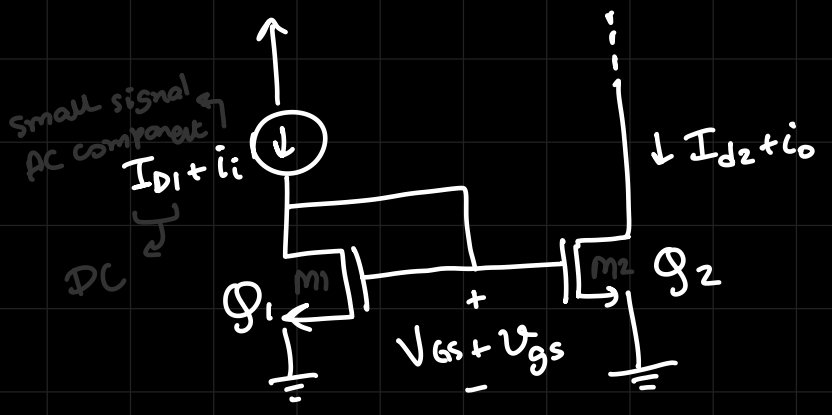
Lecture 17

⇒ Current mirror as current amplifier

low input resistance
higher output resistance wrt R_L

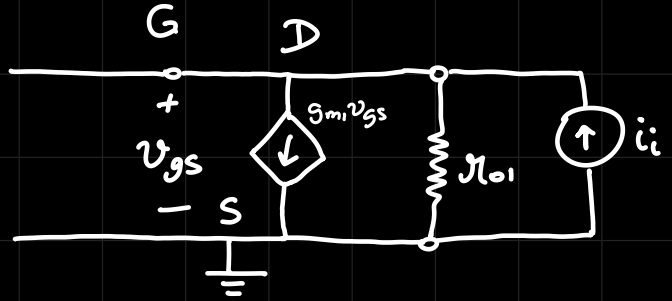


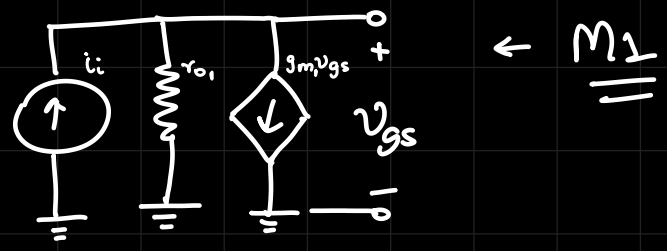
M_2 needs to be in saturation for current mirror

$$V_{DS2} > V_{GS2} - V_{T2}$$

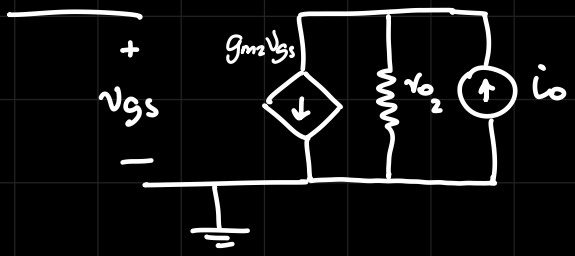
AC analysis
↳ small signal model (π)

M_1 :



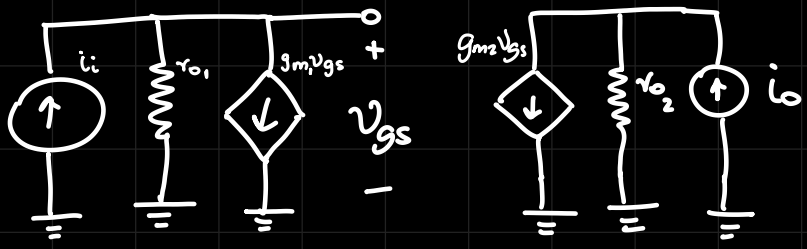


← M_1

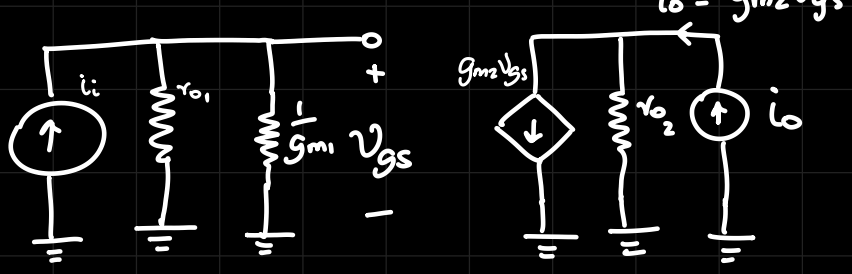


← M_2

Combined ckt :



dep I src → resistor of $R = \frac{1}{g_m}$



: we dont want current to flow trough r_{o2} hence r_{o2} should be very high so that I flows trough load

$$Z_{in} = r_{o1} \parallel \frac{1}{g_{m1}} \simeq \frac{1}{g_{m1}} \quad ; \quad Z_o = r_{o2}$$

↓

inverse of V amp

current gain: $A_i = \left.\frac{i_o}{i_i}\right|_{o/p\ R \ll\ll r_{o2}} = \frac{g_{m2} v_{gs}}{i_i}$

and $v_{gs} = i_i \cdot R_{in} \simeq i_1 \cdot \frac{1}{g_{m1}}$

assumption: $\frac{1}{g_{m1}} >>> r_{o1}$

$$A_i \simeq \frac{g_{m2}\, i_1 \cdot 1/g_{m1}}{i_1} \simeq \boxed{\frac{g_{m2}}{g_{m1}}}$$ ← current gain

<u>note</u>: we need gain ↑↑ and hence we neglected M1's early effect resistance in our assumption

i.e. $r_{o1} \to \infty$

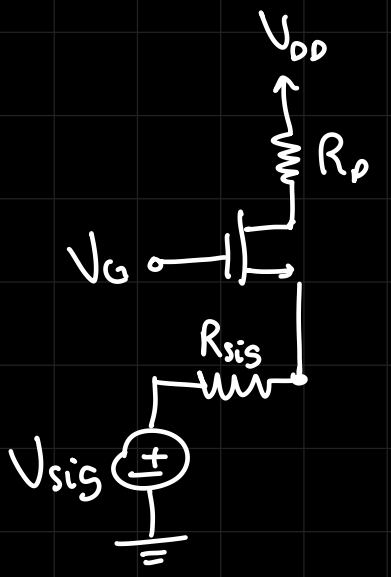
$g_{m2} = 2K_2 (V_{GS2} - V_{T2})$

$g_{m1} = 2K_1 (V_{GS1} - V_{T1})$

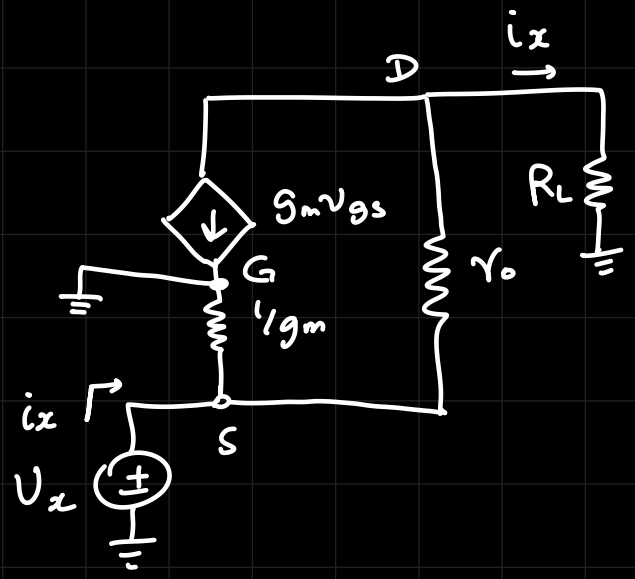
$K_1 = \frac{1}{2} \mu_1 C_{ox} \left(\frac{W}{L}\right)_1$, $K_2 = \frac{1}{2} \mu_2 C_{ox} \left(\frac{W}{L}\right)_2$

COMMON GATE

we want to distribute the gain over multiple amps to prevent clipping of input.



T model



$$I_{r_o} = g_m v_{gs} + i_x$$
$$I_{R_L} = i_x$$

$$-V_x + I_{r_o} r_o + i_x R_L = 0$$
$$V_x = i_x (r_o + R_L) + g_m v_{gs} r_o$$

note: $V_s = -V_{gs} = V_x$

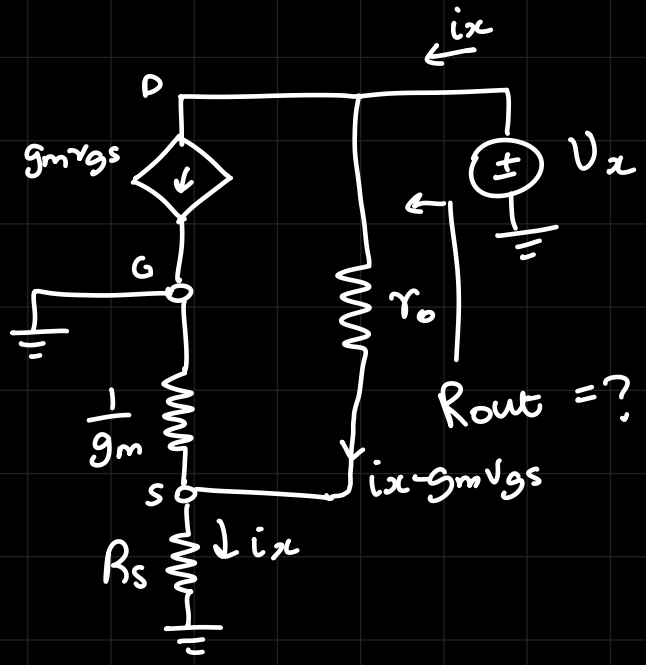
$$V_x (1 + g_m r_o) = i_x (R_L + r_o)$$

$$R_{in} = \frac{V_x}{i_x} = \frac{R_L + r_o}{1 + g_m r_o} \simeq \frac{R_L}{g_m r_o} + \frac{1}{g_m} \quad \{\text{assuming } g_m r_o >>> 1\}$$

* $\Rightarrow$ Even if $R_L \uparrow$, R_{in} scales down R_L by $g_m r_o$ and prohibits the rise of R_{in} significantly.

and hence low input resistance achieved for current amp / buffer.

Now finding out output resistance



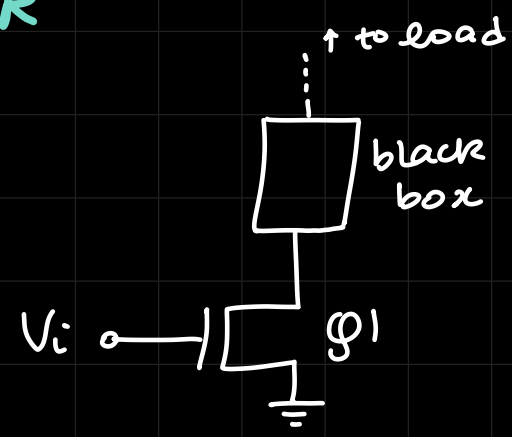
$$V_{gs} = -V_s = -i_x R_s$$

$$V_x = (i_x - g_m V_{gs}) r_o + i_x R_s = (i_x + g_m i_x R_s) r_o + i_x R_s$$

$$R_{out} = r_o + g_m R_s r_o + R_s = r_o + R_s (1 + g_m r_o)$$

The output resistance will be high : $R_{out} = R_s g_m r_o$

CASCODE AMPLIFIER

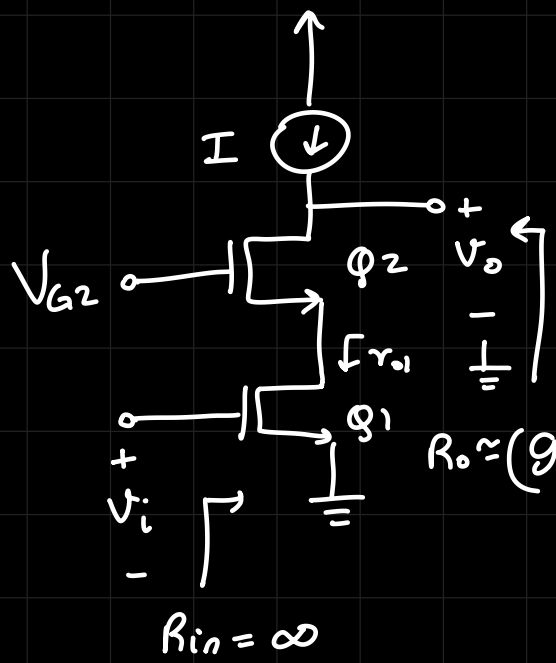


The black box can be a common gate transistor so that ...

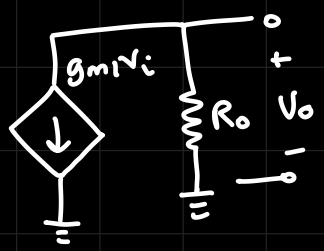
① Input impedance is not high and wrt R_L, R_{in} scales by $\frac{R_L}{g_m r_o}$

② Output impedence is very high.
$R_{out} = R_s g_m r_o$

③ Current gain = 1



$V_o = -g_{m1} V_i R_o$



for the CG config,

$R_o = g_{m2} r_{o2} R_s$: derived earlier

$R_s = r_{o1}$ because Q_1 is the src for Q_2

So, $R_o = g_{m2} r_{o2} r_{o1}$

$A_v = -g_{m1} R_o = -g_{m1} g_{m2} r_{o2} r_{o1}$

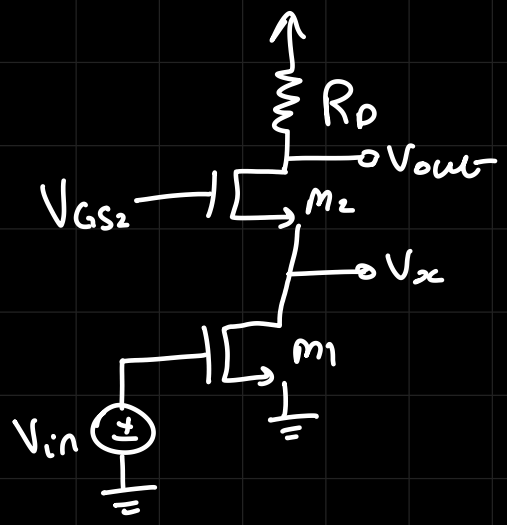
$= -g_{m1} r_{o1} \, g_{m2} r_{o2}$

let $g_{m1} = g_{m2} = g_m$ and $r_o = r_{o1} = r_{o2}$

$A_v = -(g_m r_o)^2 = -A_{vo}^2$

where A_{vo} = volt gain of regular CS transistor

TRADEOFFS:



for M1: saturation,

$V_x > V_{in} - V_{t1}$

$V_{GS2} = V_{G2} - V_{S2}$

$V_{S2} = V_{G2} - V_{GS2}$

$V_x = V_{S2} = V_{G2} - V_{GS2} > V_{in} - V_{t1}$

for M2 : saturation →

$$V_{DS2} > V_{GS2} - V_{T2}$$
$$V_{D2} - V_{S2} > V_{GS2} - V_{T2}$$
$$V_{out} - V_x > V_{GS2} - V_{T2}$$
$$V_{out} > V_{GS2} - V_{T2} + V_x$$
and $V_x > V_{in} - V_{T1}$
but $V_x = V_{in} - V_{T1}$

$$V_{out} \geq \underbrace{V_{GS2} - V_{T2}}_{V_{ov2}} + \underbrace{V_{in} - V_{t1}}_{V_{ov1}}$$

overdrive voltages

increasing more amps in cascode, will keep on increasing V_{out} depending on V_{ovs} which might distort the output signal when $V_{out} < V_{ov1} + V_{ov2} + \ldots$.

HORIZONTALLY INCREASING: gain ↑, g stable ✓
VERTICALLY INCREASING : gain ↑, distortion ↑