MULTI-STAGE AMPLIFIER HAND ANALYSIS

- THE PURPOSE OF CIRCUIT ANALYSIS IS TO GAIN INSIGHT INTO THE CIRCUIT OPERATION

- IF THE CIRCUIT DOES NOT MEET SPECIFICATIONS (GAIN, FREQ RESPONSE DISTORTION, NOISE, POWER SUPPLY REJECTION, ETC) WHAT CHANGES CAN BE MADE TO IMPROVE CIRCUIT.

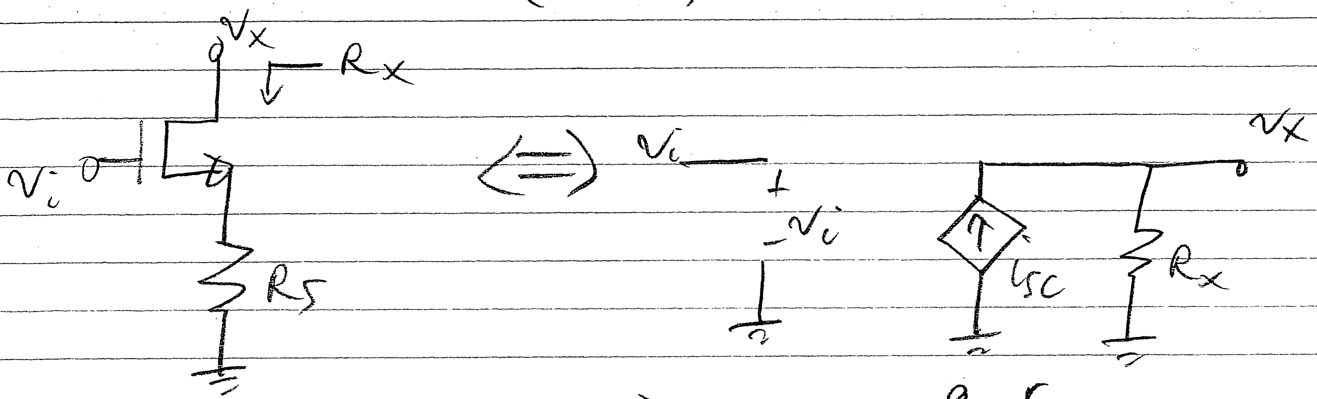
- WE ARE GENERALLY FINE WITH UP TO 5% ERRORS (COMPARED TO EXACT ANALYSIS) SINCE HAND ANALYSIS TRANSISTOR MODELS ARE SIMPLIFIED AND INEXACT (PERHAPS UP TO 15% IN ERROR)

- ONE HELPFUL APPROXIMATION IS TO ASSUME

$$g_m r_o \gg 1$$

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

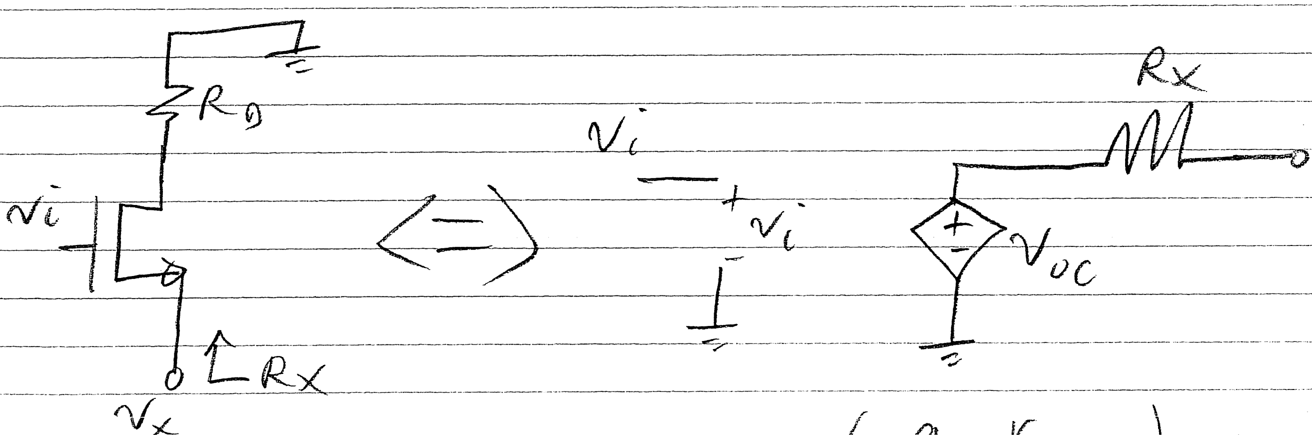
SMALL-SIGNAL MODELS (EXACT) (ALL TRANSISTORS IN ACTIVE REGION)



CS AMP

$$i_{sc} = \frac{-g_m r_o}{r_o + (1+g_m r_o) R_S} v_i$$

$$R_x = r_o + (1+g_m r_o) R_S$$

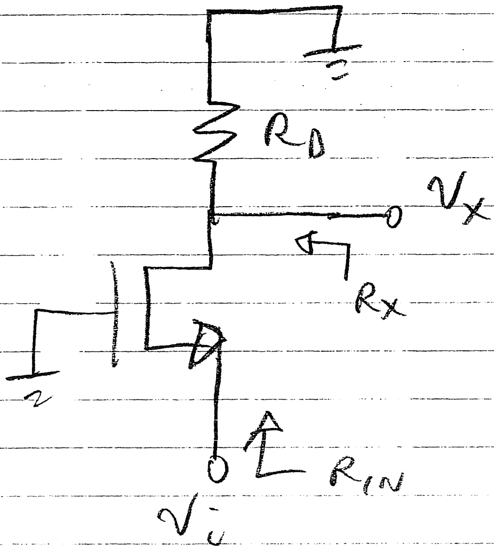


$$v_{oc} = \left(\frac{g_m r_o}{g_m r_o + 1}\right) v_i$$

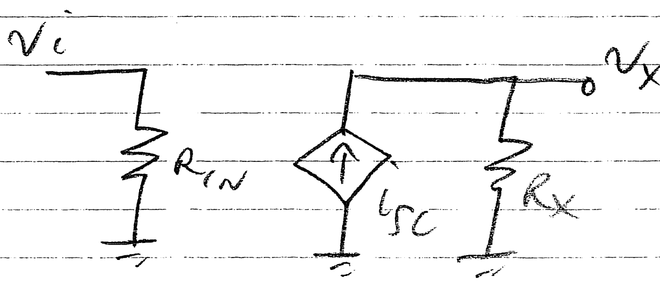
CD AMP

$$R_x = \frac{r_o + R_D}{1 + g_m r_o}$$

M52B



$\Leftrightarrow$



CG AMP

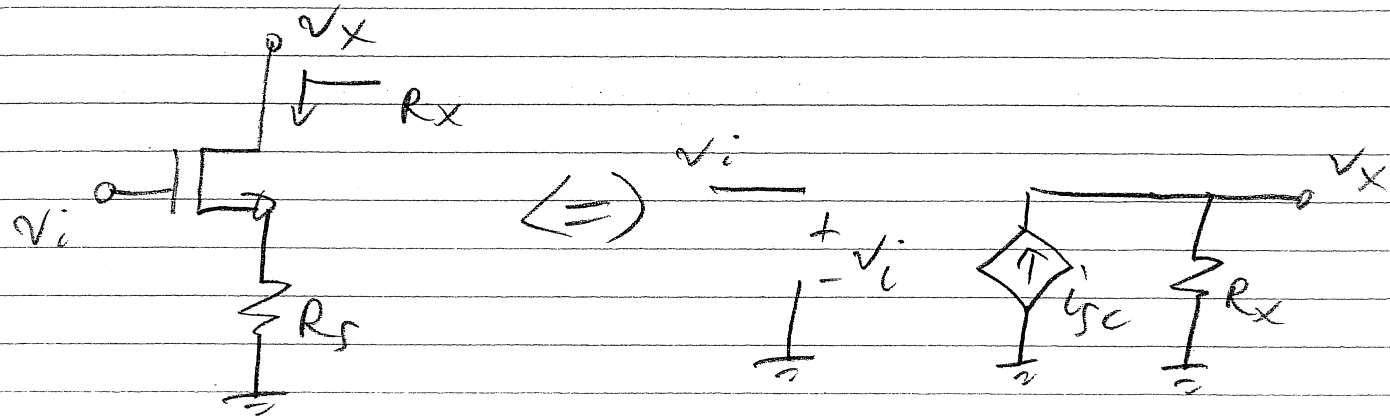
$$i_{SC} = \left(\frac{g_m r_o + 1}{r_o}\right) v_i$$

$$R_X = R_D \parallel r_o$$

$$R_{IN} = \frac{r_o + R_D}{1 + g_m r_o}$$

FOR $g_m r_o \gg 1$

M53A

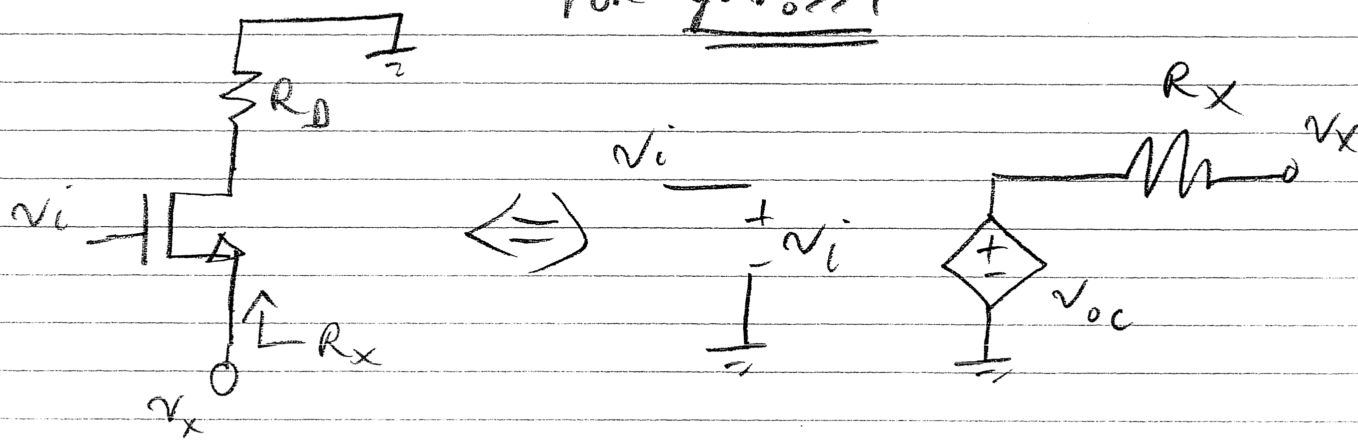


CS AMP

$$i_{SC} \approx \left(\frac{-1}{\frac{1}{g_m} + R_S} \right) v_i$$

$$R_x \approx (1 + g_m R_S) r_o$$

FOR $g_m r_o \gg 1$



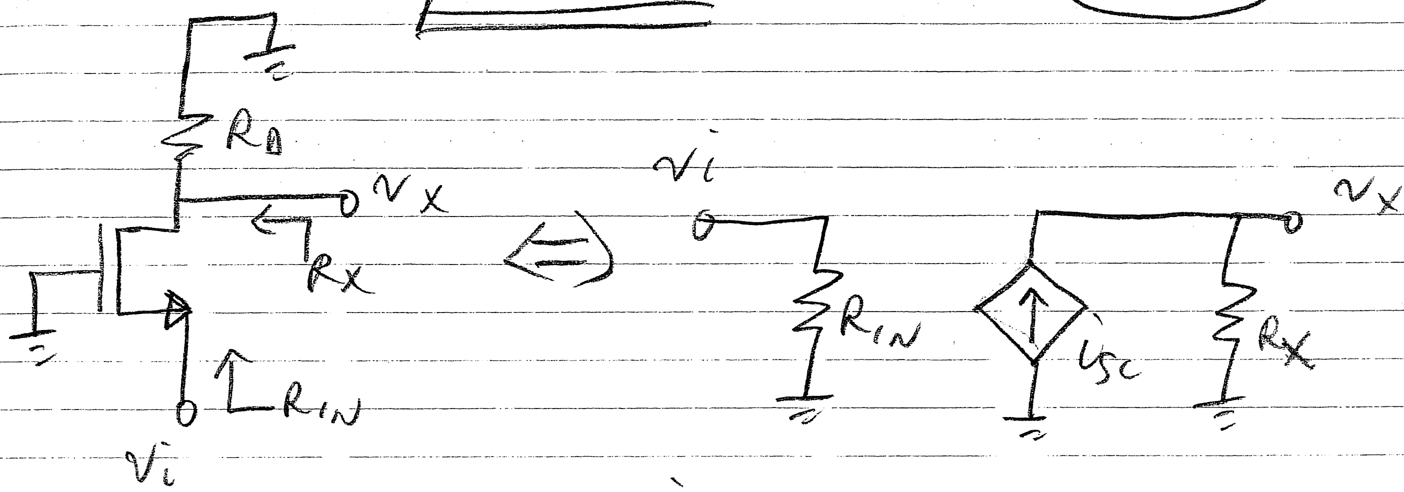
CD AMP

$$v_{oc} \approx v_i$$

$$R_x \approx \frac{1}{g_m} + \frac{R_D}{g_m r_o}$$

FOR $g_m r_o \gg 1$

M53B



CG AMP

$$i_{SC} \approx g_m v_i$$

$$R_X = R_D \parallel r_o$$

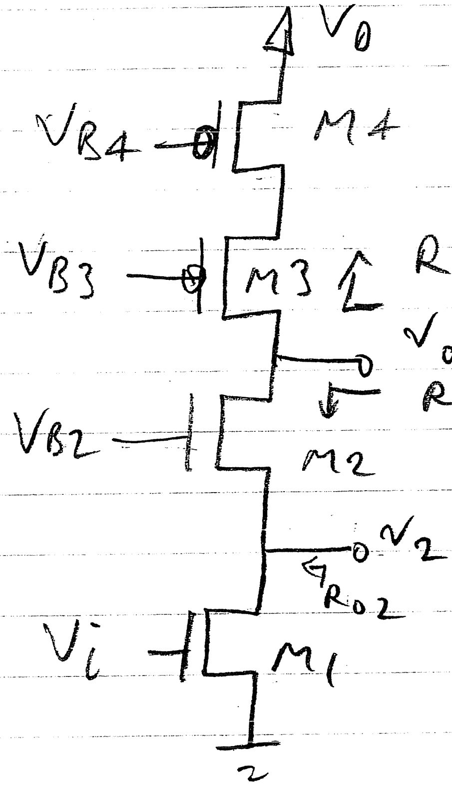
$$R_{IN} \approx \frac{1}{g_m} + \frac{R_D}{g_m r_o}$$

MS4

EXAMPLE 1

GIVEN $g_m = 1\,mA/V$ $\quad r_o = 40\,k\Omega$

(HERE $g_m r_o = 40$)



$$R_{OP} = (1 + g_{m3} r_{o4}) r_{o3} \approx g_m r_o^2 = 1.6\,M\Omega$$

$$R_{ON} = (1 + g_{m2} r_{o1}) r_{o2} \approx g_m r_o^2 = 1.6\,M\Omega$$

$$R_{o2} = r_{o1} \,||\, \left(\frac{1}{g_{m2}} + \frac{R_{OP}}{g_m r_o}\right)$$

$$R_{o2} = r_{o1} \,||\, \left(\frac{1}{g_{m2}} + r_o\right) \approx \frac{r_o}{2}$$

$$v_2 = -g_{m1} R_{o2} v_i = -\frac{g_{m1} r_o}{2} v_i$$

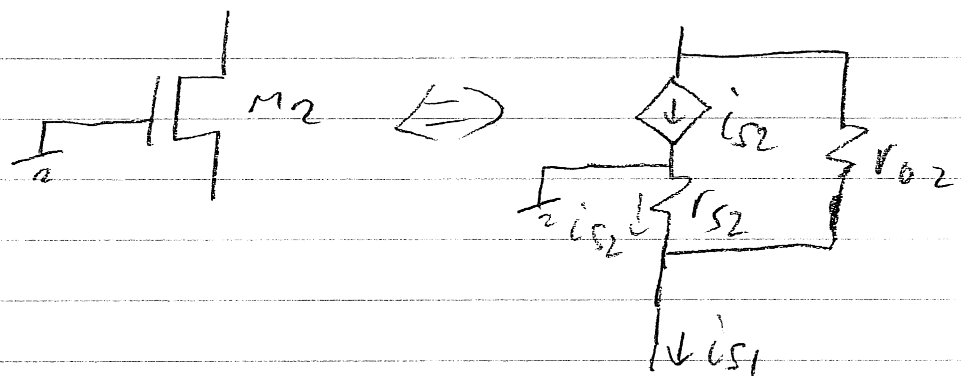
$$= -20\, v_i$$

$$\frac{v_2}{v_i} = -20\ V/V$$

M55

FOR v_o / v_i

NOTE



MOST OF i_{s1} GOES THROUGH r_{s2}

SINCE $r_{o2} \gg r_{s2} = \frac{1}{g_{m2}}$

$$v_o = -g_{m1}\left(\frac{g_m r_o^2}{2}\right) v_i$$

$$\frac{v_o}{v_i} = -\frac{(g_m r_o)^2}{2} = -800 \; V/V$$

MS5A

ALTERNATIVE FOR $\frac{v_o}{v_i}$

$$v_o \cong g_{m2}(r_{o2} \parallel R_{op})v_2 \simeq g_{m2} r_{o2} v_2$$

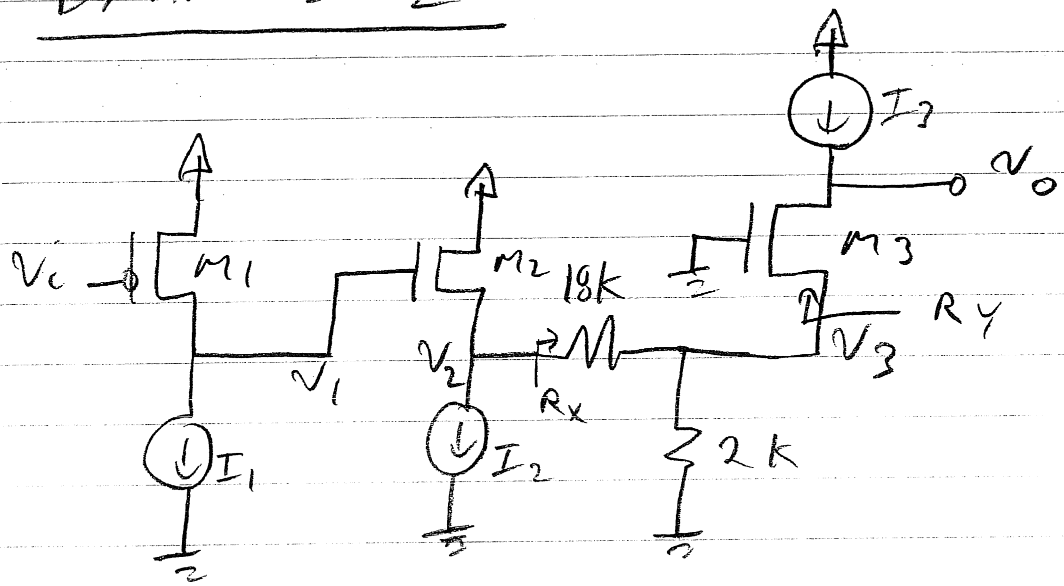
$$\frac{v_o}{v_2} \cong g_{m2} r_{o2}$$

$$\frac{v_o}{v_i} = \frac{v_o}{v_2} \times \frac{v_2}{v_i} = (g_m r_o)\left(-\frac{g_m r_o}{2}\right)$$

$$= -\frac{(g_m r_o)^2}{2} = -800 \text{ V/V}$$

MS6

EXAMPLE 2



EACH TRANSISTOR HAS $g_m = 1\,mA/V$
$r_o = 40k$

AND EACH CURRENT SOURCE HAS $r_o = 40k$

FIND $\frac{v_o}{v_i}$

$$\frac{v_1}{v_i} = -g_{m1}\left(\frac{r_o}{2}\right) = \underline{\underline{-20}}\ V/V$$

$$\frac{v_2}{v_1} = \frac{r_o \parallel R_X}{r_o \parallel R_X + \frac{1}{g_{m2}}}$$

$$R_Y = \frac{2}{g_{m3}} = 2k$$

$$R_X = 18K + \left[2K \parallel \overbrace{\left(\frac{1}{g_{m3}} + \frac{r_o}{g_{m3} r_{o3}}\right)}^{R_Y}\right]$$

M57

$$R_x = 18k + (2k \| 2k) = 19k$$

$$\frac{v_2}{v_1} = \frac{(40k \| 19k)}{(40k \| 19k) + 1k} = \frac{12.88}{13.88} = 0.928$$

$$\frac{v_2}{v_1} = \underline{\underline{0.928}} \ V/V$$

$$\frac{v_3}{v_2} = \frac{(R_y \| 2k)}{(R_y \| 2k) + 18k} = \frac{1}{1 + 18k} = 0.0526$$

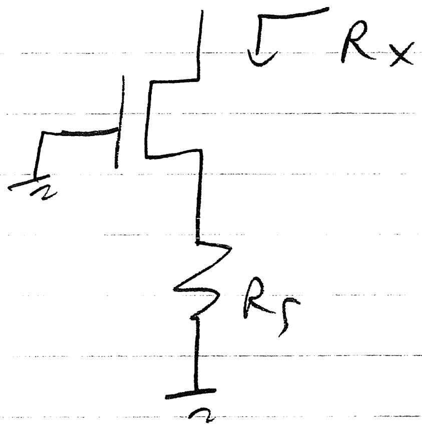
$$\frac{v_3}{v_2} = \underline{\underline{0.0526}}$$

$$\frac{v_o}{v_3} = g_{m3}\left(\frac{r_o}{2}\right) = \underline{\underline{20 \ V/V}}$$

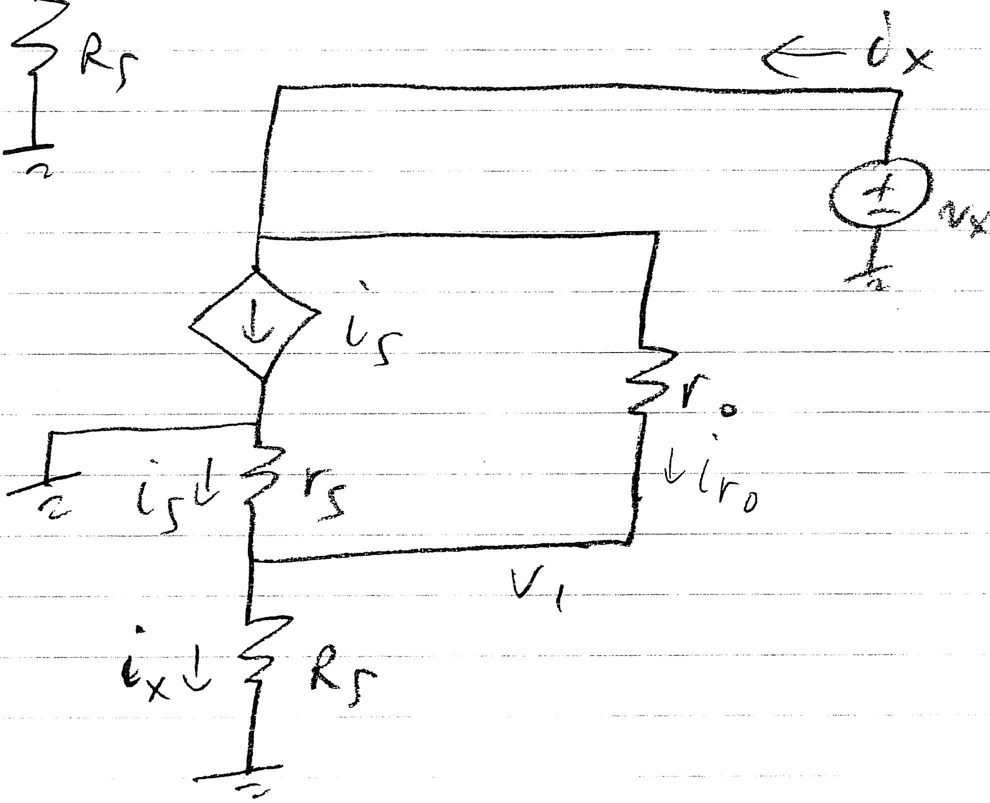
$$\frac{v_o}{v_i} = \frac{v_1}{v_i} \times \frac{v_2}{v_1} \times \frac{v_3}{v_2} \times \frac{v_o}{v_3} = -19.53 \ V/V$$

DERIVATIONS OF MODELS

(MS8)



FOR $R_x \equiv \frac{v_x}{i_x}$



$$V_1 = i_x R_S \qquad i_S = -\frac{v_1}{r_S} = -\frac{i_x R_S}{r_S}$$

$$i_{r_o} = \frac{v_x - v_1}{r_o} = \frac{v_x - i_x R_S}{r_o}$$

$$i_x = i_S + i_{r_o} = -\frac{i_x R_S}{r_S} + \frac{v_x - i_x R_S}{r_o}$$

M59

$$i_x\left(1+\frac{R_S}{r_S}+\frac{R_S}{r_o}\right)=\left(\frac{1}{r_o}\right)v_x$$

SINCE $r_S=\frac{1}{g_m}$

$$R_x\equiv\frac{v_x}{i_x}=R_S+r_o+g_m r_o R_S$$

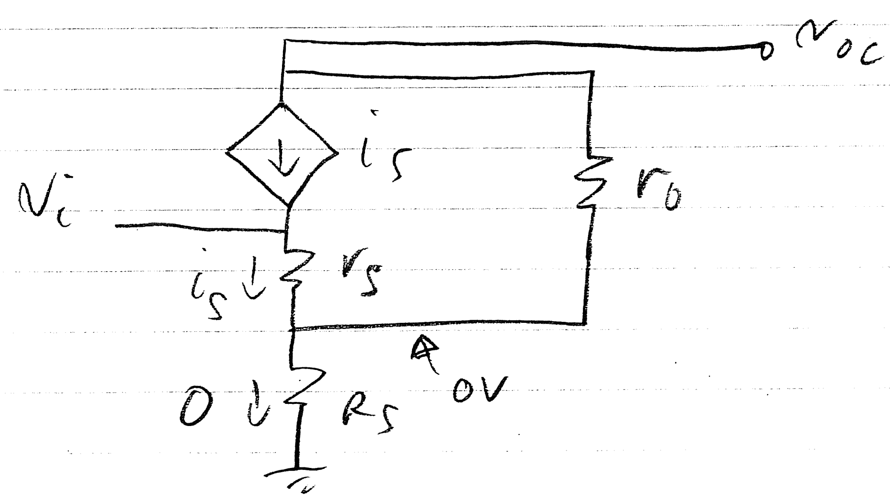
$$\underline{\underline{R_x=r_o+(1+g_m r_o)R_S}}$$

FOR $g_m r_o \gg 1$

$$R_x\simeq r_o+g_m r_o R_S$$

$$\underline{\underline{R_x\simeq(1+g_m R_S)r_o}}$$

<u>FOR i_{SC}</u> START WITH v_{OC}



MS10

$$v_{oc} = -\frac{r_o}{r_s} v_i = -g_m r_o v_i$$

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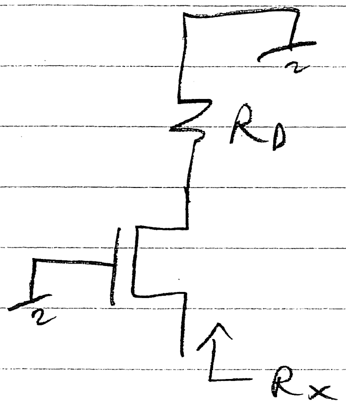
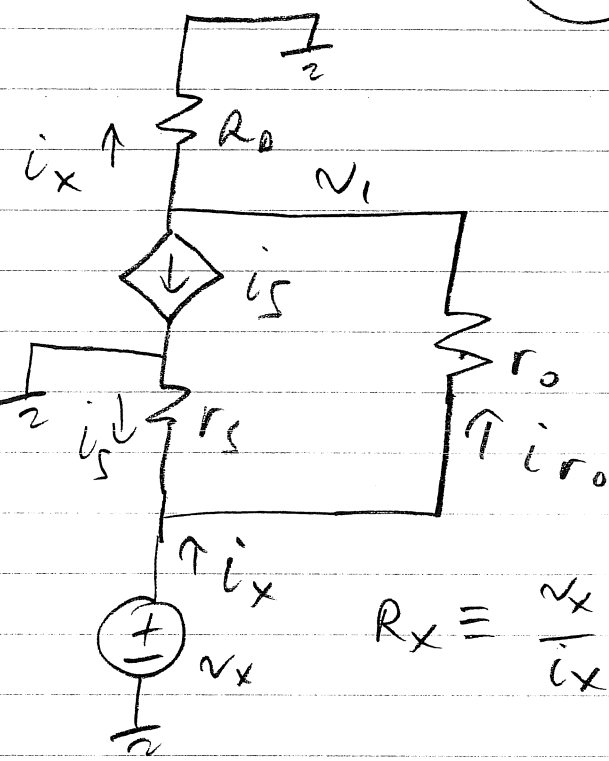
$$i_{sc} = \frac{v_{oc}}{R_X} v_i = \frac{-g_m r_o}{(1 + g_m R_S)\, r_o} v_i$$

$$= \frac{-g_m}{1 + g_m R_S} v_i$$

$$i_{sc} = \left(\frac{-1}{\frac{1}{g_m} + R_S} \right) v_i$$

MS11





$$R_x \equiv \frac{v_x}{i_x}$$

$$v_1 = i_x R_D$$

$$i_s = \frac{-v_x}{r_s} \qquad i_{r_o} = \frac{v_x - v_1}{r_o} = \frac{v_x - i_x R_D}{r_o}$$

$$-i_s + i_{r_o} = i_x$$

$$\frac{v_x}{r_s} + \frac{v_x - i_x R_D}{r_o} = i_x$$

$$i_x\left(1 + \frac{R_D}{r_o}\right) = v_x\left(\frac{1}{r_s} + \frac{1}{r_o}\right)$$

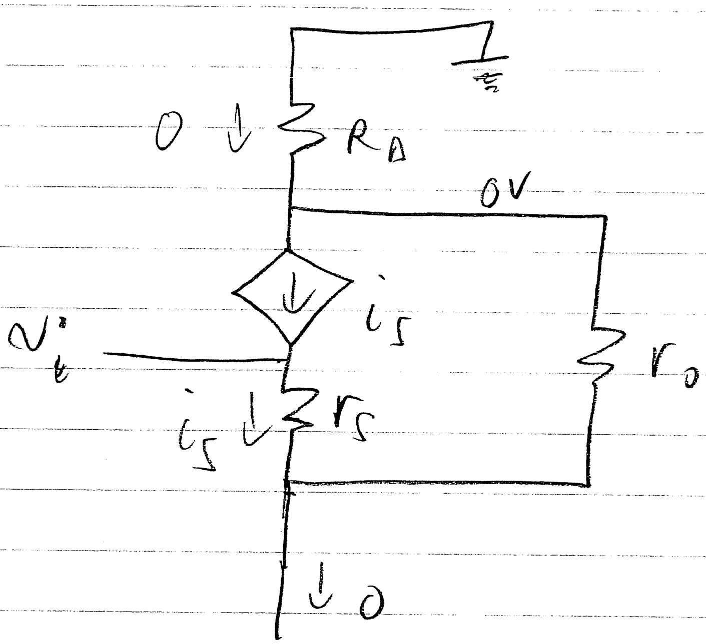
$$R_x \equiv \frac{v_x}{i_x} = \frac{1 + \frac{R_D}{r_o}}{\frac{1}{r_s} + \frac{1}{r_o}} = \frac{r_o + R_D}{1 + g_m r_o}$$

$g_m \nearrow$ ($\frac{1}{r_s}$)

MS12

$$R_X \simeq \frac{r_o + R_D}{g_m r_o} = \frac{1}{g_m} + \frac{R_D}{g_m r_o}$$

FOR v_{oc}



$$v_{oc} = \frac{r_o}{r_o + r_s} v_i$$

$$= \frac{g_m r_o}{g_m r_o + 1} v_i$$

$$v_{oc} \simeq v_i$$