ECE4902 Lecture 6

Quiz 2

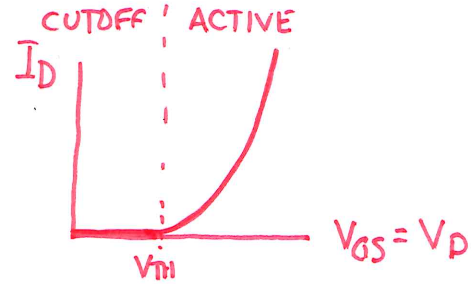
Current Mirror
- Diode connected MOSFET
- DC matching
- Small signal models

Common Source with Active Load
- Low-frequency small-signal gain
- Bandwidth
  - Gain-bandwidth product

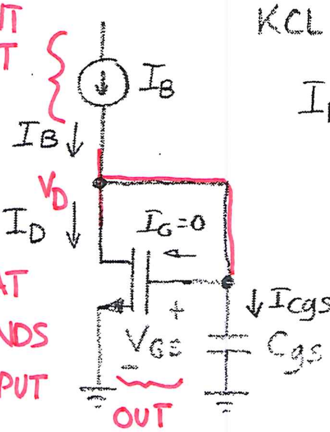
Handouts:
Lab 5 Review Slides
Diode Connected MOSFET
Small signal analysis of …
- current mirror
- CS amplifier with active load

G, D TOGETHER

Current mirror: Why does $\underbrace{\text{diode connected}}$ MOSFET have to carry $I_D = I_B$?



CURRENT WE WANT



$\downarrow I_{cgs} = I_B - I_D$

V_{GS} THAT CORRESPONDS TO I_B INPUT

OUT

KCL AT GATE NODE

$$I_B = I_D + \underbrace{I_G}_{0} + I_{cgs}$$

OXIDE

SUPPOSE $I_D \neq I_B$

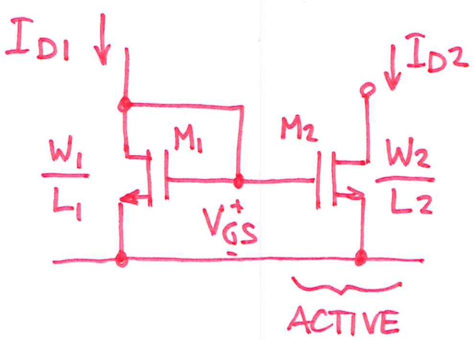
SAY V_{GS} IS TOO SMALL SO $I_D < I_B$

IF $I_D < I_B$, THEN I_{cgs} WILL BE POSITIVE
$\Rightarrow$ CHARGING UP C_{gs} $\Rightarrow$ INCREASING I_D
$\Rightarrow$ MOVES I_D CLOSER TO I_B

SIMILARLY, IF $I_D > I_B$, V_{GS} WILL DECREASE

EQUILIBRIUM WHEN $\frac{dV_{GS}}{dt} = 0 \Rightarrow I_{cgs} = 0 \Rightarrow \boxed{I_B = I_D}$

"CURRENT MIRROR"



V_{GS} MUST BE SAME FOR BOTH (CONNECTION)

$$I_{D1} = \frac{\mu_1 C_{ox1}}{2} \frac{W_1}{L_1} (V_{GS} - V_{TH1})^2 \Rightarrow V_{GS} = V_{TH1} + \sqrt{\frac{2}{\mu_1 C_{ox1}} I_{D1} \frac{L_1}{W_1}}$$

APPLY THIS V_{GS} TO M_2

$$I_{D2} = \frac{\cancel{\mu_2 C_{ox2}}}{\cancel{2}} \frac{W_2}{L_2} \Big(\overbrace{\sqrt{\frac{\cancel{2}}{\cancel{\mu_1 C_{ox1}}} I_{D1} \frac{L_1}{W_1}} + \cancel{V_{TH1} - V_{TH2}}}^{V_{GS}} \Big)^2$$

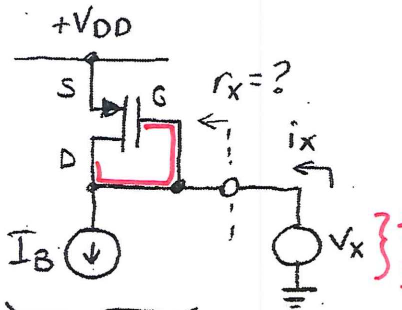
ON IC SILICON WAFER: MATCHING : $V_{TH1} = V_{TH2}$
$\mu_1 C_{ox1} = \mu_2 C_{ox2}$

$$I_{D2} = \underbrace{\left(\frac{W_2/L_2}{W_1/L_1}\right)}_{\text{SIZE RATIO}} I_{D1}$$

CHOOSE $L_1 = L_2$ (BASED ON λ TO GET r_o)

$$I_{D2} = \underbrace{\left(\frac{W_2}{W_1}\right)}_{\text{SCALE RATIO WITH WIDTH FACTOR}} I_{D1}$$

small signal resistance of diode connected MOSFET

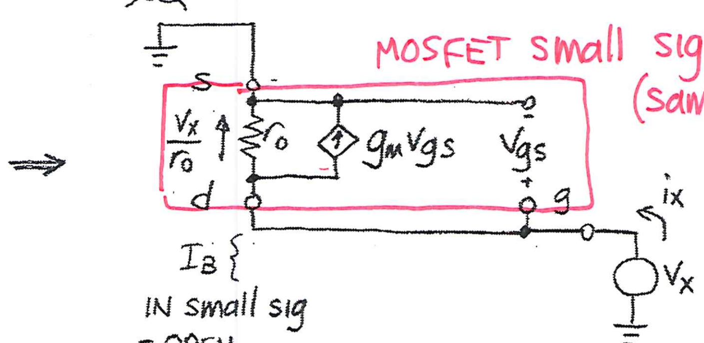


test voltage source to find $\frac{V_x}{i_x}$

REPLACE WITH SMALL SIGNAL MODEL

⇓

V_{DD} IN small sig = 0V



MOSFET small signal model (same for NMOS or PMOS)

I_B { IN small sig = OPEN

① APPLY V_x

"IMPEDANCE AT A NODE" PROCEDURE

① APPLY V_x ② CALCULATE i_x ③ $r_x = \frac{V_x}{i_x}$

② KCL AT GATE

$$i_x = g_m V_{gs} + \frac{V_x}{r_o} \qquad i_x = g_m V_x + \frac{V_x}{r_o} = V_x\left(g_m + \frac{1}{r_o}\right)$$

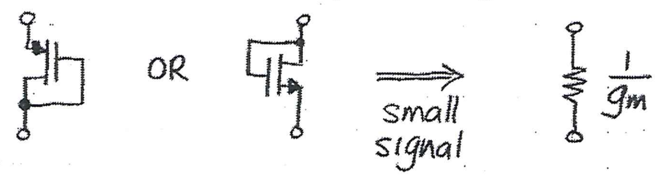
KVL AROUND GATE: $V_{gs} = V_x$

③ $r_x = V_x / i_x$

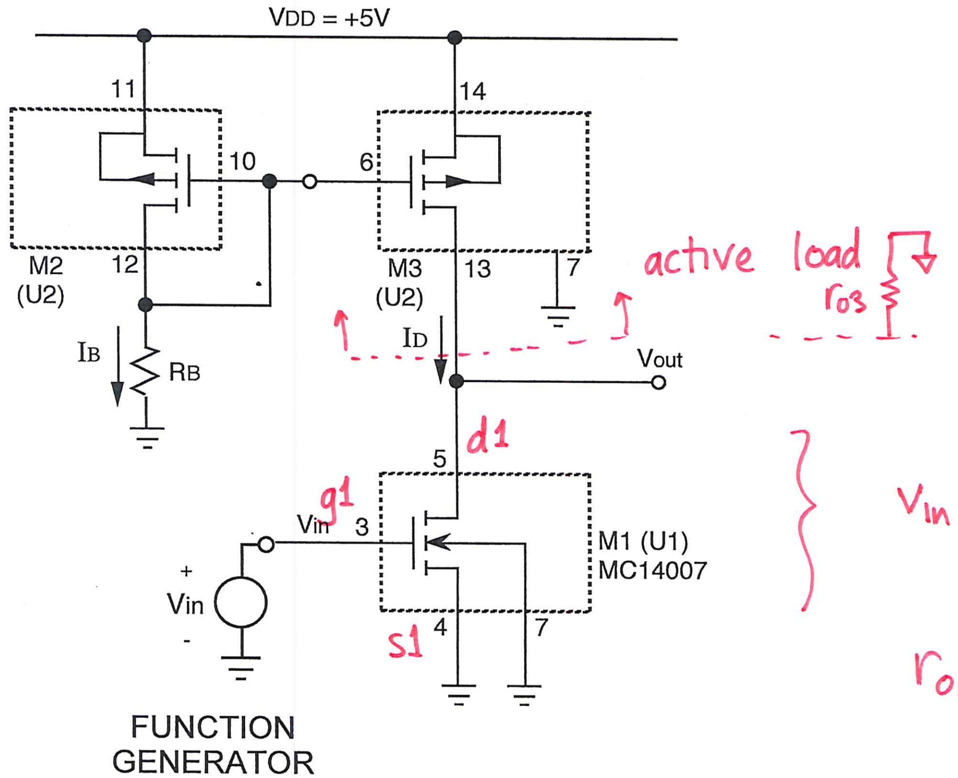
$$\frac{V_x}{i_x} = \frac{1}{g_m + \frac{1}{r_o}} = \frac{1}{g_m} \parallel r_o \qquad \text{USUALLY } r_o \gg \frac{1}{g_m}$$

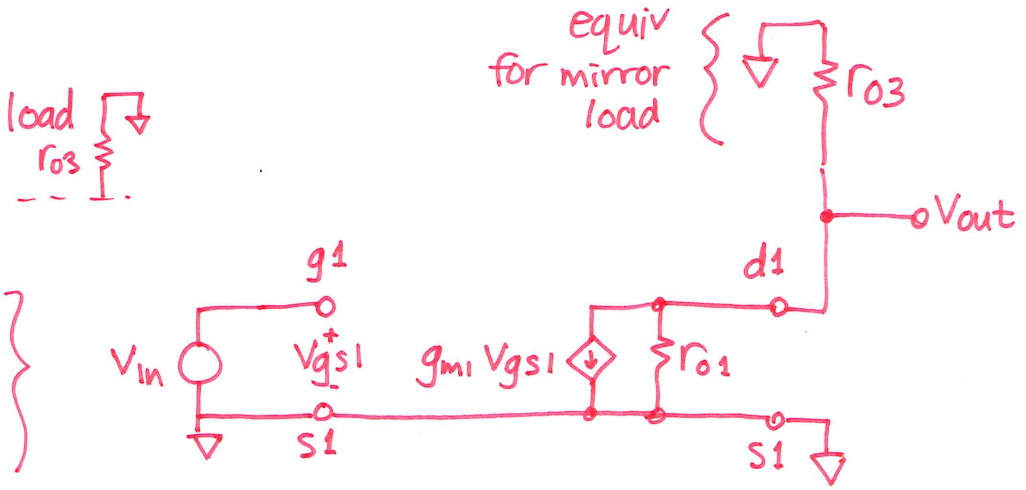
$$\boxed{r_x \approx \frac{1}{g_m}}$$

SMALL SIGNAL MODEL FOR DIODE CONNECTED MOSFET (NMOS OR PMOS) IS $1/g_m$:

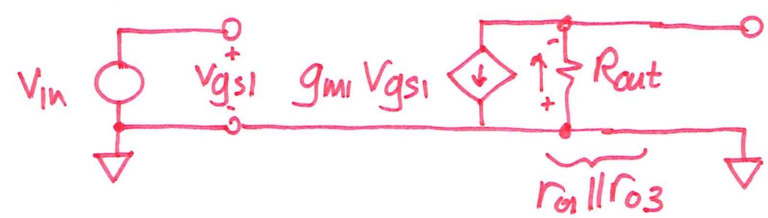


small signal model for common source amplifier with active load





r_{o1}, r_{o3} IN PARALLEL: REDRAW



$V_{out} = -g_{m1} \underbrace{V_{gs1}}_{V_{in}} R_{out}$

$$R_{out} = \underbrace{r_{o1}}_{\frac{1}{\lambda_1 I_D}} \| \underbrace{r_{o3}}_{\frac{1}{\lambda_3 I_D}} = \frac{1}{(\lambda_1+\lambda_3) I_D}$$

$$g_{m1} = \frac{2 I_D}{(V_{GS1} - V_{TH1})}$$

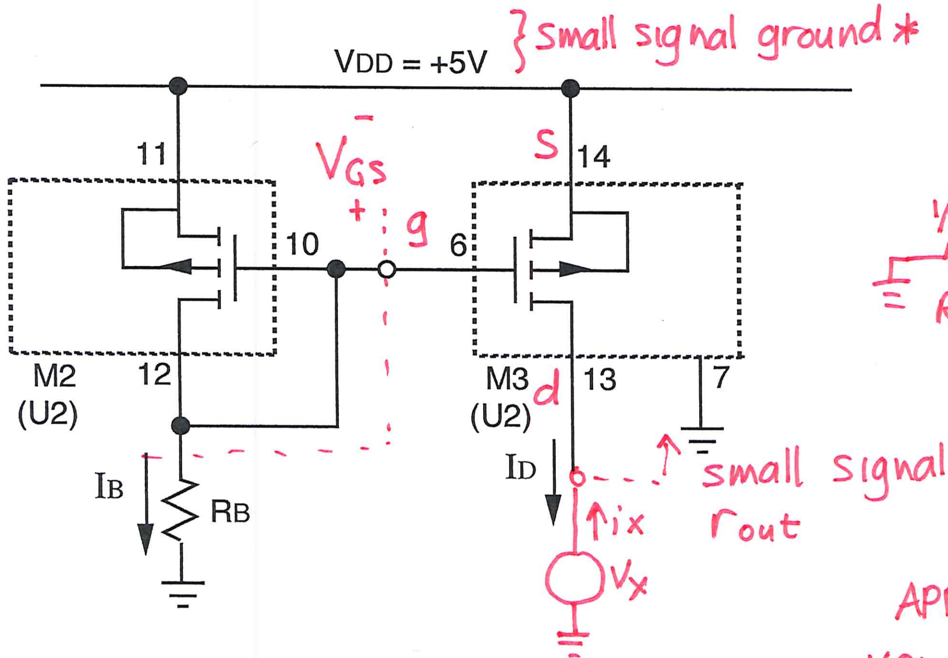
small signal gain
$$\frac{V_{out}}{V_{in}} = -g_{m1} R_{out} = \frac{2 \cancel{I_D}}{(V_{GS1} - V_{TH1})} \frac{1}{(\lambda_1+\lambda_3) \cancel{I_D}} = \frac{2}{V_{ov}(\lambda_1+\lambda_3)}$$

NUMBERS

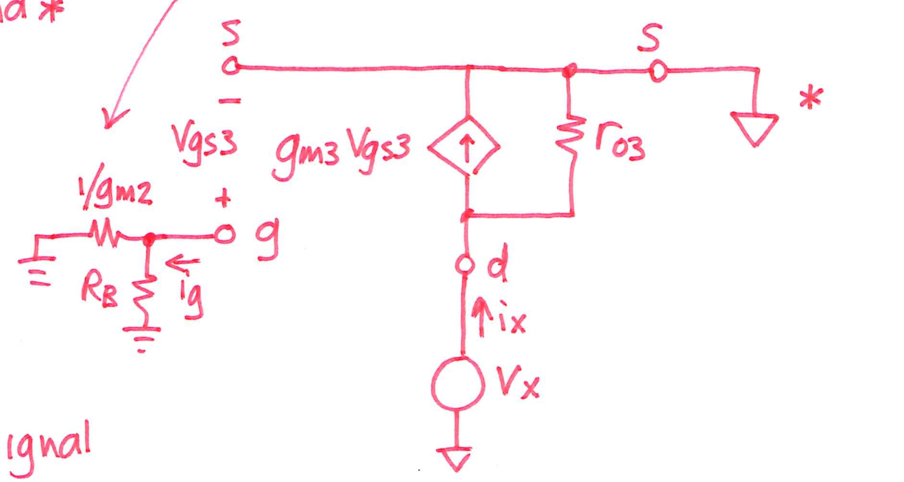
CHOOSE $V_{ov} = 0.3$ $\quad \frac{2}{(0.3V)(0.03+0.05)} = 83 \gg 10$

Example process parameters		NMOS	PMOS	Units
Threshold voltage	V_t	+1.50	-1.50	V
Mobility- C_{ox} product	μC_{ox}	7.0 E-6	2.5 E-6	A/V^2
Channel length modulation	λ	0.03	0.05	V^{-1}

small signal resistance "looking into" drain of current mirror:



model of diode connected MOSFET



APPLY V_x, CALCULATE i_x

KCL AT d NODE

$$i_x = g_{m3} \overset{\to 0}{V_{gs3}} + \frac{V_x}{r_{o3}} \qquad [1]$$

KVL LOOP TO FIND V_{GS3}

$$V_{gs3} - \underbrace{i_g}_{=0} \left(R_B \,\|\, \frac{1}{g_{m2}}\right) = 0 \Rightarrow V_{gs3} = 0 \qquad [2]$$

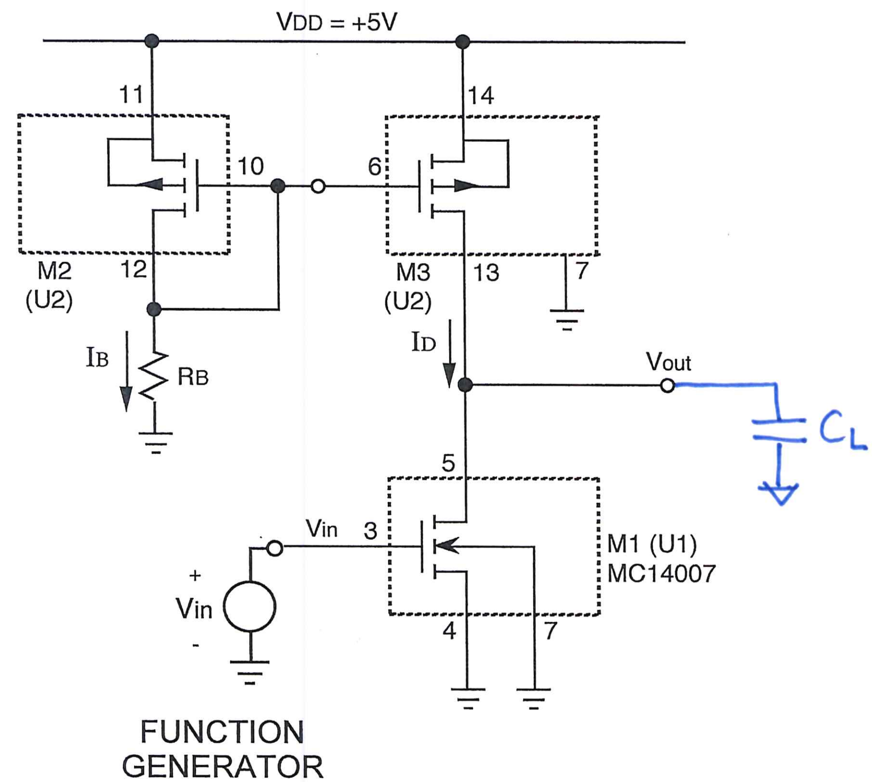
=0 (GATE OXIDE)

SUB [2] INTO [1]

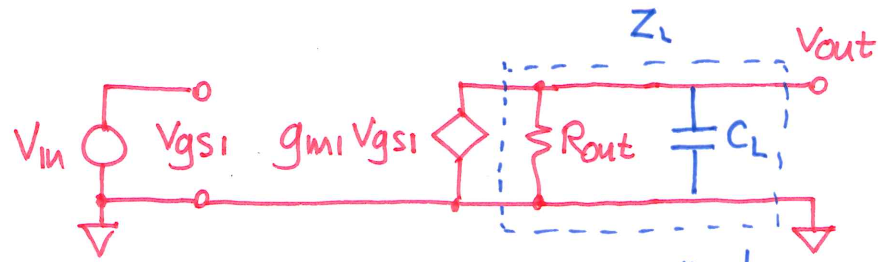
$$\frac{V_x}{i_x} = r_{o3}$$ HIGH! GOOD FOR HIGH GAIN!

Bandwidth: small signal model for common source amplifier with active load

ASSUME $C_L >> C_{par}$



small signal model (low freq)



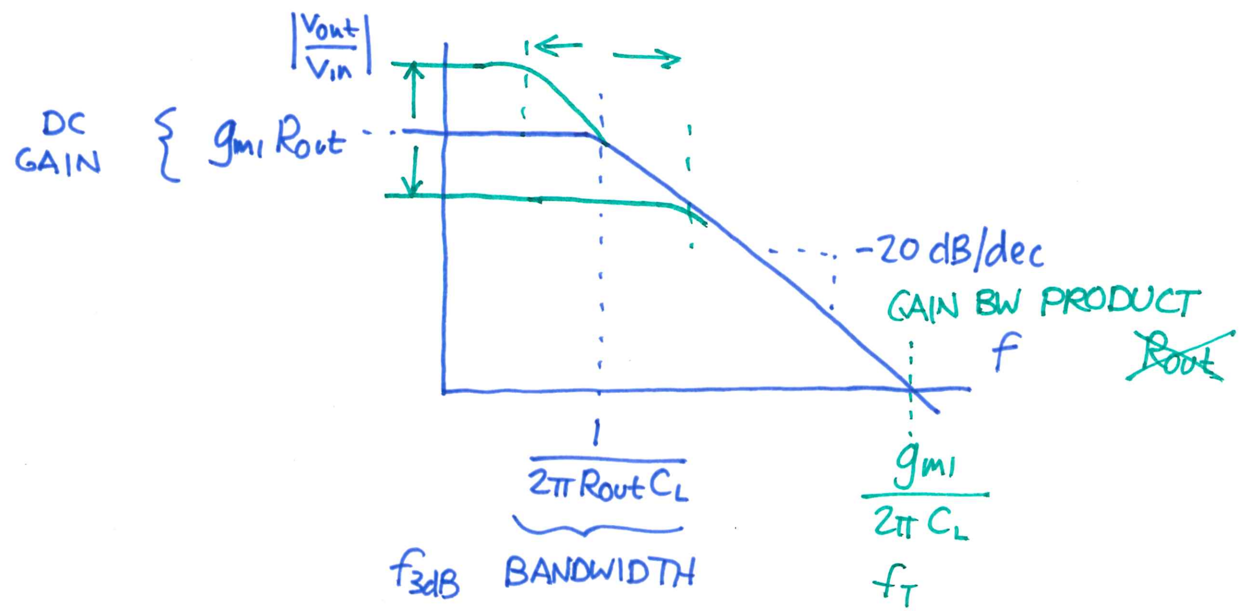
$$Z_L = R_{out} \parallel \frac{1}{sC_L}$$

$$Z_L = \frac{R_{out}}{1 + sR_{out}C_L}$$

small signal gain

$$\frac{V_{out}}{V_{in}} = -g_{m1}\underbrace{R_{out}}_{Z_L}$$

$$\frac{V_{out}}{V_{in}} = -g_{m1}Z_L = \frac{-g_{m1}R_{out}}{1 + sR_{out}C_L}$$



PROBLEM?

Rout POORLY CONTROLLED!

GAIN × BW

$$g_{m1}\cancel{R_{out}} \; \frac{1}{2\pi \cancel{R_{out}} C_L} = \frac{g_{m1}}{2\pi C_L}$$