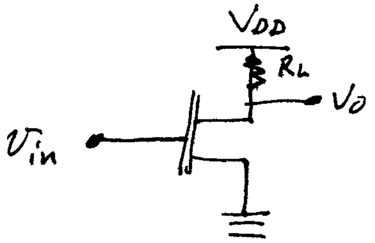
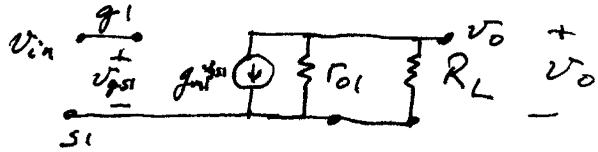
CH 22

Single Stage Amps

COMMON SOURCE

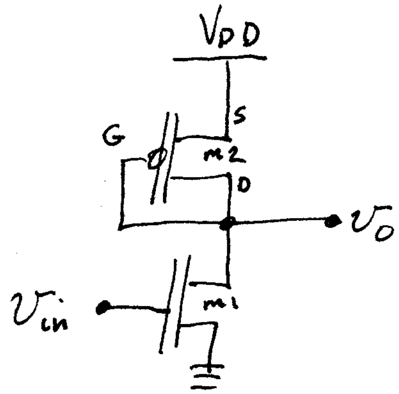


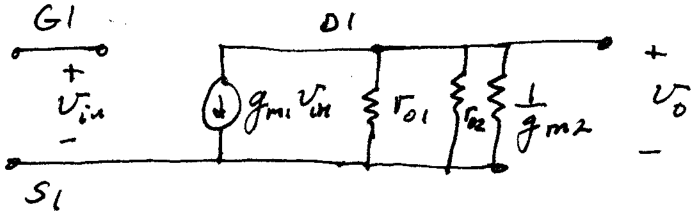


$v_{gs1} = v_{in}$

$v_o = -g_m v_{in}\, r_{o1} \| R_L$

$A_v \equiv \dfrac{v_o}{v_{in}} = -g_m\, r_{o1} \| R_L$



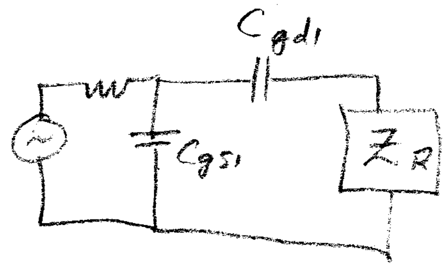


$$A_v = -g_{m1}\Big(r_{o1} \| \underbrace{r_{o2} \| \tfrac{1}{g_{m2}}}_{R_L}\Big)$$

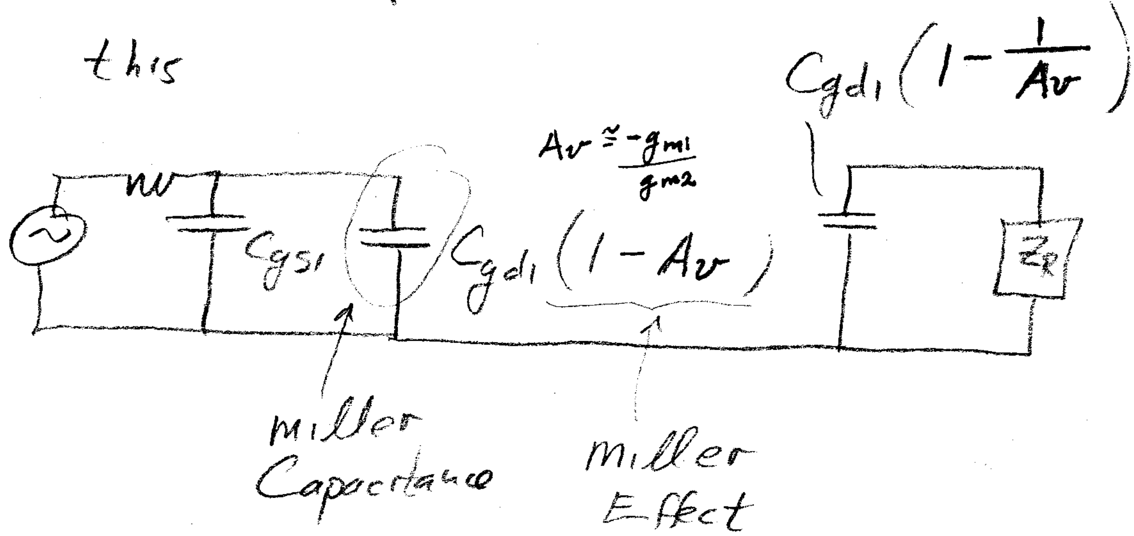
$$\approx -\frac{g_{m1}}{g_{m2}} \qquad \left(\tfrac{1}{g_{m2}} << r_{o1}, r_{o2}\right)$$

FREQUENCY RESPONSE

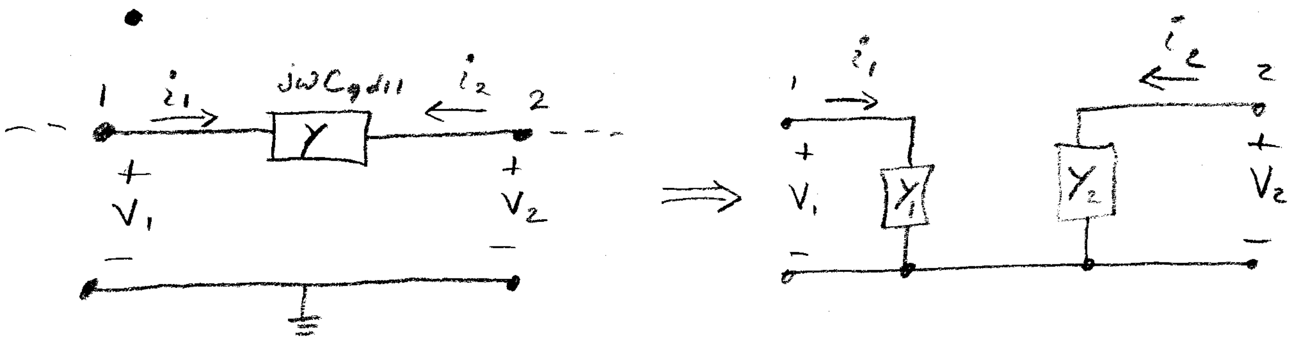
Use MILLERS THM to write this



As this



MILLER'S THM



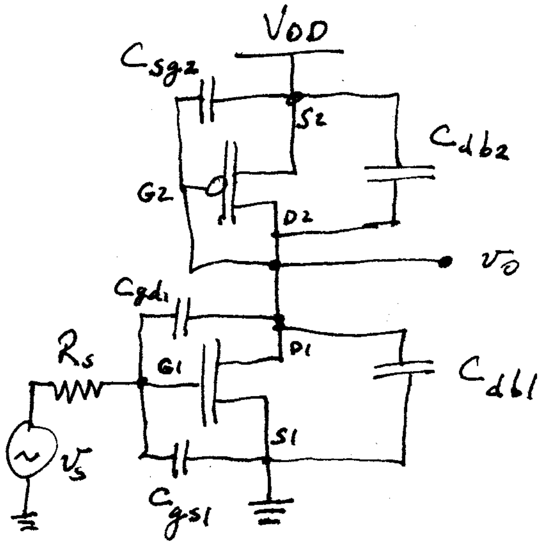
$$i_1 = Y(V_1 - V_2) = YV_1\left(1 - \underbrace{\frac{V_2}{V_1}}_{A_v}\right) = \underbrace{Y(1-A_v)}_{Y_1}V_1$$

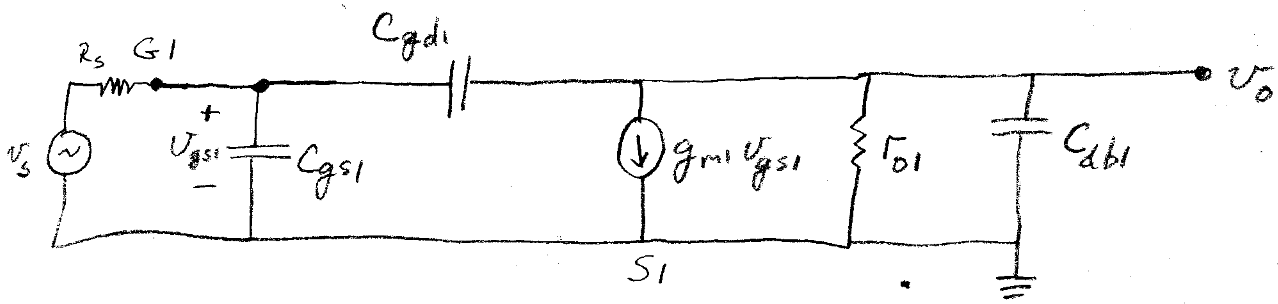
$$i_2 = Y(V_2 - V_1) = \underbrace{Y\left(1 - \frac{V_1}{V_2}\right)}_{Y_2}V_2 = Y\left(1 - \frac{1}{A_v}\right)V_2$$

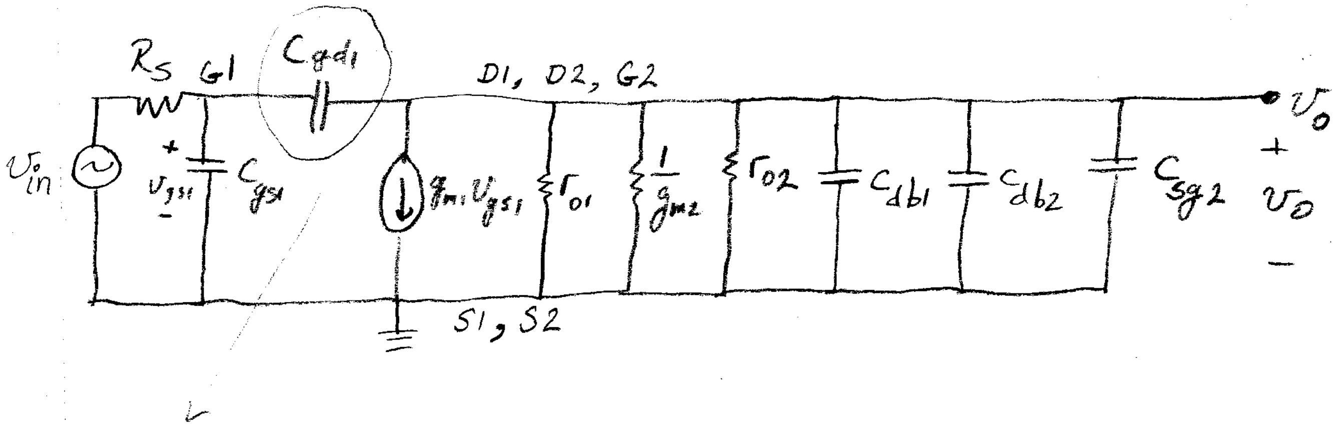
* Get effective large C on chip.

Used in Op-Amps to get large effective C for compensation. $j\omega C \rightarrow j\omega C(1+|A_v|)$

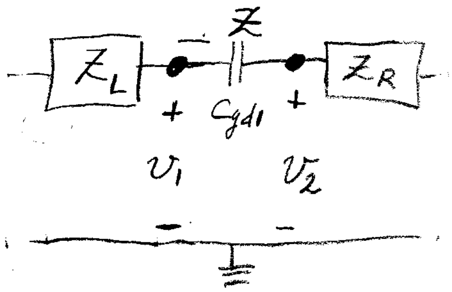
In an Op-Amp, $A_v \sim 1000 - 100{,}000$.

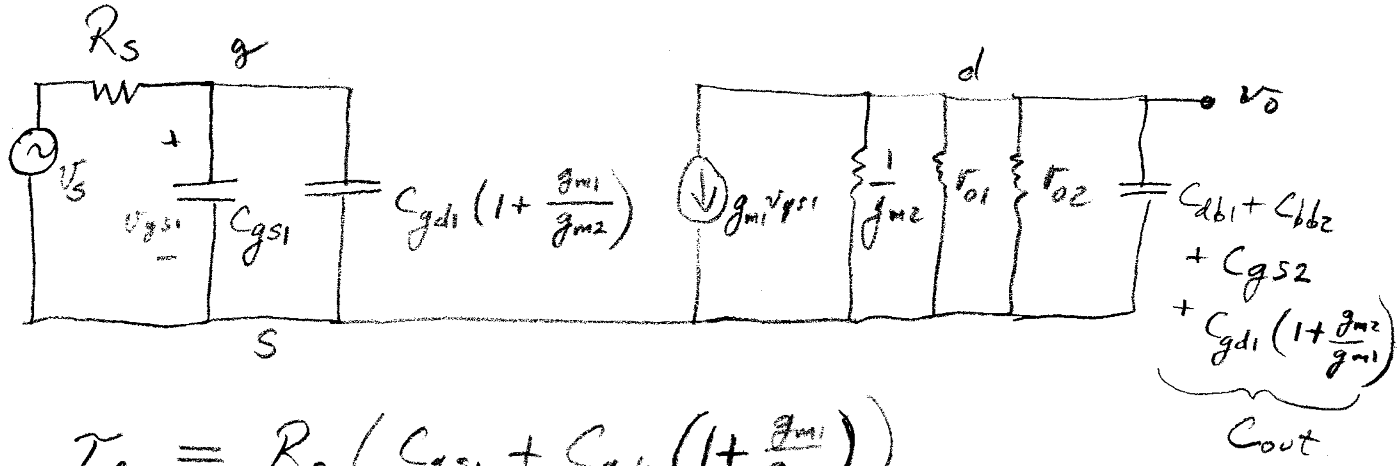






makes analysis hard.





$$T_{in} = R_S\left(C_{gs1} + C_{gd1}\left(1+\frac{g_{m1}}{g_{m2}}\right)\right)$$

$$T_{out} \approx \frac{1}{g_{m2}}\left(C_{gs2} + C_{gd1}\left(1+\frac{g_{m2}}{g_{m1}}\right) + C_{db1} + C_{db2}\right)$$

$$v_{gs1} = \frac{v_S\,\frac{1}{j\omega\, C}}{R_S + \frac{1}{j\omega\,(C_{gs1} + \;)}} = v_S\,\frac{1}{1+j\omega R_S C}$$

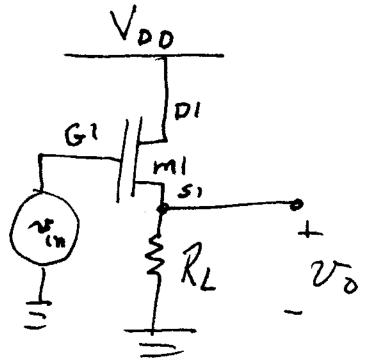
$$v_{gs1} = v_S\,\frac{1}{1+j\omega T_{in}}$$

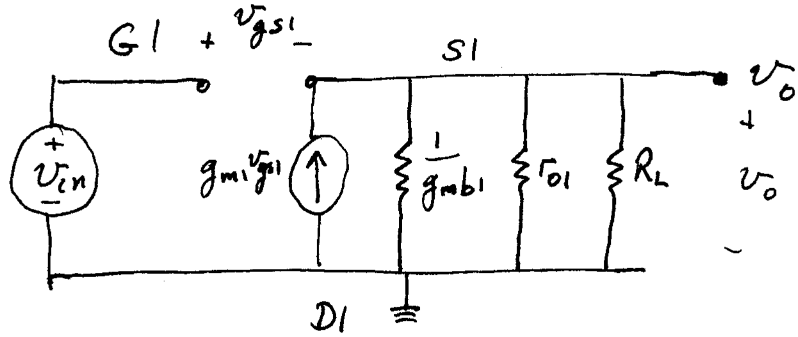
$$\frac{v_o}{v_S} \cong -g_{m1}\, v_S\,\frac{1}{(1+j\omega T_{in})}\underbrace{\left(\frac{1}{g_{m2}}\,\Big\|\,\frac{1}{j\omega C_{out}}\right)}_{\frac{1/g_{m2}}{1+j\omega\frac{1}{g_{m2}}C_{out}}}$$

$$A_v = \frac{-g_{m1}/g_{m2}}{(1+j\omega T_{in})(1+j\omega T_{out})}$$

Impedence Transformer

COMMON DRAIN (Source Follower)





$v_{sb} = v_{sd}$

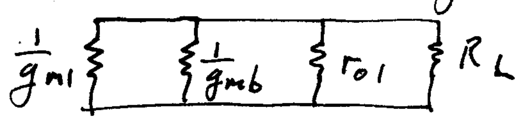
$$v_{in} - v_o = v_{gs1}$$

$$v_o = g_m (v_{in} - v_o)\left(\frac{1}{g_{mb1}} \| r_{o1} \| R_L\right)$$

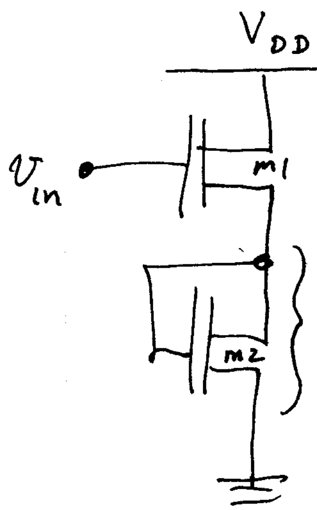
$$v_o\left(1 + g_m\left(\frac{1}{g_{mb1}} \| r_{o1} \| R_L\right)\right) = g_m v_{in}\left(\quad\right)$$

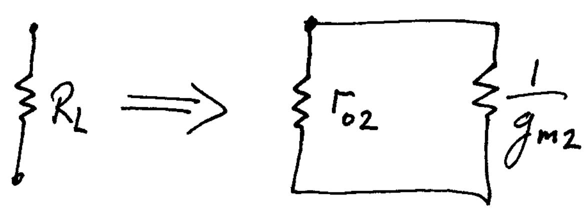
$$\frac{v_o}{v_{in}} = A_v = \frac{g_{m1}\left(\frac{1}{g_{mb1}} \| r_{o1} \| R_L\right)}{1 + g_{m1}\left(\frac{1}{g_{mb1}} \| r_{o1} \| R_L\right)} < 1$$

$R_o =$ $\quad v_o = v_{sd} = v_{sg} = -v_{gs}$

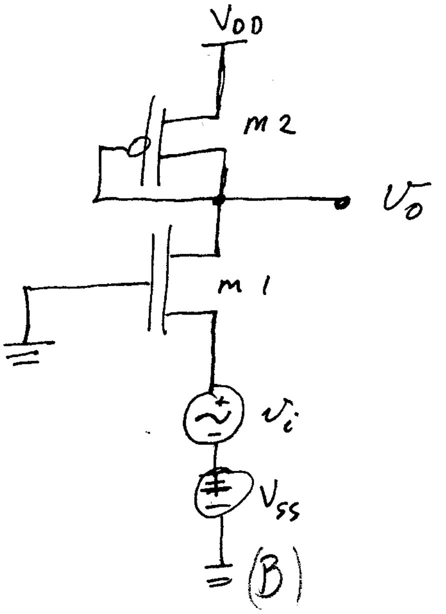


$\sim \frac{1}{g_m}$ (low)

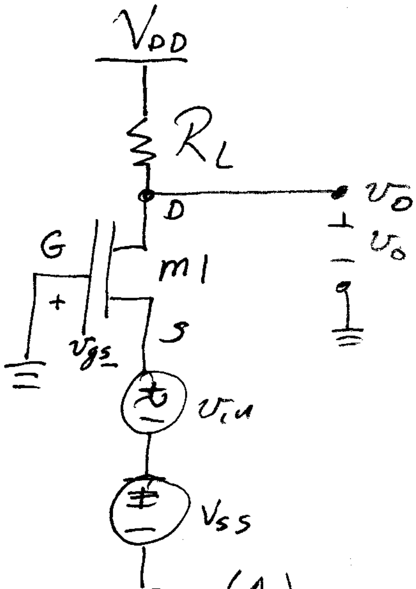




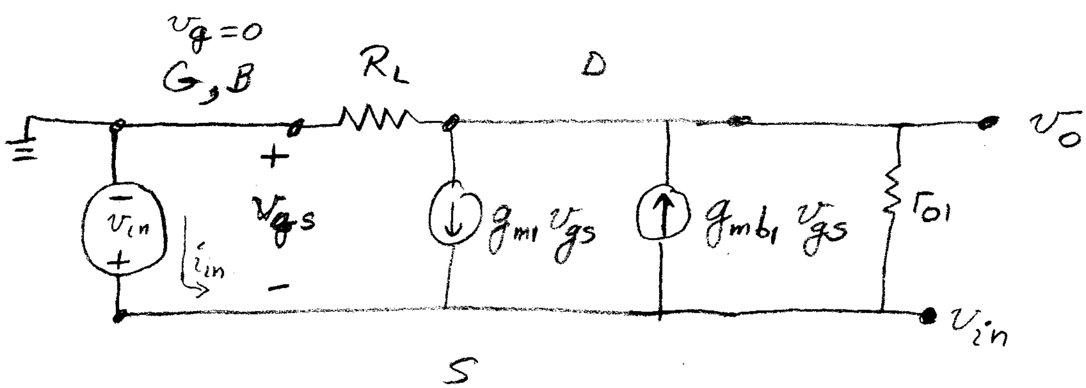
Common Gate



(B)



(A)



$$v_{gs} = -v_{in} = -v_S$$

$$\frac{v_o}{R_L} + \frac{v_o - v_{in}}{r_{o1}} + g_{m1}(1-\chi)(-v_{in}) = 0$$

$$v_o\left(\frac{1}{R_L} + \frac{1}{r_{o1}}\right) = v_{in}\left(\frac{1}{r_{o1}} + g_{m1}(1-\chi)\right)$$

$$\boxed{\frac{v_o}{v_{in}} \equiv A_v = \frac{\frac{1}{r_{o1}} + g_{m1}(1-\chi)}{\frac{1}{R_L} + \frac{1}{r_{o1}}}} \approx R_L g_{m1}(1-\chi)$$

$r_{o1} >> R_L$

$$R_{in} = \frac{v_{in}}{i_{in}} = \frac{v_{in}}{v_o / R_L} = \frac{R_L}{A_v} \approx \frac{1}{g_{m1}(1-\chi)}$$

$$R_{out} = r_{o1} \| R_L$$

FOR (B) $R_L \Rightarrow \frac{1}{g_{m2}} \| r_{o2} \approx \frac{1}{g_{m2}}$

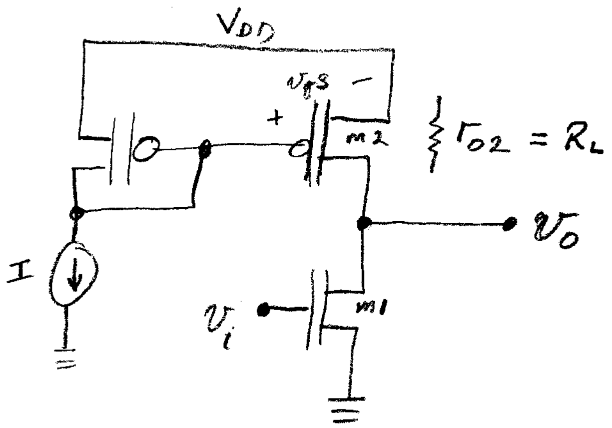
$$A_v = \frac{g_{m1}}{g_{m2}}(1-\chi)$$

$$R_{in} = \frac{1}{g_{m2}} \frac{g_{m2}}{g_{m1}(1-\chi)} = \frac{1}{g_{m1}(1-\chi)}$$

$$R_{out} = r_{o1} \| \frac{1}{g_{m2}} = \frac{1}{g_{m2}}$$

CURRENT SOURCE LOADS

Common Source



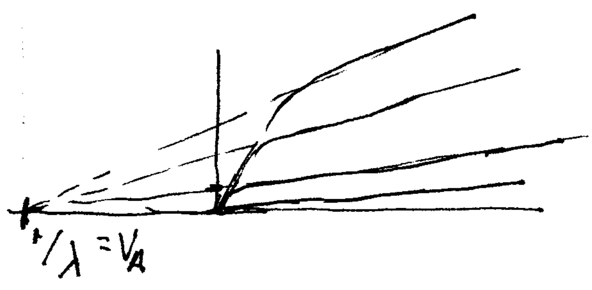
$R_L = r_{o2}$

$$A_v = -g_{m1}\, r_{o1} \| r_{o2} \quad \text{(high)}$$

$$R_o = r_{o1} \| r_{o2} \quad \text{(high)}$$

$$A_v = -\frac{\sqrt{2\beta_1 I_D}}{(\lambda_1 + \lambda_2) I_D} \quad \left(r_o = \frac{1}{\lambda I_D} \right)$$

$$= -\frac{\sqrt{2\beta_1}}{(\lambda_1 + \lambda_2)\sqrt{I_D}} \sim \frac{1}{\sqrt{I_D}}$$



$$r_o = \frac{1}{\lambda I_D} \sim \frac{1}{I_D}$$

$\lambda = 0.6$

$r_o(5\mu A) = 333\,k\Omega$

$r_o(5mA) = 333\,\Omega$

FREQ. RESPONSE

$R_L \to r_{o2}$

$A_v = -g_{m1} \, r_{o1} \| r_{o2}$

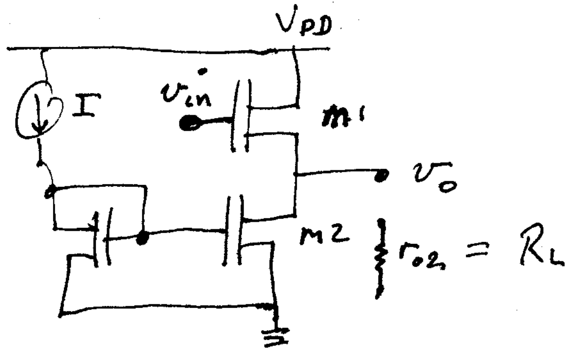
Miller Capacitance

$C_m = C_{gd1}(1 - A_v)$ large $\to Z_{in} = R_s C_{in}$ long

Gain Band Width Product

$$|A_v| \frac{1}{R_s C_{gd1} |A_v|}$$

Source follower (Impedance Transformer)



$A_v =$

$(r_{o1} = r_{o2} = r_o)$

$$A_v = \frac{g_{m1}\left(\frac{1}{g_m \chi} \| r_{o1} \| r_{o2}\right)}{1 + g_{m1}\left(\frac{1}{\chi g_m} \| r_{o1} \| r_{o2}\right)} = \frac{1}{1 + \chi + \frac{2}{g_m r_o}} < 1$$

$$R_o = \frac{1}{g_{m1}} \| \frac{1}{\chi g_{m1}} \| r_{o1} \| r_{o2} = g_{m1}(1+\chi) \| r_{o1} \| r_{o2}$$

$$\Big(g_{m1}(1+\chi) + \underbrace{\frac{1}{r_{o1}} + \frac{1}{r_{o2}}}_{\frac{2}{r_o}}\Big)^{-1} = \frac{r_o}{g_{m1}(1+\chi) r_o + 2}$$

$$= \frac{1/g_{m1}}{1 + \chi + \frac{2}{g_{m1} r_o}}$$

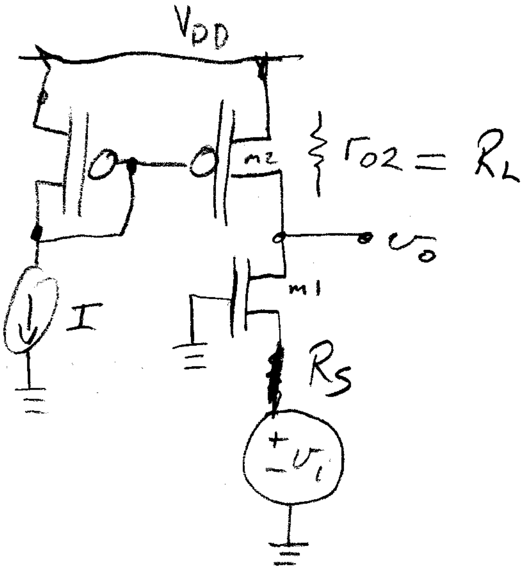
$$\left(\frac{g_m \chi r_o + 2}{r_o}\right)^{-1} = \frac{r_o}{g_m r_o \chi + 2}$$

$$A_v = \frac{g_{m1}\dfrac{r_o}{g_m r_o \chi + 2}}{1 + g_{m1}\left(\dfrac{r_o}{g_m r_o \chi + 2}\right)}$$

$$= \frac{g_m r_o}{g_m r_o (1+\chi) + 2}$$

$$= \frac{1}{1 + \chi + \dfrac{2}{g_m r_o}} < 1$$

Common Gate



$$A_v = \frac{1}{r_{o1}} + g_{m1}(1-\chi)\, r_{o1} \| r_{o2}$$

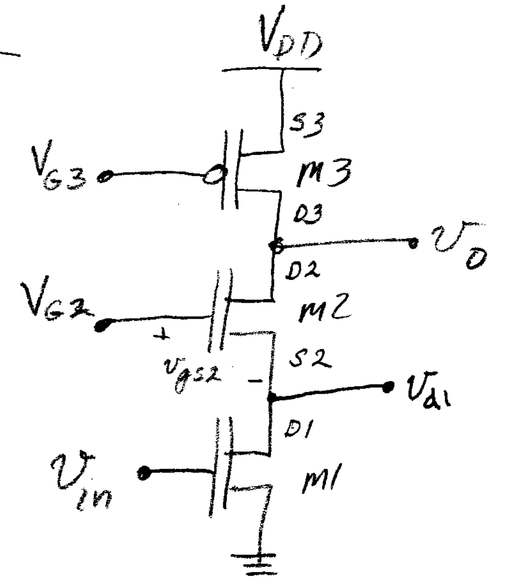
$$\approx g_{m1}(1-\chi)\, r_{o1} \| r_{o2}$$

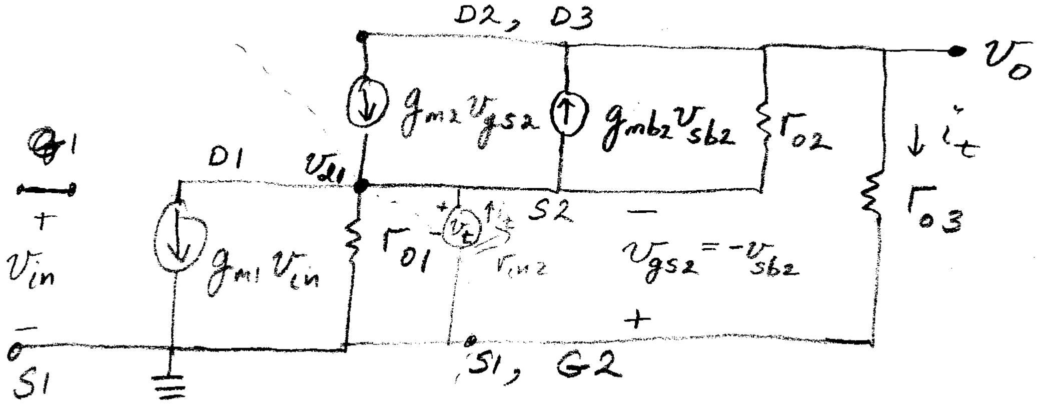
$$R_{in} = \frac{r_{o2}}{A_v} \approx \frac{r_o}{g_{m1}(1-\chi)\frac{r_o}{2}}$$

$$= \frac{2}{g_{m1}(1-\chi)}$$

$$R_o = r_{o1} \| r_{o2}$$

Cascode Amp





$$v_{d1} = -g_{m1} v_{in} \, r_{o1} \| r_{in2}$$

$$v_t = -v_{gs2} = v_{sb2}$$

$$i_t + g_{m2}(-v_t) - g_{mb2} v_t + \frac{v_o - v_t}{r_{o2}} = 0$$

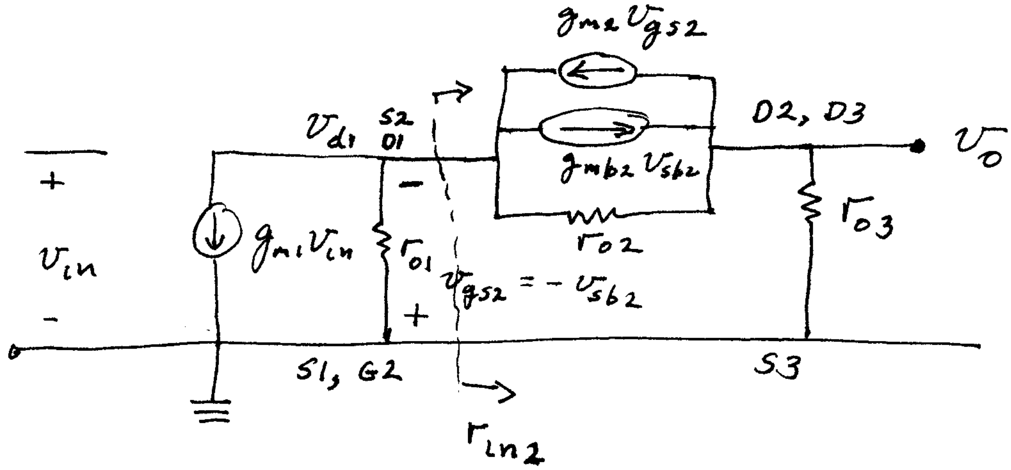
$$-\frac{v_o}{r_{o3}} - \frac{(v_o - v_t)}{r_{o2}} + g_{mb2} v_t + g_{m2} v_t = 0$$

$$v_o = i_t r_{o3}$$

$$i_t \left(1 + \frac{r_{o3}}{r_{o2}}\right) = v_t \left(g_{m2}(1+\chi) + \frac{1}{r_{o2}}\right)$$

$$r_{in2} = \frac{v_t}{i_t} = \frac{1 + \frac{r_{o3}}{r_{o2}}}{\left(g_{m2}(1+\chi) + \frac{1}{r_{o2}}\right)}$$

$$r_{in2} = \frac{r_{o2} + r_{o3}}{g_{m2} r_{o2}(1+\chi) + 1} \approx \frac{1}{g_{m2}(1+\chi)}\left(1 + \frac{r_{o3}}{r_{o2}}\right)$$



$g_{m2}v_{gs2}$
v_{d1}
S2
D1
D2, D3
v_o
+
v_{in}
-
$g_{mb2}v_{sb2}$
r_{o3}
$g_{m1}v_{in}$
r_{o1}
r_{o2}
$v_{gs2} = -v_{sb2}$
S1, G2
S3
r_{in2}

$$A_{v1} \equiv \frac{v_{d1}}{v_{in}} = -g_{m1}\, r_{o1} \,\|\, \frac{1}{g_{m2}}\left(1+\frac{r_{o3}}{r_{o2}}\right)$$

$$A_{v1} \approx -\frac{g_{m1}}{g_{m2}}\left(1+\frac{r_{o3}}{r_{o2}}\right) \qquad \left(r_{o1} >> \frac{1}{g_{m2}}\right)$$

M2 is acting as a common gate amp.

$$A_{v2} = \frac{\frac{1}{r_{o2}} + g_{m2}(1-\chi)}{\frac{1}{r_{o3}} + \frac{1}{r_{o2}}}$$

$$i_t = \frac{v_{d1}}{r_{in2}}; \quad v_o = i_t\, r_{o3} = \frac{v_{d1}}{r_{in2}}\, r_{o3}$$

$$v_{d1} = A_{v1}\, v_{in}$$

$$v_o = \frac{A_{v1}\, v_{in}}{r_{in2}}\, r_{o3}$$

$$A_v = A_{v1}\, \frac{r_{o3}}{r_{in2}} =$$

$$A_{v1} = -g_{m1}\, r_{o1} \,\|\, r_{in2} = -g_{m1}\, \frac{r_{o1}\, r_{in2}}{r_{o1}+r_{in2}}$$

$$A_v = -g_{m1}\, \frac{r_{o1}\, r_{o3}}{r_{o1}+r_{in2}}$$

$$\cong -g_{m1}\, \frac{r_{o1}\, r_{o3}}{r_{o1} + \frac{r_{o2}+r_{o3}}{g_{m2} r_{o2}(1+\chi) + \chi}} \cong \frac{r_{o1}\, r_{o3}}{r_{o1} + \frac{1}{g_{m2}(1+\chi)}\,(1+}$$

$$= -g_{m1}\, \frac{r_{o1}\, r_{o3}}{r_{o1} + \frac{r_{o2}+r_{o3}}{g_{m2} r_{o2}(1+\chi)}}$$

$$= -g_{m1} \frac{g_{m2} r_{o1} r_{o2} r_{o3}}{g_{m2} r_{o1} r_{o2} + \frac{r_{o2} + r_{o3}}{(1+x)}}$$

$$\cong -g_{m1} r_{o3}$$

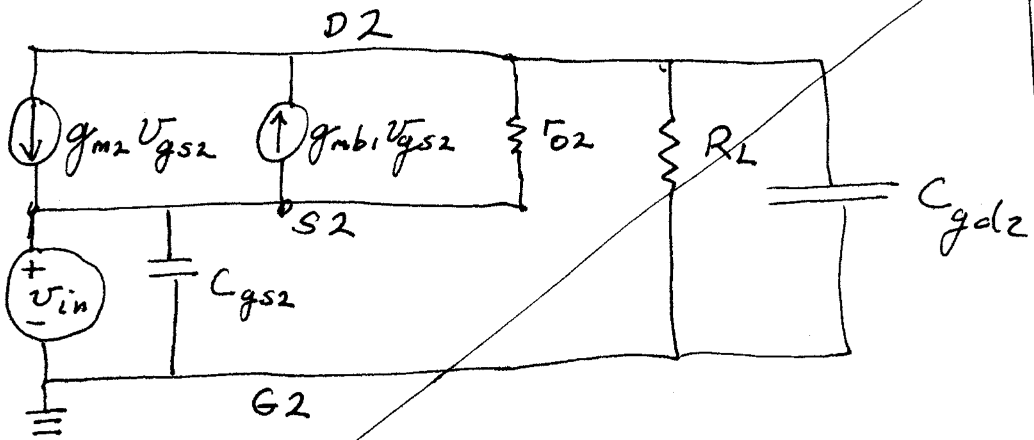
For Com. Source w/ current mirror load

$$A_v = -g_{m1} r_{o1} \| r_{o2} \cong -g_{m1} \frac{r_o}{2}$$

⇒ The cascode ≈ doubles A_v.

FREQUENCY RESPONSE

Common Gate M2



$$\left(j\omega C + \frac{1}{R}\right)^{-1} = \frac{R}{1 + j\omega RC}$$

$$Y = \frac{1 + j\omega RC}{R}$$

$$Y_m = \frac{1 + j\omega RC}{R}(1 - g_m R) \approx -g_m - j\omega g_m RC$$

$$= -g_m (1 + j\omega RC)$$

$$R_m = -\frac{1}{g_m} \Big/ (1 + j\omega RC)$$

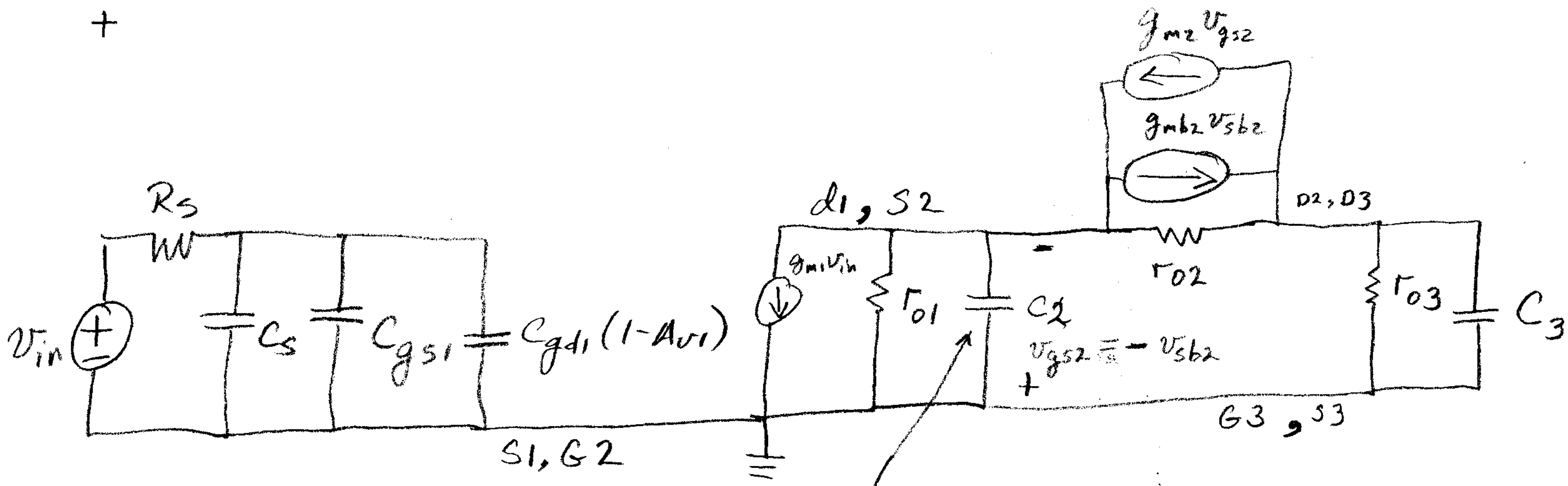
$$\tau_{in} = R_s\left(C_s + C_{gs1} + C_{gd1}\frac{g_{m1}}{g_{m2}}\left(1+\frac{r_{o2}}{r_{o3}}\right)\right)$$

MILLER EFFECT SMALL SINCE A_{v1} small

$$\tau_2 = C_2\, r_{o1} \parallel r_{in2} = C_2\, r_{o1} \parallel \frac{1}{g_{m2}}\left(1+\frac{r_{o2}}{r_{o3}}\right) \approx C_2\frac{1}{g_{m2}}$$ (SMALL) since $\frac{1}{g_{m2}}$ low R

$$\tau_{out} \cong r_{o3}\, C_3 \approx r_{o3}\, C_L$$

+



$C_{db1} + C_{sb2} + C_{gs2} + C_{gd1}\left(1 - \frac{1}{A_v}\right)$

$$C_3 = \underbrace{C_{gd3} + C_{gd2} + C_{db2} + C_{db3}}_{\text{Small}} + C_L$$

$$\frac{v_{s2}}{r_{o1}} + g_{m2}v_{s2}(1+\chi) + \frac{v_{s2}-v_{D2}}{r_{o2}} = 0$$

$$v_{s2}\left(\frac{1}{r_{o1}} + g_{m2}(1+\chi) + \frac{1}{r_{o2}}\right) = \frac{v_{D2}}{r_{o2}}$$

W5