Lecture #4, Jan 12th, 2022

- Review Chapter 1 and 2 of Razavi book as needed. Course will start with Chapter 3. Read and Review Chapter 3.1 – 3.5
- CAD 1 out, CAD 2 coming very soon.
- Homework 1 coming.
- Discuss Single-Transistor Amplifier Configurations
  - Common-Source Amplifier
  - Common-Source w/ Active Load
  - Common-Source w/ Degeneration
  - Common-Gate Amplifier
  - Common-Drain Amplifier

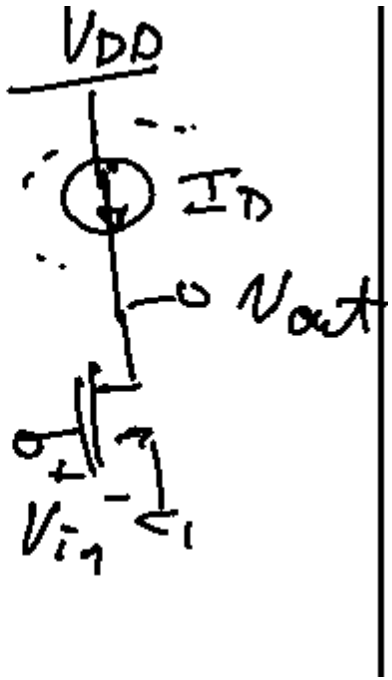
CMOS Intrinsic Gain

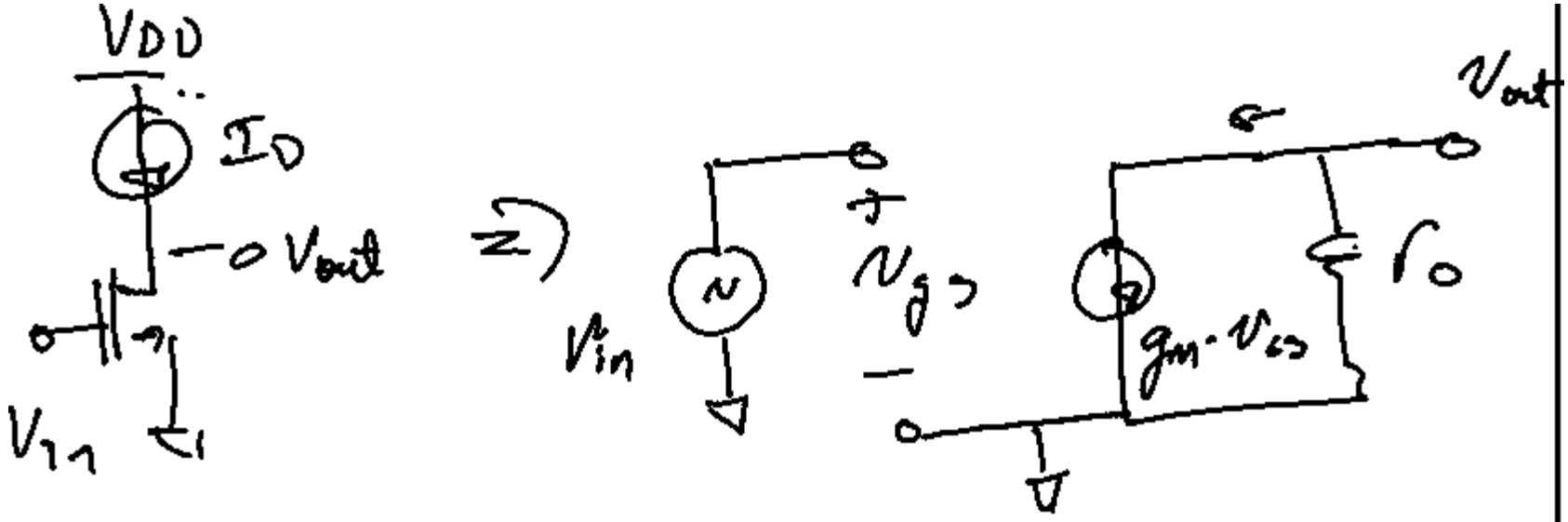
$\equiv$

LOOK AT

IDEAL CASE

$R_D \to \infty$



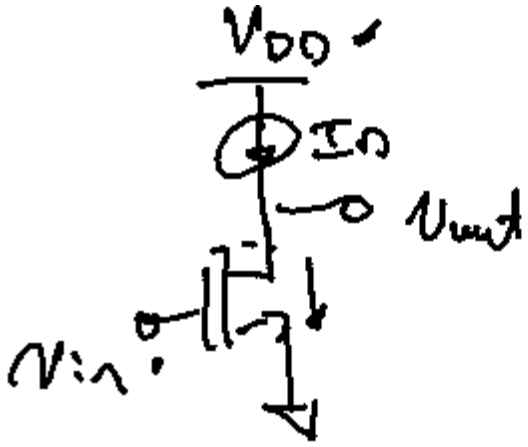


$V_{out} = -g_m \cdot V_{gs} \cdot r_o$ $\quad V_{gs} = V_{in}$

V_{in}

$$A_v = -g_m \cdot r_o$$ ← DEVICE INTRINSIC GAIN

MOSFET Gain Limitations



$$a_v = -g_m \cdot r_o$$

$$r_o = \frac{1}{\lambda I_D}$$

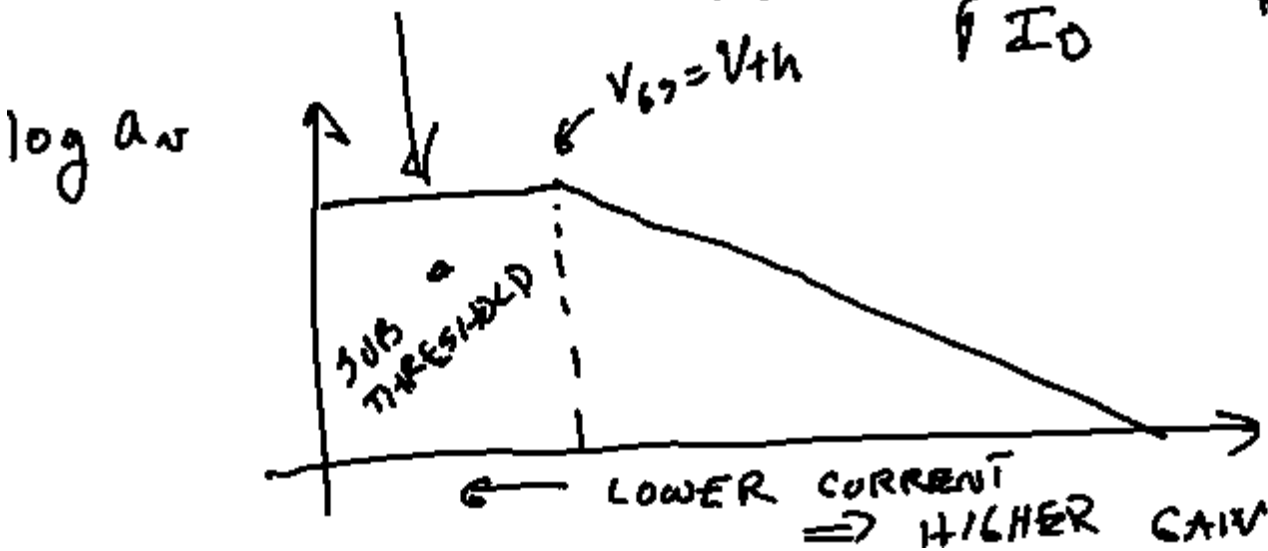
λ : TECH DEP.

$$a_v = -\frac{\sqrt{2K_n'(W/L)I_D}}{\lambda I_D}$$

(g_m)

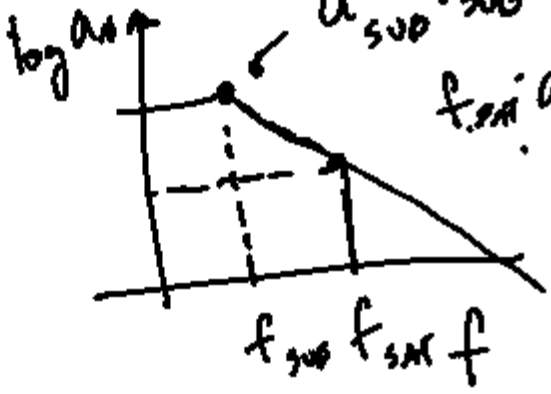
SUBTHRESHOLD OR WEAK INVERSION

$$a_v \propto \frac{1}{\sqrt{I_D}}$$

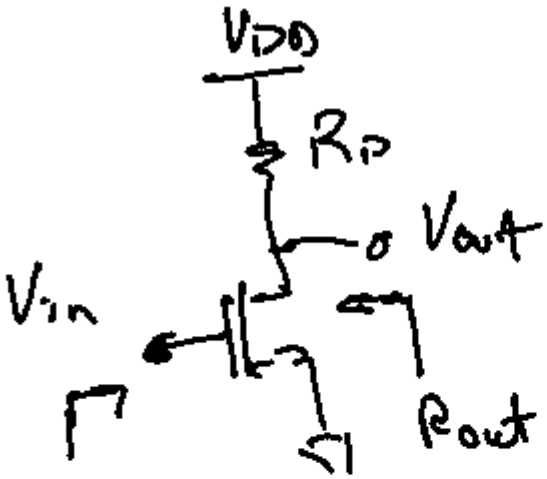


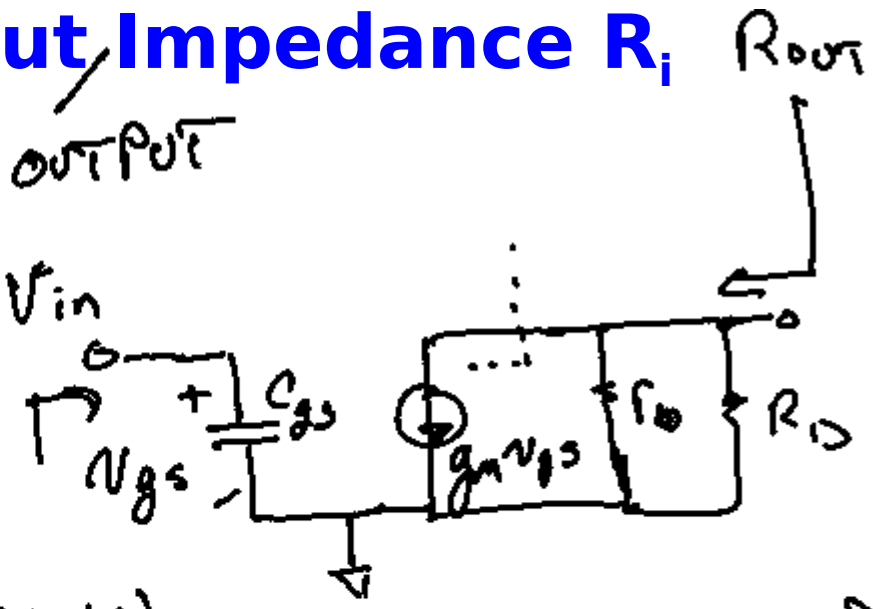
GBWP

$a_{sub} f_{sub} =$



Common-Source Input Impedance R_i





INPUT Rin Rin

IF R UNKNOWN

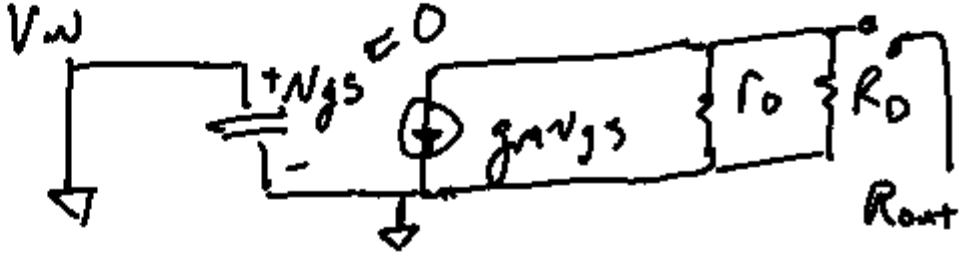
- APPLY TEST SOURCE (CURRENT / VOLTAGE)
- SHORT ALL INDEP. V SOURCES
- OPEN ALL INDEP. I CURRENT SOURCES

$R_{in} \to \infty$

$Z_{in} \cong \frac{1}{j\omega C_{gs}}$

- OUTPUT Rout

$R_{out} = r_o // R_D$



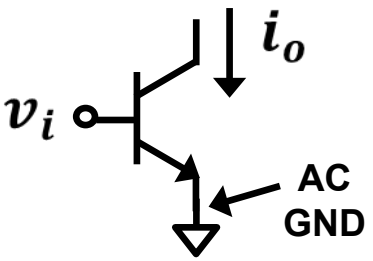
Common-Source Output Impedance R_o

Chapter 3: Single Transistor Amps

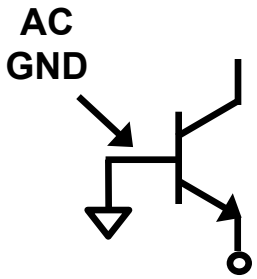
Three Basic Amplifier Configurations

Assume devices are properly biased in saturation (CMOS) or Forward Active (BJT)

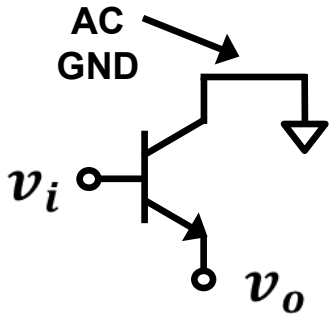
Common Emitter



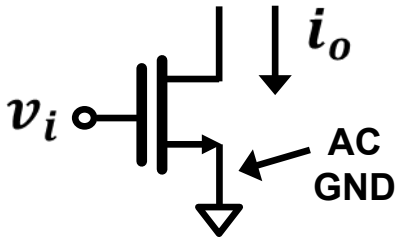
Common Base



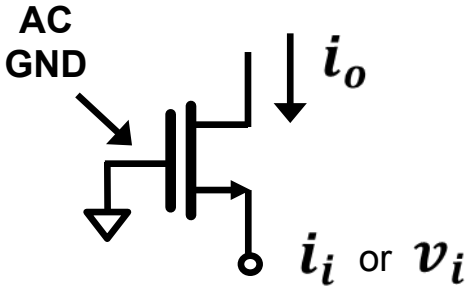
Common Collector
or "Emitter Follower"



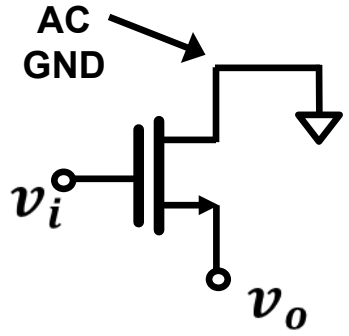
Common Source



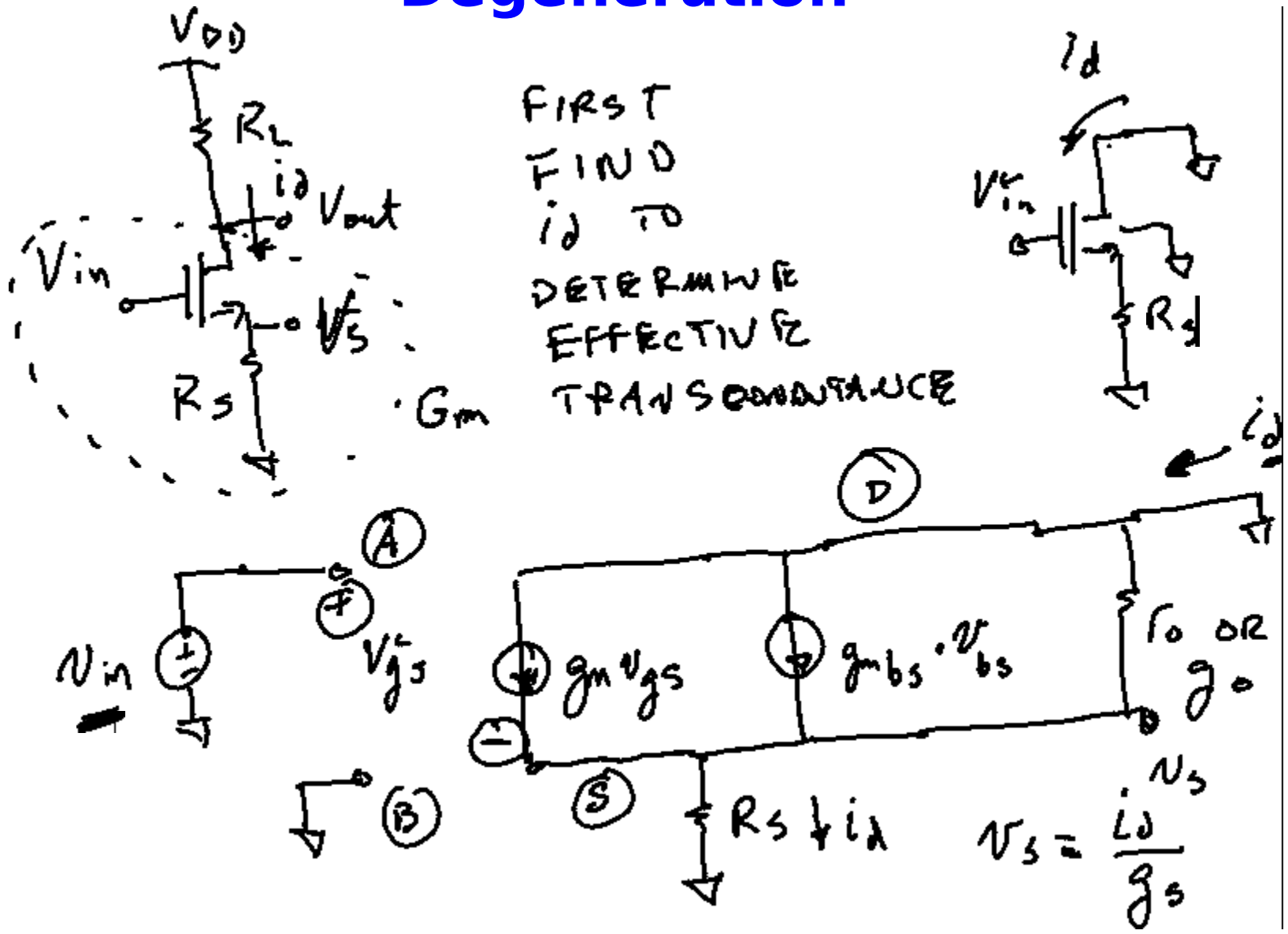
Common Gate



Common Drain
or "Source Follower"



Common-Source w/ Resistive Degeneration



Common-Source w/ Resistive Degeneration

$$V_{gs} = V_{in} - V_s$$

$$V_{bs} = 0 - V_s$$

KCL @ V_{out}

$$i_d = g_m \cdot (V_{in} - V_s) + g_{mbs}(0 - V_s) + g_o(0 - V_s)$$

$$\therefore \; i_d = g_m V_{in} - g_m \frac{i_d}{g_s} - g_{mbs} \frac{i_d}{g_s} - g_o \frac{i_d}{g_s}$$

$$G_m \triangleq \frac{i_d}{V_{in}} = \frac{g_m}{1 + \frac{(g_m + g_{mbs} + g_o)}{g_s}}$$

$$\cong \frac{g_m}{1 + (g_m + g_{mbs}) \cdot R_s}$$

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

($g_{mbs} \ll g_m$, $1 \ll g_m \cdot R_s$)

$$G_m \cong \frac{1}{R_s}$$

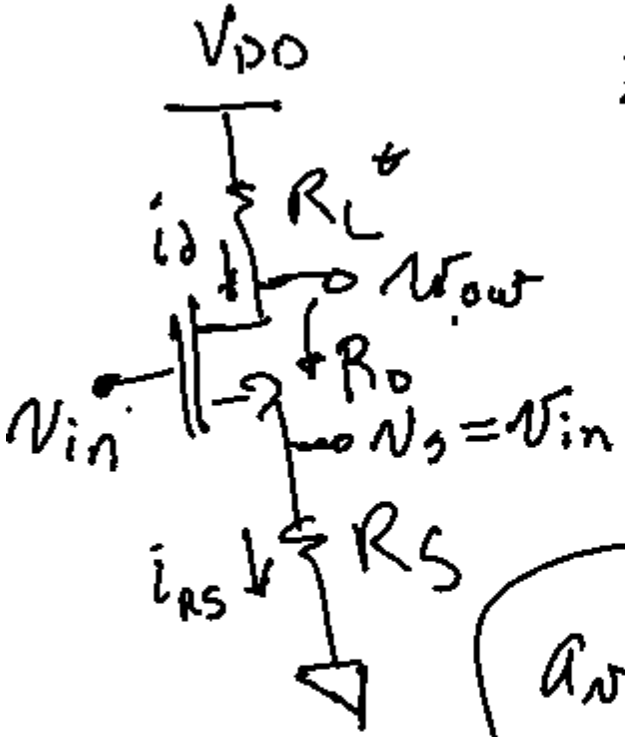
Common-Source w/ Resistive Degeneration

(Intuitive Approach)

$$A_V = -G_m' \cdot R_o$$

$$\simeq -\left(\frac{1}{R_S}\right) \cdot \left[R_o \,//\, R_L\right)$$

$$\simeq -\left(\frac{1}{R_S}\right) \cdot \left[(g_m \cdot \cancel{R_S} \cdot r_o) \,//\, R_L\right]$$



TYPICALLY

$R_L \ll R_o$

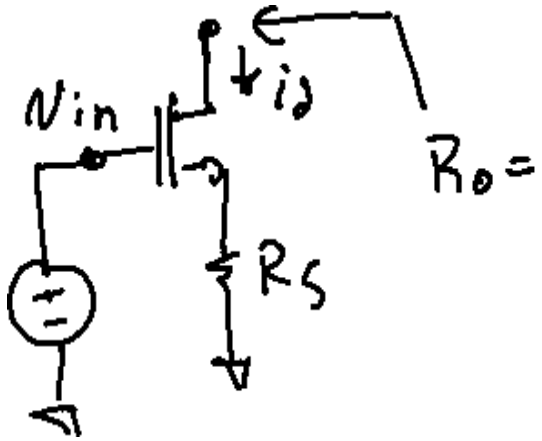
$$A_V \simeq -\frac{R_L}{R_S}$$

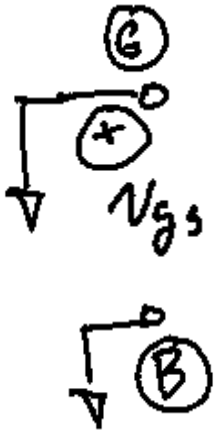
$$i_{RS} \simeq \frac{V_{in}}{R_S} \qquad i_D = i_{RS} = \frac{V_{in}}{R_S}$$

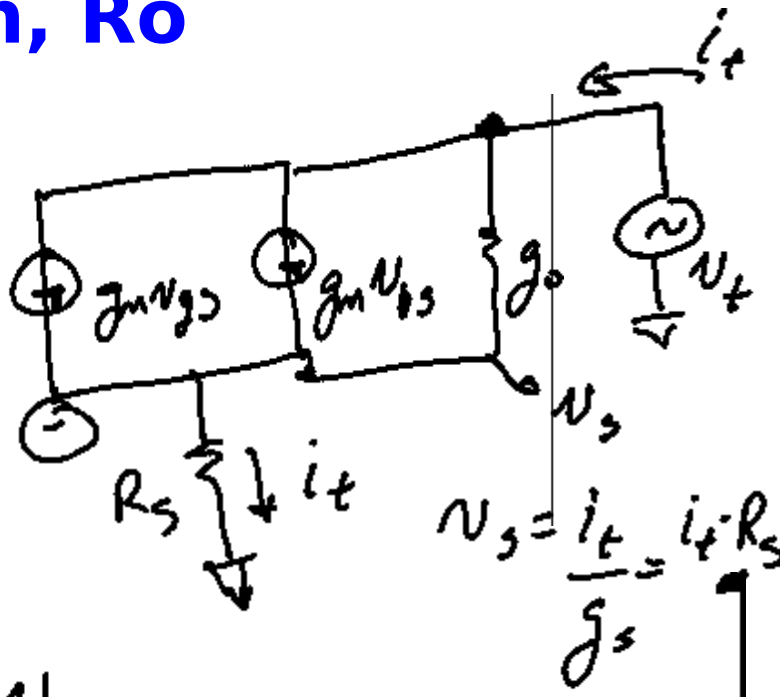
$$V_o = -i_D \cdot R_D \,//\, R_L = -\frac{V_{in}}{R_S} R_L$$

$$A_V = \frac{V_{out}}{V_{in}} = -R_L/R_S$$

Common-Source w/ Resistive Degeneration, Ro







KCL @ OUTPUT NODE

$$i_t = g_m \underbrace{\left(0 - \frac{i_t}{g_s}\right)}_{V_{gs}} + g_{mbs} \underbrace{\left(0 - \frac{i_t}{g_s}\right)}_{V_{bs}} + g_o \left(V_t - \frac{i_t}{g_s}\right)$$

$V_g = 0$ $\qquad$ $V_b = 0$

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

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

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

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

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

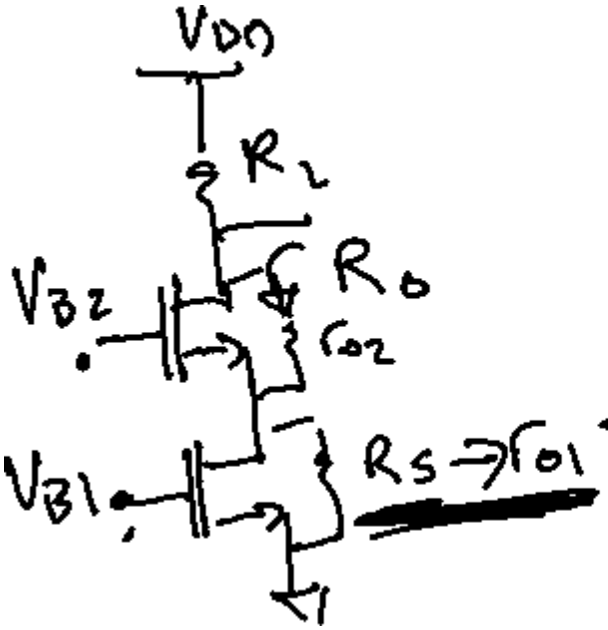
$$\boxed{R_o \cong r_o \left[1 + g_m \cdot R_s\right]}$$

TYPICALLY
$g_{mbs} \ll g_m$
$g_o \ll g_m$
ASSUME
$1 \ll g_m \cdot R_s$

$\Downarrow$ BORN INTO MEMORY!

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

Cascode Gain



$$R_o \cong g_m \cdot r_{o1} \cdot r_{o2}$$

1KΩ - 5KΩ