Lecture 17:

Common Source/Gate/Drain Amplifiers

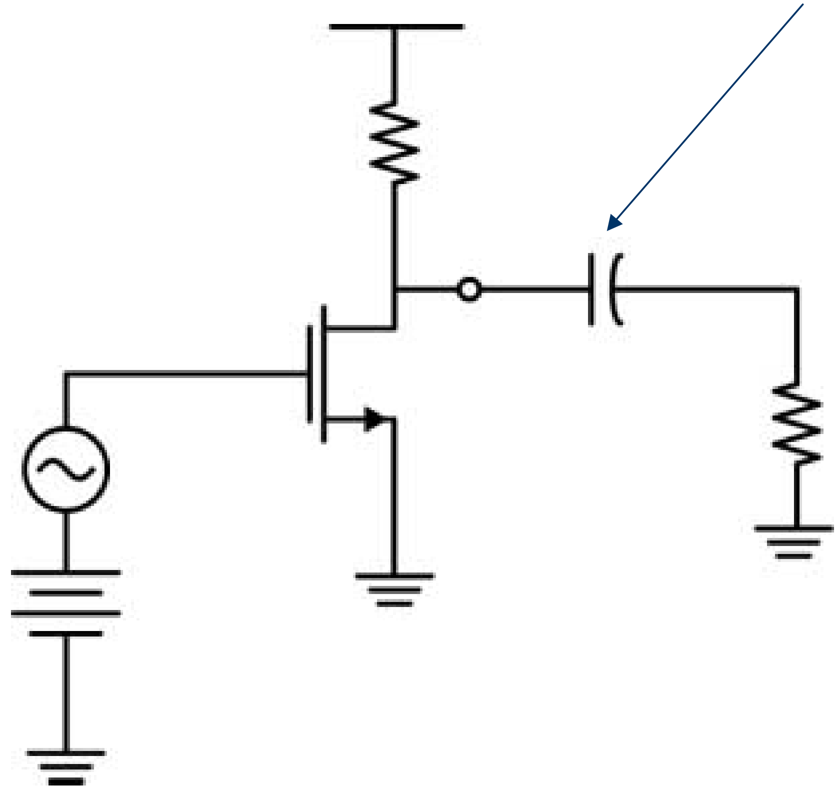
Prof. Niknejad

Lecture Outline

- MOS Common Source Amp
- Current Source Active Load
- Common Gate Amp
- Common Drain Amp

Common-Source Amplifier

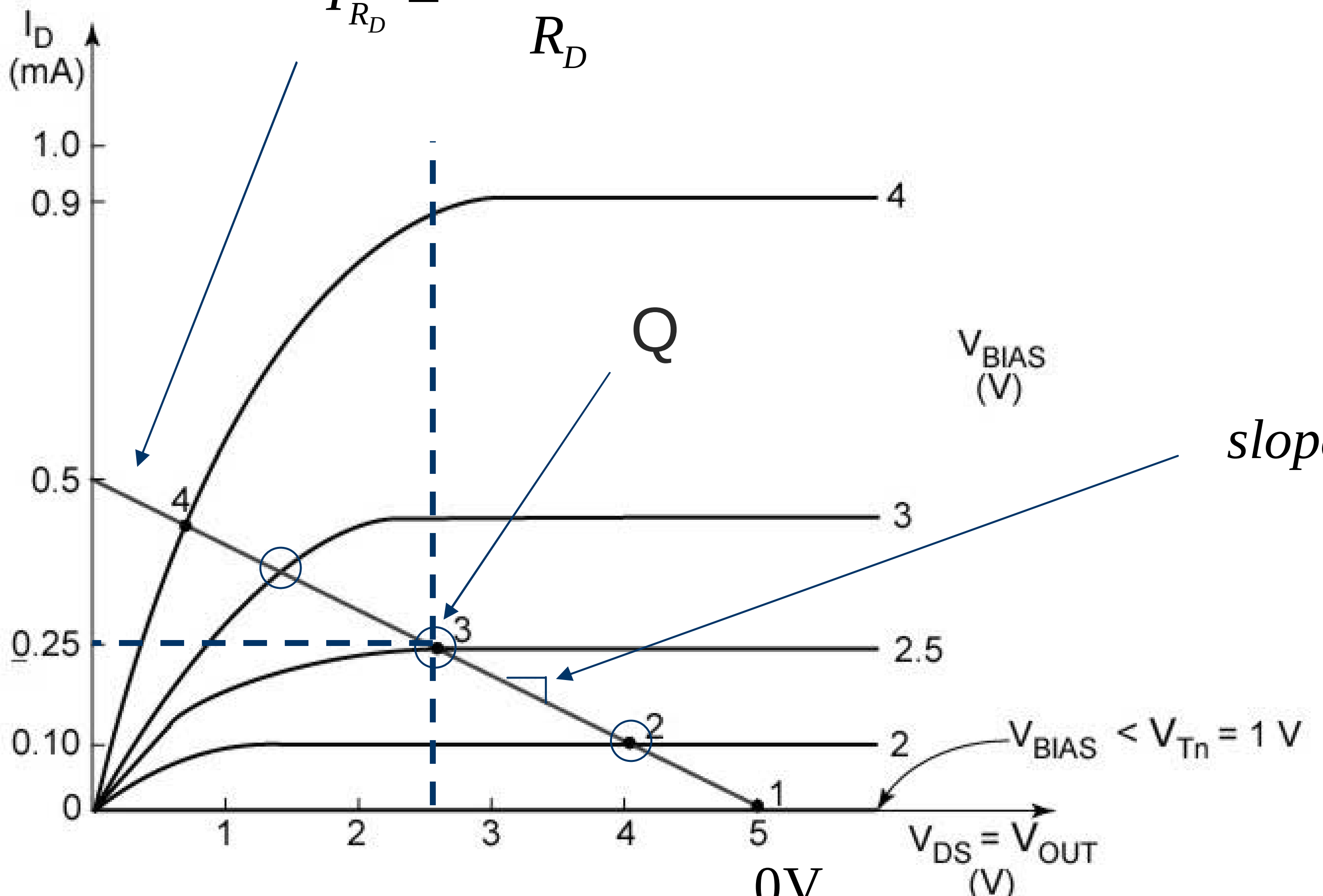
Isolate DC level



Load-Line Analysis to find *Q*

$$I_{R_D} = \frac{V_{DD} - V_{out}}{R_D}$$

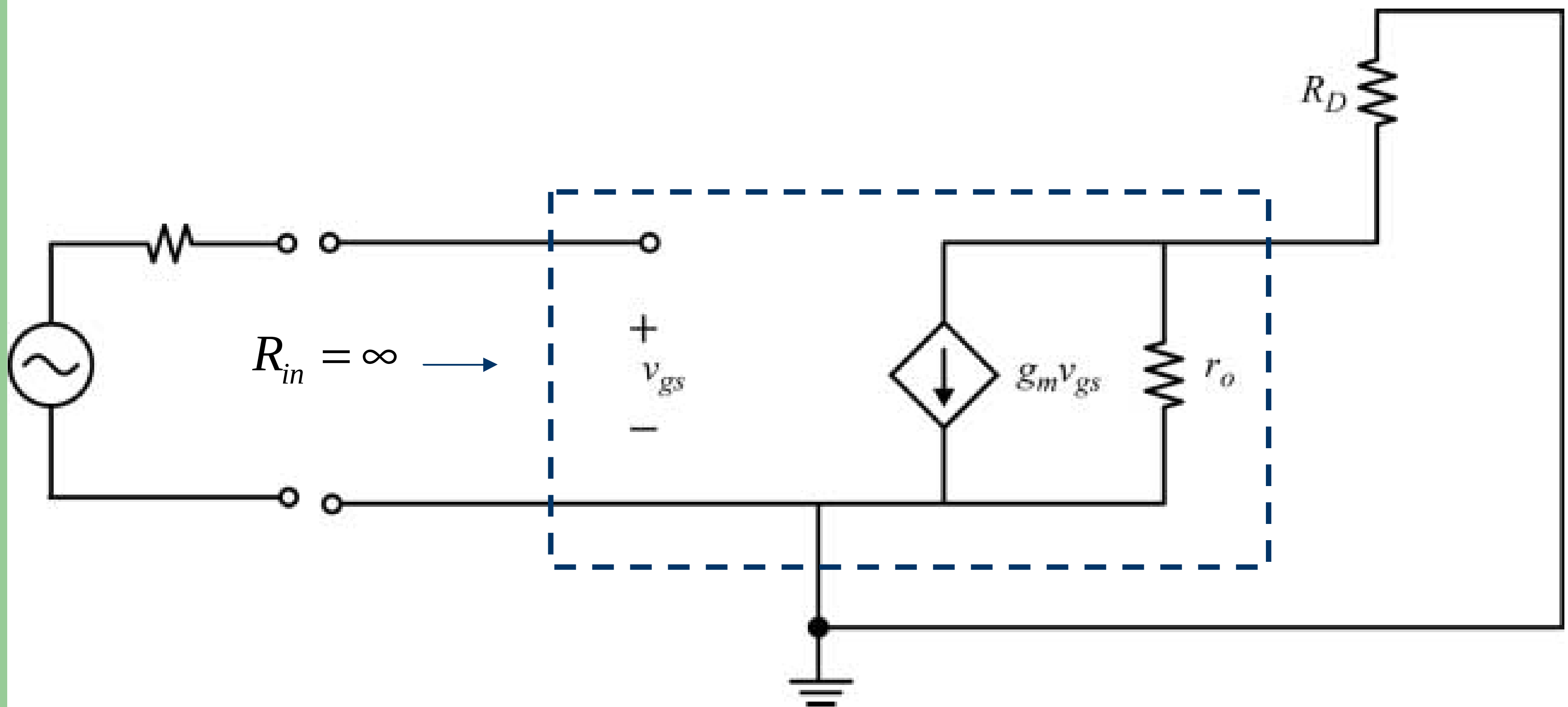
$$I_D = \frac{5V}{10k}$$



$$slope = \frac{1}{10k}$$

$$I_D = \frac{0V}{10k}$$

Small-Signal Analysis



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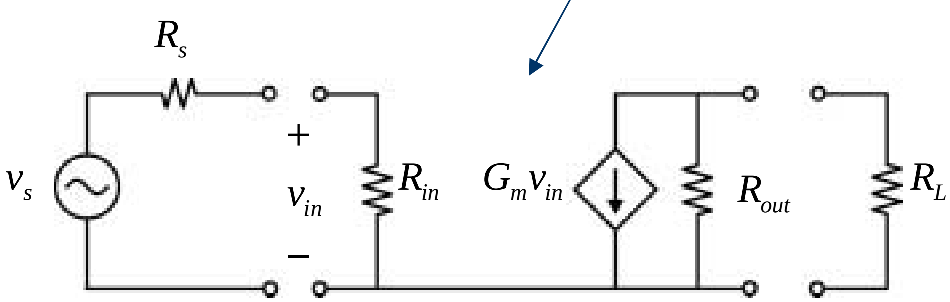
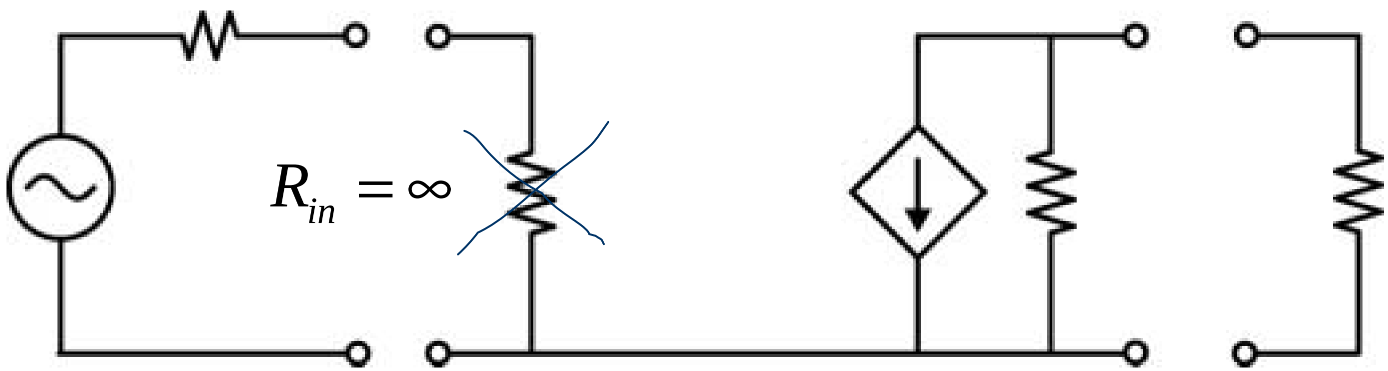
Two-Port Parameters:

Generic Transconductance Amp



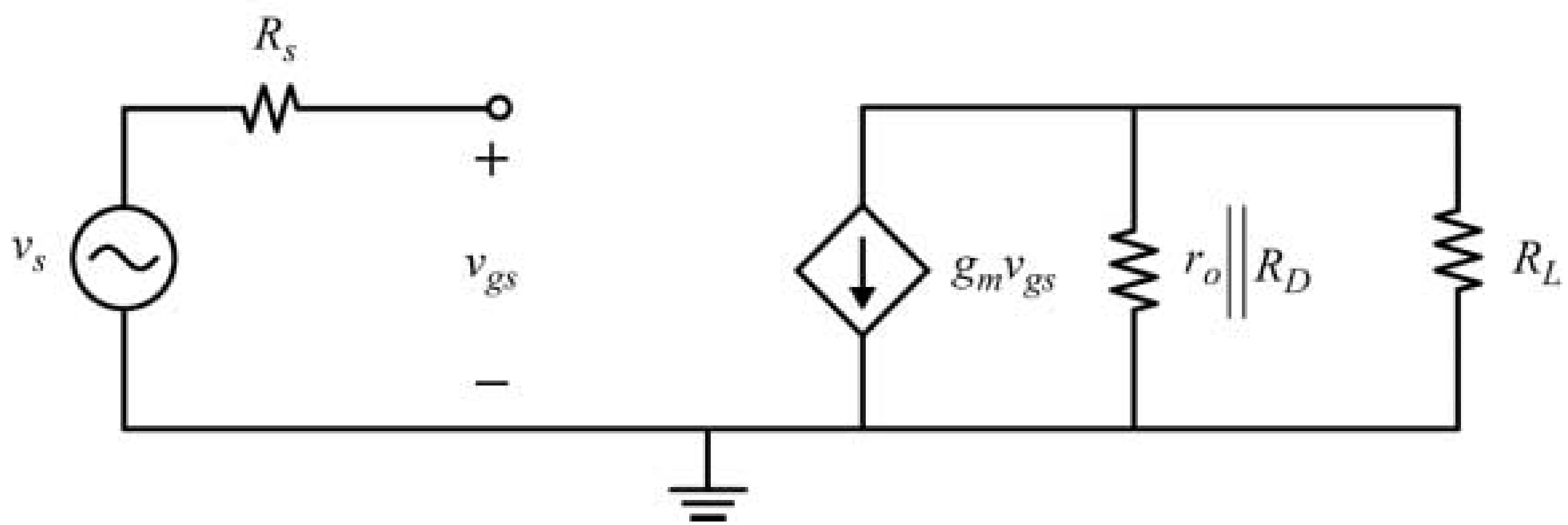
Find R_{in}, R_{out}, G_m



$$G_m = g_m \quad R_{out} = r_o \,||\, R_D$$

Two-Port CS Model

Reattach source and load one-ports:



Maximize Gain of CS Amp

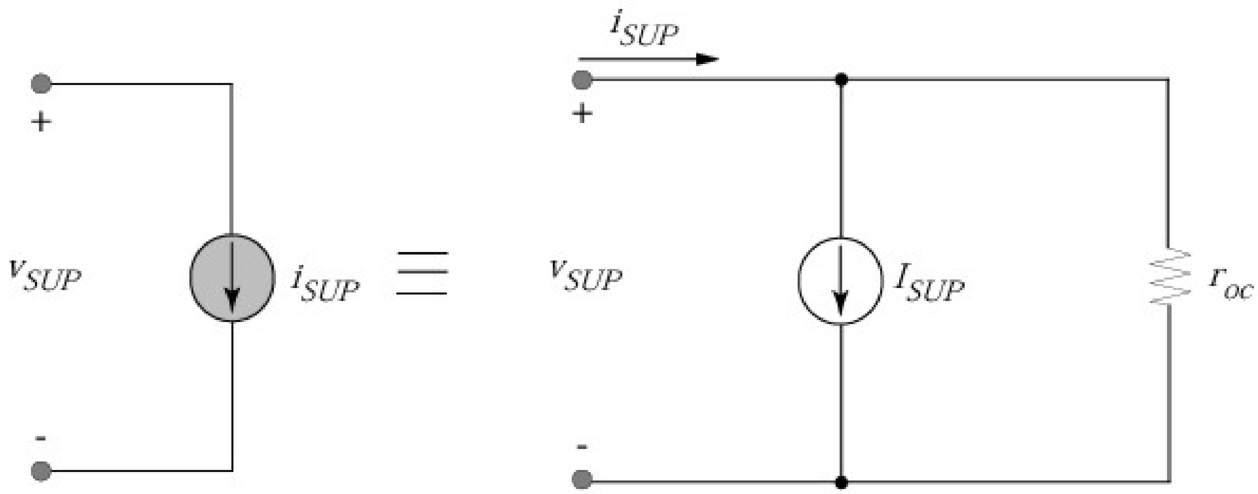
$$A_v = -g_m R_D \| r_o$$

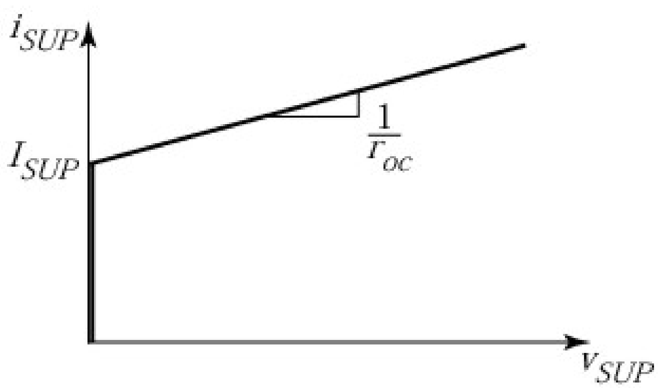
- Increase the g_m (more current)
- Increase R_D (free? Don't need to dissipate extra power)
- Limit: Must keep the device in saturation

$$V_{DS} = V_{DD} - I_D R_D > V_{DS,sat}$$

- For a fixed current, the load resistor can only be chosen so large
- To have good swing we'd also like to avoid getting to close to saturation

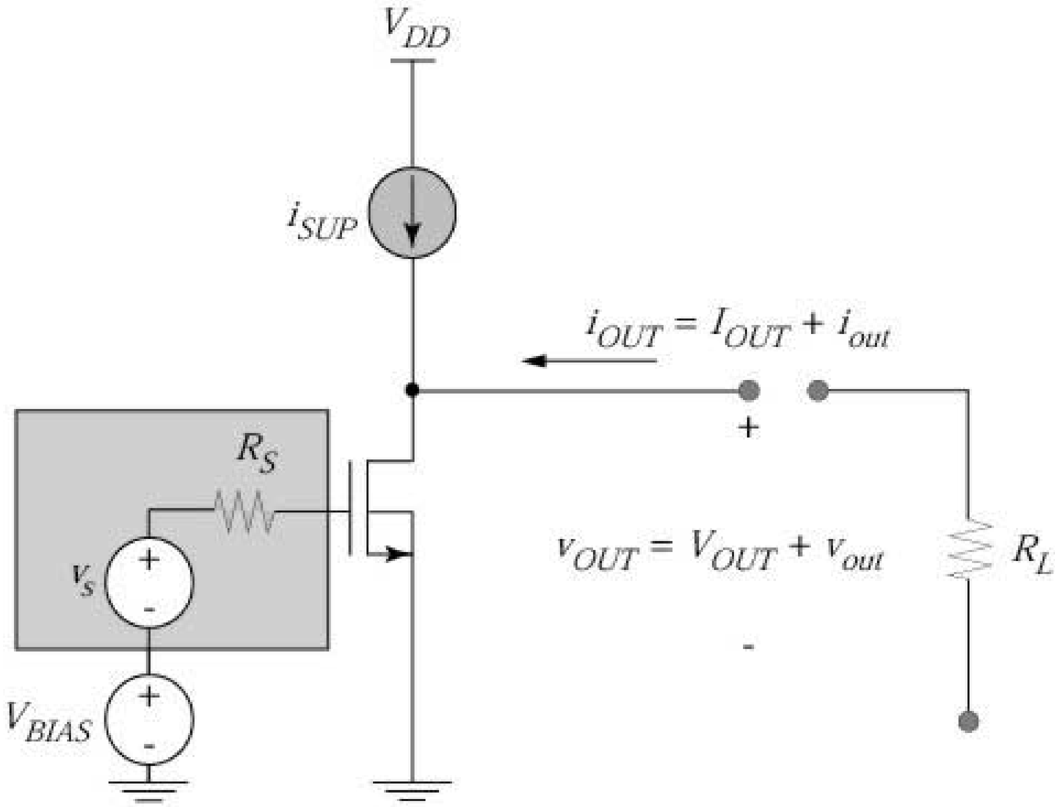
Current Source Supply



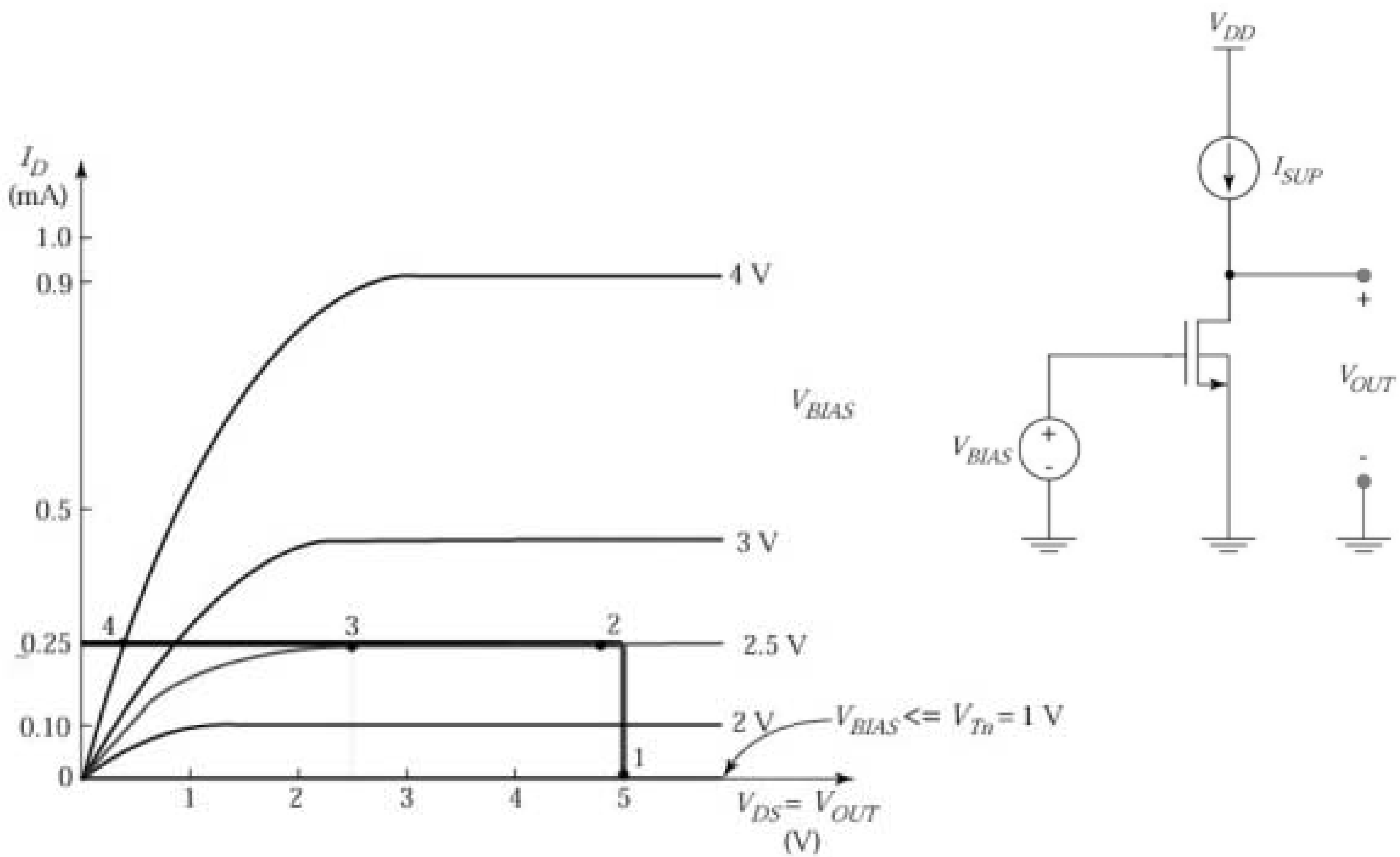


- Solution: Use a current source!
- Current independent of voltage for ideal source

CS Amp with Current Source Supply

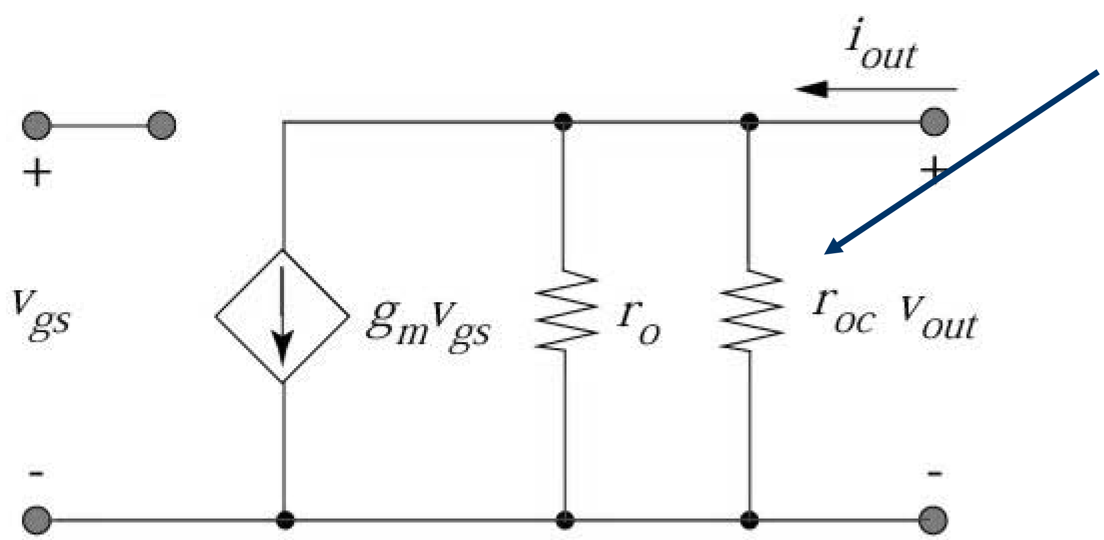


Load Line for DC Biasing



Both the I-source and the transistor are idealized for DC bias analysis

Two-Port Parameters



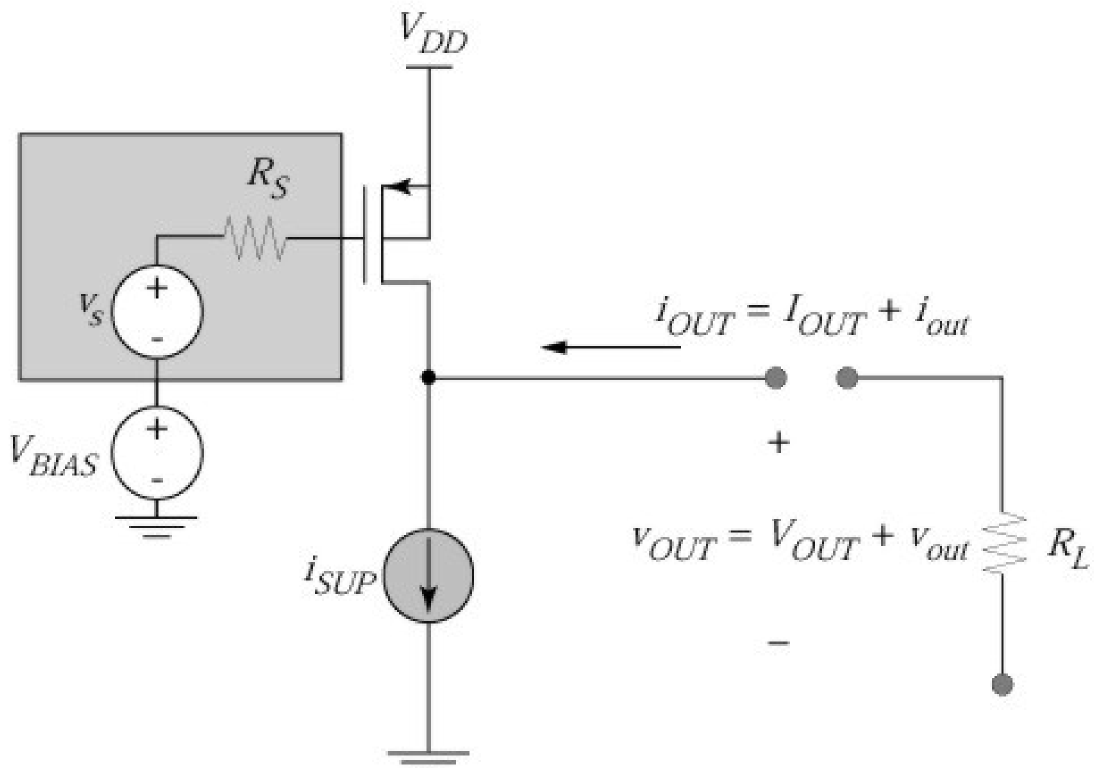
From current source supply

$$R_{in} = \infty$$

$$G_m = g_m$$

$$R_{out} = r_o \,||\, r_{oc}$$

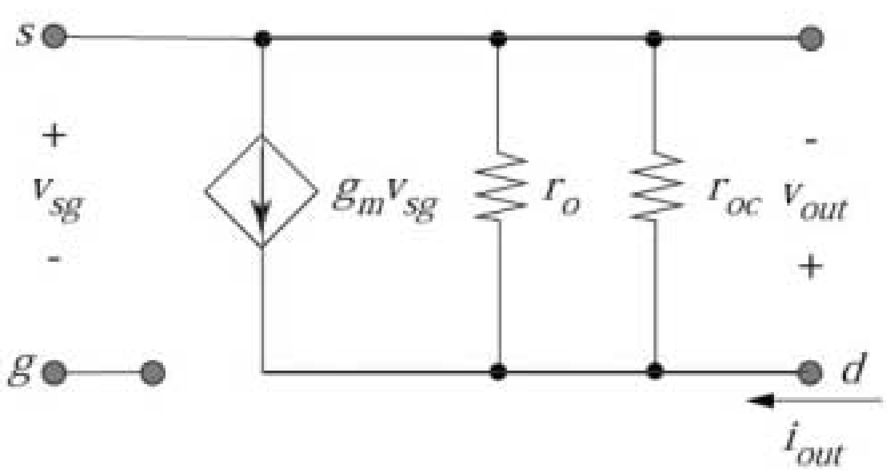
P-Channel CS Amplifier

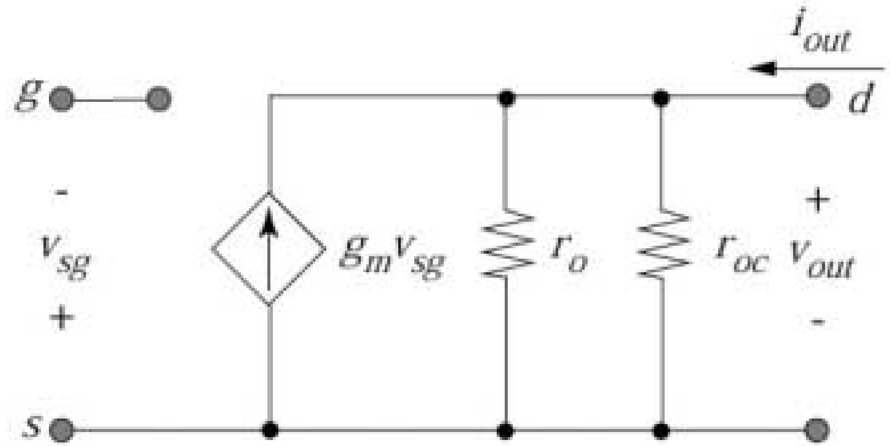


DC bias: $V_{SG} = V_{DD} - V_{BIAS}$ sets drain current $-I_{Dp} = I_{SUP}$

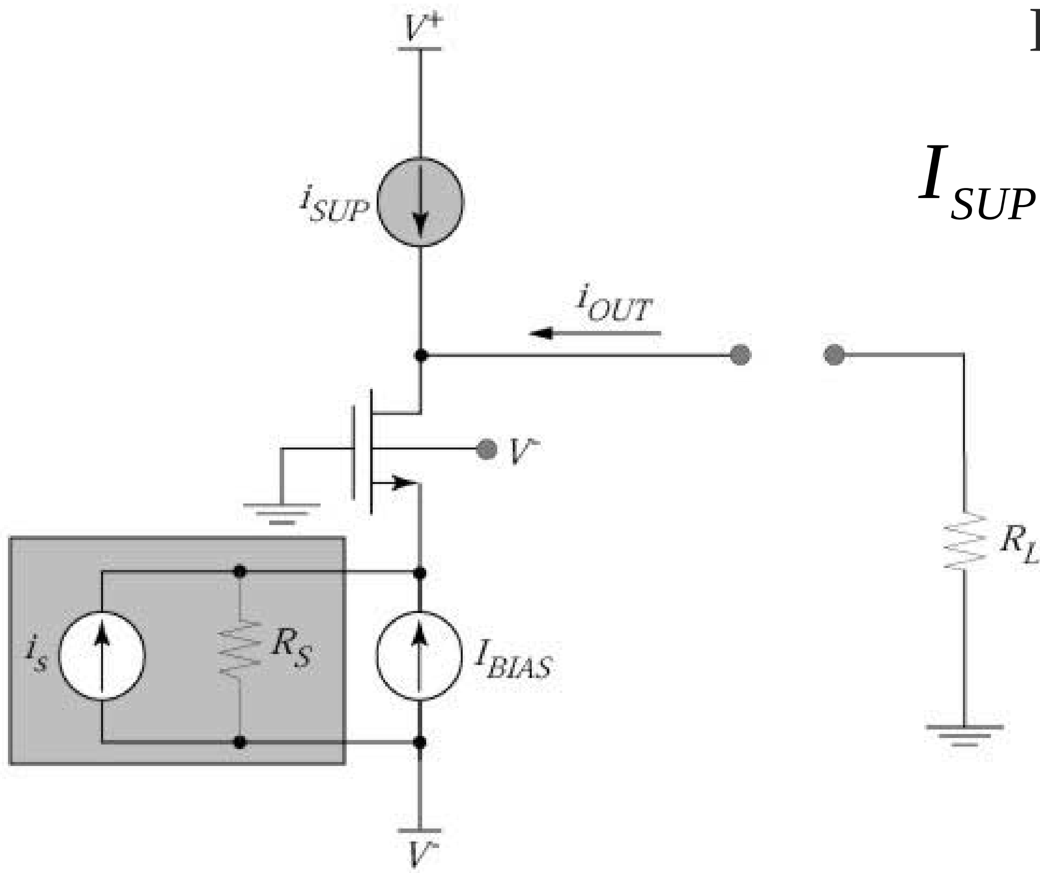
Two-Port Model Parameters

Small-signal model for PMOS and for rest of circuit





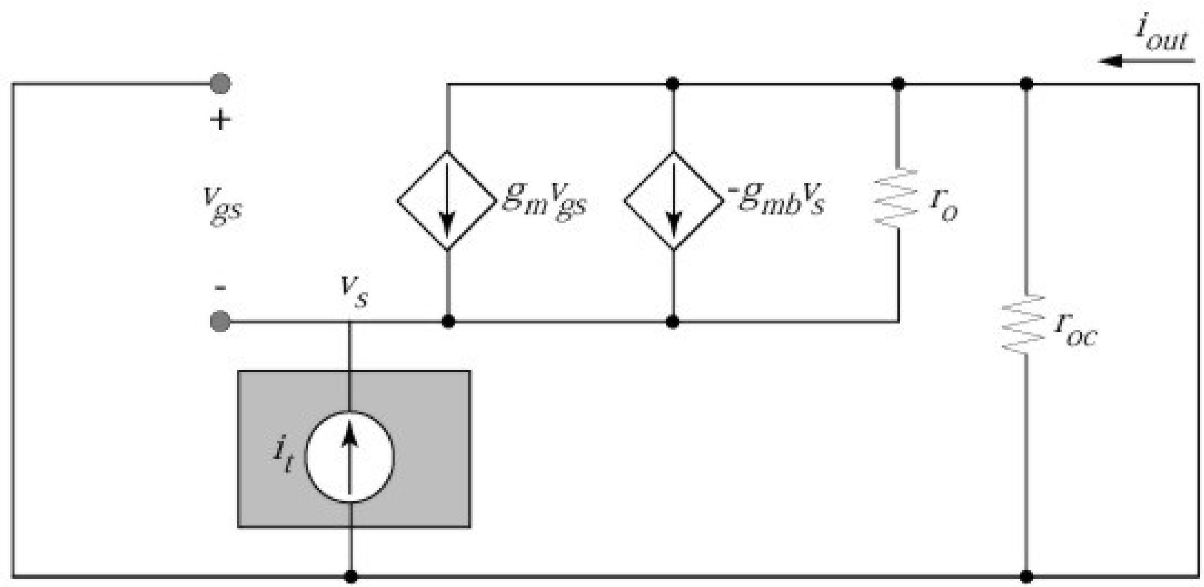
Common Gate Amplifier



DC bias:

$$I_{SUP} = I_{BIAS} = I_{DS}$$

CG as a Current Amplifier: Find A_i

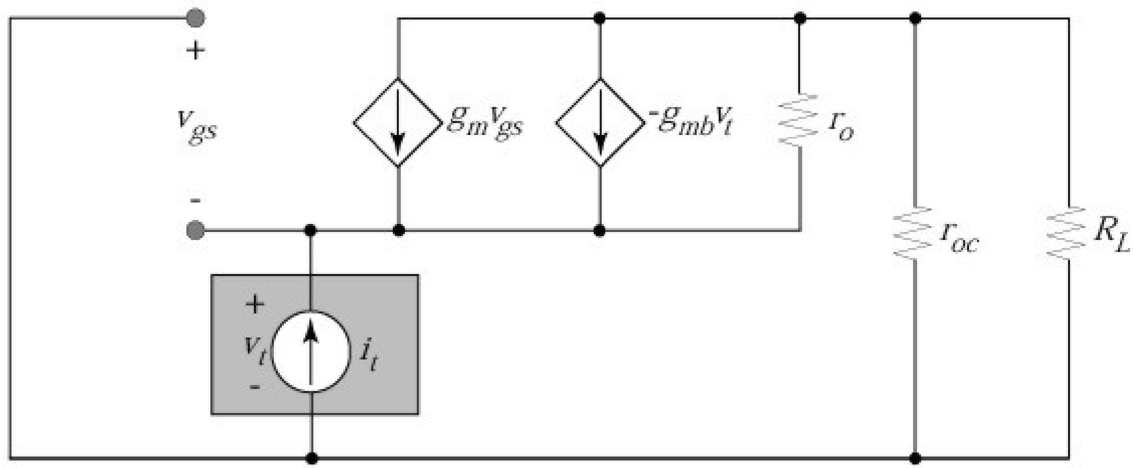


$$i_{out} = i_d = -i_t$$

$$A_i = -1$$

CG Input Resistance

$$v_{gs} = -v_t$$



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

Output voltage: $$v_{out} = -i_d (r_{oc} \parallel R_L) = i_t (r_{oc} \parallel R_L)$$

$$i_t = g_m v_t + g_{mb} v_t + \left(\frac{v_t - (r_{oc} \parallel R_L) i_t}{r_o} \right)$$

Approximations…

- We have this messy result

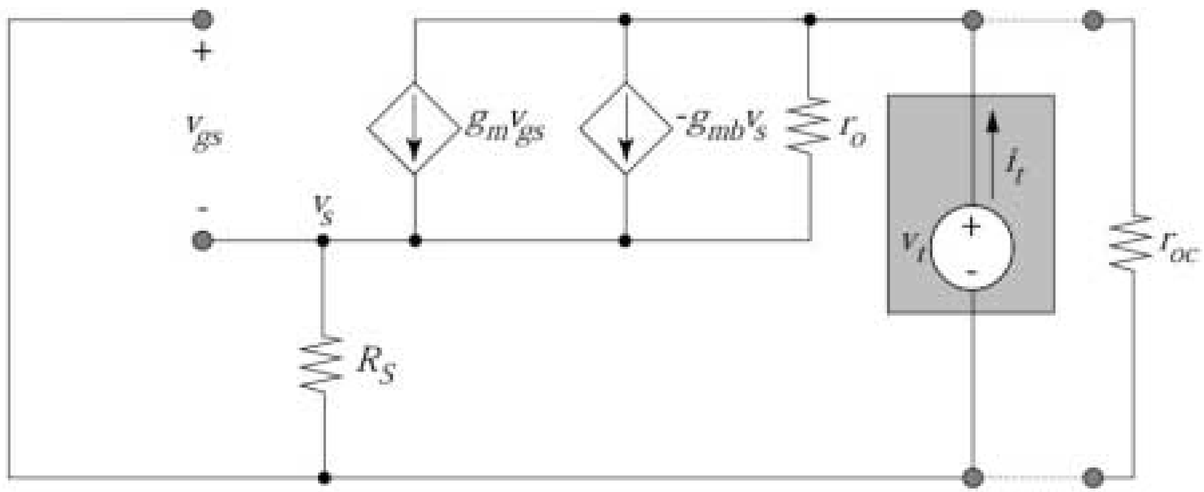
$$\frac{1}{R_{in}} = \frac{i_t}{v_t} = \frac{g_m + g_{mb} + \frac{1}{r_o}}{1 + \frac{r_{oc} \| R_L}{r_o}}$$

- But we don't need that much precision. Let's start approximating:

$$g_m + g_{mb} >> \frac{1}{r_o} \qquad r_{oc} \| R_L \approx R_L \qquad \frac{R_L}{r_o} \approx 0$$

$$R_{in} = \frac{1}{g_m + g_{mb}}$$

CG Output Resistance



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

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

CG Output Resistance

Substituting $v_s = i_t R_S$

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

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

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

Approximating the CG R_{out}

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

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

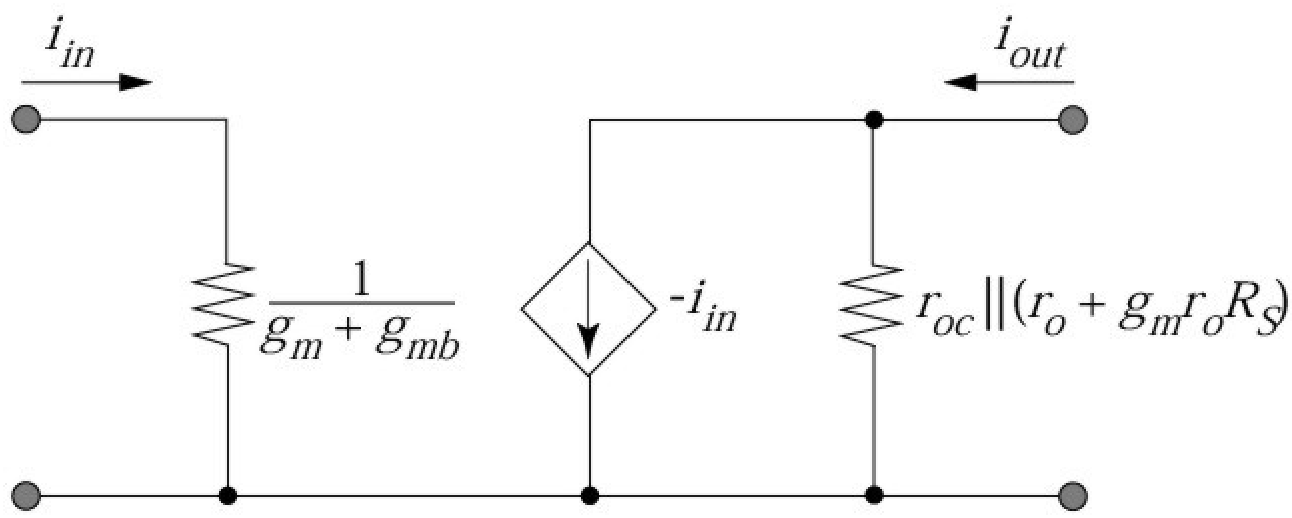
$$g_m \approx 500\mu S \quad g_{mb} \approx 50\mu S \quad r_o \approx 200k\Omega$$

$$R_{out} \cong r_{oc} \parallel [r_o + g_m r_o R_S + R_S]$$

Assuming the source resistance is less than r_o,

$$R_{out} \approx r_{oc} \parallel [r_o + g_m r_o R_S] = r_{oc} \parallel [r_o (1 + g_m R_S)]$$

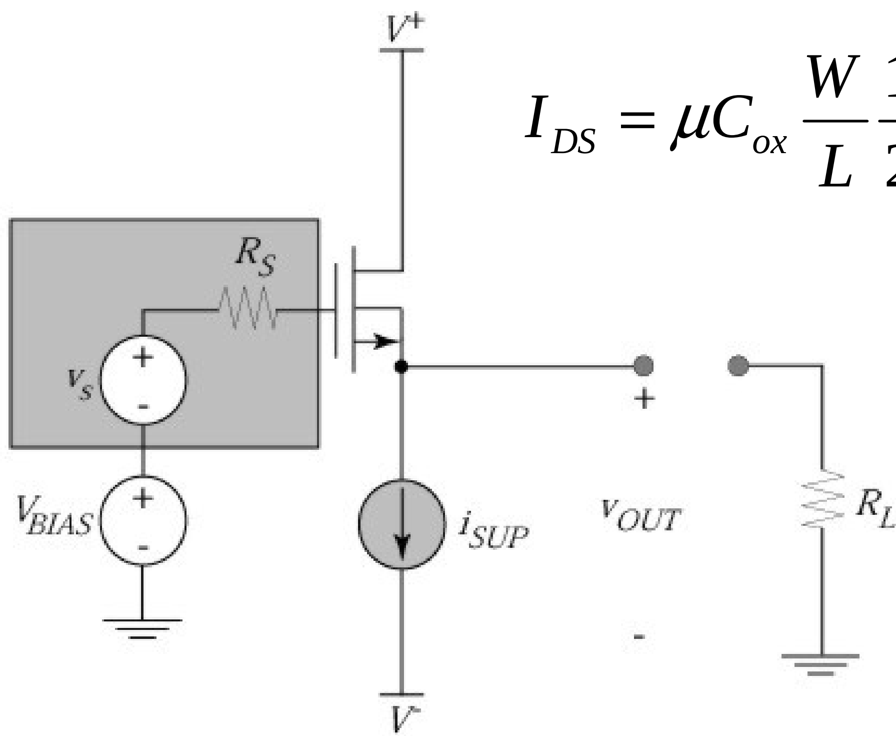
CG Two-Port Model



Function: a current buffer

- Low Input Impedance
- High Output Impedance

Common-Drain Amplifier

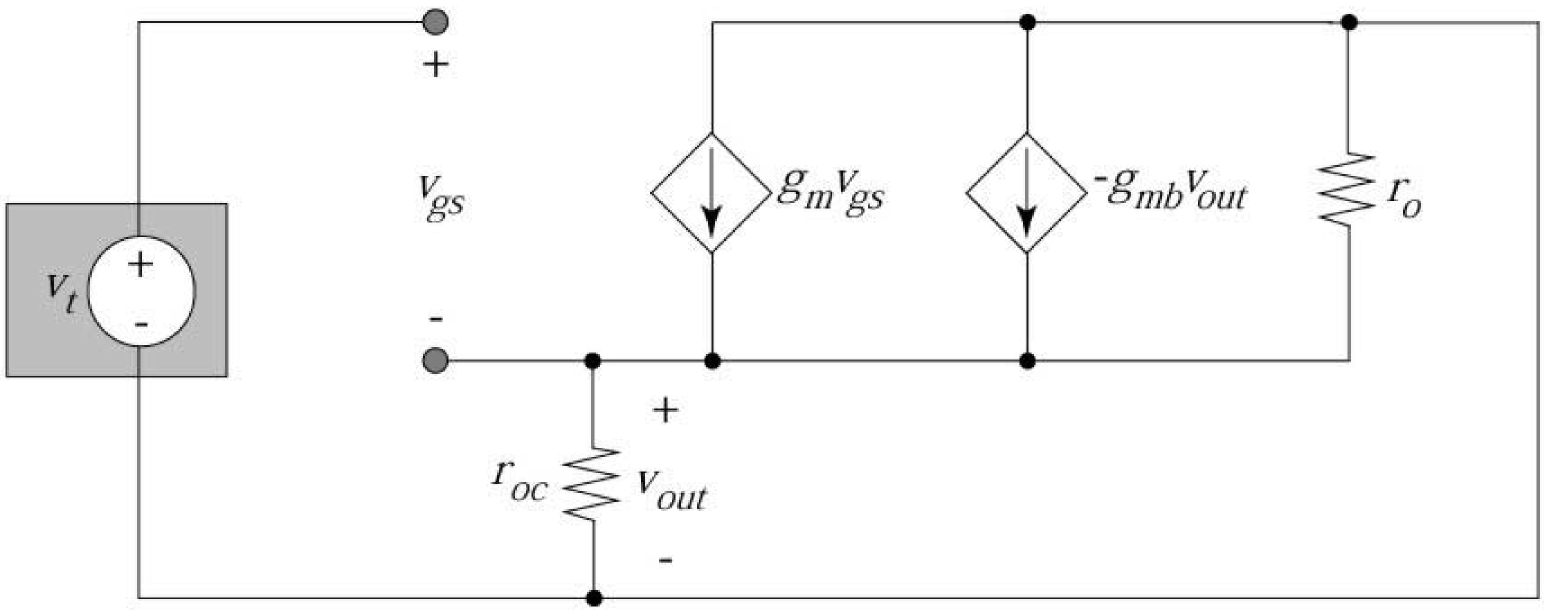


$$I_{DS} = \mu C_{ox} \frac{W}{L} \frac{1}{2} (V_{GS} - V_T)^2$$

$$V_{GS} = V_T + \sqrt{\frac{2I_{DS}}{\mu C_{ox} \frac{W}{L}}}$$

Weak I_{DS} dependence

CD Voltage Gain



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

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

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

CD Voltage Gain (Cont.)

KCL at source node: $$\frac{v_{out}}{r_{oc} \,\|\, r_o} = g_m\left(v_t - v_{out}\right) - g_{mb}v_{out}$$

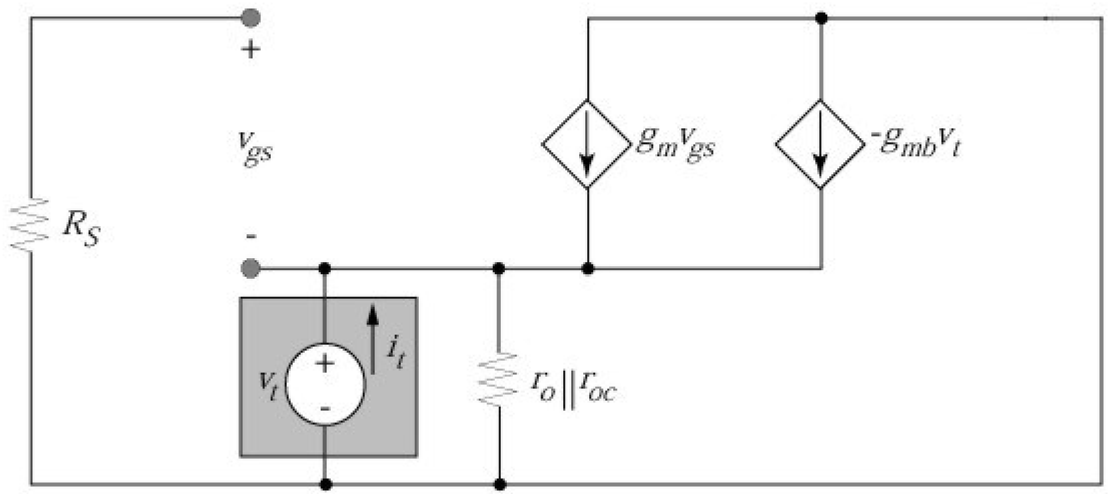
$$\left(\frac{1}{r_{oc} \,\|\, r_o} + g_{mb} + g_m\right)v_{out} = g_m v_t$$

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

$$\frac{v_{out}}{v_{in}} = \frac{g_m}{\dfrac{1}{r_{oc} \,\|\, r_o} + g_{mb} + g_m}$$

$$\frac{v_{out}}{v_{in}} \approx \frac{g_m}{g_{mb} + g_m} \approx 1$$

CD Output Resistance



Sum currents at output (source) node:

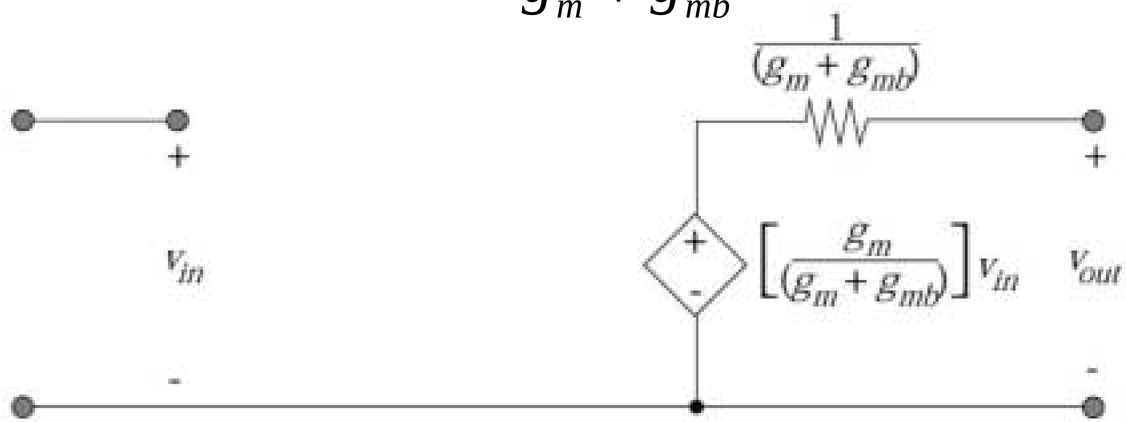
$$R_{out} = r_o \,||\, r_{oc} \,||\, \frac{v_t}{i_t} \qquad\qquad i_t = g_m v_t + g_{mb} v_t$$

$$R_{out} \approx \frac{1}{g_m + g_{mb}}$$

CD Output Resistance (Cont.)

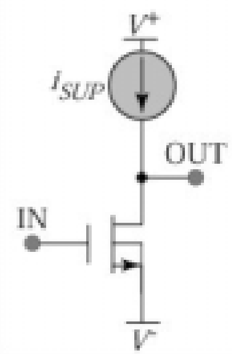
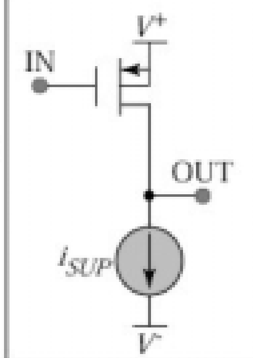
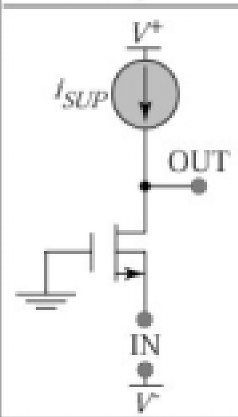
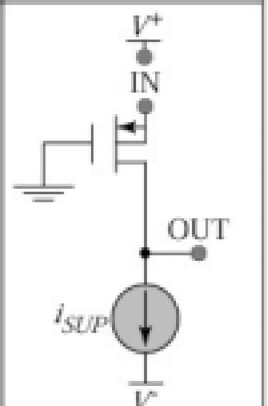
$r_o \| r_{oc}$ is much larger than the inverses of the transconductances → ignore

$$R_{out} \approx \frac{1}{g_m + g_{mb}}$$



Function: a voltage buffer

- High Input Impedance
- Low Output Impedance

	Transistor Type	
	NMOS	PMOS
Common Source/ Common Emitter (*CS*/*CE*)		
Common Gate/ Common Base (*CG*/*CB*)		
Common Drain/ Common Collector (*CD*/*CC*)