text{ k}\Omega$$

$$R_{gd} = R_L \,\square\, R_{out} = 100 \,\square\, 298 = 75 \text{ k}\Omega$$

$$\tau_H = C_{gs} R_{gs} + C_{gd} R_{gd} = 20 \times 3 + 5 \times 75 = 60 + 375 = 435 \text{ ps}$$

$$f_H \cong \frac{1}{2\pi\tau_H} = \frac{1}{2\pi \times 435 \times 10^{-12}} = 366 \text{ MHz}$$



(c)

능동부하 CG/CB 증폭기

Ex 6.11 W/L=7.2μm/0.36μm, k_n'=387μA/V^2, r_o=18kΩ, I_D=100μA, g_m=1.25mA/V, χ=0.2, R_s=10kΩ, R_L=100kΩ, C_{gs}=20fF, C_{gd}=5fF, C_L=0. A_{vo}, R_{in}, R_{out}, G_v, G_{is}, G_i, f_H=?

$$G_{is} = \frac{A_{vo} R_s}{R_{out}} = \frac{28 \times 10}{298} = 0.94\,\text{A/A}$$

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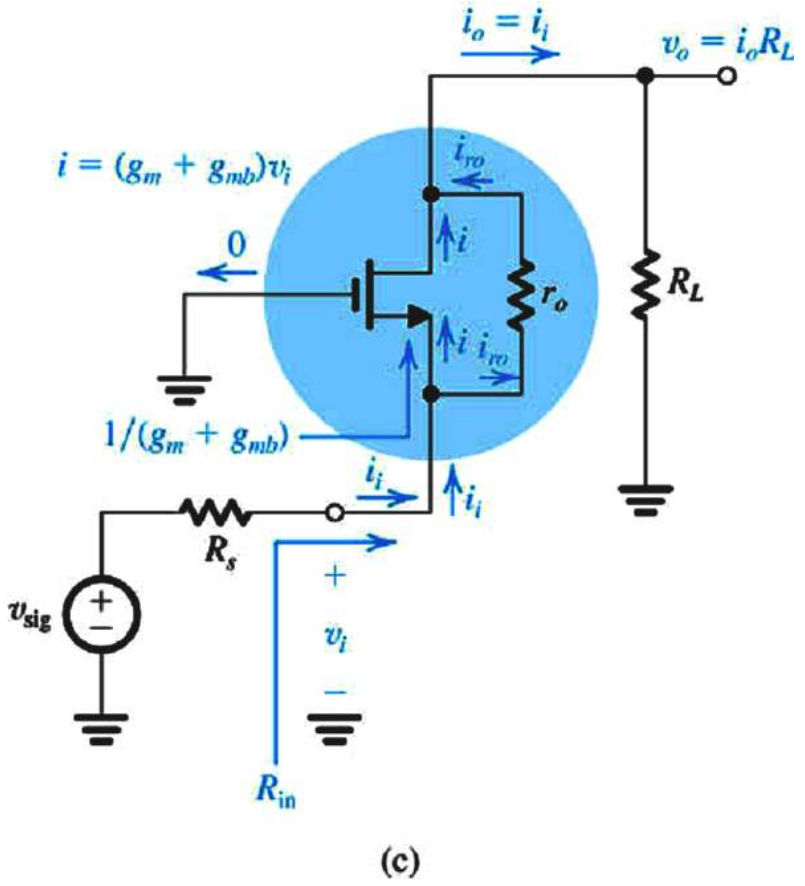


능동부하 CG/CB 증폭기

공통 베이스 증폭기

- 입력저항

$$i_o = i_i - v_i / r_\pi$$

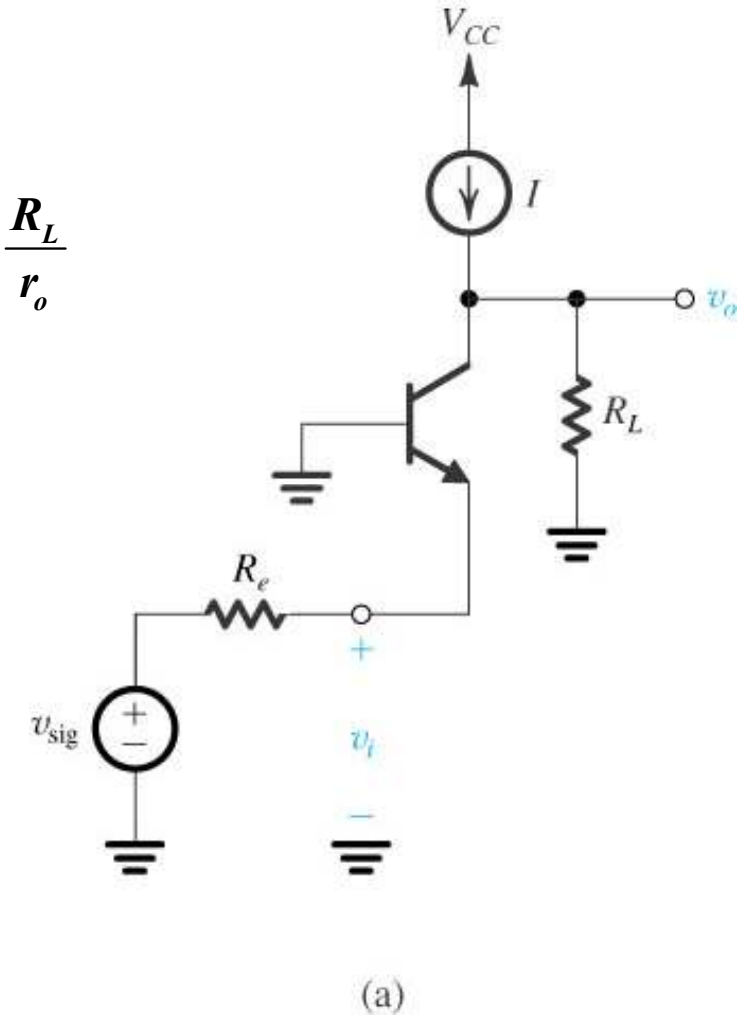
$$i_{ro} = \frac{v_i - v_o}{r_o} = \frac{v_i - i_o R_L}{r_o} = \frac{v_i}{r_o} - (i_i - v_i / r_\pi)\frac{R_L}{r_o}$$

$$i_i = v_i / r_e + i_{ro}$$

$$R_{in} = \frac{r_o + R_L}{1 + r_o / r_e + R_L / (\beta + 1) r_e}$$

$$R_{in} = r_e \frac{r_o + R_L}{r_e + r_o + R_L / (\beta + 1)}$$

$$\cong r_e \frac{r_o + R_L}{r_o + R_L / (\beta + 1)}$$

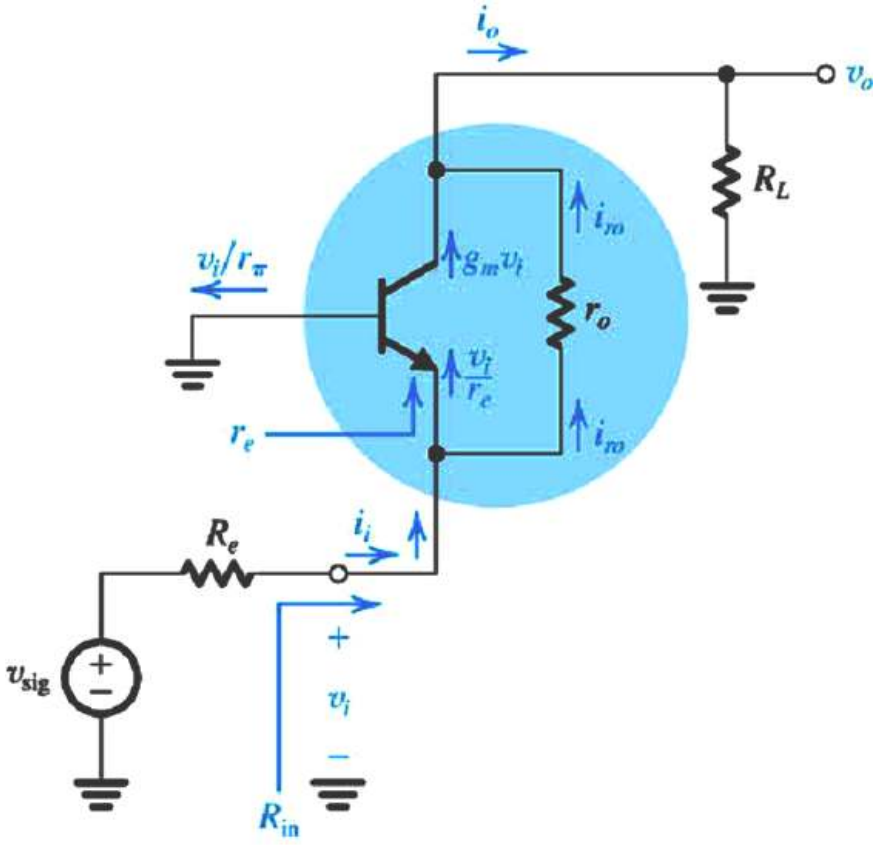


능동부하 CG/CB 증폭기

공통 베이스 증폭기

- r_o를 무시하면($r_o=\infty$), $R_{in}= r_e$
- $R_L=0$ 이면, $R_{in}= r_e // r_o$
- $R_L=\infty$ 이면, $R_{in}= R_i= (1+\beta)\, r_e= r_\pi$
- $R_L/(1+\beta) \ll r_o$ 이므로,

$$R_{in} \cong r_e + \frac{R_L}{g_m r_o} = r_e + \frac{R_L}{A_0}$$



(b)

능동부하 CG/CB 증폭기

공통 베이스 증폭기

- 입력저항

$$i_o = i_i - v_i / r_\pi$$

$$i_{ro} = \frac{v_i - v_o}{r_o} = \frac{v_i - i_o R_L}{r_o} = \frac{v_i}{r_o} - (i_i - v_i / r_\pi)\frac{R_L}{r_o}$$

$$i_i = v_i / r_e + i_{ro}$$

$$R_{in} = \frac{r_o + R_L}{1 + r_o / r_e + R_L / (\beta + 1) r_e}$$

$$R_{in} = r_e \frac{r_o + R_L}{r_e + r_o + R_L / (\beta + 1)}$$

$$\cong r_e \frac{r_o + R_L}{r_o + R_L / (\beta + 1)}$$

- r_o를 무시하면($r_o = \infty$), $R_{in} = r_e$
- $R_L = 0$ 이면, $R_{in} = r_e // r_o$
- $R_L = \infty$ 이면, $R_{in} = R_i = (1+\beta) r_e = r_\pi$
- $R_L/(1+\beta) \ll r_o$ 이므로,

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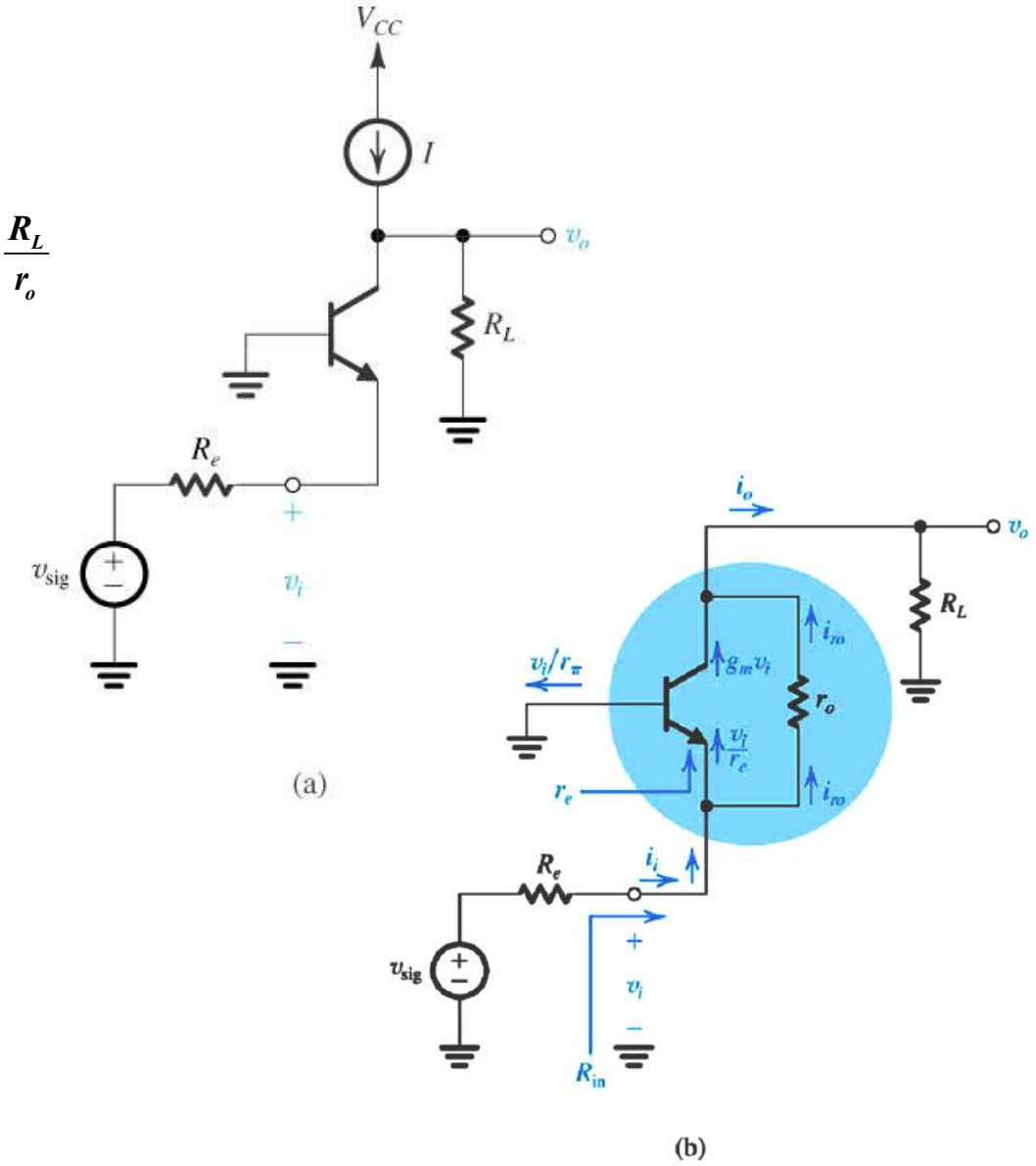

능동부하 CG/CB 증폭기

- 개방회로 전압이득

$$A_{vo} = 1 + g_m r_o = 1 + A_0$$

$$R_i = r_\pi$$

- 출력저항

$$R_o = r_o$$

$$R_{out} = r_o + \left(1 + g_m r_o\right) R_e^{'} , \qquad R_e^{'} = R_e \,//\, r_\pi$$

$$R_{out} = r_o + A_{vo} R_e^{'}$$

- 전체 전압이득

$$G_v = G_{vo} \frac{R_L}{R_L + R_{out}}$$

$$G_{vo} = \frac{R_i}{R_i + R_e} A_{vo} = \frac{r_\pi}{r_\pi + R_e} A_{vo}$$