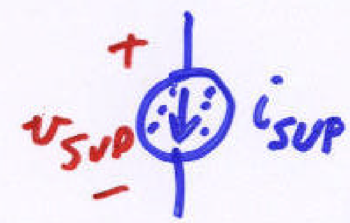
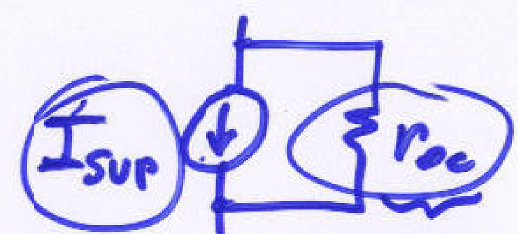
Lecture 27

A_i

- Last time:
  - ✓ Current-source supplies
  - ✓ Common-gate amplifier
- Today :
  - Finish common-gate
  - Common-drain amplifier

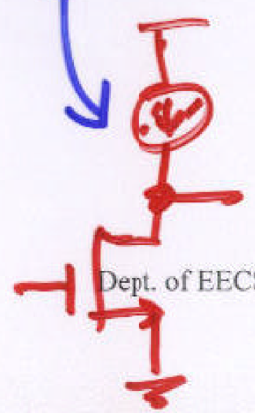


→ IMPERFECT CURRENT "SOURCE"



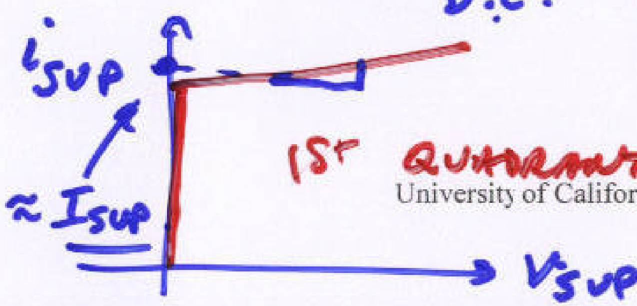
D.C. LINEAR RESISTOR.

ABSTRACT



• LARGE r_{oc}

• LARGE I_{SUP} ⇒ LARGE I_D ⇒ g_m



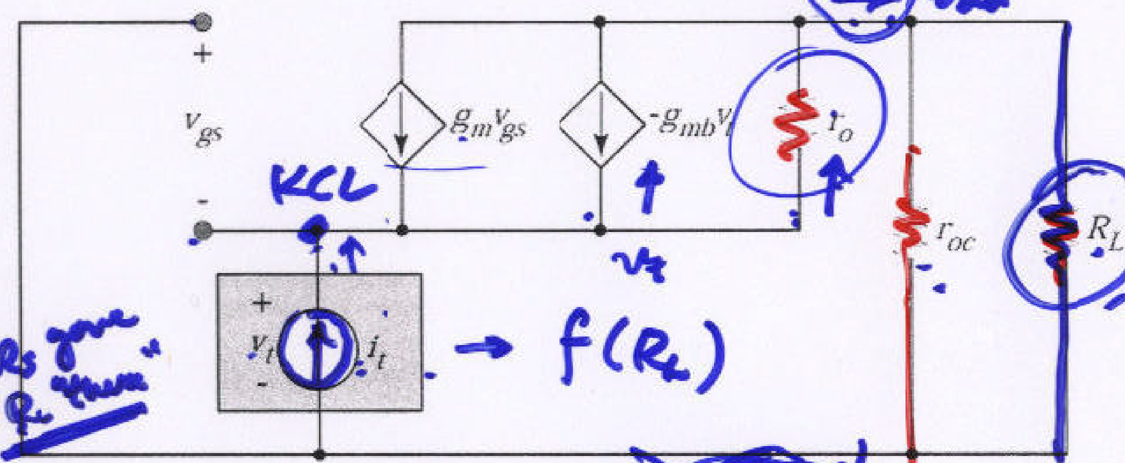
1st QUADRANT.

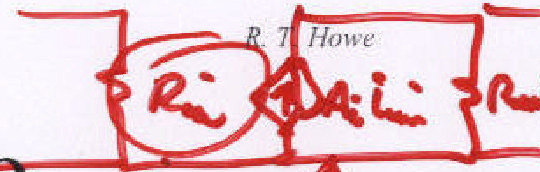
R. T. Howe

*1 A_i ✓ *3 R_{out}

*2 R_{in}

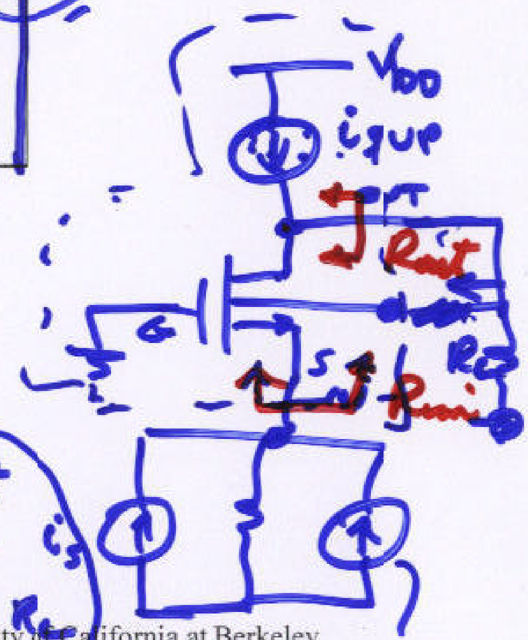
CG Input Resistance





$R_{in} = \frac{v_t}{i_t}\Big|_{R_S \text{ gone}, R_L \text{ there}} \rightarrow f(R_L)$

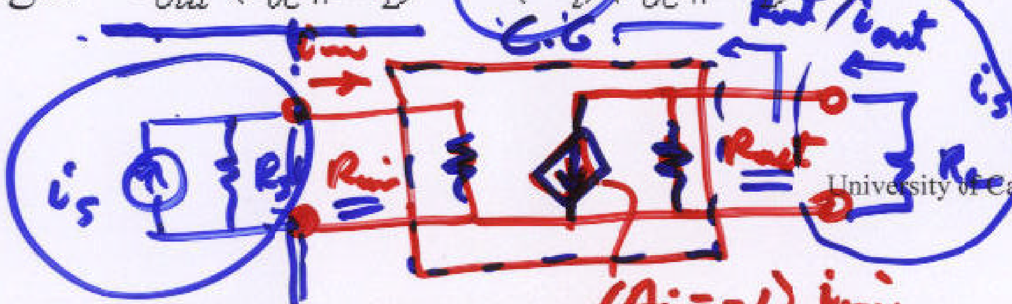
$\frac{v_t}{i_t}\Big|_{R_S=0,\ R_L \text{ left on}}$



At input: $i_t = -g_m v_{gs} + g_{mb}v_t + \left(\frac{v_t - v_{out}}{r_o}\right)$

$v_{gs} = -v_t$

Output voltage: $-i_{out}(r_{oc} \| R_L) = -(-i_t)(r_{oc} \| R_L)$



$(A_i = -1)\ i_{in}$

$I_{BMS} = -I_{SUP}$

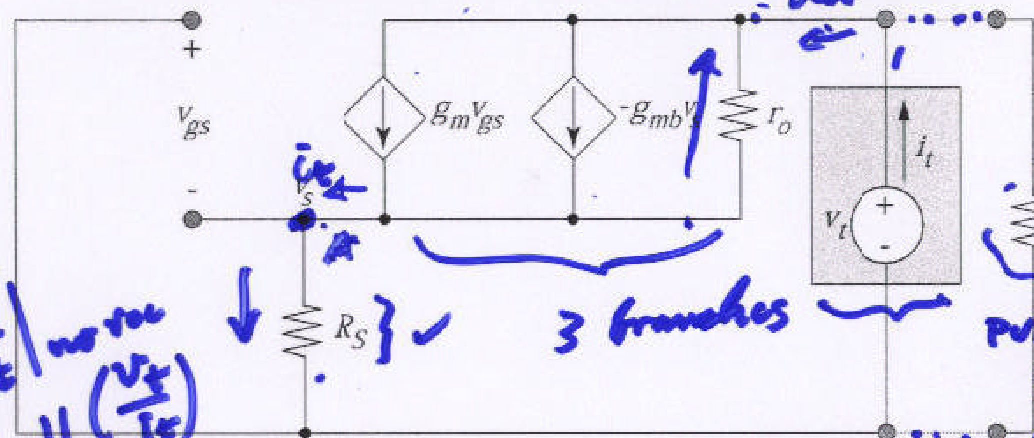
CG Output Resistance

$i_t \approx (g_m + g_{mb})\, v_t$

$0.5\,mS = \frac{1}{2k\Omega}$

$g_{mb} = 0.1\, g_m$.

$r_o = 250k\Omega$.



$\frac{v_t}{i_t} = R_{in}$ (A) $= \frac{1}{g_m + g_{mb}}$ $\approx$ $\frac{1}{g_m}$ (B)

"SMALL".

$R'_{out} = \frac{v_t}{i_t}$ no r_{oc}

$R_{out} = r_{oc} \,\|\, \left(\frac{v_t}{i_t}\right)$

* Kirchhoff's current law at the source resistor node: sum currents leaving node

A $$\frac{v_s}{R_S} - g_m \underbrace{v_{gs}}_{-v_s} - (-g_{mb} v_s) + \frac{v_s - v_t}{r_o} = 0$$

$$\rightarrow \quad v_s\left(\frac{1}{R_S} + g_m + g_{mb} + \frac{1}{r_o}\right) = \frac{v_t}{r_o}.$$

$i_t R_S$

Common-Gate Output Resistance

"A PAIN"

Substituting $\boxed{v_s = i_t R_S}$

$$i_t R_S \left(\frac{1}{R_S} + g_m + g_{mb} + \frac{1}{r_o} \right) = \frac{v_t}{r_o}$$

The output resistance is $(v_t / i_t) \| r_{oc}$

SIMPLIFY

$$R_{out} = r_{oc} \| \underbrace{(R_S [r_o / R_S + g_m r_o + g_{mb} r_o + 1])}_{\text{BIG}_2} = \text{BIG!}$$

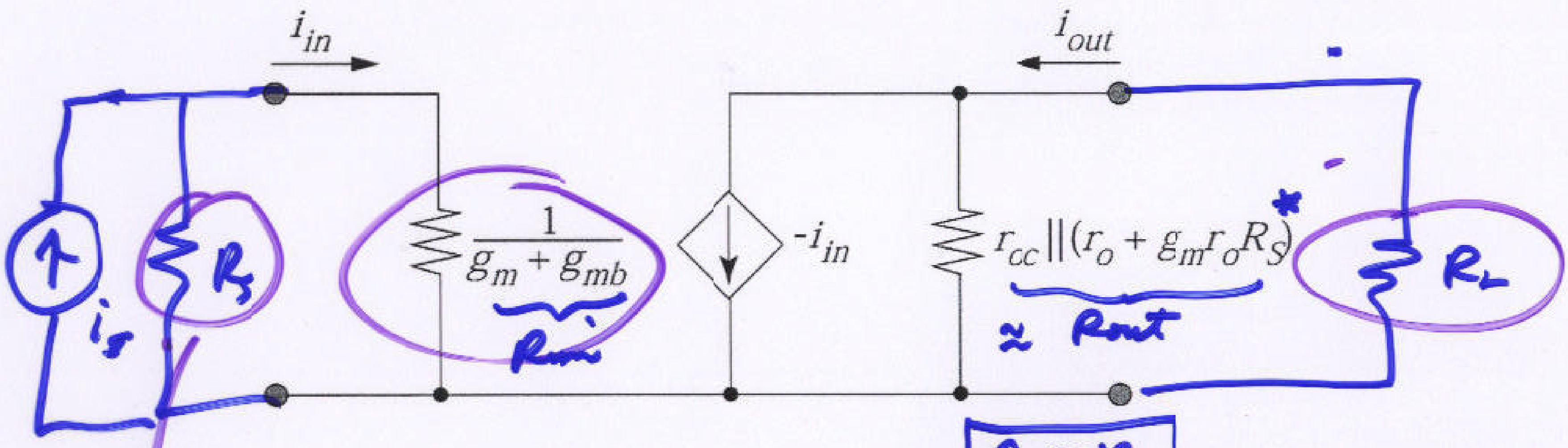
HUGE!

BIG, $= r_{oc} \| (\text{LESS}) \quad \frac{v_t}{i_t}$

$\left(\frac{1}{2\,k\Omega} \cdot 200\,k\Omega\right) \approx 100.$

WE ARE FINISHED!

Common-Gate Two-Port Model



$\boxed{R_S \ll r_o,}$

Function: a current buffer

POOR → SMALL R_S

OFTEN $\}$ LARGE

$$\frac{i_{out}}{i_s} = \left[\frac{R_S}{R_S + \frac{1}{g_m + g_{mb}}}\right](-1)\left[\frac{r_{oc} \| (r_o(1 + g_m R_S))}{R_L + r_{oc} \| [r_o(1 + g_m R_S)]}\right]$$

SMALL

1.

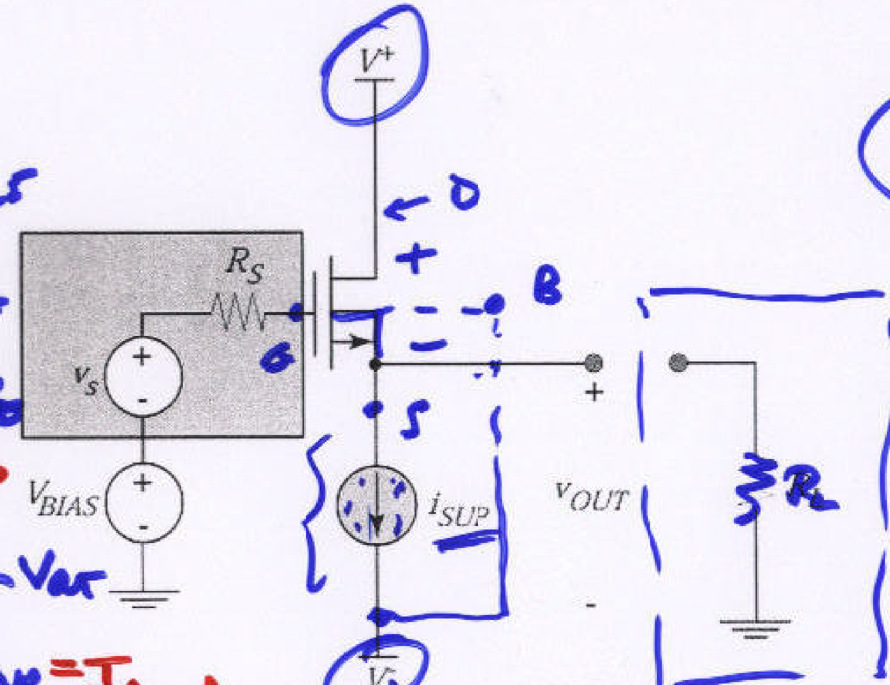
$I_D = \mu_n C_{ox}(W/2L)(V_{GS} - V_{Tn})^2 \cancel{(1 + \lambda_n V_{DS})}$

Common-Drain Amplifier

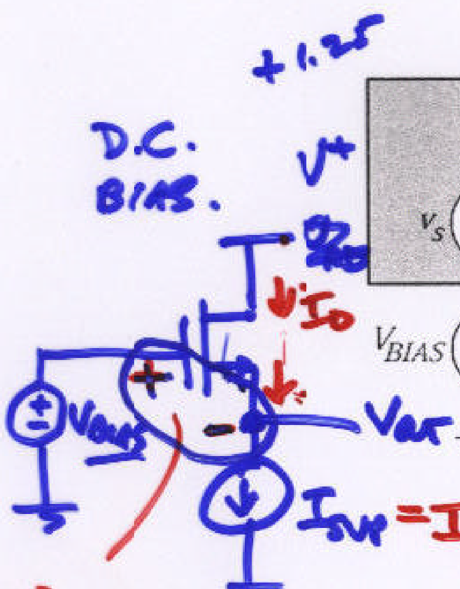
CS ✓
CG ✓

$\left.\frac{d v_{out}}{d v_{BIAS}}\right|_Q = 1$

Backgate terminal



D.C. BIAS.



$V_{GS} = V_{BIAS} - V_{OUT} = V_{BIAS}$.
LET'S MAKE

$\underline{V_{OUT} = 0V}$.

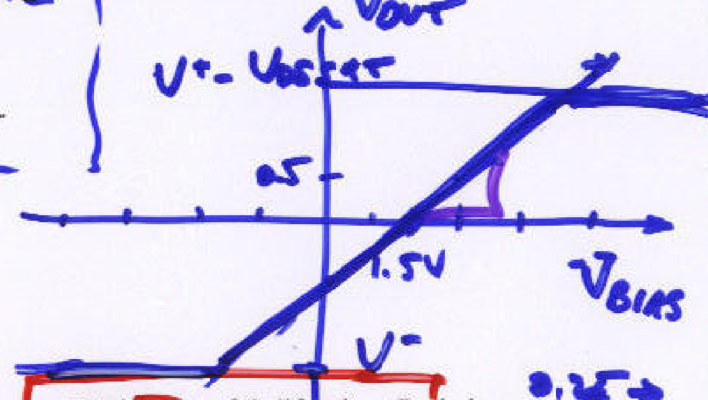
← EASY!

$V_{OUT} = V_{BIAS} - 1.5V$

$V_{OUT} = V_{BIAS} - V_{GS}$

1.5V

$V_{GS} = V_{Tn} + \sqrt{\frac{2I_D}{\mu_n C_{ox}(W/L)}}$



0.25 →
← 0.5

Approximating the CG R_{out}

0.1 $g_m r_o R_S$

$$R_{out} = r_{oc} \,||\, [r_o + g_m r_o R_S + \cancel{g_{mb} r_o R_S} + R_S]$$

The exact result is complicated, so let's try to make it simpler:

$$g_m \approx \underbrace{500\mu S}_{\frac{1}{2k\Omega}} \quad g_{mb} \approx \underbrace{50\mu S}_{\frac{1}{20k\Omega}} \quad r_o \approx 200k\Omega$$

$$R_{out} \cong r_{oc} \,||\, [r_o + g_m r_o R_S + R_S]$$ PRETTY GOOD

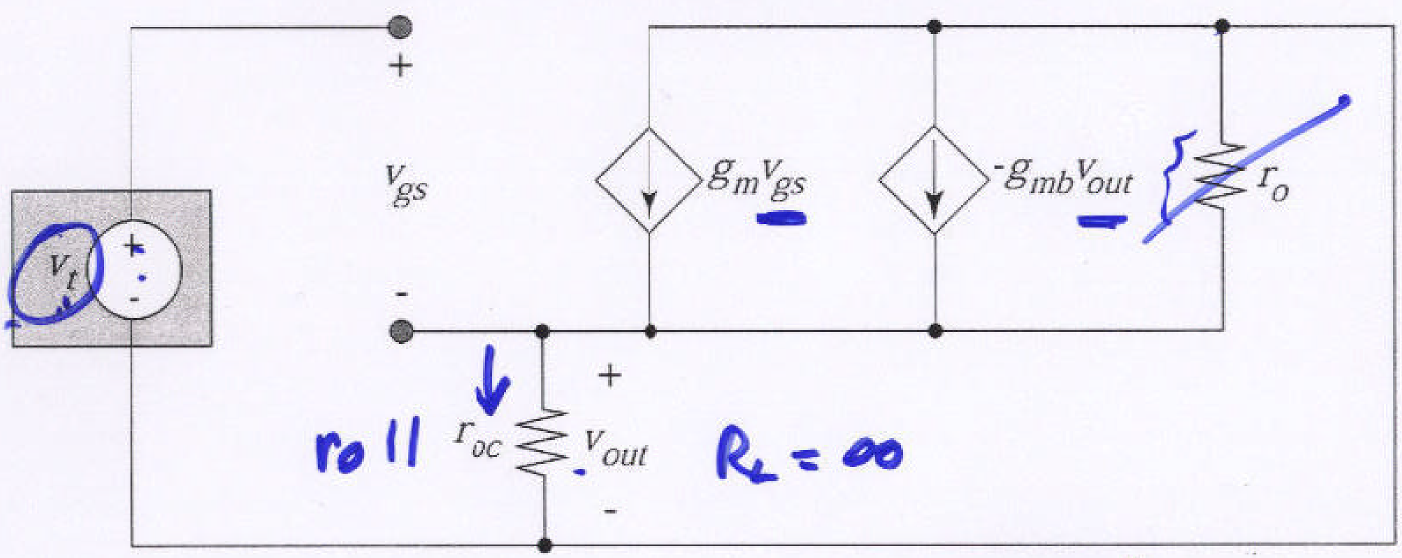
Assuming the source resistance is less than r_o,

$$\boxed{R_{out} \approx r_{oc} \,||\, [r_o + g_m r_o R_S] = r_{oc} \,||\, [r_o(1 + g_m R_S)]}\ *$$

$R_S << r_o$

$r_{oc} \,||\, r_o(1+25)$

CD Voltage Gain



Note $v_{gs} = v_t - v_{out}$

$$A_v = \left.\frac{v_{out}}{v_{in}}\right|_{\substack{R_S = 0 \\ R_L = \infty}}$$

$$\frac{v_{out}}{r_o \parallel r_{oc}} = g_m v_{gs} - g_{mb} v_{out}$$

$$= g_m (v_t - v_{out}) - g_{mb} v_{out}$$

CD Voltage Gain (Cont.)

KCL at source node:

$$v_{out}\left(\frac{1}{r_o \| r_{oc}} + g_m v_{out} + g_{mb} v_{out}\right) = g_m v_t$$

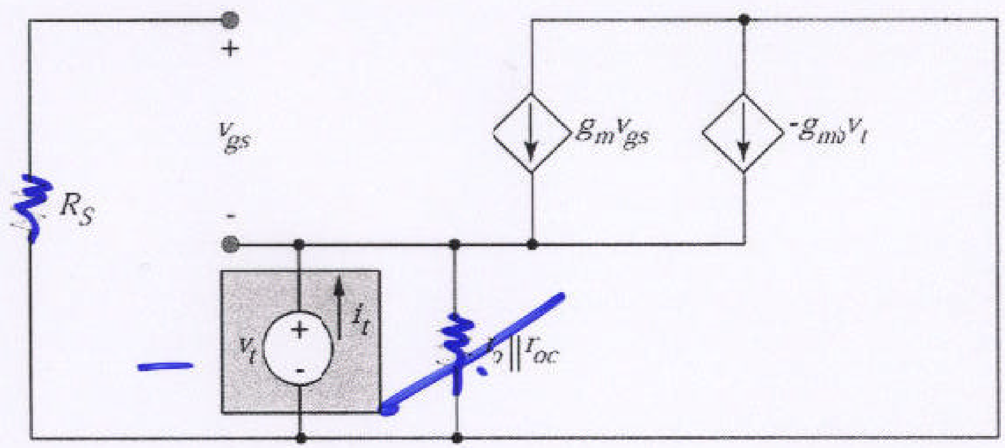
Voltage gain (for v_{SB} not zero):

$$\frac{v_{out}}{v_t} \equiv A_v = \frac{g_m}{g_m + g_{mb} + \cancel{\frac{1}{r_o \| r_{oc}}}}$$

$$\approx \frac{g_m}{g_m + g_{mb}} \approx 1.$$

$R_{in} = \infty$.

CD Output Resistance



Sum currents at output (source) node:

$$R_{out} = (r_o \| r_{oc}) \| \left\{ \frac{v_t}{i_t} \right\}$$

$$i_t + g_m \cancel{v_{gs}}^{\,-v_t} + -g_{mb} v_t = 0$$

$$i_t = (g_m + g_{mb}) v_t$$

CD Output Resistance (Cont.)

$r_o \| r_{oc}$ is much larger than the inverses of the transconductances → ignore

$$R_{out} = \cancel{(r_o \| r_{oc})} \,\|\, \left\{ \frac{1}{g_m + g_{mb}} \right\} = \frac{1}{g_m + g_{mb}}$$