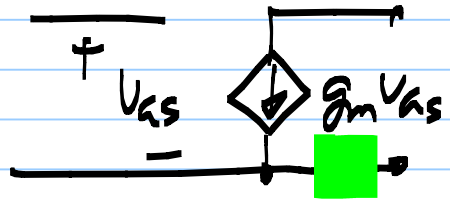
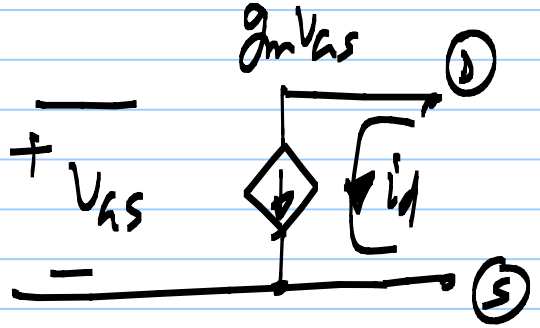
VCCS using a MOS transistor



g_m: changes with temperature

VCCS: $i_o' = v_{in} \cdot \overbrace{G_1}^{G_m} = \frac{v_{in}}{R_1}$ $\quad R_1 = 1/G_1$



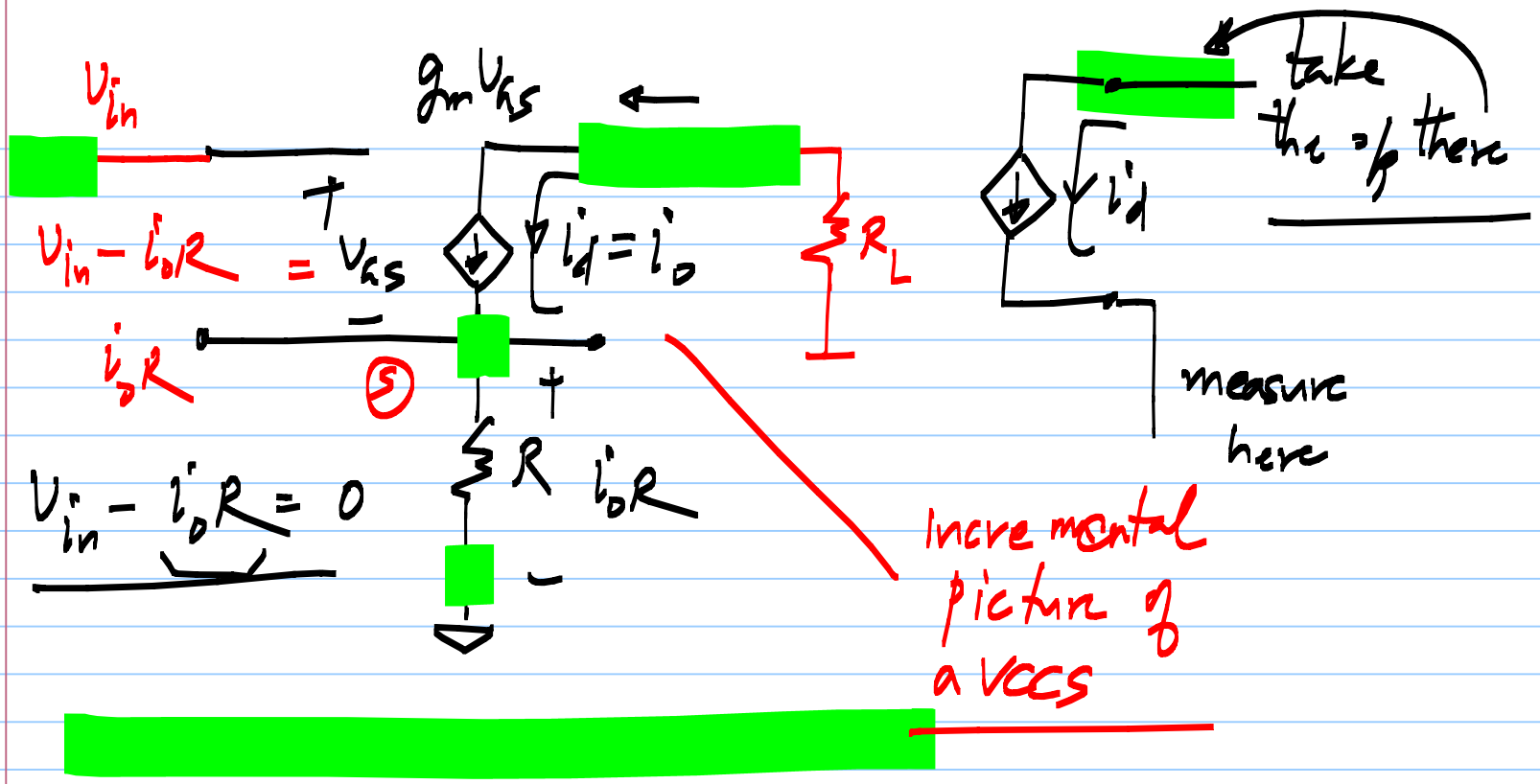
$(v_{in} - i_o' R_1) = 0$

v_{gs} : $i_o' R_1 - v_{in}$

i_o': large ⇒ v_{gs} must ↓

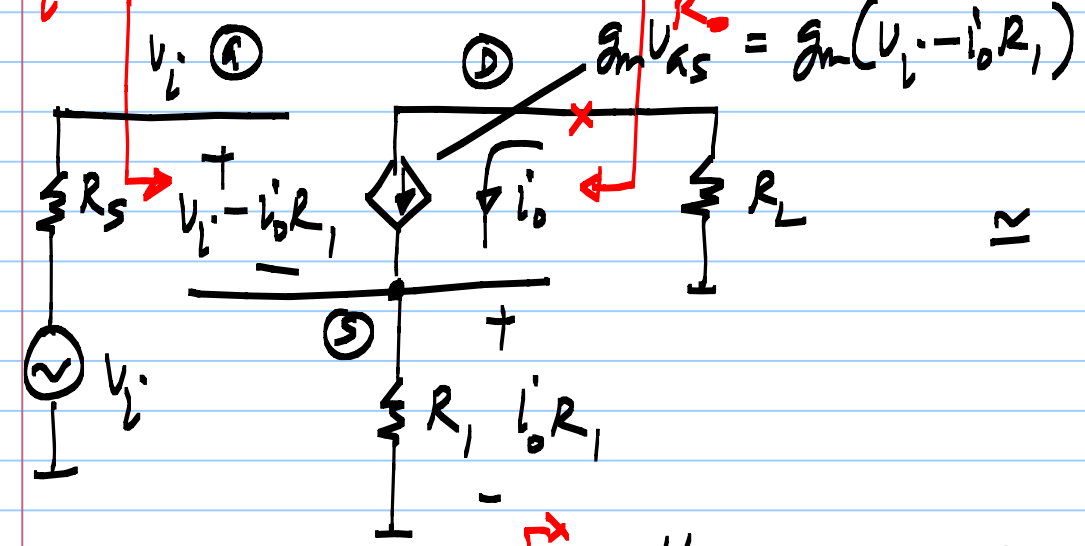
i_o': small ⇒ v_{gs} must ↑

$v_{gs} = v_{in} - i_o' R_1$:


v_{in}
$g_m v_{GS}$
$v_{in} - i_o R = v_{GS}$
$i_d = i_o$
R_L
$i_o R$
S
R
$i_o R$
$v_{in} - i_o R = 0$
take the i_d out there
i_d
measure here
incremental picture of a VCCS

VCCS using a MOS transistor

$R_i = \infty$

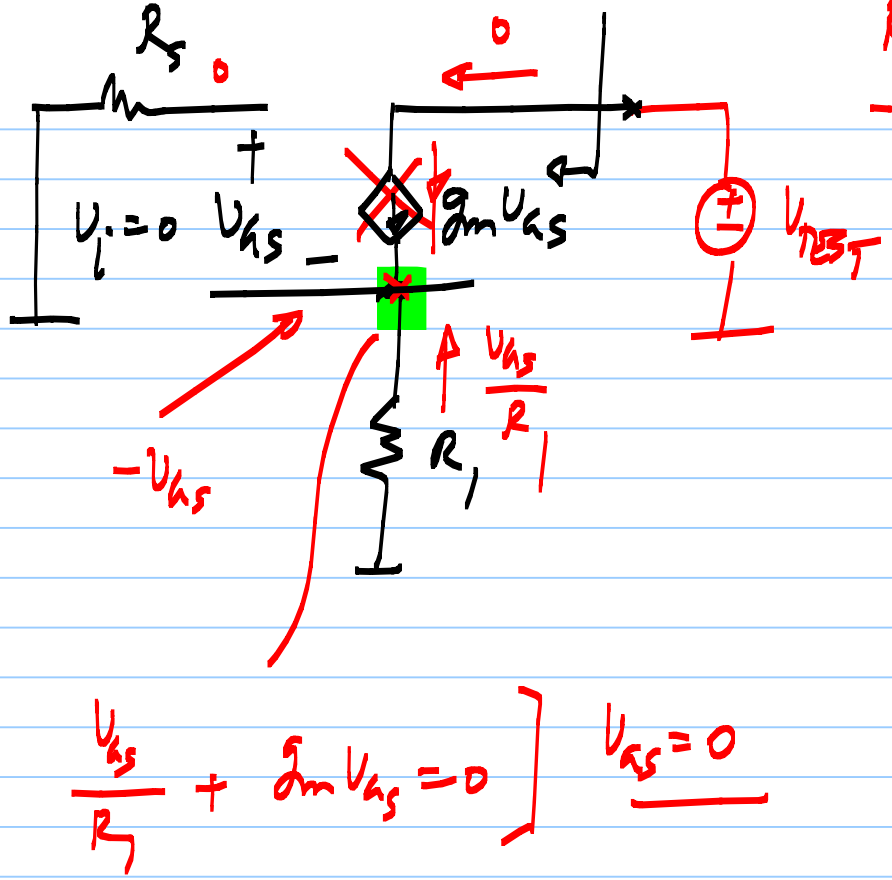


$$i_o = g_m (v_i - i_o R_1) \qquad i_o = v_i \cdot G_1$$

$$\boxed{i_o = \frac{g_m}{1 + g_m R_1} \cdot v_i} \; ; \qquad i_o = \frac{v_i}{R_1}$$

$$\simeq \frac{v_i}{R_1} \quad \text{if} \quad g_m R_1 \gg 1 \qquad g_m \gg G_1$$

$$\frac{i_o}{v_i} = \frac{g_m}{1 + g_m R_1} = \frac{1/R_1}{1 + 1/g_m R_1} \simeq 1/R_1$$

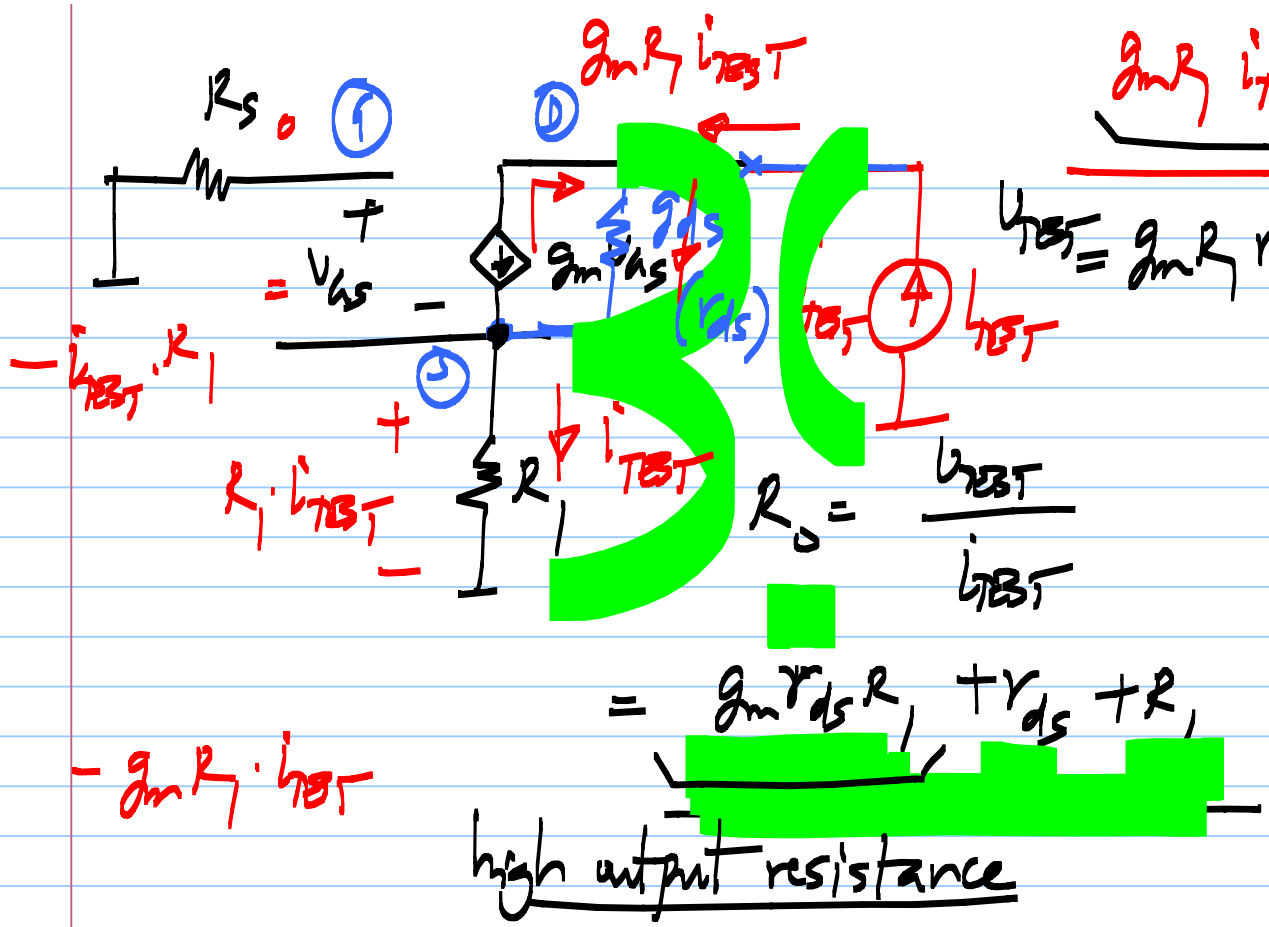


$R_{out} = \infty$

VCCS

$R_i = \infty$; $R_{out} = \infty$

$$\frac{V_{gs}}{R_1} + g_m V_{gs} = 0 \quad \Rightarrow \quad V_{gs} = 0$$



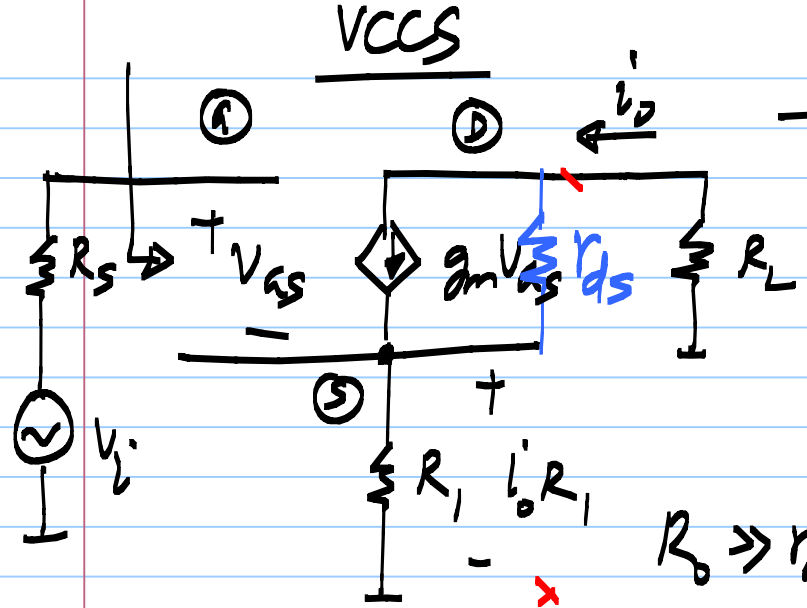
$$v_{TEST} = g_m R_1 r_{ds} \cdot i_{TEST} + r_{ds} \cdot i_{TEST} + R_1 i_{TEST}$$

$$g_m R_1 i_{TEST} + i_{TEST}$$

$$R_o = \frac{v_{TEST}}{i_{TEST}}$$

$$= \frac{g_m r_{ds} R_1 + r_{ds} + R_1}{}$$

high output resistance



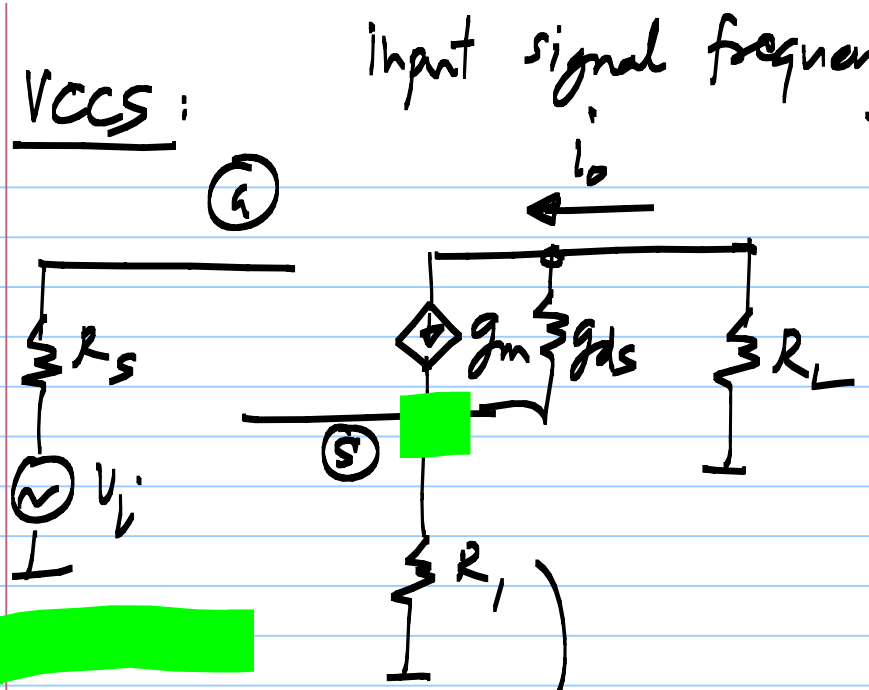
$$\frac{i_o}{v_i} = \frac{g_m}{1 + g_m R_1} \simeq \frac{1}{R_1} \quad \text{if} \quad \frac{g_m R_1 \gg 1}{g_m \gg G_1}$$

$$R_i = \infty$$

$$R_o = g_m r_{ds} R_1 + r_{ds} + R_1$$

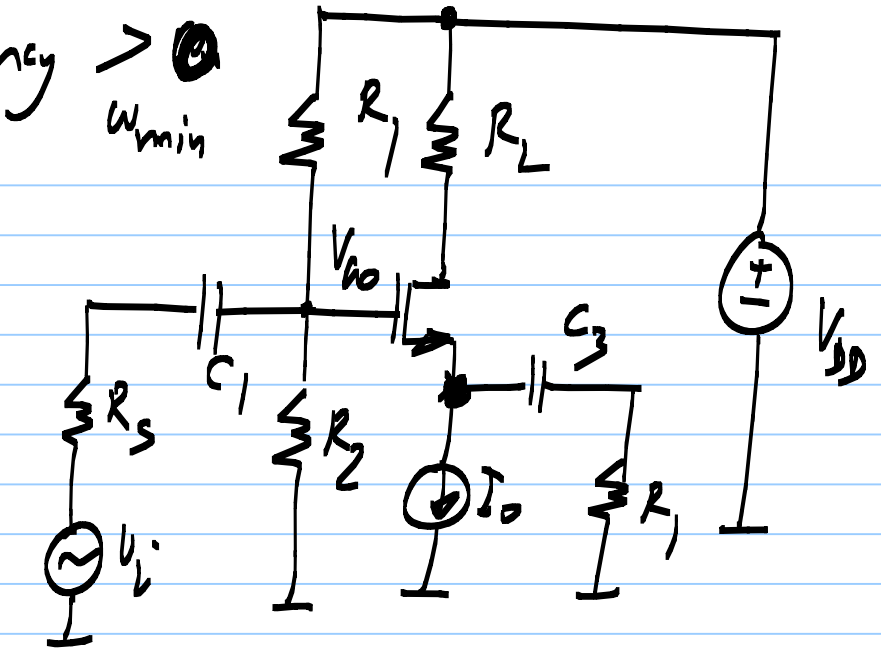
$$R_o \gg r_{ds}, R_1$$

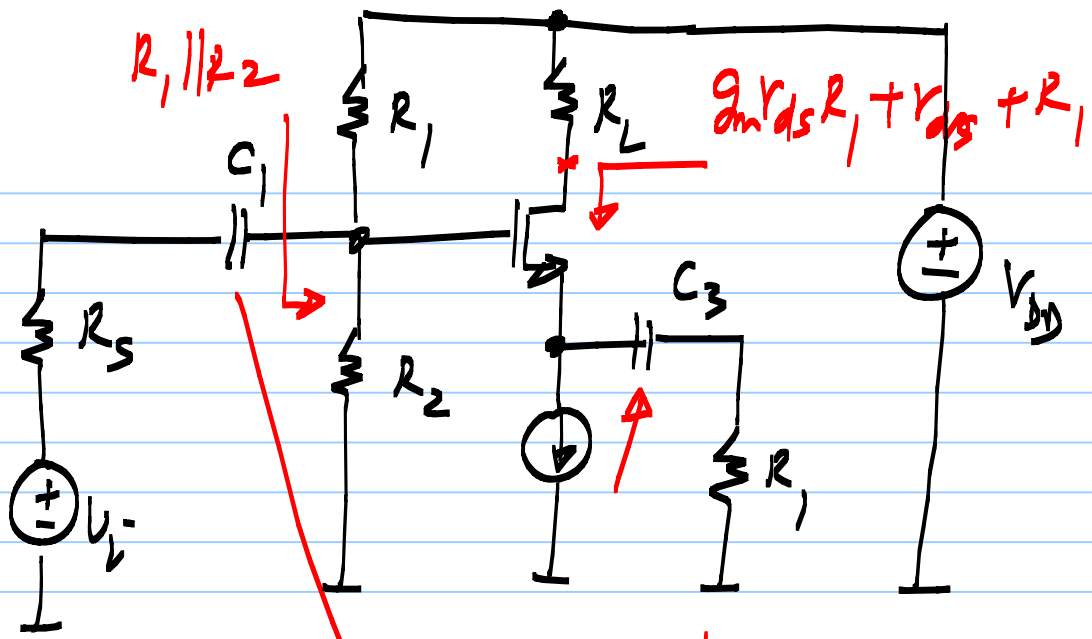
VCCS:



defines the transconductance of the VCCS

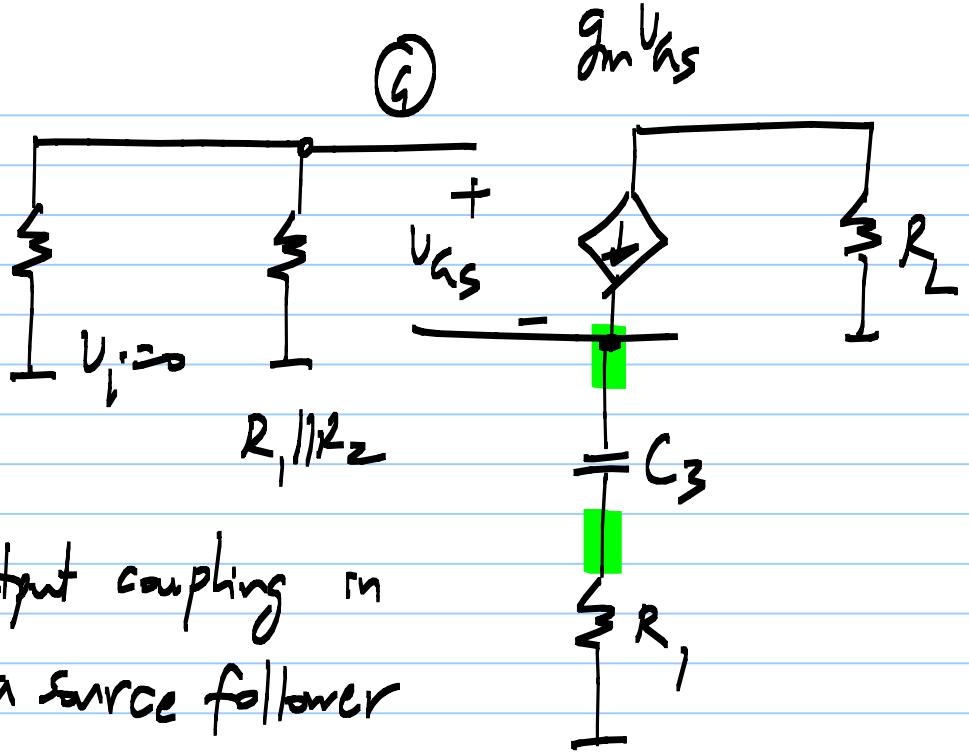
Input signal frequency > ω_{min}





$R_1 \| R_2 \gg R_S$

$C_1 \gg \dfrac{1}{\omega (R_S + R_1 \| R_2)}$



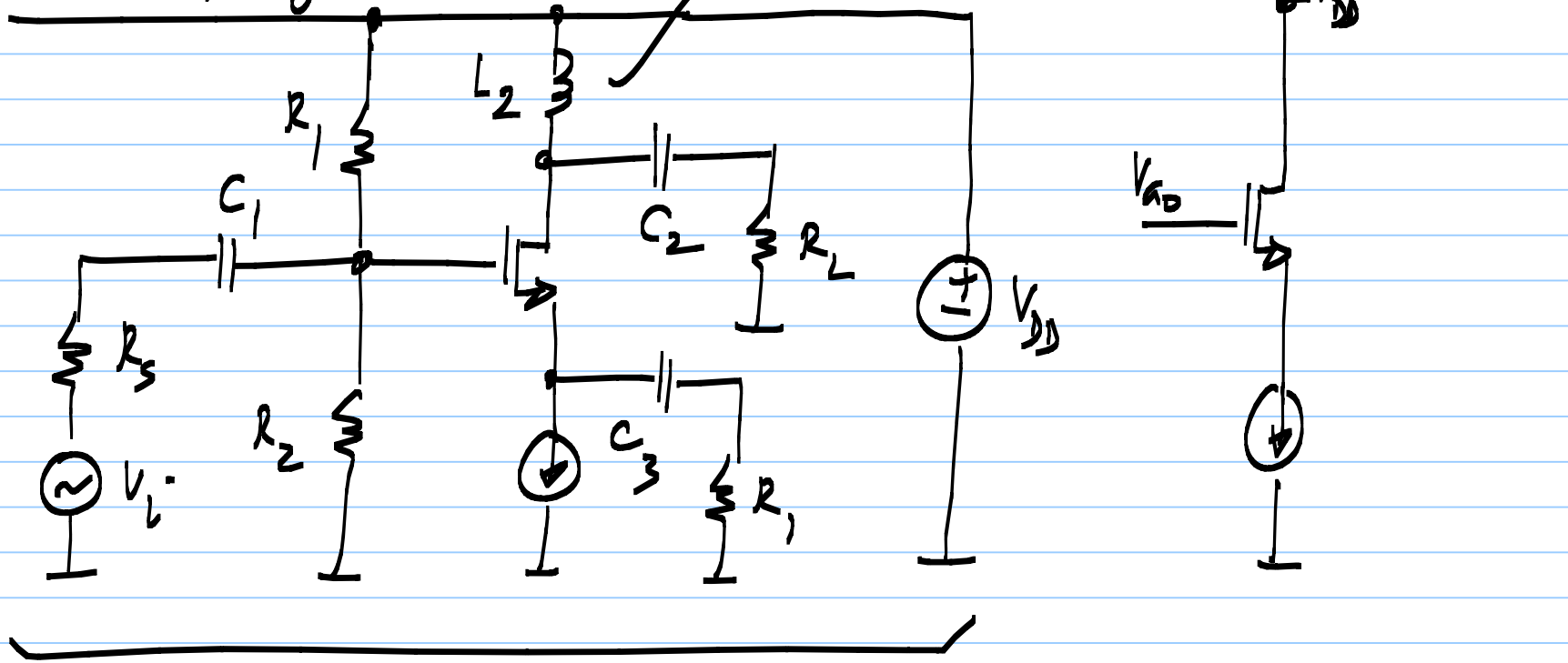
output coupling in a source follower

Resistance across C_3

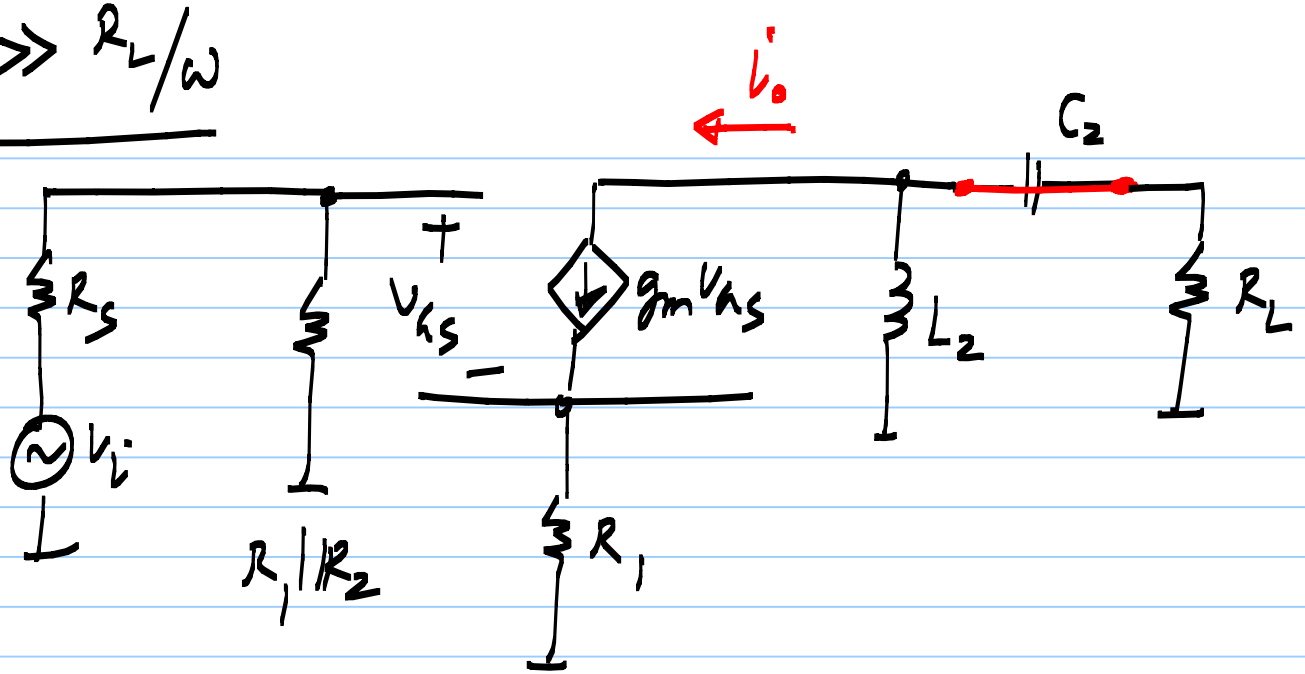
$$= \frac{1}{g_m} + R_1$$

$$C_3 \gg \frac{1}{\omega\left(\frac{1}{g_m} + R_1\right)}$$

ac coupling the load. short circuit for dc, open for ac



$L_2 \gg R_L/\omega$

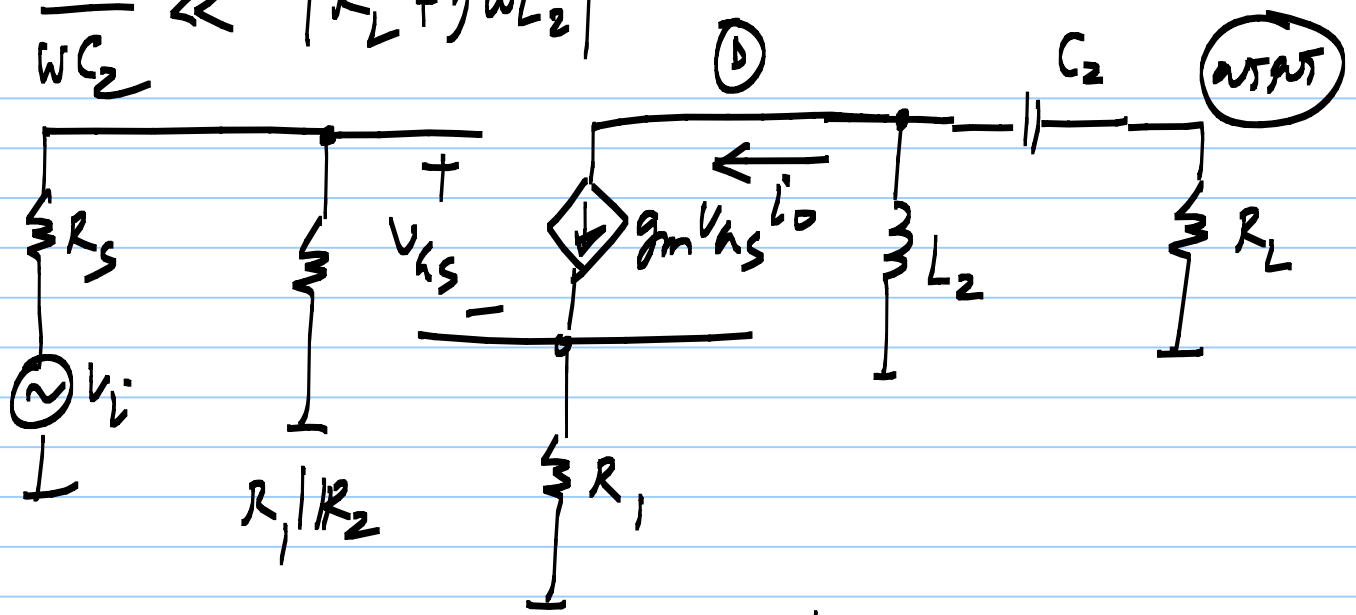


Almost all of i_o' flows into R_L if

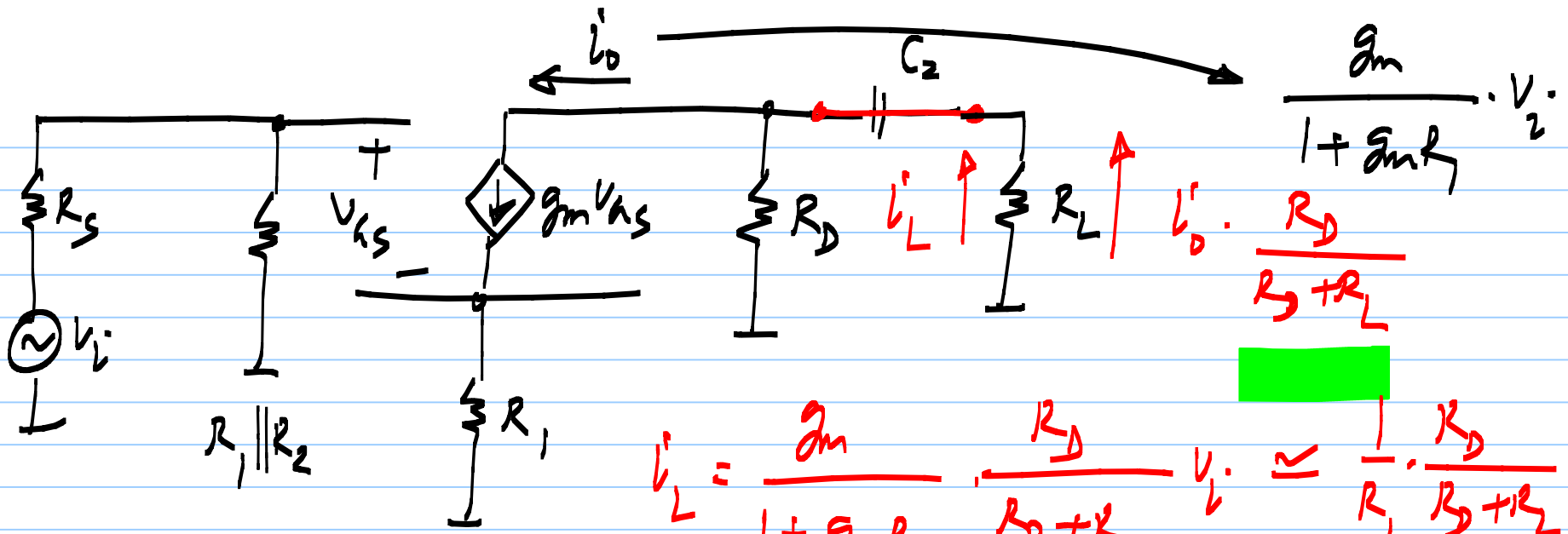
$\omega L_2 \gg R_L$

$\frac{1}{\omega C_2} \ll |R_L + j\omega L_2|$

$C_2 \gg \frac{1}{\omega R_2}$

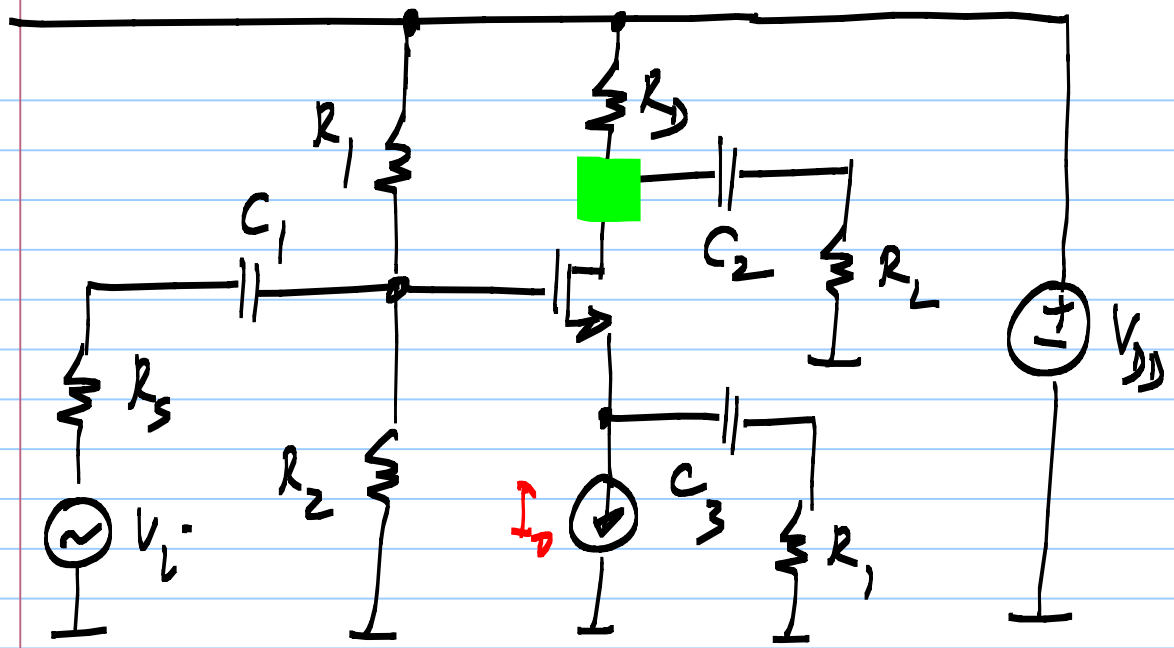


Reactance of C_2 ($1/\omega C_2$) $\ll$ |impedance| across C_2



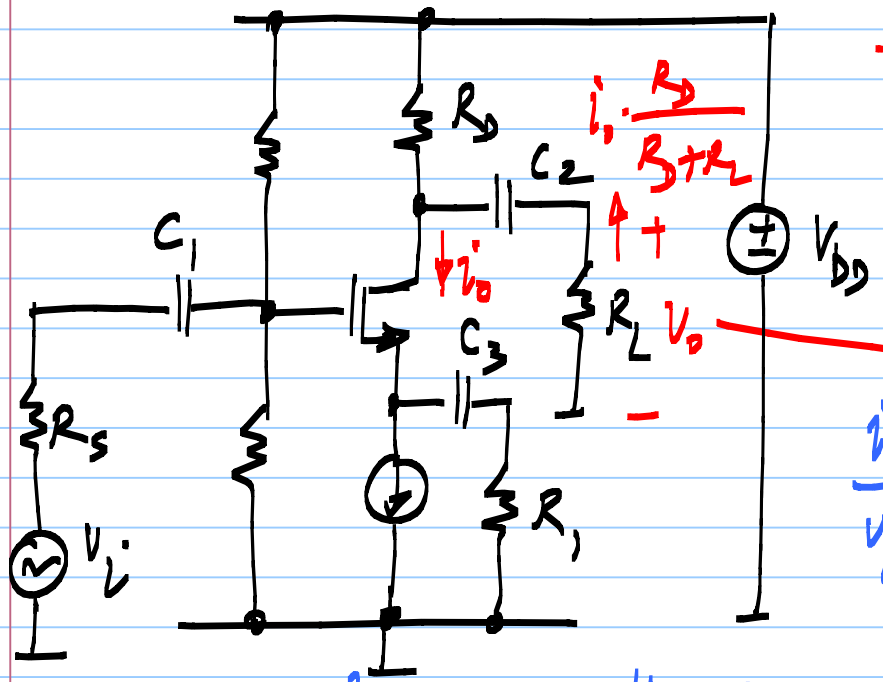
$$i_L = \frac{g_m}{1+g_m R_1} \cdot \frac{R_D}{R_D+R_L} V_i \simeq \frac{1}{R_1} \cdot \frac{R_D}{R_D+R_L}$$

$\frac{1}{\omega C_2} \ll R_D + R_L$; $\frac{1}{\omega C_2} \ll R_L$ ✓



$R_D \uparrow \Rightarrow V_{DD}$ has to be $\uparrow$ to maintain the transistor in saturation

VCCS with a resistive load



$i_o \cdot \frac{R_D}{R_D + R_L}$

$$\frac{i_o}{v_i} \simeq \frac{1}{R_1} \quad \text{if } g_m R_1 \gg 1$$

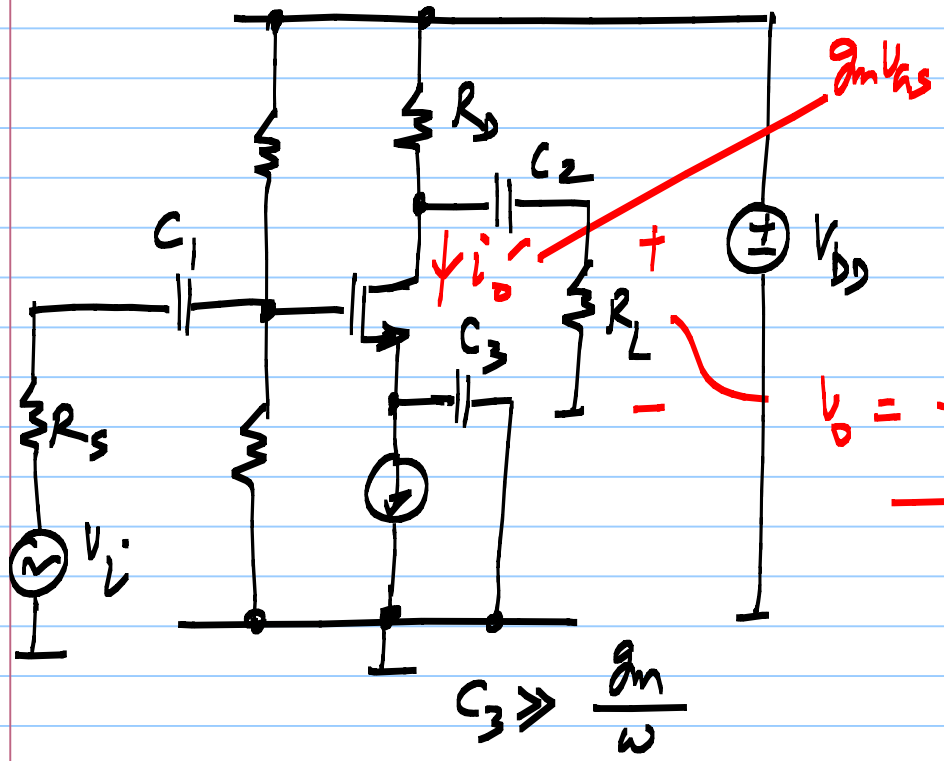
$$v_o = -i_o\left(\frac{R_D}{R_D + R_L} \cdot R_L\right)$$

$$= -\frac{g_m}{1 + g_m R_1} \cdot v_i \cdot (R_D \| R_L) \simeq -v_i \cdot \frac{R_D \| R_L}{R_1}$$

$$\frac{i_o}{v_i} = \frac{g_m}{1 + g_m R_1} \simeq \frac{1}{R_1} < g_m$$

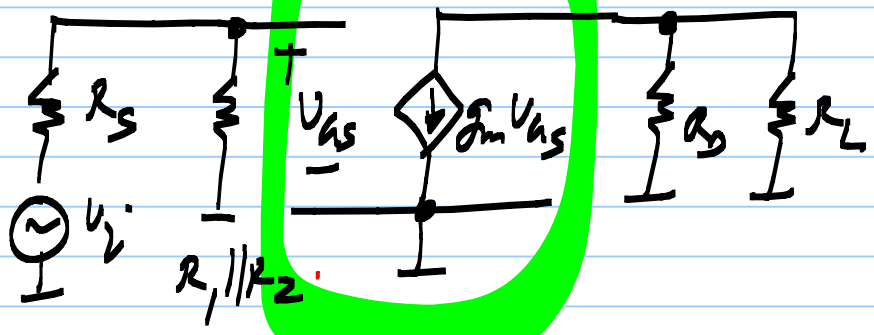
CS amplifier with source degeneration

CS amplifier w/ source feedback bias



$C_3 \gg \frac{g_m}{\omega}$

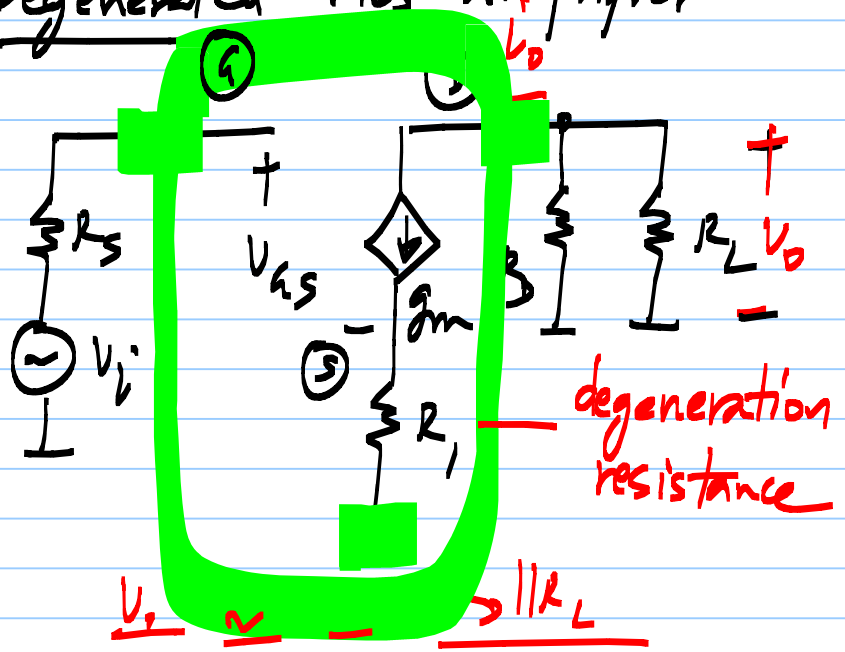
VCCS



$v_o = -g_m (R_D \| R_L) \cdot v_i$

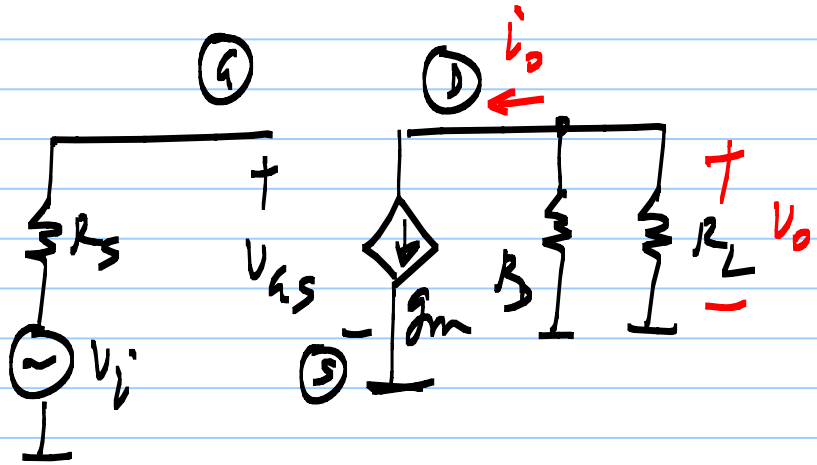
VCCS w/ resistive load

Degenerated MOS amplifier



$$\frac{v_o}{v_i} = \frac{-g_m R_L}{1 + g_m R_1}$$

CS amplifier

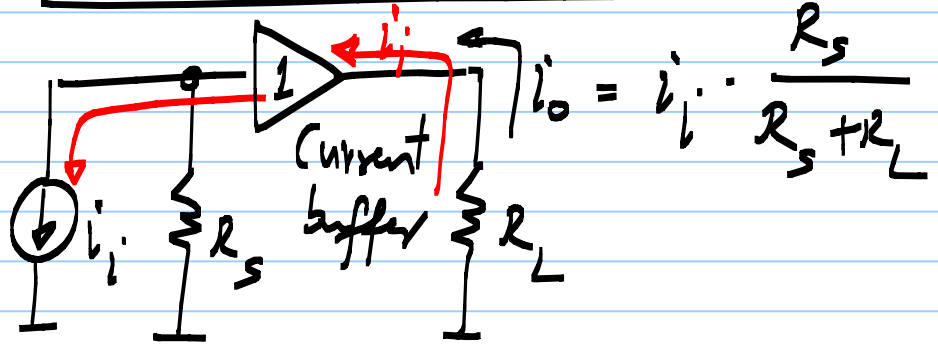


$$\frac{v_o}{v_i} = -g_m(R_D \| R_L)$$

Current controlled current source (CCCS)

$i_o = k\, i_i$; $k = 1$ $\quad i_o = i_i$ Current buffer

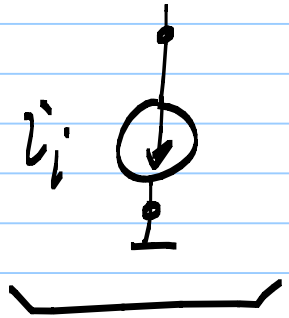
$R_i \to 0$; $R_o \to \infty$

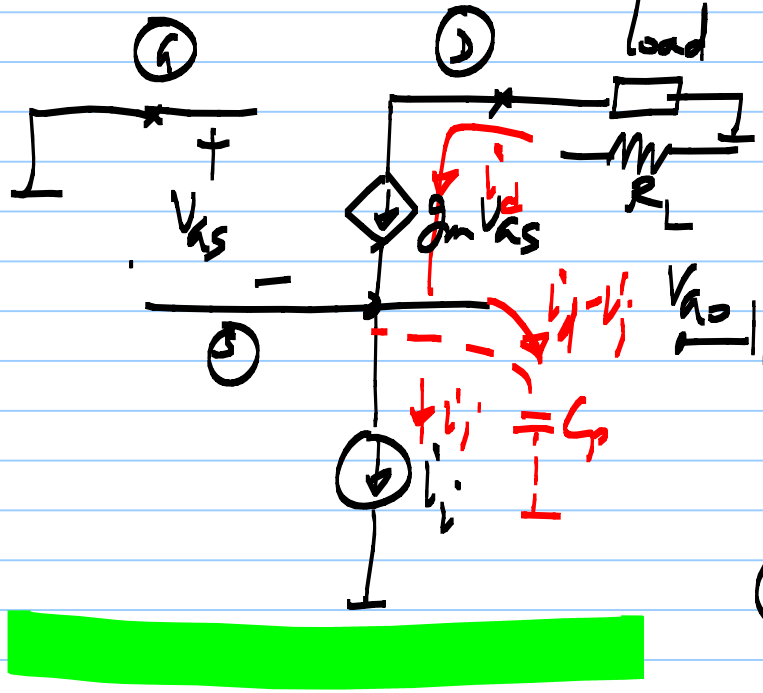


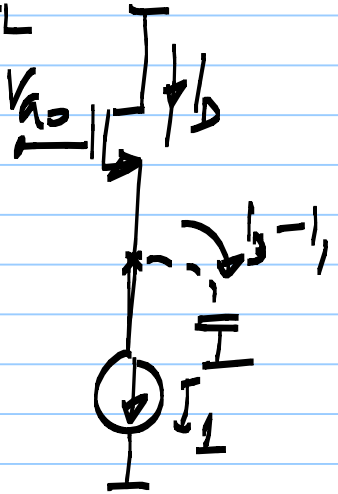
$$i_o = i_i \cdot \frac{R_s}{R_s + R_L}$$

CCCS using a NOS transistor

$i_o = i_i$







Compare i_o & i_i

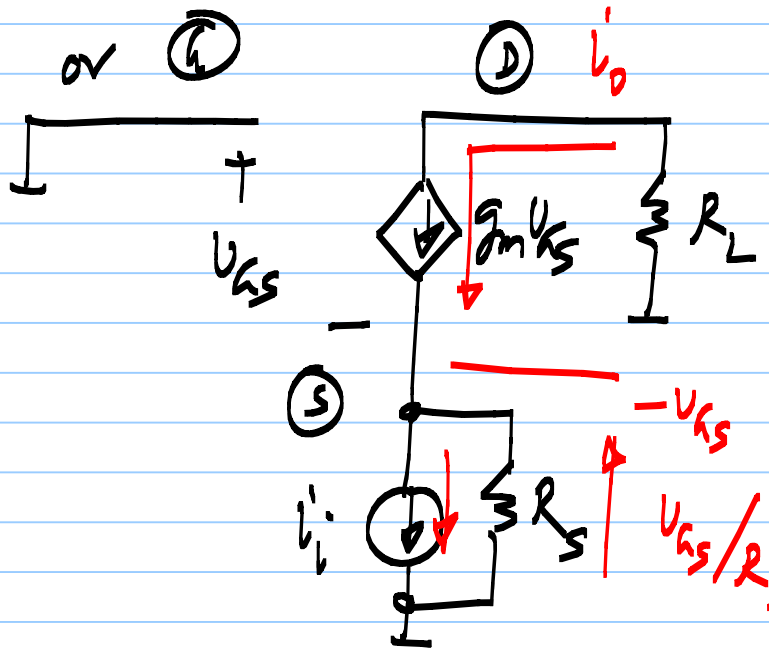
$i_o > i_i$ reduce V_{GS}

$i_o < i_i$ increase V_{GS}

CCVS using a MOS transistor

$$i_i = g_m v_{GS} + v_{GS}/R_S \qquad v_{GS} \cdot G_S$$

$$v_{GS} = \frac{i_i}{g_m + G_S}$$



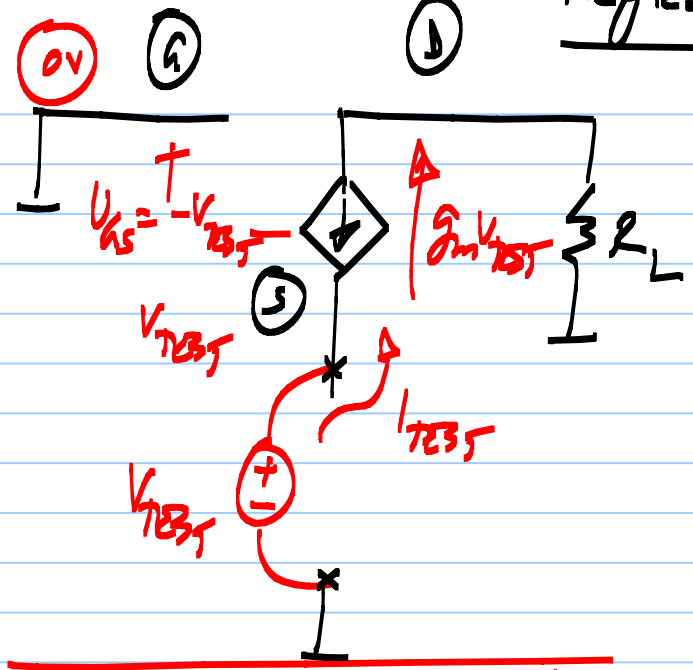
$$i_o = \frac{g_m}{g_m + G_S} \cdot i_i$$

$$i_o = i_i$$

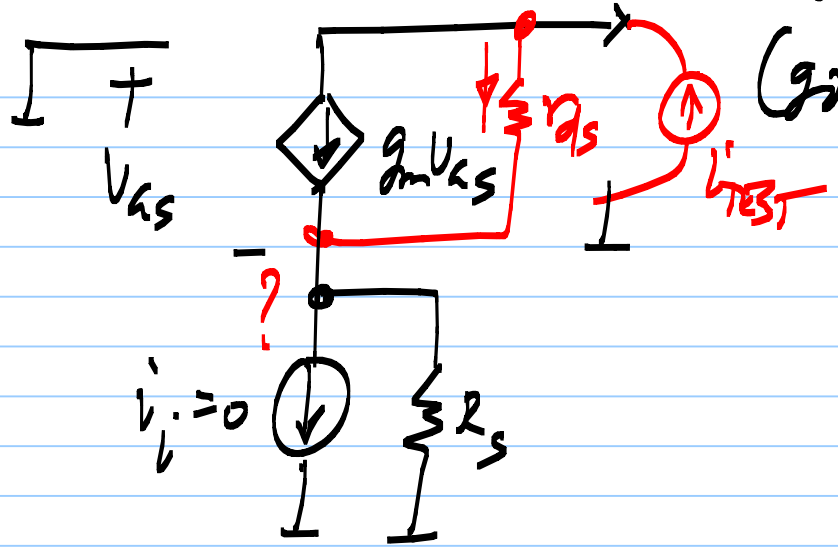
$$v_{GS}/R_S \simeq i_i \quad \text{if} \quad g_m \gg G_S$$

$g_m R_S \gg 1$

reflected r_{ds}



$$R_i = \frac{V_{TEST}}{I_{TEST}} = \frac{1}{g_m}$$



$R_{out} = \infty$

$(g_{ds} = 0)$

$R_{out} = g_m \cdot R_s \cdot r_d + r_{ds} + R_s$

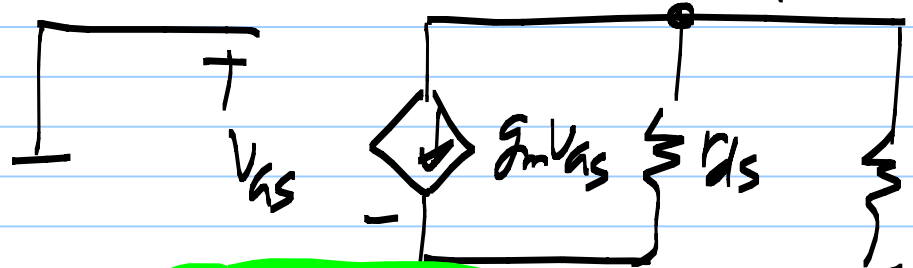
$R_{out} \gg R_s$

$R_{out} \gg r_{ds}$

$g_m R_s \gg 1$

R_{out} of a VCCS

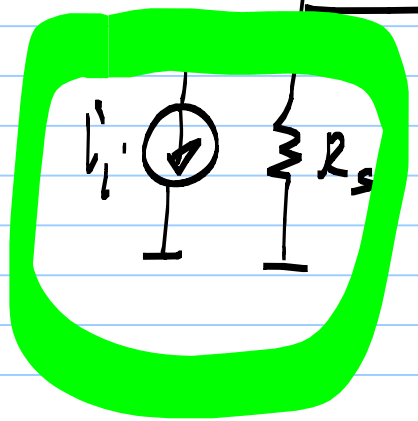
CCCS



$$\frac{i_o}{i_i} = \frac{g_m}{g_m + G_s} \simeq 1 \qquad g_m \gg G_s$$

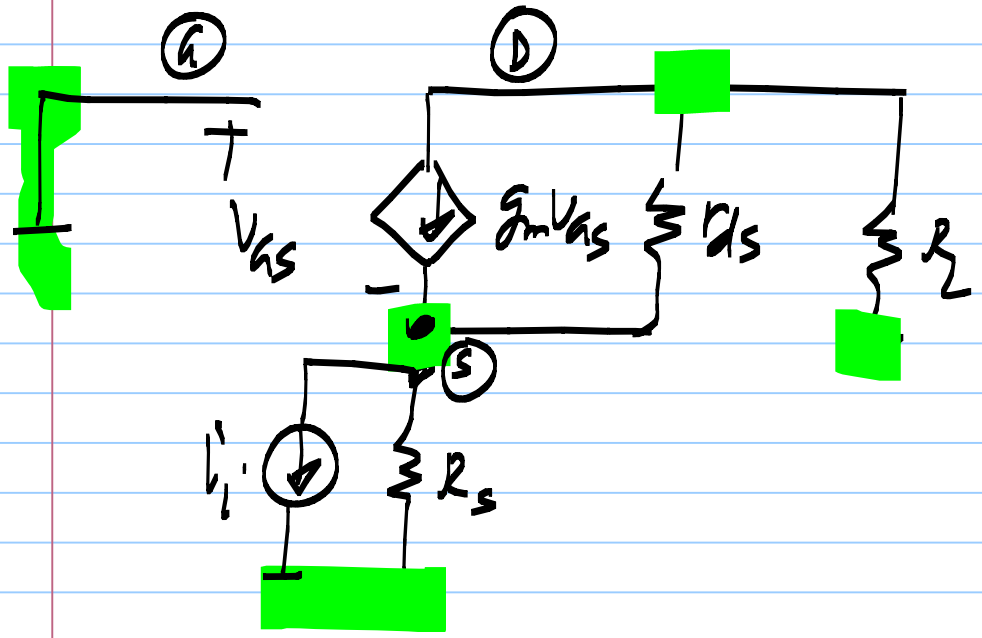
$$R_s \gg \frac{1}{g_m}$$

$$R_i = \frac{1}{g_m}$$



$$R_{out} = g_m R_s r_{ds} + R_s + r_{ds}$$

CCCS

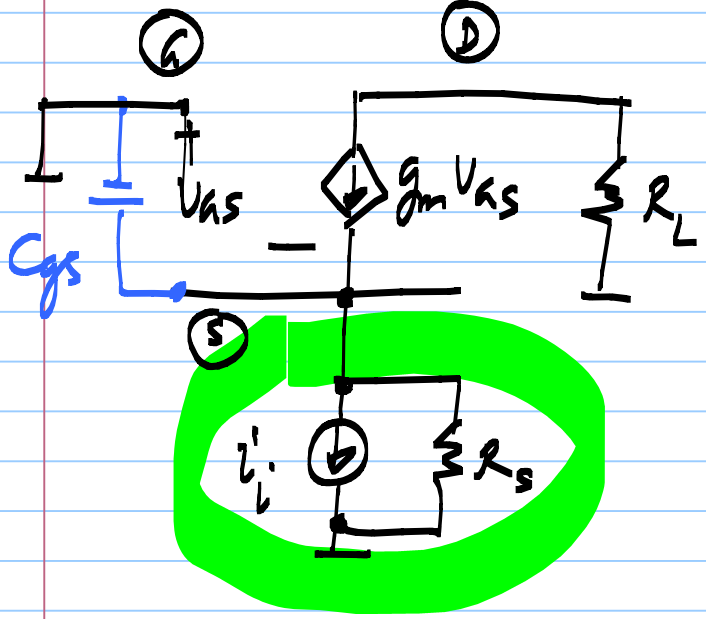


Input: Source - gate
output: drain - gate

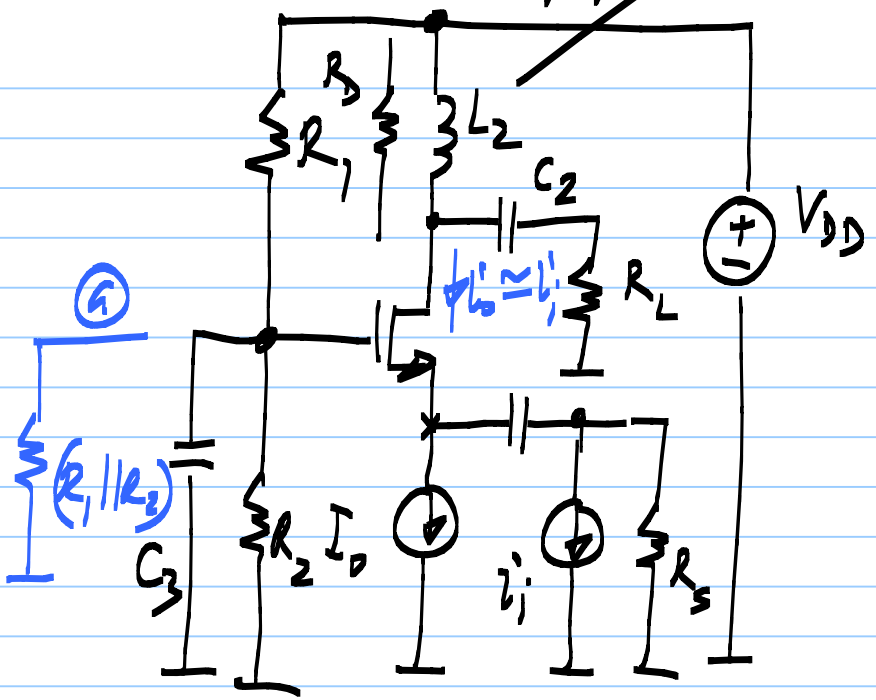
Common gate amplifier

CCCS with gain = 1

(Common gate amplifier)

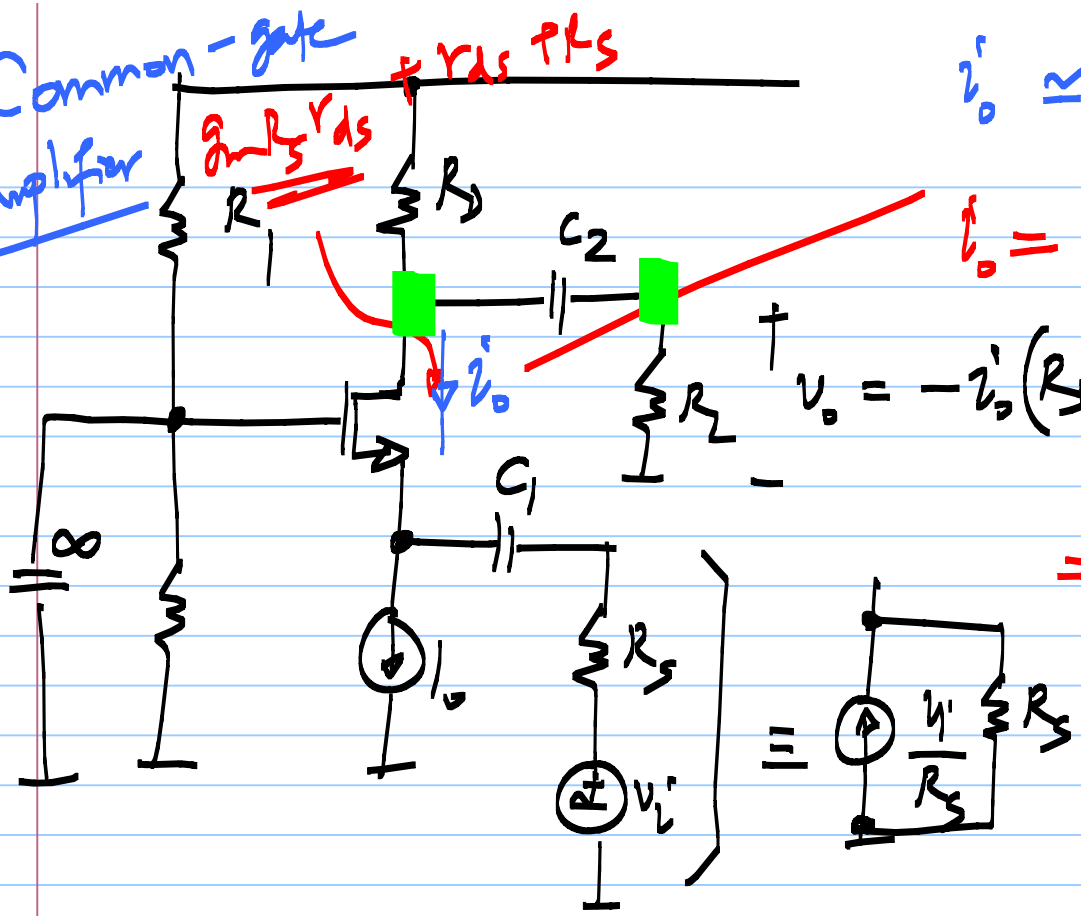


Common gate amplifier choke



$C_3 \gg C_{gs} \simeq C_{ox} WL$

Common-gate amplifier



$$i_o' \simeq -\frac{v_i'}{R_S}$$

neglecting r_{ds}

$$i_o = -\frac{v_i'}{R_S}\left[\frac{g_m}{g_m + G_S}\right]$$

$$v_o = -i_o'(R_3 \| R_L) = v_i' \frac{R_3 \| R_L}{R_S}$$

if $g_m R_S \gg 1$

$$= v_i' \frac{R_3 \| R_L}{R_S}\left(\frac{g_m}{g_m + G_S}\right)$$

$$\frac{g_m R_S}{g_m R_S + 1}$$

Transimpedance amplifier

Current controlled voltage source (CCVS) — using a MOS transistor

$$v_o = i_i \cdot R_m$$

R_m: Transresistance

$v_o - i_i R_m > 0$

output v_o must be pulled down

must be current drawn from the o/p node

$v_o - i_i R_m < 0$

output v_o must be pushed up

current must be pushed into the o/p node.

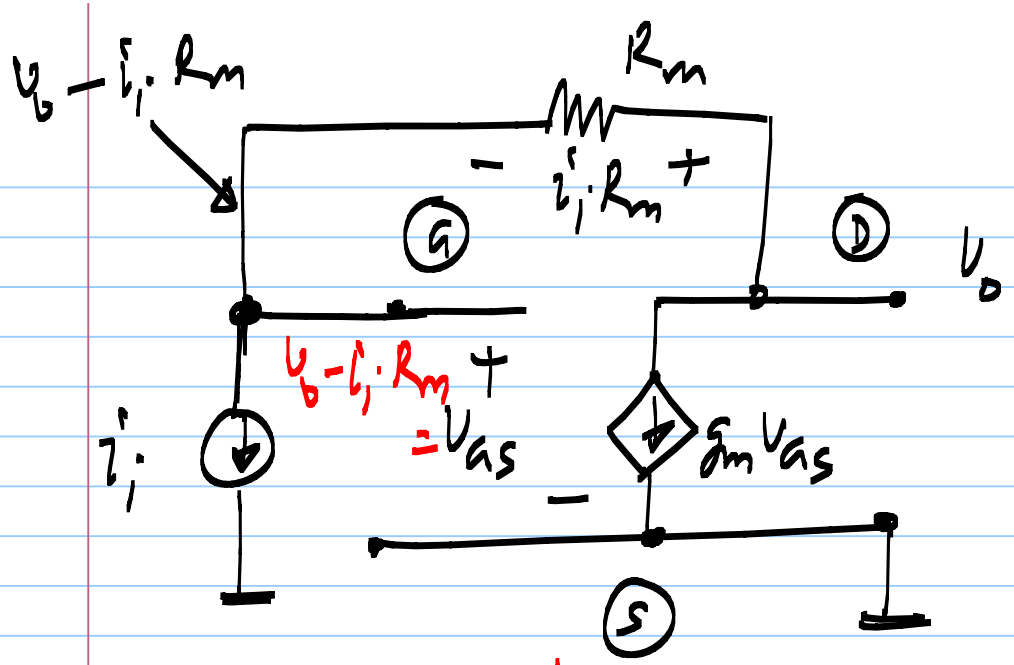
CCVS Error	o/p voltage
$v_o - i_i R_m > 0$	must be reduced
$v_o - i_i \cdot R_m < 0$	must be increased

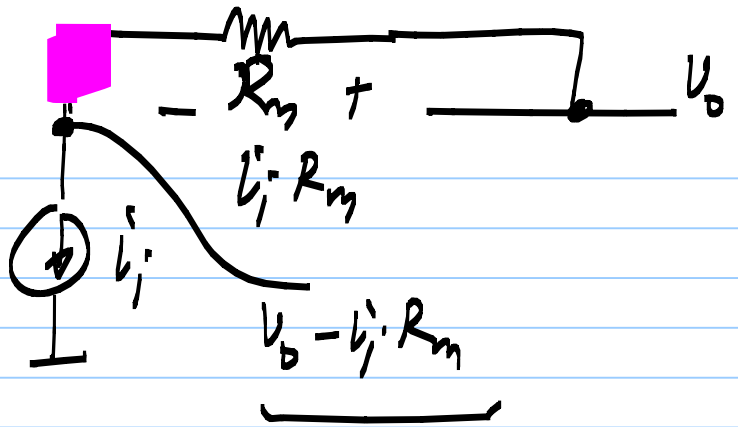
Transistor:

$v_{gs} > 0$	pulls current from the drain; pushes current out of the source;

$v_{gs} = v_o - i_i \cdot R_m$;

o/p : drain terminal

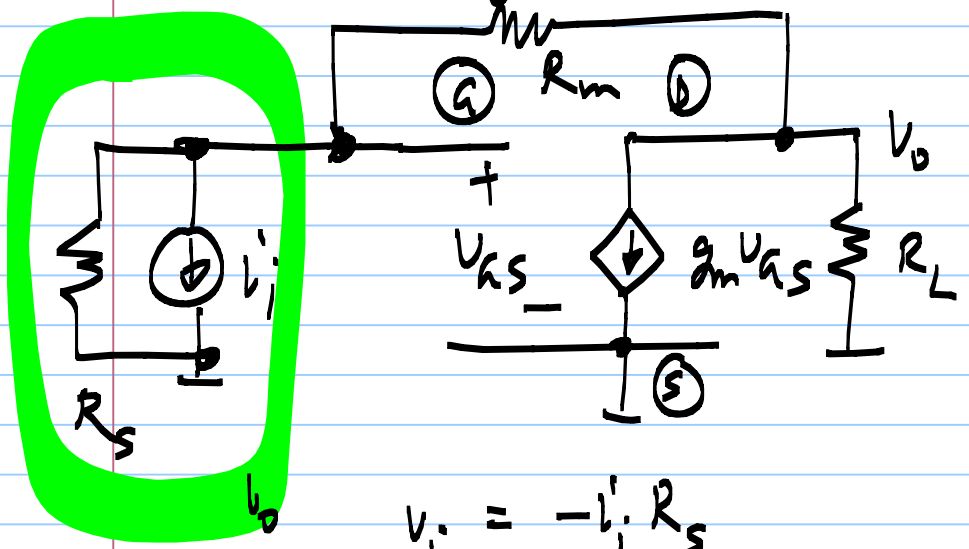




$v_o - i_i \cdot R_m$

CCVS using a MOS transistor

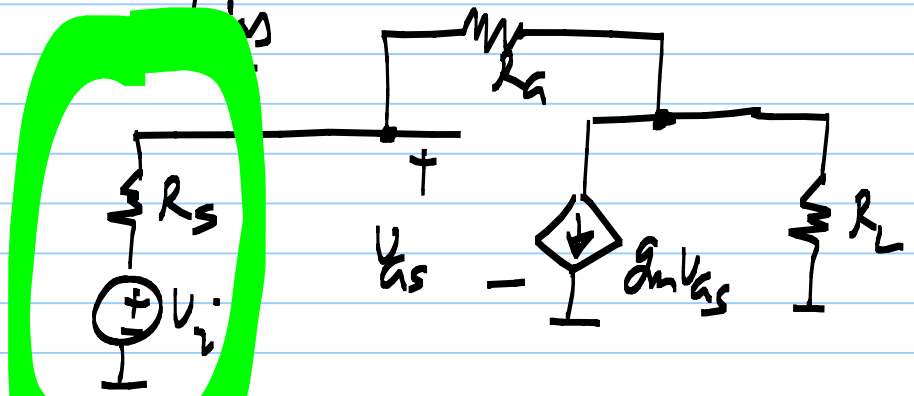
CCVS using a MOS transistor



$$v_i = -i_i' R_s$$

$$v_o = i_i' R_m$$

CS amplifier using drain-fe



CS amp. w/ drain fb bias,

$$\frac{v_o}{v_i} = -\left(\frac{g_m R_a R_L - R_L}{g_m R_L R_s + R_s + R_a + R_L}\right)$$

$$\frac{v_o}{i_i} = R_m$$

$g_m R_m \gg 1$; $g_m R_L R_s \gg R_s, R_m, R_L$

$-i_i R_s$

$$\frac{v_o}{i_i} = \frac{\left(g_m R_m R_L - R_L\right) R_s}{g_m R_L R_s + R_s + R_m + R_L} \simeq R_m$$

$$\frac{v_o}{i_i} = \frac{(g_m R_m R_L - R_L) R_s}{g_m R_L R_s + R_s + R_m + R_L}$$

$$\frac{g_m R_m R_L - R_L}{g_m R_L + 1 + \cancel{\frac{R_m + R_L}{R_s}}}$$

$R_s = \infty$ (ideal input current source).

$R_s \to \infty$

$$\frac{R_m - 1/g_m}{1 + 1/g_m R_L} \simeq R_m$$

$g_m R_m \gg 1$

$g_m R_L \gg 1$

$$\frac{v_o}{i_i} = \frac{(g_m R_m R_L - R_L) R_s}{g_m R_L R_s + R_s + R_m + R_L}$$

CCVS

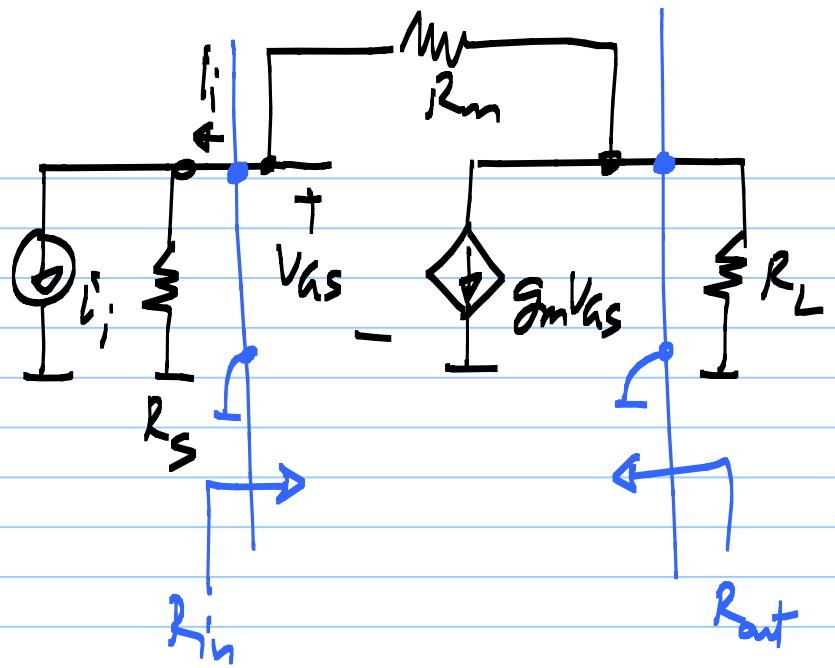
dominant $\Rightarrow \frac{v_o}{i_i} \simeq R_m$

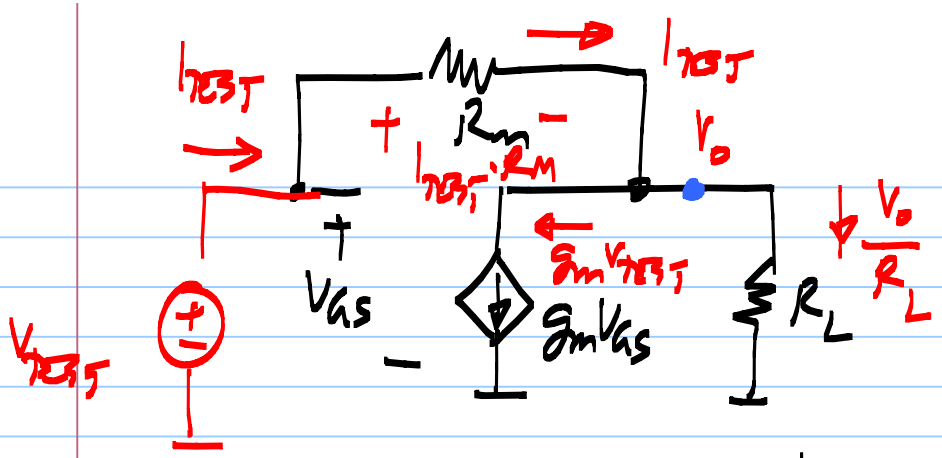
$$\frac{v_o}{v_i} = -\left(\frac{g_m R_a R_L - R_L}{g_m R_L R_s + R_s + R_a + R_L}\right)$$

CS amplifier w/ drain fb. bias

dominant

$$\frac{v_o}{v_i} \simeq -g_m R_L$$


i_i
R_m
i_i
$+$
V_{gs}
$-$
$g_m V_{gs}$
R_L
R_S
R_{in}
R_{out}

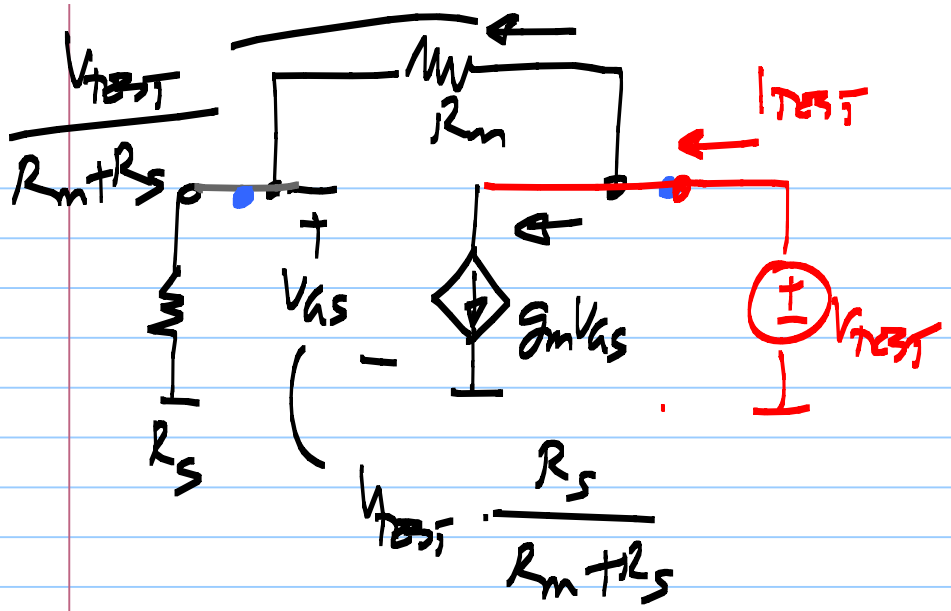


R_{in}

$$V_o = V_{TEST} - I_{TEST} R_m$$

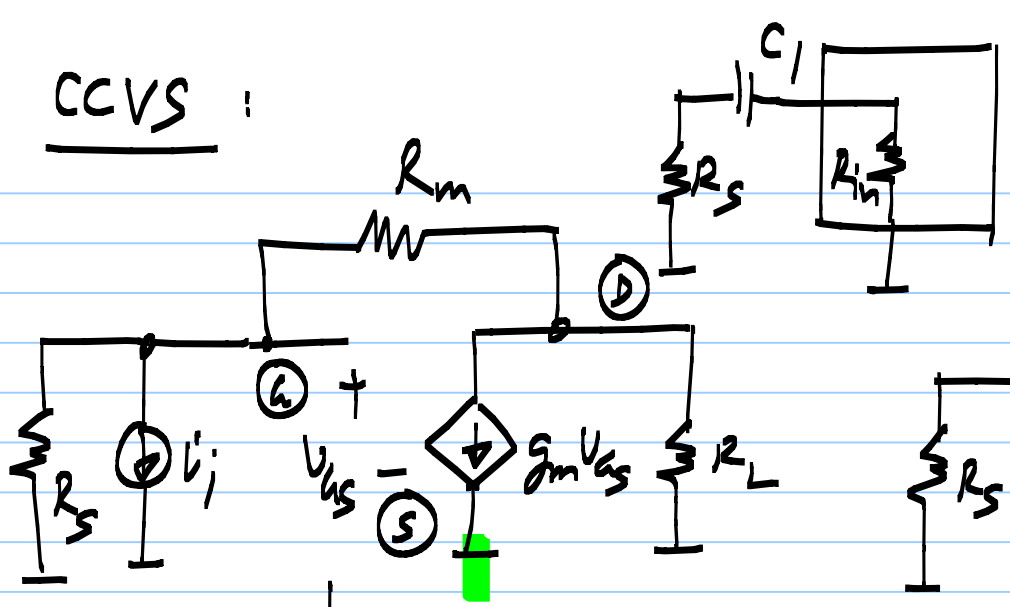
$$I_{TEST} = g_m V_{TEST} + \frac{V_o}{R_L}$$

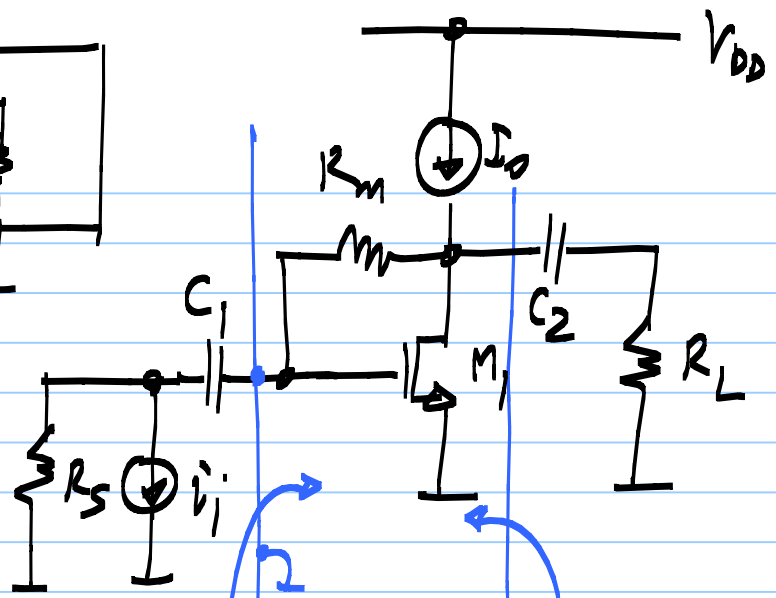
$$R_{in} = \frac{V_{TEST}}{I_{TEST}} = \frac{R_L + R_m}{g_m R_L + 1} \to 0 \text{ if } g_m \to \infty$$



$$R_{out} = \frac{V_{TEST}}{I_{TEST}} = \frac{R_s + R_m}{g_m R_s + 1} \longrightarrow 0 \quad \text{as } g_m \to \infty$$

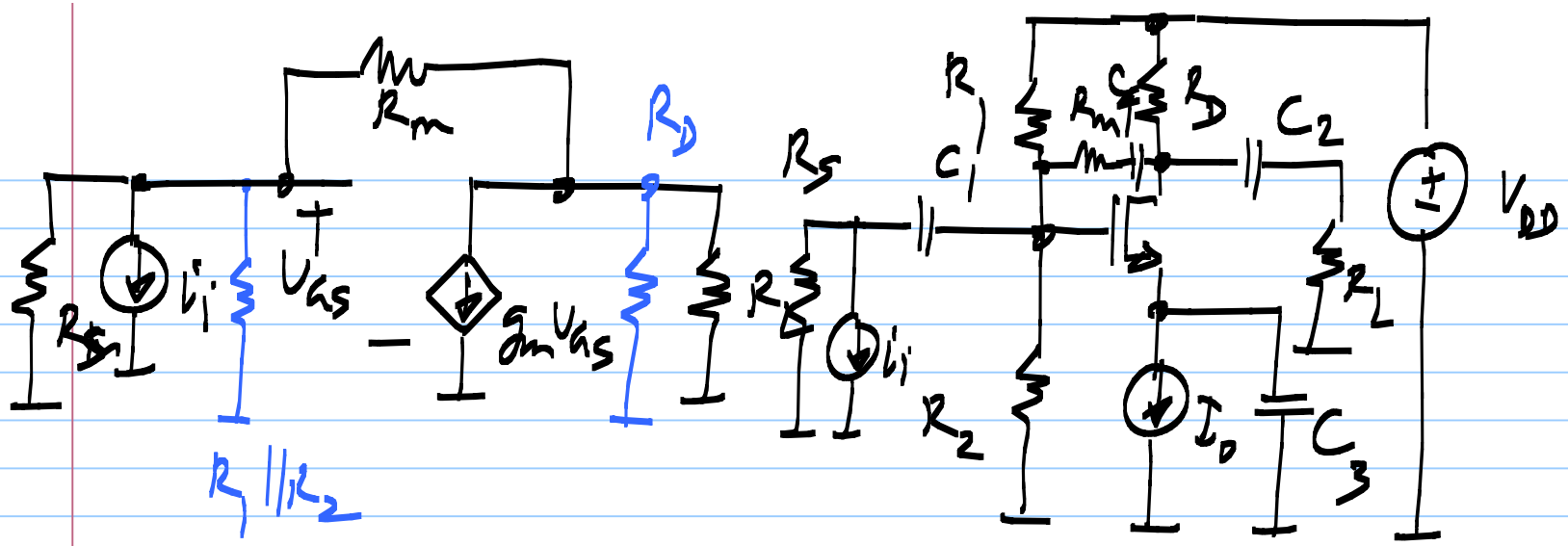
CCVS :





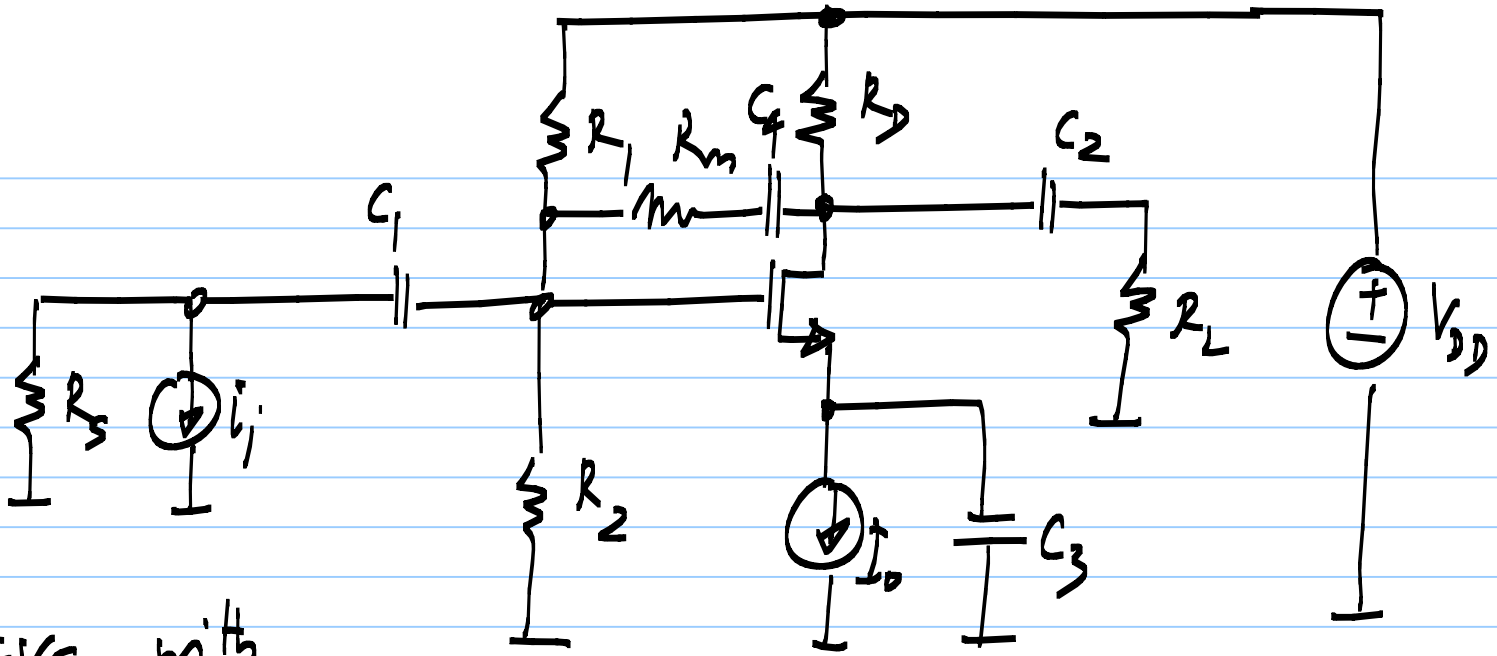
$$C_1 \gg \frac{1}{\omega (R_S + R_{in})}$$

$$C_2 \gg \frac{1}{\omega (R_{out} + R_L)}$$



$R_S \longrightarrow R_1 \| R_2 \| R_S$

$R_L \longrightarrow R_L \| R_D$



CCVS with

Source feedback bias