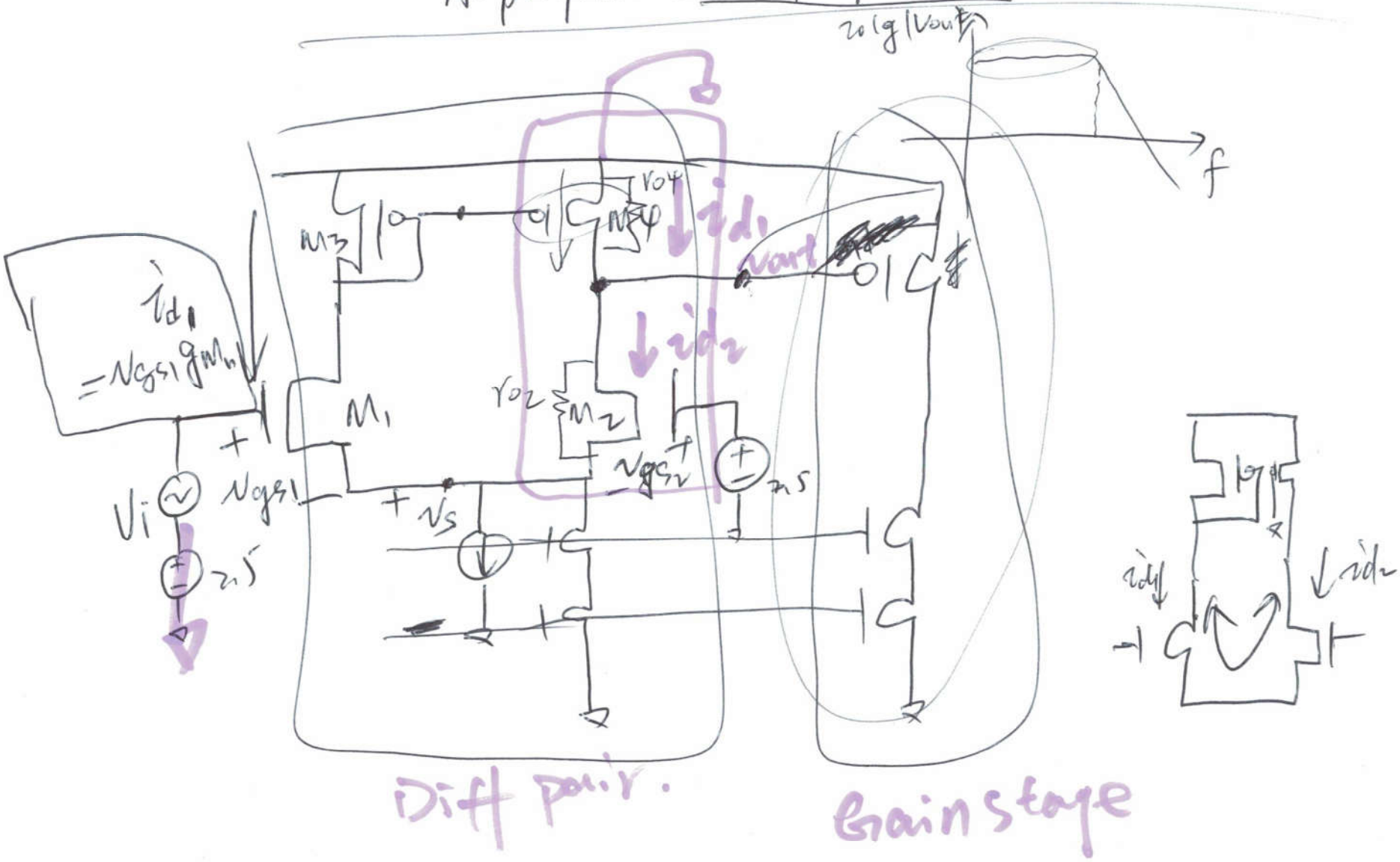
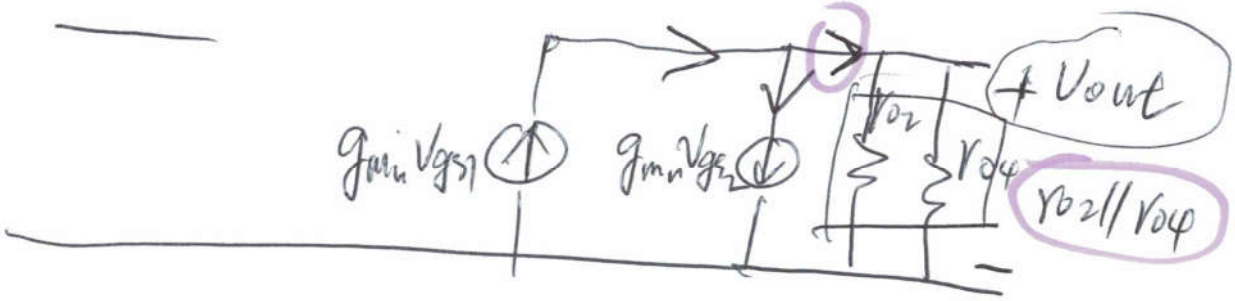
Amplifiers (low-frequency open-loop gain)



small-signal model



$$\begin{cases} v_{out} = (g_{mn}v_{gs1} - g_{mn}v_{gs2})(r_{o2}//r_{o4}) \\ v_{di} = (v_{gs1} + v_S) - (v_{gs2} + v_S) = v_{gs1} - v_{gs2} \end{cases}$$

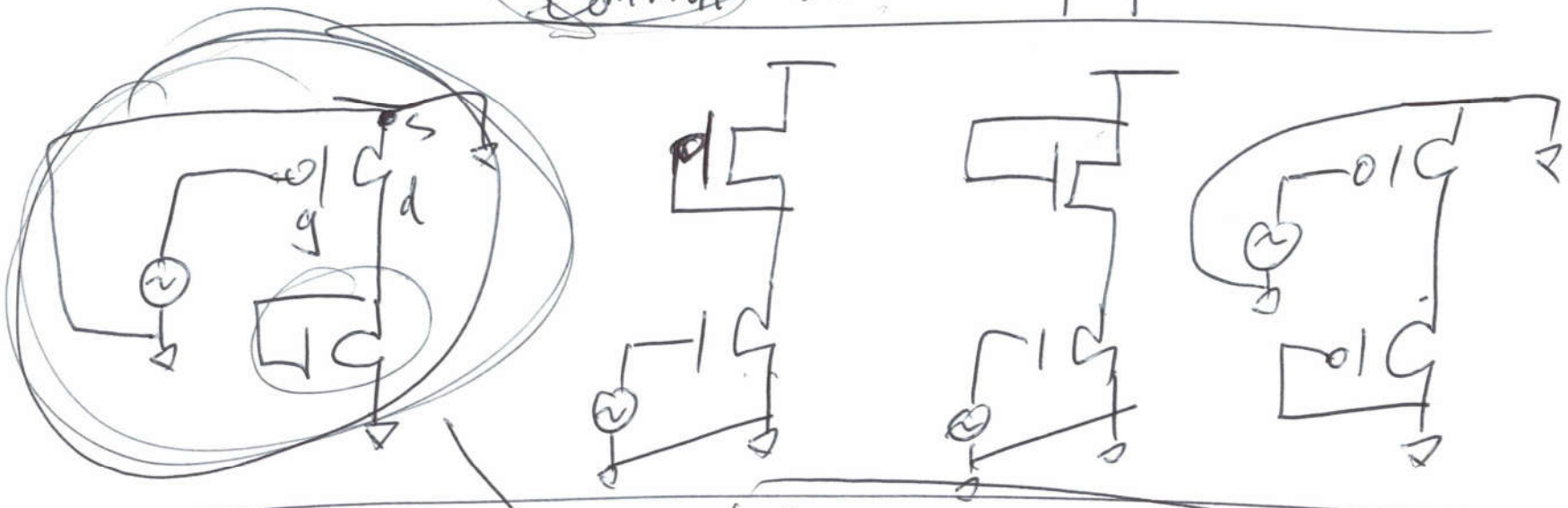
$$v_{out} = g_{mn}(v_{gs1} - v_{gs2})(r_{o2}//r_{o4})$$

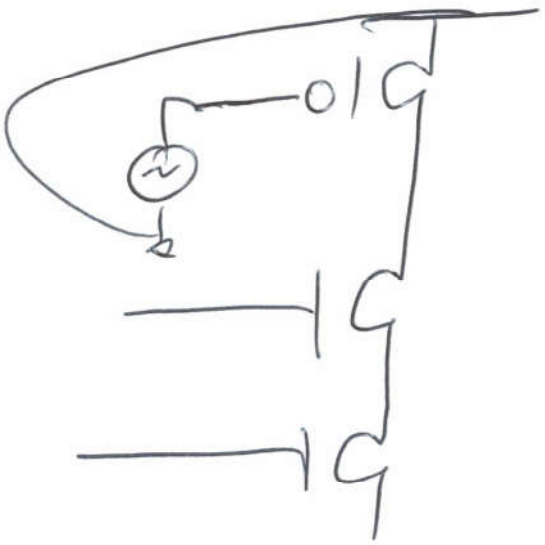
$$= g_{mn} \cdot v_{di} (r_{o2}//r_{o4})$$

$$\boxed{\frac{v_{out}}{v_{di}} = g_{mn}(r_{o2}//r_{o4})}$$

$$\begin{cases} g_{mn} = \beta(V_{GS} - V_{TH}) \\ r_o = \frac{1}{\lambda I_D} \end{cases}$$

Common-source Amplifier





v_{sg} + s
g
d $\Rightarrow$ $1/g_{mp}$

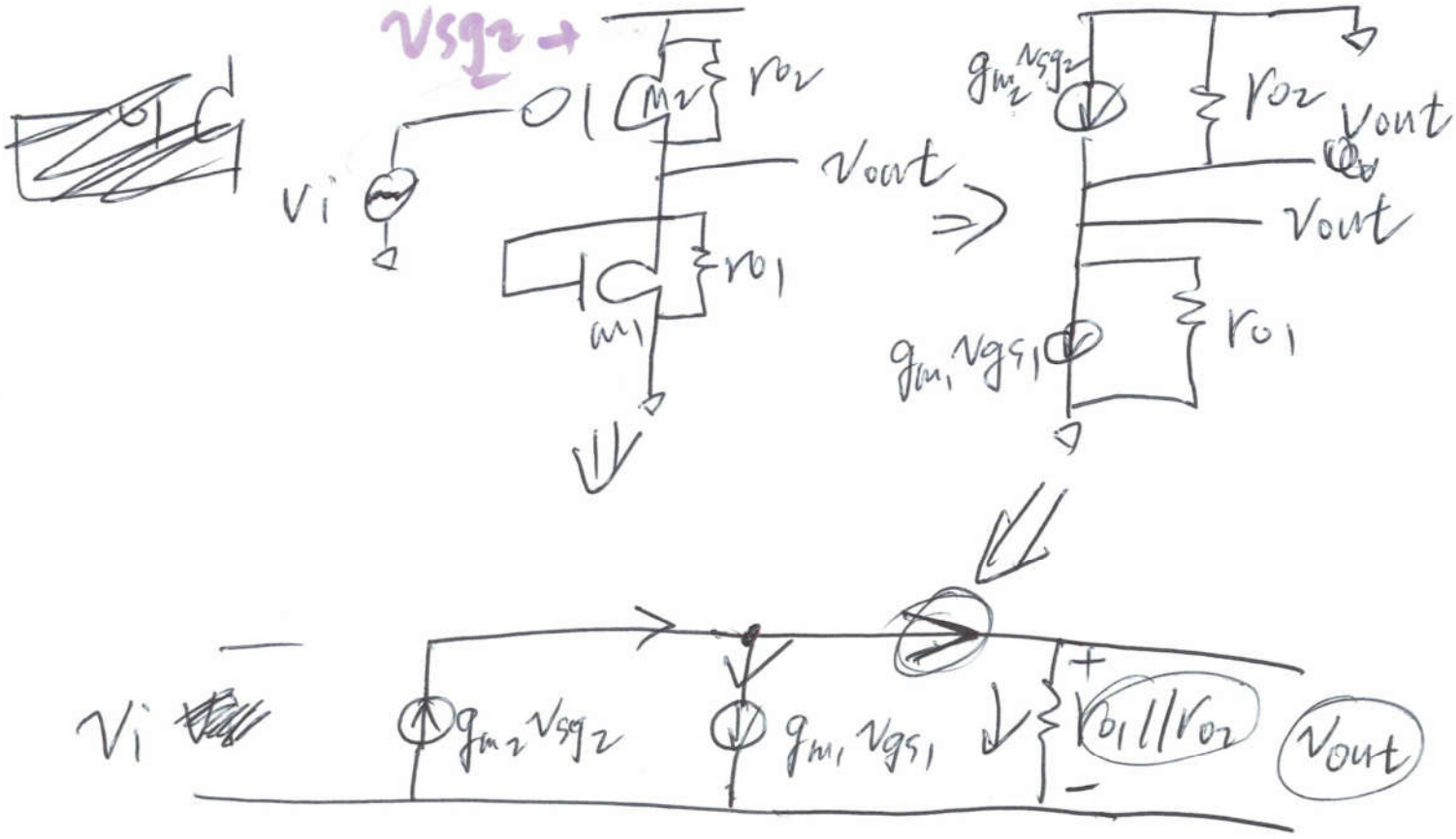
remember

$i_d = g_{mp} v_{sg} = g_{mp} v_{sd}$

$\frac{v_{sd}}{i_d} = 1/g_{mp}$

$\Rightarrow$ $1/g_{mn}$

remember



$$\frac{v_{out}}{v_i}$$

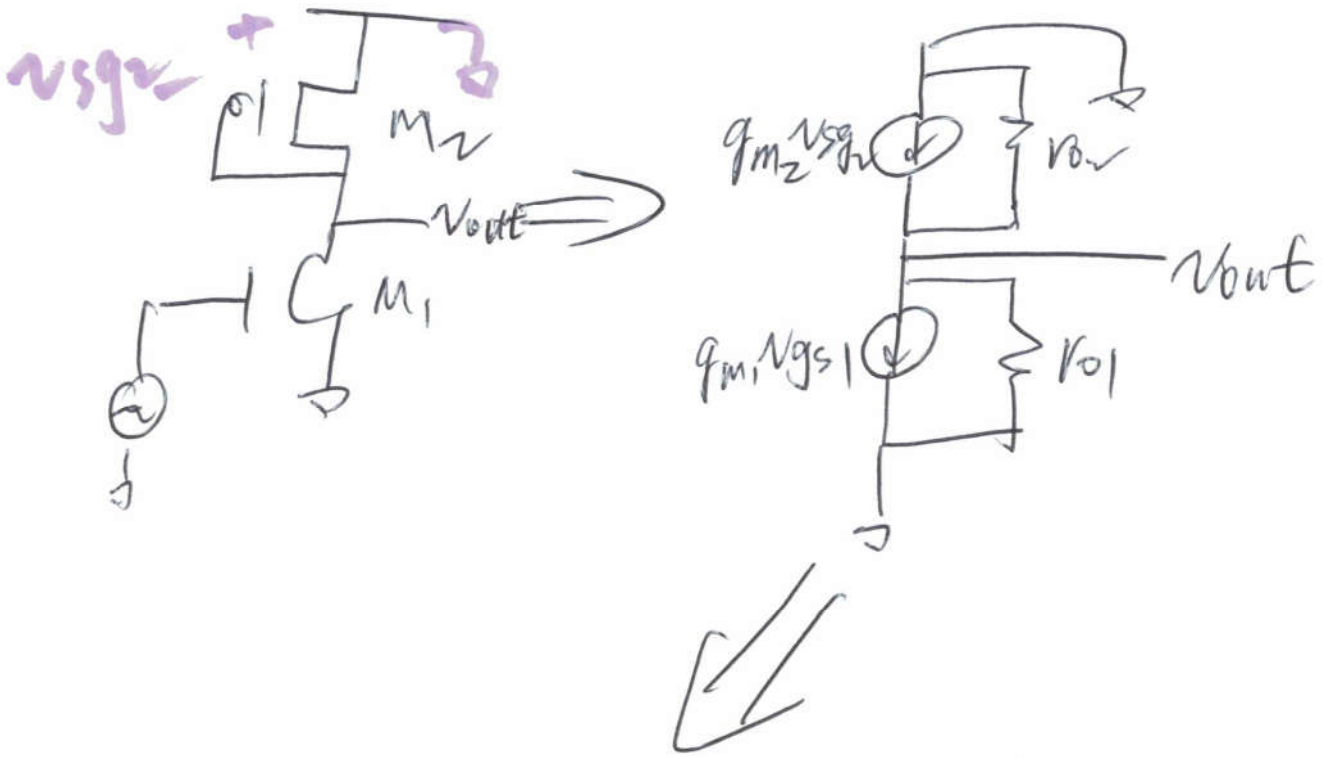
$$v_{out} = \left(g_{m2}v_{sg2} - g_{m1}v_{gs1}\right)(r_{o1}\|r_{o2})$$

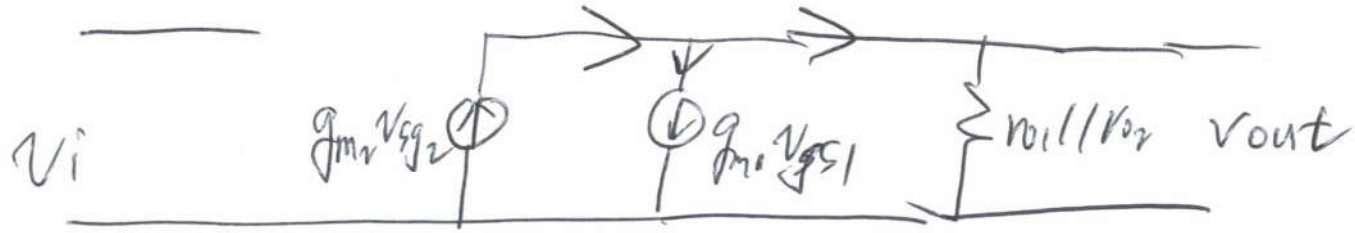
$v_{sg2} = -v_i$, $v_{gs1} = v_{out}$

$$v_{out} = \left(-g_{m2}v_i - g_{m1}v_{out}\right)(r_{o1}\|r_{o2})$$

$$v_{out}\left(1 + g_{m1}(r_{o1}\|r_{o2})\right) = -g_{m2}v_i(r_{o1}\|r_{o2})$$

$$\frac{v_{out}}{v_i} = \frac{-g_{m2}(r_{o1}\|r_{o2})}{1 + g_{m1}(r_{o1}\|r_{o2})} = -\frac{g_{m2}}{g_{m1}}$$





$$v_{out} = \left(g_{m2}v_{sg2} - g_{m1}v_{gs1}\right)(r_{o1}//r_{o2})$$

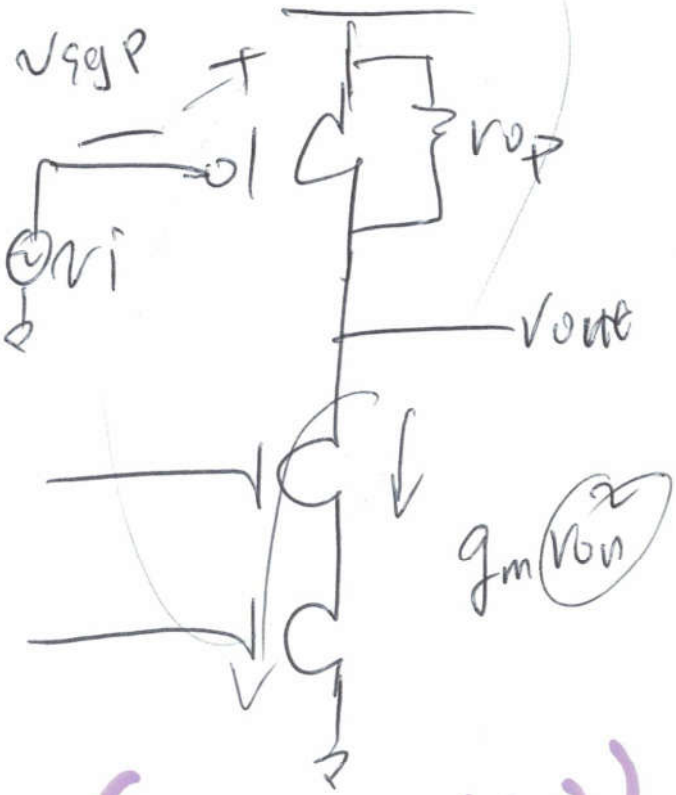
$-v_{out}$ v_i

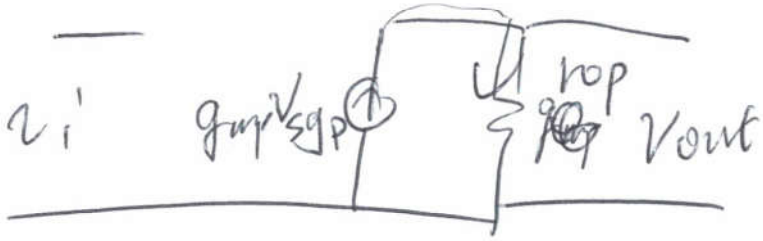
$$= \left(-g_{m2}v_{out} - g_{m1}v_i\right)(r_{o1}//r_{o2})$$

$$v_{out}\left(1+g_{m2}(r_{o1}//r_{o2})\right) = -g_{m1}v_i\,(r_{o1}//r_{o2})$$

$$\frac{v_{out}}{v_i} = \frac{-g_{m1}(r_{o1}//r_{o2})}{1+g_{m2}(r_{o1}//r_{o2})} \simeq -\frac{g_{m1}}{g_{m2}}$$

(7)





$$\begin{cases} v_{out} = (g_{mp} v_{sgp})\, r_{op} \\ v_{sgp} = -v_i \end{cases}$$

$$\frac{v_{out}}{v_i} = -g_{mp} r_{op}$$

$-(g_{mn}(r_{on2} \| r_{on1}))$ ~~$\times (g_{mp} r_{op})$~~