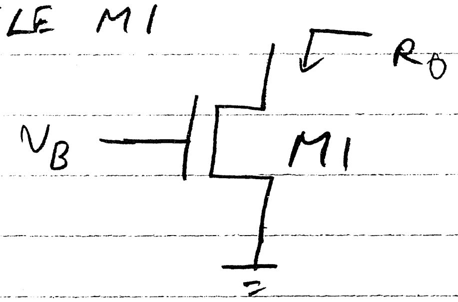
CASCODE AMPLIFIER

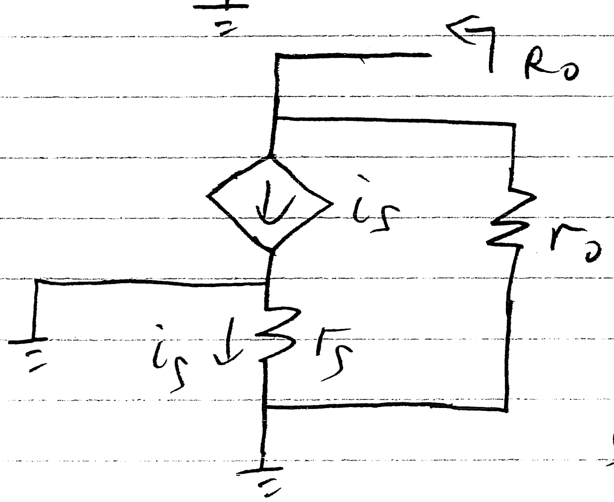
TO INCREASE GAIN OF AMPLIFIER
(AND ALSO INCREASE FREQUENCY RESPONSE
→COVERED IN FREQ RESPONSE SECTION)

OUTPUT IMPEDANCE

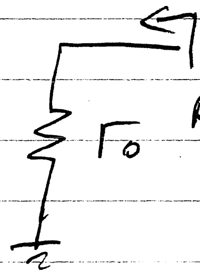
SINGLE M1



M1 ACTIVE



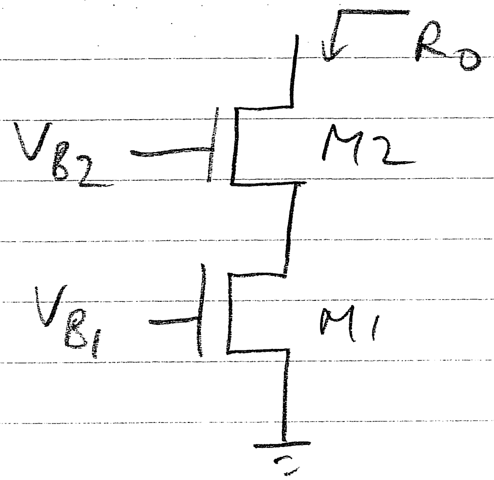
⇒



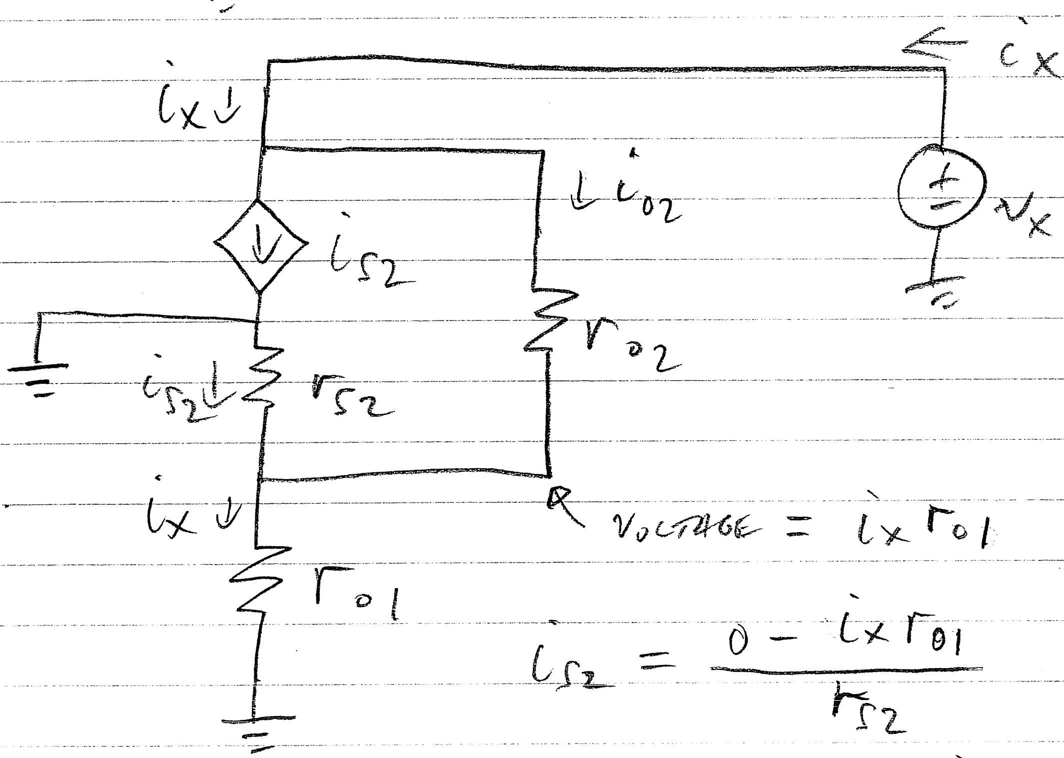
$R_O = r_o$

SINCE $i_s = 0$

CASCODE TRANSISTOR



M_1, M_2 ACTIVE



VOLTAGE $= i_x r_{o1}$

$$i_{s2} = \frac{0 - i_x r_{o1}}{r_{s2}}$$

$$i_{o2} = \frac{v_x - i_x r_{o1}}{r_{o2}}$$

$$i_x = i_{o2} + i_{s2} = \frac{v_x - i_x r_{o1}}{r_{o2}} + \frac{-i_x r_{o1}}{r_{s2}}$$

$$i_x\left(1+\frac{r_{o1}}{r_{o2}}+\frac{r_{o1}}{r_{s2}}\right)=\frac{v_x}{r_{o2}}$$

$$R_o \equiv \frac{v_x}{i_x} = \left(1+\frac{r_{o1}}{r_{o2}}+\frac{r_{o1}}{r_{s2}}\right) r_{o2}$$

$$\boxed{R_o = r_{o1} + r_{o2} + g_{m2} r_{o1} r_{o2}}$$ EXACT

SINCE $r_{s2} = \frac{1}{g_{m2}}$

SINCE $g_{m2} r_o \gg 1$
(MORE OR LESS)

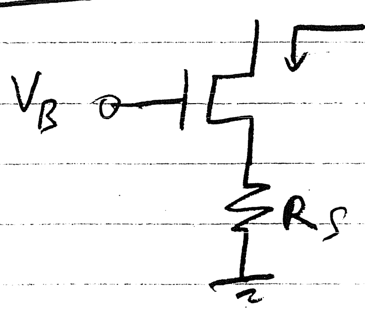
APPROX

$$\boxed{R_o \simeq g_{m2} r_{o1} r_{o2}}$$

IF $r_o = r_{o1} = r_{o2}$
& $g_m = g_{m1} = g_{m2}$

$$R_o \cong g_m r_o^2$$

<u>IN GENERAL</u>

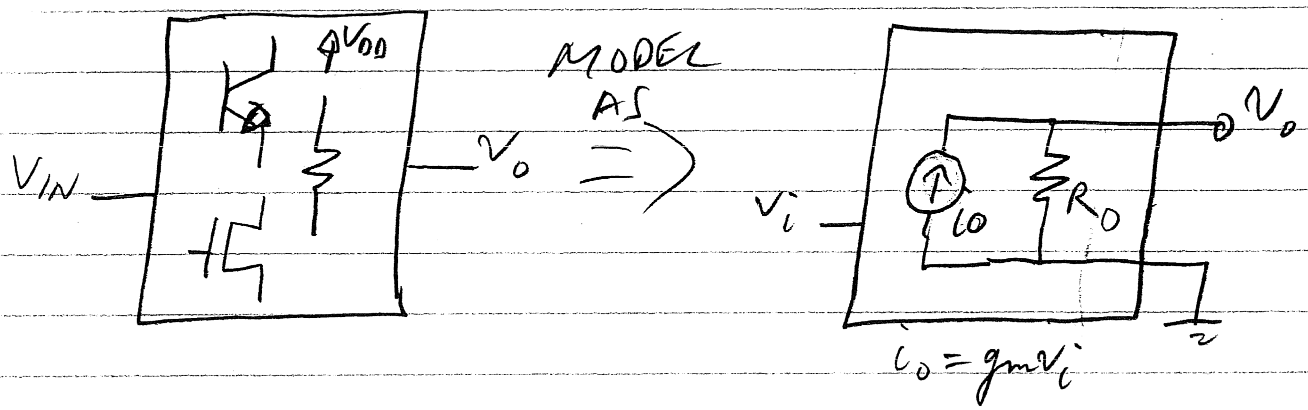


$$R_{OUT} = R_S + r_o + g_m r_o R_S$$

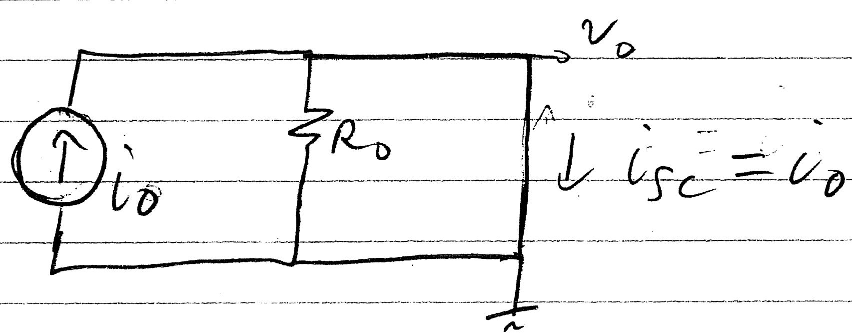
$$\boxed{R_{OUT} \simeq (1 + g_m R_S)\, r_o}$$

FOR $g_m R_o \gg 1$
(OR $\frac{R_o}{r_s} \gg 1$)

A METHOD TO FIND GAIN IN A CIRCUIT



FIND SHORT CIRCUIT CURRENT, i_{sc}



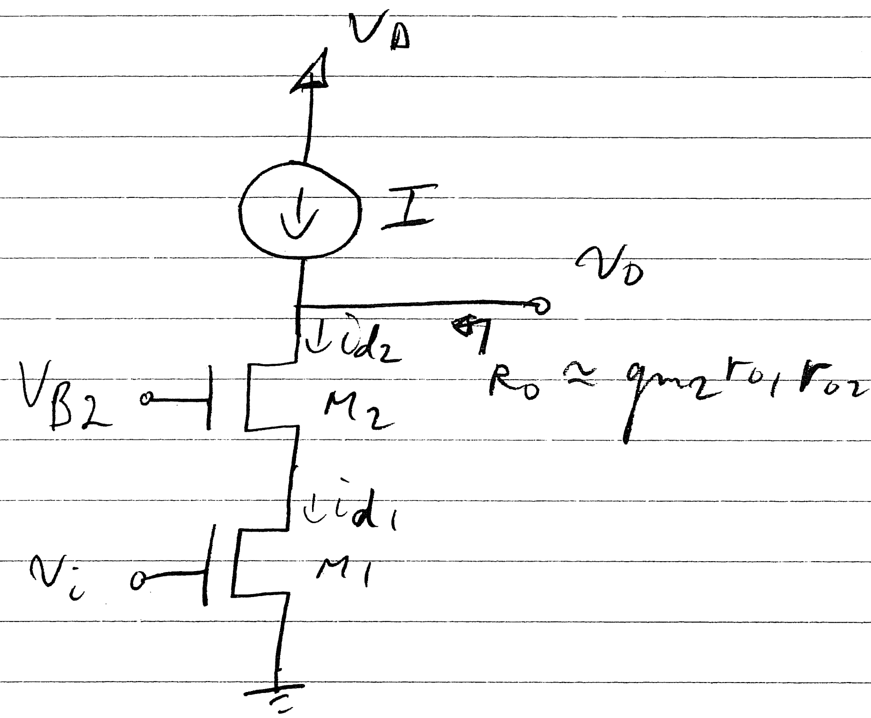
SO OPEN CIRCUIT VOLTAGE $v_o = i_o R_o$

WHERE R_o IS OUTPUT IMPEDANCE OF CIRCUIT.

$\frac{v_o}{v_i}$ GAIN

(CA4)

CASCODE AMP WITH IDEAL CURRENT SOURCE



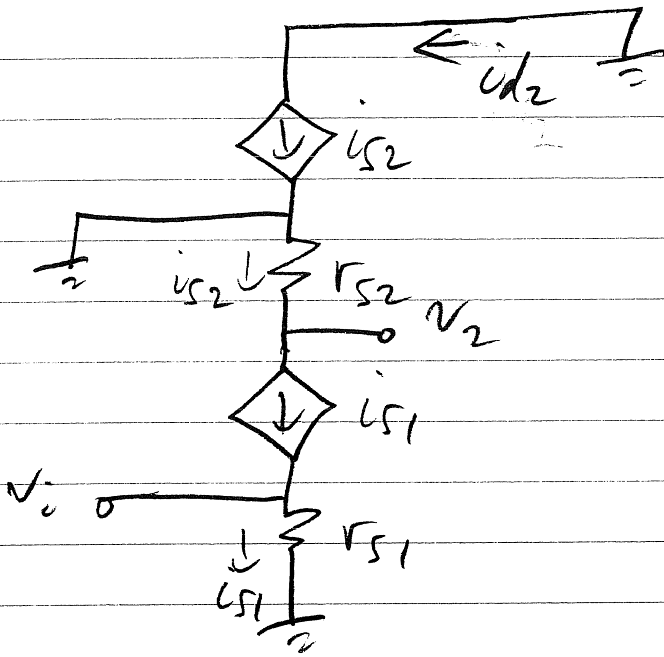
FIRST FIND i_{d2} IF v_o GROUNDED

THEN $\frac{v_o}{v_i} = -i_{d2} R_o$

CA5

i_{d2}

ASSUME $r_{o1} = r_{o2} \to \infty$



$$i_{d2} = i_{s2} = \frac{0 - v_2}{r_{s2}} = i_{s1} = \frac{v_i}{r_{s1}} = g_{m1} v_i$$

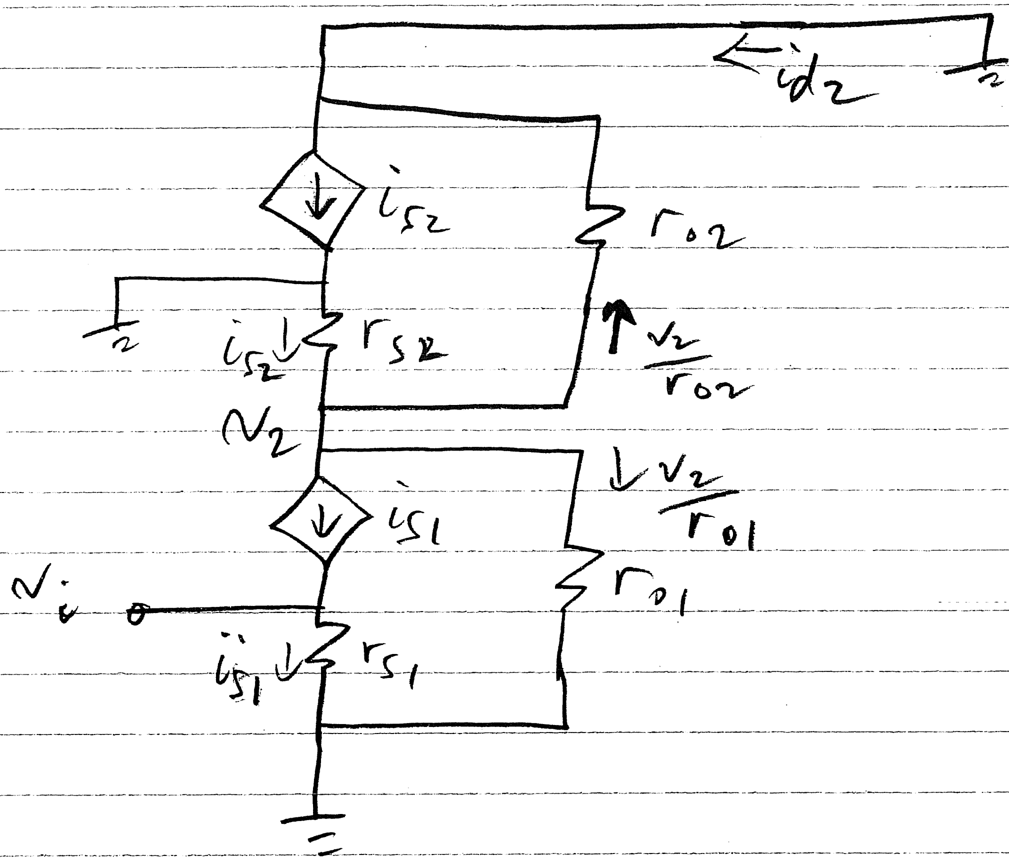
$$i_{d2} = g_{m1} v_i$$

SO $\frac{v_o}{v_i} = -g_{m1} R_o$

CA6

i_{d2}

IF r_{o1} & r_{o2} FINITE



$$\frac{v_i}{r_{s1}} + \frac{v_2}{r_{o1}} + \frac{v_2}{r_{o2}} + \frac{v_2}{r_{s2}} = 0$$

$$v_i\left(\frac{1}{r_{s1}}\right) = -v_2\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + \frac{1}{r_{s2}}\right)$$

BUT $r_{s2} \ll r_{o1}$ & r_{o2} SO

$$v_i\left(\frac{1}{r_{s1}}\right) \simeq -v_2\left(\frac{1}{r_{s2}}\right)$$

$$v_2 \simeq -\left(\frac{r_{s2}}{r_{s1}}\right) v_i$$

$$i_{d2} = -\frac{v_2}{r_{o2}} + i_{s2}$$

$$= -\frac{v_2}{r_{o2}} - \frac{v_2}{r_{s2}}$$

$$= v_2\left(\frac{-1}{r_{o2}} + \frac{-1}{r_{s2}}\right) \qquad r_{s2} \ll r_{o2}$$

$$i_{d2} \approx v_2\left(\frac{-1}{r_{s2}}\right)$$

$$\simeq \left(\frac{-r_{s2}}{r_{s1}}\right)\left(\frac{-1}{r_{s2}}\right) v_i$$

$$i_{d2} \simeq \left(\frac{1}{r_{s1}}\right) v_i = g_{m1} v_i$$

AS BEFORE

ASSUMING

$r_{o1}, r_{o2} \gg r_{s1}, r_{s2}$

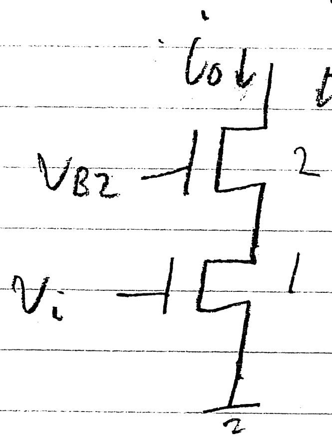
SO $$\frac{v_o}{v_i} = -g_{m1} R_o$$

C7A

IN GENERAL,

LET $r_o \to \infty$ WHEN FINDING i_{SC} **BUT** MUST INCLUDE r_o WHEN FINDING R_O

THEN $v_o = i_o R_O$



$R_o \cong g_{m2} r_{o1} r_{o2}$

$$i_o = i_{SC} = -g_{m1} v_i$$

$$v_o = i_o R_O$$

$$\frac{v_o}{v_i} = -g_{m1} g_{m2} r_{o1} r_{o2}$$

$$\frac{v_o}{v_i^+} = -g_{m1} R_o$$

$$= -g_{m1}\, g_{m2}\, r_{o1}\, r_{o2}$$

IF $g_{m1} = g_{m2}$ & $r_{o1} = r_{o2}$

$$\frac{v_o}{v_i} = -g_m^2 r_o^2 = -(g_m r_o)^2$$

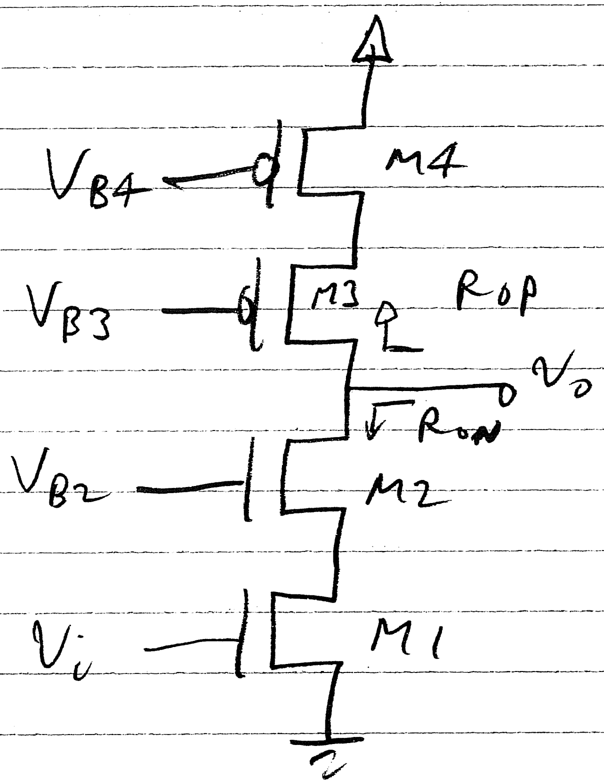
THE GAIN IS "A^2" COMPARED TO A SINGLE TRANSISTOR!

IF $A = 40$ FOR SINGLE TRANSISTOR

CASCODE GAIN $= 40^2 = 1600$

CA9

PRACTICAL CASE



$$R_{ON} = g_{m2} r_{o1} r_{o2}$$

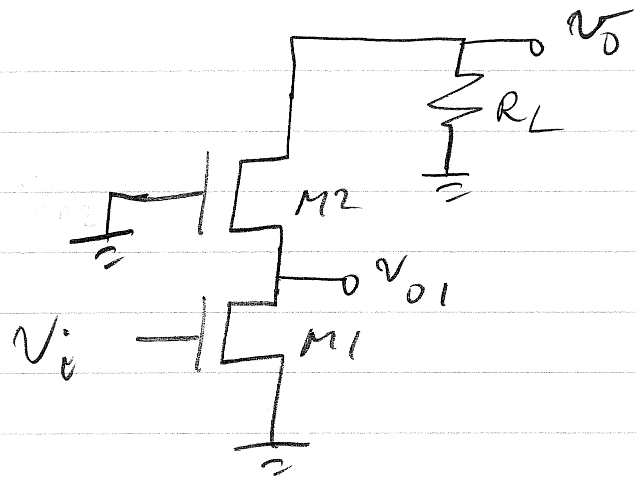
$$R_{OP} = g_{m3} r_{o3} r_{o4}$$

$$\frac{v_o}{v_i} = -g_{m1}(R_{ON} \parallel R_{OP})$$

$$\approx -\frac{1}{2} g_{m1} g_{m2} r_{o1} r_{o2}$$

IF $R_{ON} = R_{OP}$

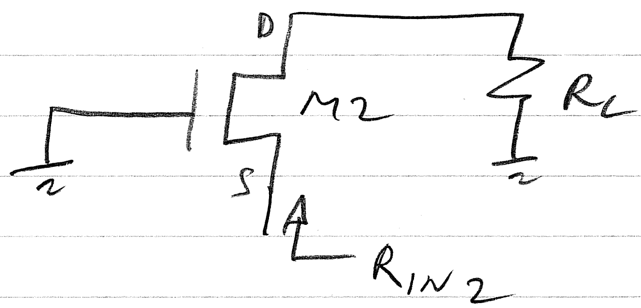
CA10



SMALL-SIGNAL MODEL BUT DRAWN WITH TRANSISTORS

WHAT IS $\frac{v_{O1}}{v_i}$?

CAN SHOW



$$R_{IN2} = \frac{R_L + r_{o2}}{1 + g_{m2} r_{o2}} \quad \text{EXACT}$$

IF $g_m R_o \gg 1$

$$R_{IN2} \approx \frac{R_L}{g_{m2} r_{o2}} + \frac{1}{g_{m2}}$$

IN THIS CASE $R_L = R_{OP} = g_{m3} r_{o3} r_{o4}$

SO $$R_{IN2} \approx \frac{g_{m3} r_{o3} r_{o4}}{g_{m2} r_{o2}} + \frac{1}{g_{m2}}$$

CA11

ASSUMING $g_m \equiv g_{m2} = g_{m3} = g_{m1}$

$r_o \equiv r_{o2} = r_{o3} = r_{o4} = r_{o1}$

$R_{IN2} \approx r_o + \frac{1}{g_m}$ & SINCE $g_m r_o >> 1$

$R_{IN2} \approx r_o$

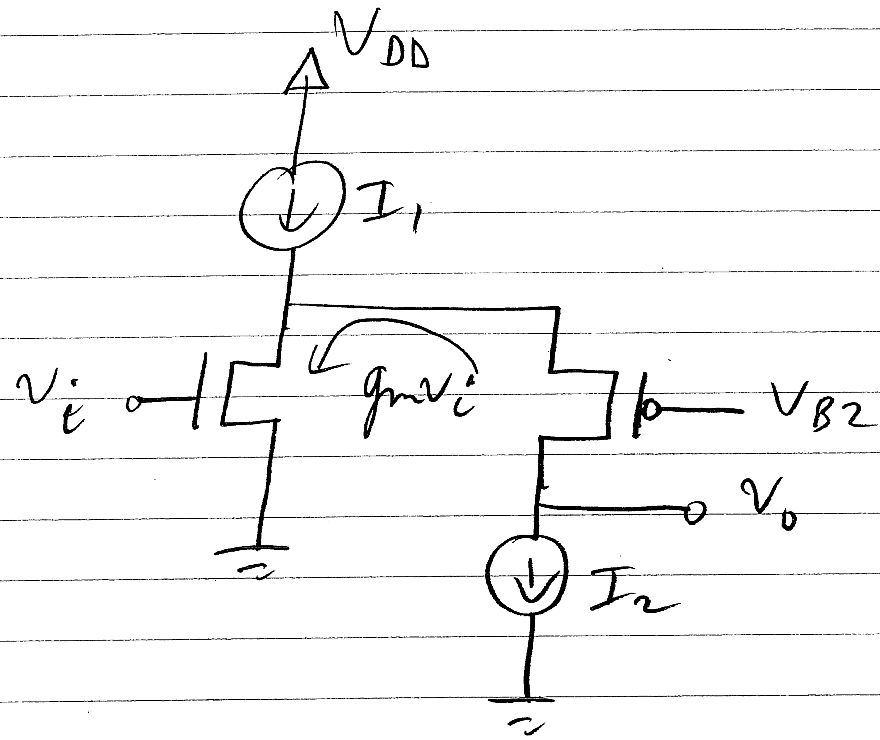
r_{o1}

SO $\frac{v_{o1}}{v_i} \approx -g_{m1}(R_{IN2} \| r_o)$

$\frac{v_{o1}}{v_i} \approx -\frac{1}{2} g_m r_o$

WHILE $\frac{v_o}{v_i} \approx -\frac{1}{2}(g_m r_o)^2$

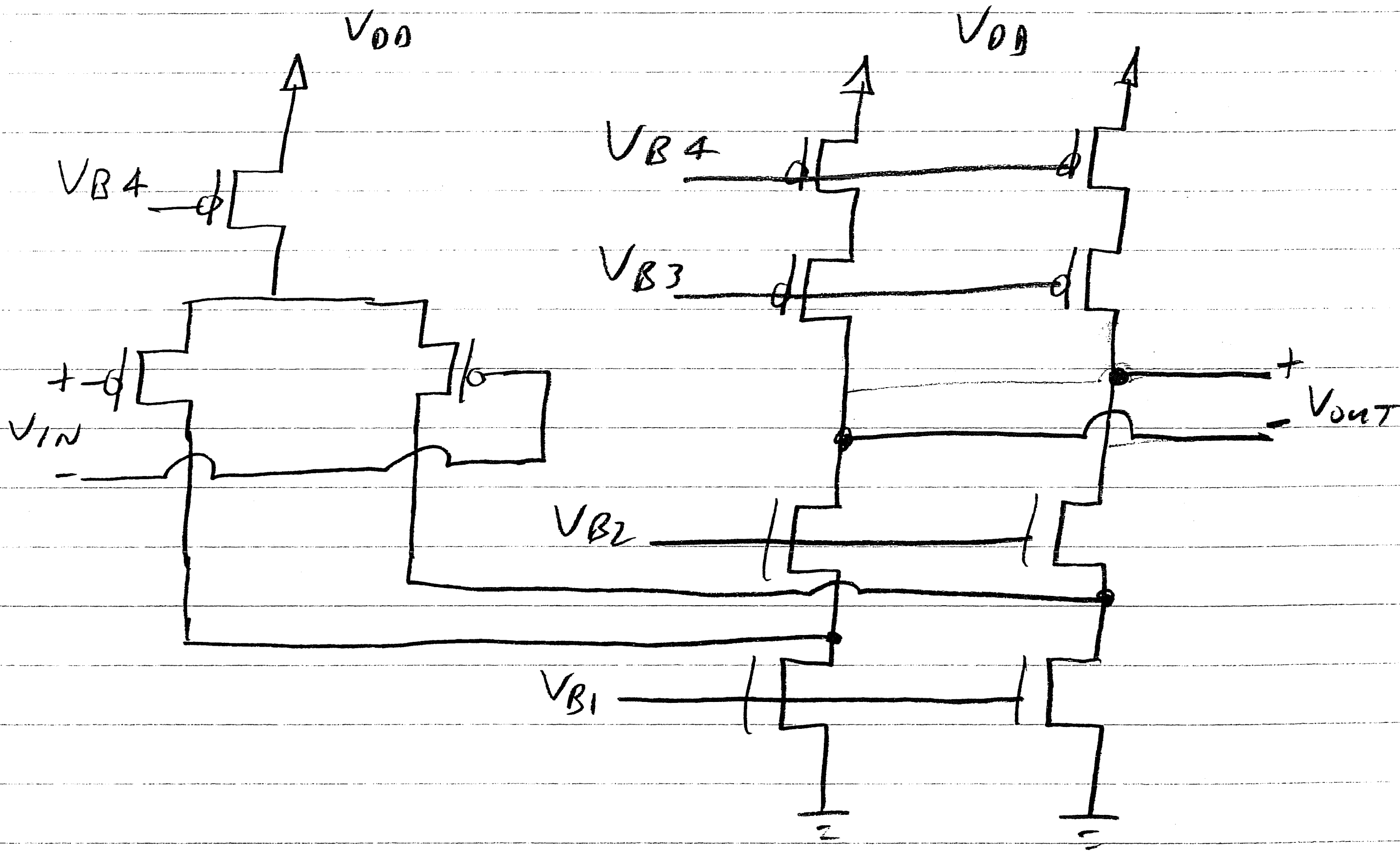
SOMETIME POWER SUPPLIES WILL NOT LET CASCODE WORK BUT CAN **FOLD** IT



CA13

FOR INFORMATION ONLY

A FOLDED-CASCODE OPAMP USED IN INTEGRATED CIRCUITS



REQUIRES COMMON-MODE FEEDBACK CIRCUIT - NOT SHOWN