Lecture 13

VE 311 Analog Circuits

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Recap of Last Lecture

- MOSFET Circuits: Diode Connected Load

Topics to Be Covered

- MOSFET Circuits

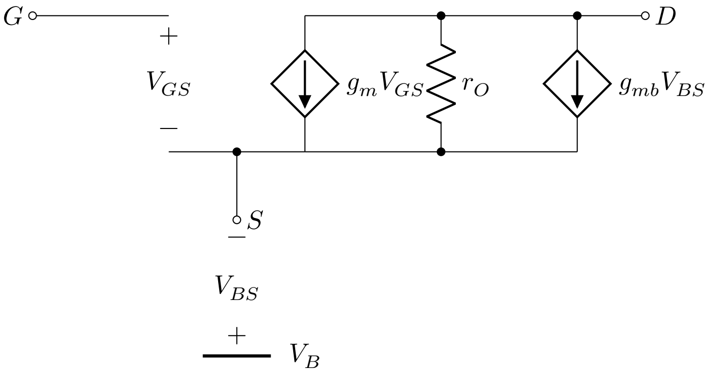
Schedule

SHANGHAI JIAO TONG UNIVERSITY

	Apr	May					Jun				Jul				Aug					Sep
Monday	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	4
Tuesday	25	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5
Wednesday	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	6
Thursday	27	4	11	18	25*	1*	8*	15*	22	29*	6*	13*	20*	27*	3	10	17	24	31	7
Friday	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25	1	8
Saturday	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	9
Sunday	30	7	14	21	28	4	11	18	25	2	9	16	23	30	6	13	20	27	3	10
JI Week			1	2	3	4	5	6	7	8	9	10	11	12	13					
JI Semester	**Spr. Brk.**		**Summer Term**													**Summer Break**				
SJTU Week	11	12	13	14	15	16	17	18	1	2	3	4								
SJTU Semester	**Spring Term**								**Summer Term**				**Summer Break**							

- Midterm on 30^{th}. It will focus on the fundamentals, semiconductors, Diodes, Op-amps, BJT, MOSFET DC biasing.
- No MOSFET SS analysis, only BJT SS models.

Sign of η



Sign of η

Razavi Textbook, equation 2.50

$$g_{mb} = \frac{\partial I_D}{\partial V_{SB}} = \frac{\partial I_D}{\partial V_{TH}} \cdot \frac{\partial V_{TH}}{\partial V_{SB}} = -\eta g_m \quad (1)$$

$$g_{mb} = \frac{\partial I_D}{\partial V_{SB}} \quad (2)$$

$$= \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) \left(-\frac{\partial V_{TH}}{\partial V_{BS}} \right) \quad (3)$$

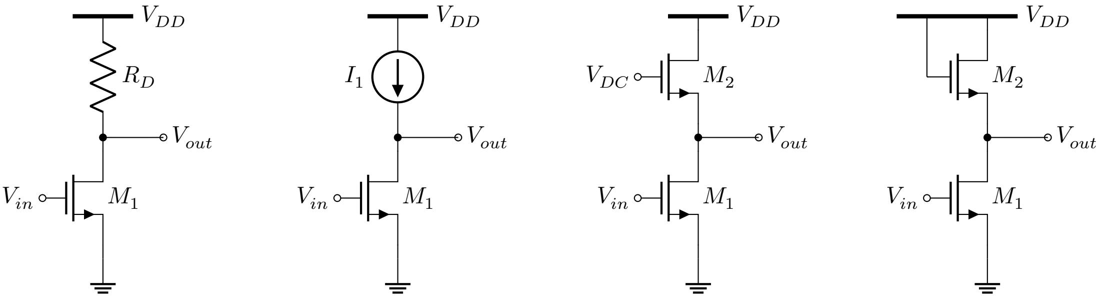
$$\frac{\partial V_{TH}}{\partial V_{BS}} = -\frac{\partial V_{TH}}{\partial V_{SB}} \quad (4)$$

$$= -\frac{\gamma}{2}(2\Phi_F + V_{SB})^{-1/2} \quad (5)$$

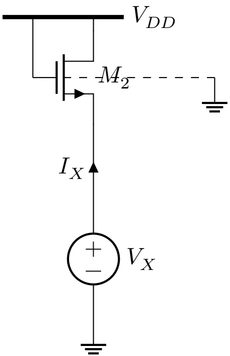
$$g_{mb} = g_m \frac{V}{2\sqrt{2\Phi_F + V_{SB}}} \quad (6)$$

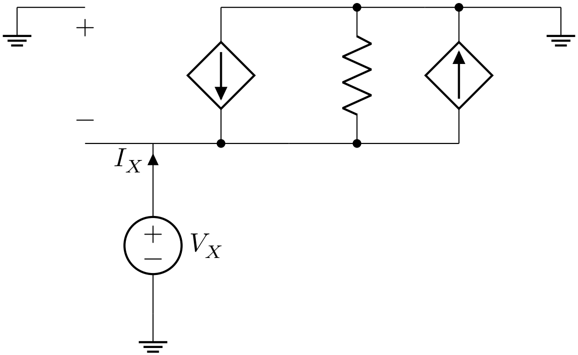
$$= \eta g_m \quad (7)$$

Different Load

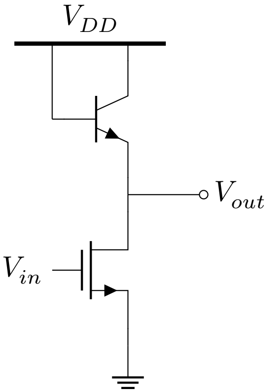


Different Load



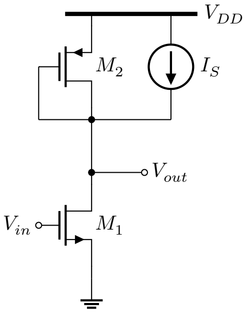


Example



Example

M_1 in saturation and $I_S = 0.75 \times I_1$. How do the disadvantages of CS stage with diode-connected load get improved?

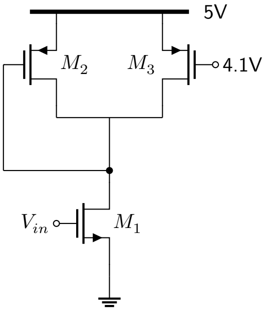


Solution: Small-signal Analysis ($\lambda = 0$):

$$A_v = \frac{V_{out}}{V_{in}} = -\frac{g_{m1}}{g_{m2}} = -\frac{\sqrt{2\mu_n C_{ox}\left(\frac{W}{L}\right)_1 I_{D1}}}{\sqrt{2\mu_p C_{ox}\left(\frac{W}{L}\right)_2 I_{D2}}} \tag{8}$$

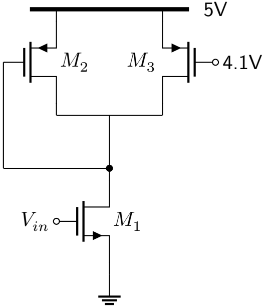
$$= -\frac{\sqrt{4\mu_n\left(\frac{W}{L}\right)_1}}{\sqrt{\mu_p\left(\frac{W}{L}\right)_2}} = \frac{4\left(V_{SG2} - V_{TH2}\right)}{\left(V_{GS1} - V_{TH1}\right)} \tag{9}$$

Example ($\lambda = \gamma = 0$)



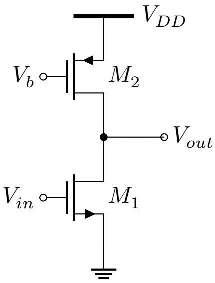
$$W_{drawn}/L_{drawn} = 10u/2u$$
$$V_{in} = 0.8V + 0.001\sin(2\pi 100t)$$

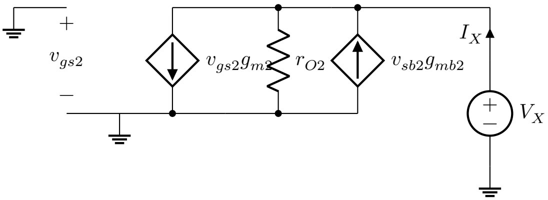
Example ($\lambda = \gamma = 0$)



$$W_{drawn}/L_{drawn} = 10u/2u$$
$$V_{in} = 0.8V + 0.001\sin(2\pi 100t)$$

CS with Current-Source Load ($\lambda \neq 0$, $\gamma \neq 0$)

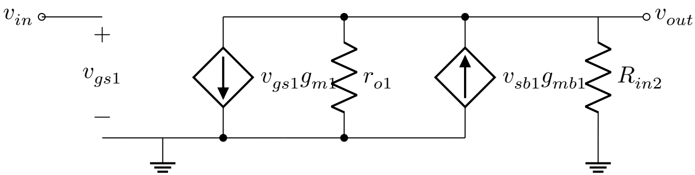




$$v_{sb2} = v_{gs2} = 0 \tag{10}$$

$$R_{in2} = \frac{V_x}{i_x} = r_{o2} \tag{11}$$

CS with Current-Source Load

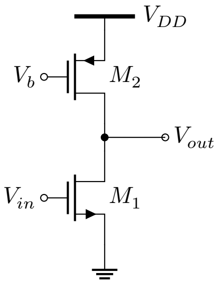


$$A_v = \frac{v_{out}}{v_{in}} \tag{12}$$

$$= -g_{m1}(r_{o2} \parallel r_{o1}) \tag{13}$$

- To achieve high A_v, the output swing is severely limited in the CS stages with resistive load and diode-connected load.
- Here $V_{out,max} = V_{DD} - (V_{SG2} - V_{TH2})$, which can be quite close to V_{DD}

CS with Current-Source Load



$$A_v = \frac{v_{out}}{v_{in}} \tag{14}$$

$$= -g_{m1}(r_{o2} \parallel r_{o1}) \tag{15}$$

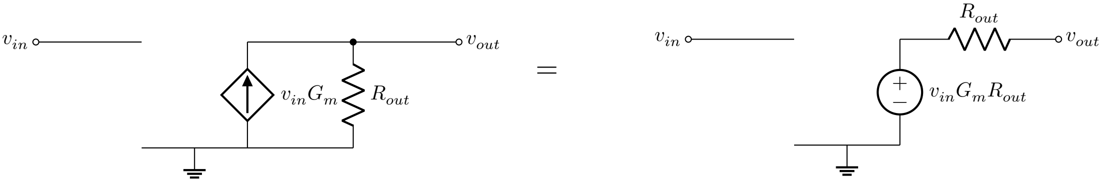
$$r_o \approx \frac{1}{\lambda I_D} \tag{16}$$

$$V_{out,max} = V_{DD} - (V_{SG2} - V_{TH2}) \tag{17}$$

$$V_{out,min} = V_{GS1} - V_{TH1} \tag{18}$$

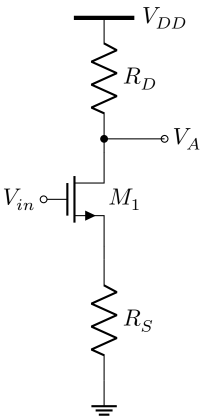
- For high g_{m1} and small $(V_{GS1} - V_{TH1})$, W of M_1 needs to be large.
- For high r_{o1} and r_{o2}, L of M_1 and M_2 need to be large and L of M_1 and M_2 needs to be increased proportionally. The cost is the large parasitic drain junction capacitance at the output.

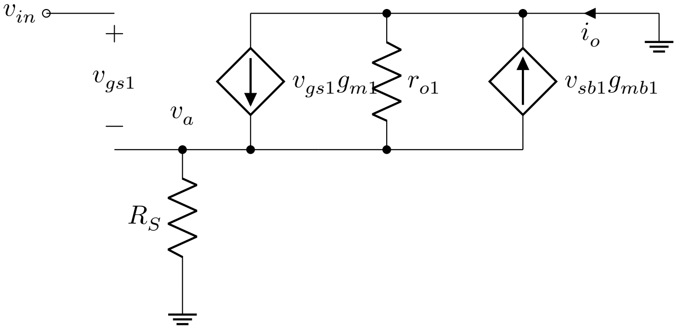
Amplifier Equivalent Circuit



- How to calculate G_m? v_{out} shorted to ground. $G_m = i_{out}/v_{in}$
- How to calculate R_{out}? v_{in} shorted to ground and v_{out} connected to v_{test}. $R_{out} = v_{test}/i_{test}$

CS with Source Degradation





CS with Source Degradation

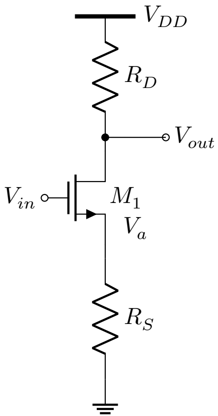
$$i_O = \frac{-v_a}{R_S} \tag{19}$$

$$(v_{in} - v_a)g_{m1} + i_O = \frac{v_a}{r_{o1}} + v_a g_{mb1} \tag{20}$$

$$G_m = \frac{i_O}{v_{in}} = \frac{-g_{m1}r_{o1}}{R_S + r_{o1} + (g_{m1} + g_{mb1})r_{o1}R_S} \approx -\frac{1}{R_S} \tag{21}$$

If $(g_{m1} + g_{mb1}r_{o1}R_S >> r_{o1}$ and R_S

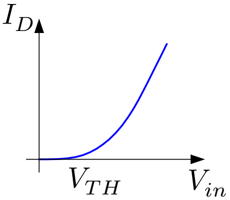
CS with Source Degradation

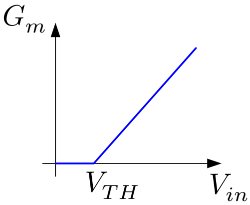


- At low V_{in} (g_m small), turn-on behavior of $R_S \neq 0$ is similar to that of $R_S = 0$.
- $V_{in} = 0V \rightarrow M_1$ off, no current flowing $\rightarrow$ $V_a = 0V$ and $V_{out} = V_{DD}$.

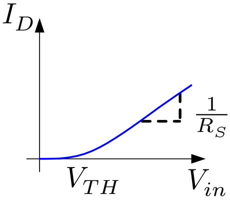
CS with Source Degradation

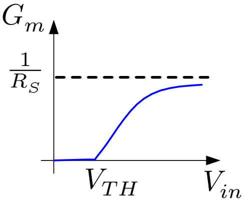
$R_S = 0$



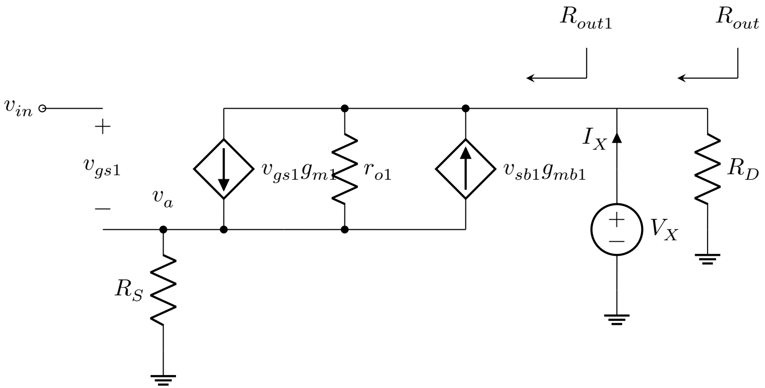


$R_S \neq 0$





CS with Source Degradation ($\lambda \neq 0, \gamma \neq 0$)



CS with Source Degradation

$$i_o = \frac{-v_a}{R_S} \tag{22}$$

$$v_a g_{m1} + v_a g_{mb1} + \frac{v_a - v_x}{r_o} + i_x = 0 \tag{23}$$

$$R_{out} = R_{out1} \parallel R_D = [R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S] \parallel R_D \approx R_D \tag{24}$$

CS with Source Degradation

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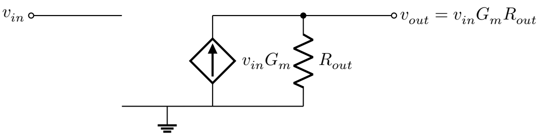

$$A_v = \frac{v_{out}}{v_{in}} = G_m R_{out} \tag{25}$$

$$= \frac{-g_{m1} r_{o1}}{R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S} \cdot \frac{[R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S] R_D}{[R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S] + R_D} \tag{26}$$

$$\approx -\frac{R_D}{R_S} \tag{27}$$

If $(g_{m1} + g_{mb1}) r_{o1}$, the intrinsic gain is large.