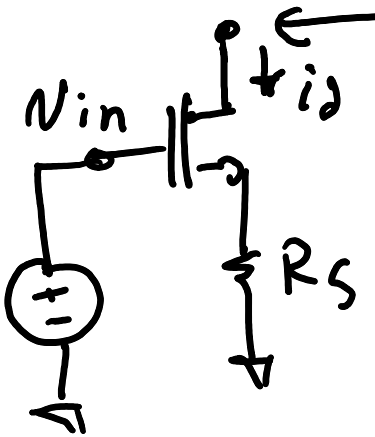
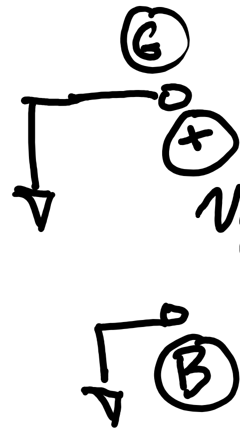
Lecture #5, Jan 14^{th}, 2022

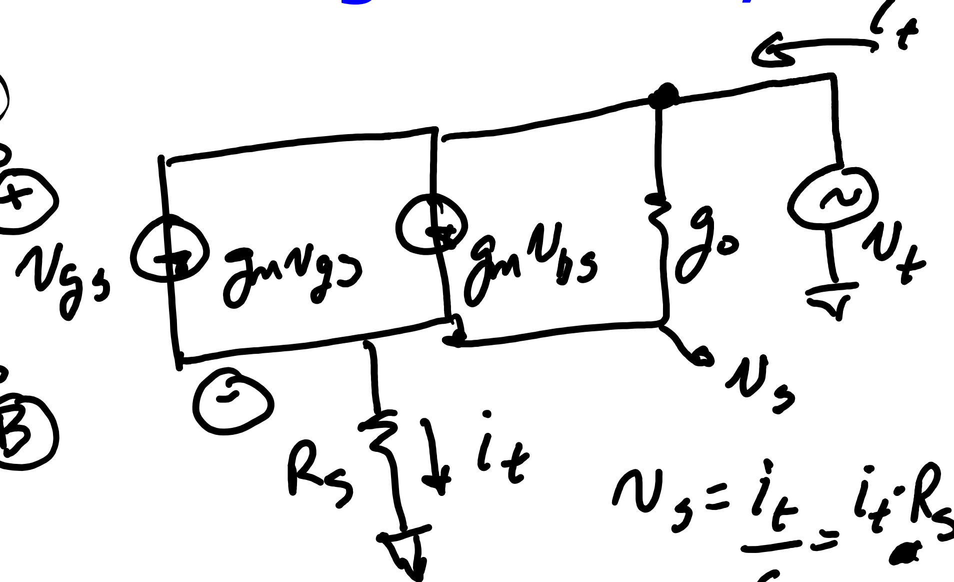
- Review Chapter 1 and 2 of Razavi book as needed. Course will start with Chapter 3.
- CAD 1 out, CAD 2 coming very soon – hopefully today.
- Homework 1 out, due 1 week from today.
- NDAs coming out with New CAD.
- Monday is MLK day.
- Class will be on campus next week w/ virtual option.
- Quiz 1 on Monday 1/24
- Discuss Single-Transistor Amplifier Configurations
  - Common-Source Amplifier
  - Common-Source w/ Active Load
  - Common-Source w/ Degeneration
  - Common-Gate Amplifier
  - Example problem.

Common-Source w/ Resistive Degeneration, Ro



$R_o =$





$$v_s = \frac{i_t}{g_s} = i_t \cdot R_s$$

KCL @ OUTPUT NODE

$$i_t = g_m \overbrace{\Big(0 - \frac{i_t}{g_s}\Big)}^{v_{gs}} + g_{mbs} \overbrace{\Big(0 - \frac{i_t}{g_s}\Big)}^{v_{bs}} + g_o \Big(v_t - \frac{i_t}{g_s}\Big)$$

$v_g = 0$ $\qquad$ $v_b = 0$

$$R_o = \frac{v_t}{i_t} \Rightarrow \quad i_t \cdot \left[1 + \frac{(g_m + g_{mbs} + g_o)}{g_s} \right] = g_o \cdot v_t$$

$$i_t \cdot \left[1 + \frac{(g_m + g_{mbs} + g_o)}{g_s} \right] = g_o \cdot v_t$$

$$R_o = \frac{v_t}{i_t}$$

$$\frac{v_t}{i_t} = \frac{\left[1 + \frac{(g_m + g_{mbs} + g_o)}{g_s} \right]}{g_o} \qquad g_o = \frac{1}{r_o}$$

$$= r_o \left[1 + (g_m + g_{mbs} + g_o) R_s \right]$$

TYPICALLY $g_{mbs} \ll g_m$

$$\boxed{R_o \cong r_o \left[1 + g_m \cdot R_s \right]}$$

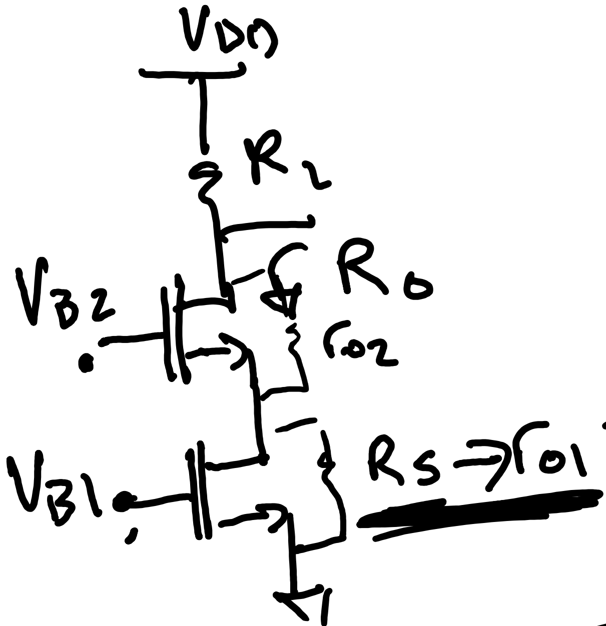
$\Downarrow$ BURN INTO MEMORY! $g_o \ll g_m$

ASSUME

$1 \ll g_m \cdot R_s$

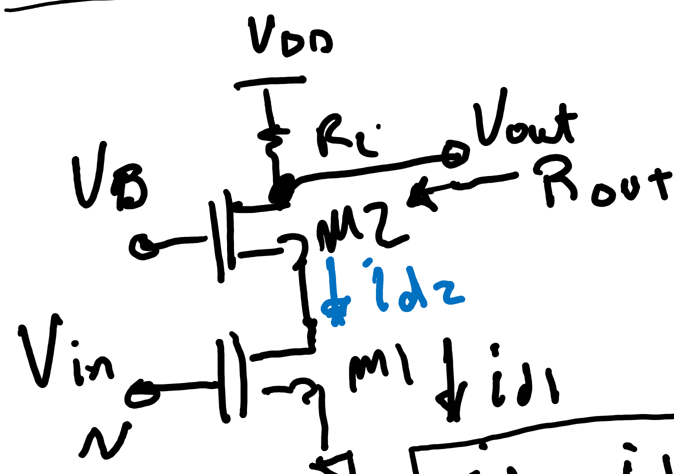
$$\boxed{R_o \cong g_m \cdot R_s \cdot r_o}$$

Cascode Gain



$$R_o \approx g_{m2} \cdot r_{o1} \cdot r_{o2}$$

$1k\Omega - 5k\Omega$



$$\boxed{i_{d1} = i_{d2} = g_{m1} v_{in}}$$

• BY INSPECTION $G_m = g_{m1}$

$$R_{OUT} = R_L // R_O$$

$$\approx R_L // g_{m2} \cdot r_{o1} \cdot r_{o2}$$

$$a_v = -G_m \cdot R_{out}$$

$$= \frac{-g_{m1} r_{o1} \cdot g_{m2} \cdot r_{o2} \cdot R_L}{g_{m2} \cdot r_{o2} \cdot r_{o1} + R_L}$$

Ideal Cascode Gain, R_L -> ∞

$$A_v = \frac{-g_{m1} r_{o1} \cdot g_{m2} \cdot r_{o2} \cdot R_L}{g_{m2} \cdot r_{o2} \cdot r_{o1} + R_L}$$

$$= \frac{-g_{m1} r_{o1} g_{m2} \cdot r_{o2}}{1 + (g_{m2} r_{o2} r_{o1}) / R_L}$$

INTRINSIC GAIN OF CASCODE.

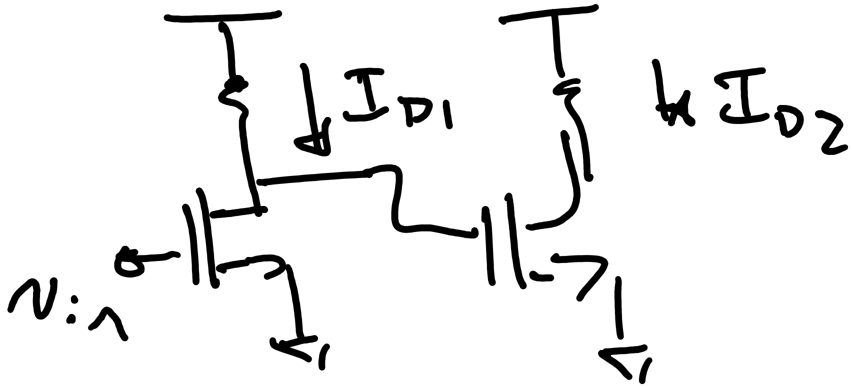
$\Rightarrow R_L \to \infty$

$$\boxed{A_v \cong -\underbrace{g_{m1} r_{o1}}\, \underbrace{g_{m2} r_{o2}}}$$

BURN IN MEMORY.

INTRINSIC GAIN OF CS AMP.

CASCADED CS AMPS



$$A_v = g_{m1} r_{o1} \cdot g_{m2} \cdot r_{o2}$$

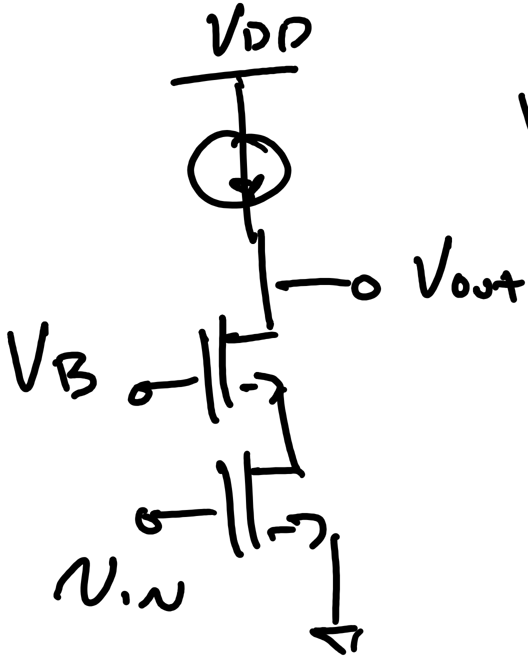
CASCODE

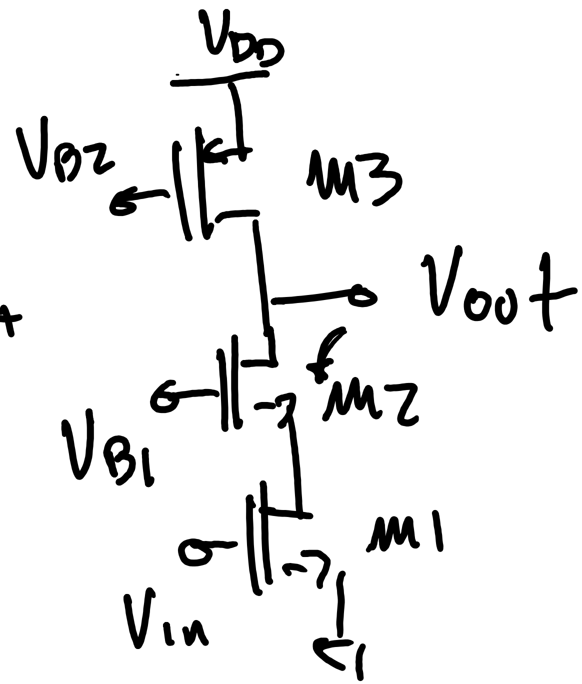
- HAS CURRENT REUSE.
- VERY HIGH GAIN.
- LIMITED OUTPUT VOLTAGE SWING.

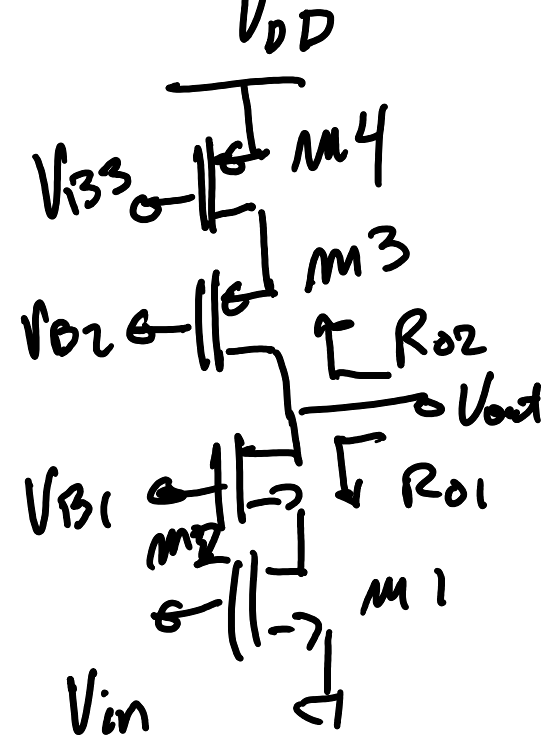
$\Rightarrow$ LOW-END OF SIGNAL [illegible]

"V_{OUT}" LIMITED TO $2 V_{DSATS}$ [illegible] $R_{L\,LOW}$

FOR M1 & M2







$$A_v \cong -g_{m1} \cdot r_{o3}$$

$$R_{o2} \cong g_{m3} \cdot r_{o4} \cdot r_{o3}$$

$$R_{o1} \cong g_{m2} \cdot r_{o1} \cdot r_{o2}$$

$$A_v \cong -g_{m1} \cdot (R_{o2} \parallel R_{o1})$$ ← Assume $R_{o1} = R_{o2}$

$$A_v = -g_{m1} \cdot \left(\frac{g_m \cdot r_o \cdot r_o}{2}\right)$$

Example Problem 3.4

3.4. Suppose the common-source stage of Fig. 3.4(a) is to provide an output swing from 1 V to 2.5 V. Assume that $(W/L)_1 = 50/0.5$, $R_D = 2\ k\Omega$, and $\lambda = 0$.

(a) Calculate the input voltages that yield $V_{out} = 1$ V and $V_{out} = 2.5$ V.

(b) Calculate the drain current and the transconductance of M_1 for both cases.

(c) How much does the small-signal gain, $g_m R_D$, vary as the output goes from 1 V to 2.5 V? (Variation of small-signal gain can be viewed as nonlinearity.)

ASSUME $V_{DD} = 3V$

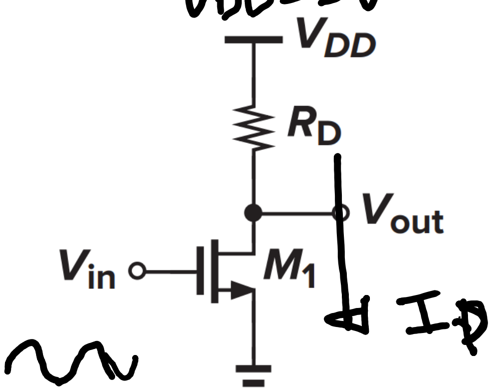
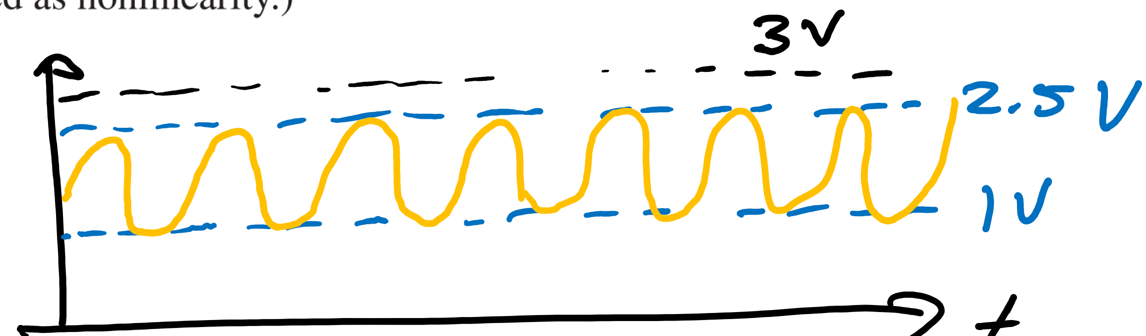


FIG 3.4 a



$$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)(V_{GS}-V_{tn})^2(1+\cancel{\lambda V_{DS}})$$

$\lambda = 0$

1st FIND $V_{IN} = V_{GS}\big|_{V_{OUT}=2.5V}$

$$I_D = \frac{V_{DD}-V_{OUT}}{R_D} = \frac{3V-2.5V}{2k\Omega} = 0.25\ mA$$

$$I_D\big|_{V_{out}=1V} = \frac{3V-1V}{2k\Omega} = 1\ mA$$

$$V_{IN} = V_{GS} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\left(\frac{W}{L}\right)}} + V_{th}$$

$V_{out} = 2.5V$

$$= \sqrt{\frac{2 \cdot 0.25\,mA}{1.34\times10^{-4}\left(\frac{50}{0.5}\right)}} + 0.7V = \underline{0.89V}$$

$V_{out} = 1V.$

$$= \sqrt{\frac{2 \cdot 1mA}{1.34\times10^{-4}\left(\frac{50}{0.4}\right)}} + 0.7V = \underline{1.086V}$$