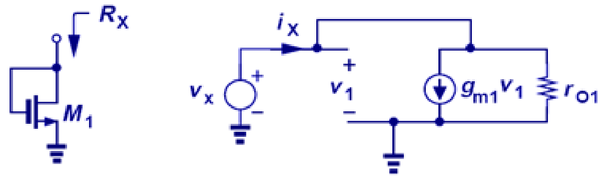
Digital Electronics Spring 2016 Final Exam 06/24/2016

Name: ID#

$\mu_n C_{ox}$ =200 μA/V^2 , $\mu_p C_{ox}$ =100 μA/V^2 , NMOS V_{TH}=0.4 V, PMOS V_{TH}=–0.4 V,

Saturation current $I_D=(1/2)\,\mu_n C_{ox}(W/L)(V_{GS}-V_{TH})^2$; $g_m=[2\mu_n C_{ox}(W/L)\,I_D]^{1/2}$; $r_o=[1/(\lambda I_D)]$

1. (10%) Find R_X of the following circuit.



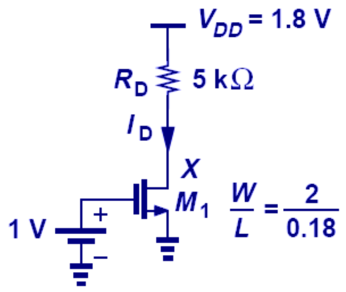
ANS:

$$R_X = \frac{v_X}{i_X} \Rightarrow (g_{m1}v_X + \frac{v_X}{r_{O1}}) = i_X$$

$$(g_{m1} + \frac{1}{r_{O1}})v_X = i_X$$

$$R_X = \frac{v_X}{i_X} = \frac{1}{g_{m1} + \frac{1}{r_{O1}}} = \frac{1}{g_{m1}} \| r_{O1}$$

2. (10%) Determine the W/L of the figure that place the M_1 at the edge of saturation. In this case, the edge of saturation should follow $V_{DS} = V_{GS} - V_{TH}$



ANS:

$$V_{GS} = +1V, \quad \text{drain voltage must fall to } V_{GS} - V_{TH} = 0.4V \text{ for } \mathrm{M_1} \text{ enter triode region.}$$

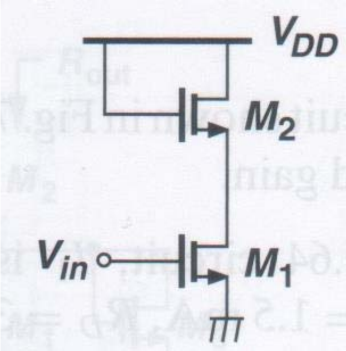
$$I_D = \frac{V_{DD} - V_{DS}}{R_D} = 280uA = I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$280uA = \frac{1}{2} \times 200uA/V^2 \times \frac{\mathrm{W}}{\mathrm{L}}(1 - 0.4)^2$$

$$\frac{\mathrm{W}}{\mathrm{L}} = \frac{280}{100 \times 0.36} = \frac{1.4}{0.18} = 7.78$$

3. (10%) I_D = 1 mA, $(W/L)_2$ =5/1, $(W/L)_1$ = 10/1, $\lambda_1 = 0.1\ V^{-1}$, $\lambda_2 = 0.1\ V^{-1}$, calculate R_{out}.

$R_{out} = (1/g_{m2}) || (r_{O2}) || (r_{O1})$,



ANS:

$$r_{O2} = \frac{1}{\lambda I_D} = \frac{1}{0.1\times 10^{-3}} = 10\text{k}\Omega.$$

$$r_{O1} = \frac{1}{\lambda I_D} = 10\text{k}\Omega.$$

$$g_{m_2} = \sqrt{2\times 200\times 10^{-6}\times \frac{5}{1}\times 1\times 10^{-3}} = 0.00141\text{S}.$$

$$R_{out} = \frac{1}{g_{m_2}} \| r_{O2} \| r_{O1} = 709 \| 10\text{k}\Omega \| 10\text{k}\Omega \,\square\, 709\,\Omega.$$

4. (10%) In Fig. 6.42, what is the current when $V_{GS} = 2V_{TH}$ and W/L=10/0.14? Find the region in which the device operates. [$V_{DS} > V_{GS} - V_{TH}$→Saturation, $V_{DS} < V_{GS} - V_{TH}$→Triode]

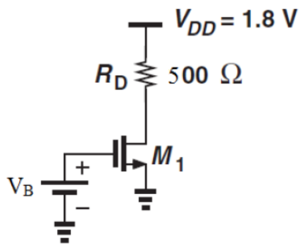


Fig 6.42

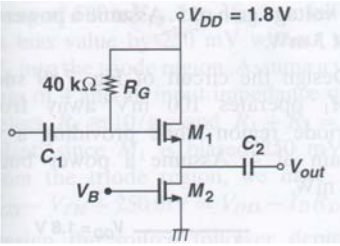
ANS:

$$\begin{aligned}
I_D &= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 \\
&= \frac{1}{2}\times 200\times 10^{-6}\times \frac{10}{0.14}(2V_{TH}-V_{TH})^2 \\
&= \frac{1}{2}\times 200\times 10^{-6}\times \frac{10}{0.14}(V_{TH})^2 \\
&= \frac{1}{2}\times 200\times 10^{-6}\times \frac{10}{0.14}(0.4)^2 \\
&= 1.142\ \text{mA} \\
V_{DS} &= V_{DD} - I_D R_D \\
&= 1.8 - 500\times 1.142\times 10^{-3} \\
&= 1.23\ \text{V}.
\end{aligned}$$

Since $V_{DS} > V_{GS} - V_{TH}$, the device operates in the saturation region.

5. (10%) Calculate voltage gain, RG=40kΩ, ID=5mA, $\lambda_1=\lambda_2=0.001V^{-1}$, $(W/L)_1 = (W/L)_2 = 300/1$.

$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} \qquad A_V = \frac{r_{O1}\|r_{O2}}{\frac{1}{g_{m1}} + r_{O1}\|r_{O2}}$$



ANS:

$$A_V = \frac{r_{01}\|r_{02}}{\frac{1}{gm_1} + (r_{01}\|r_{02})}$$

$$r_{01} = r_{02} = \frac{1}{\lambda \cdot I_D} = \frac{1}{0.001\times 5\times 10^{-3}} = 200\text{k}\Omega.$$

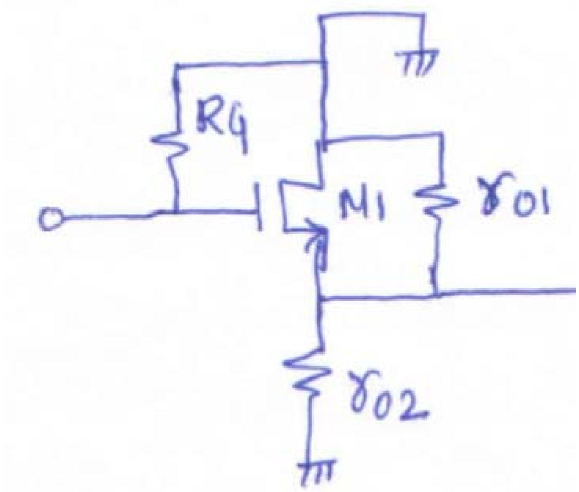
$$g_{m1} = \sqrt{2\mu_n C_0 \times \frac{W}{L} \times I_D}$$

$$= \sqrt{2\times 200\times 10^{-6} \times \frac{300}{1} \times 5\times 10^{-3}} = 0.0245\text{S}$$

$$A_V = \frac{200\text{k}\|200\text{k}}{(1/0.0245) + (200\text{k}\|200\text{k})}$$ XXXXXXXX.

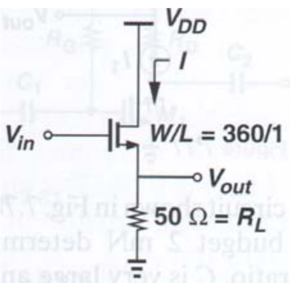
=0.9995 V/V

circuit is,



6. (10%) Transistor with W/L = 360, R_L = 50Ω, power is 20 mW, find voltage gain (V_{DD} = 2 V).

$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} \qquad A_V = \frac{R_L}{\frac{1}{g_m} + R_L}$$



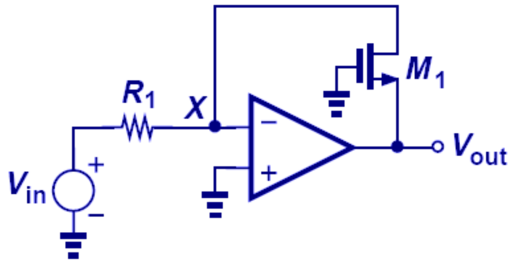
ANS:

Solution $p = 20\text{mW}; V_{DD} = 2V \Rightarrow \max I = \frac{20\times 10^{-3}}{2\text{V}} = 10\text{mA}$

We know $g_m = \sqrt{2\mu_n C_0 \times \frac{W}{L} I_D} = \sqrt{2\times 200\times 10^{-6} 360\times 10\times 10^{-3}} = 0.0379\text{S}$

We have $A_v = \frac{R_L}{\frac{1}{g_m} + R_L} = \frac{50}{26.38 + 50} = 0.65\text{ v/v.}$

7. (10%) For the square root amplifier, Find the expression for V_{out} in terms of V_{in}.



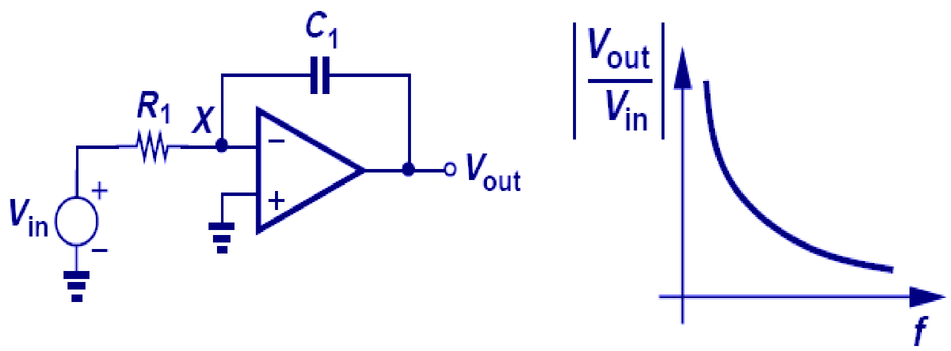
ANS:

$$\frac{V_{in}}{R_1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$V_{out} = -\sqrt{\frac{2V_{in}}{\mu_n C_{ox}\frac{W}{L}R_1}} - V_{TH}$$

$$(V_{GS} = -V_{out})$$

8. (10%) Derive the expression (V_{out}/V_{in})? [X_{C1}=1/(sC1)]

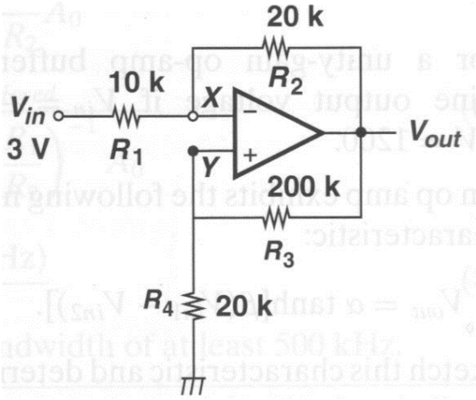


ANS:

$$\frac{V_{out}}{V_{in}} = -\frac{\frac{1}{C_1 s}}{R_1}$$

$$\frac{V_{out}}{V_{in}} = -\frac{1}{R_1 C_1 s}$$

9. (10%) Calculate output voltage V_{out}.



ANS:

$$\frac{V_{in}-V_X}{10\text{K}}=\frac{V_X-V_{out}}{20\text{K}}$$

$$\frac{V_{in}}{10\text{K}}+\frac{V_{out}}{20\text{K}}=V_X\left(\frac{1}{20\text{K}}+\frac{1}{10\text{K}}\right).$$

$$V_Y=\frac{20\text{K}}{(20\text{K}+200\text{K})}\cdot V_{out}$$

$V_X = V_Y$ due to virtual grand concept.

So,

V(Y)=(1/11)Vout

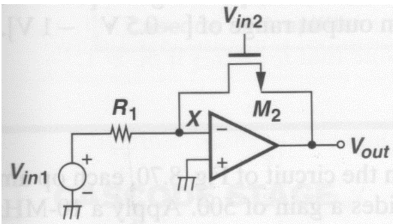
V(X)=(20Vin+10Vout)/30

V(X)=V(Y) 220Vin+110Vout= 30Vout

Vout/Vin=-(11/4) V/V

10. (10%) analyze the function of a circuit and verify its function mathematically.

$$R_{on}=\frac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})}$$



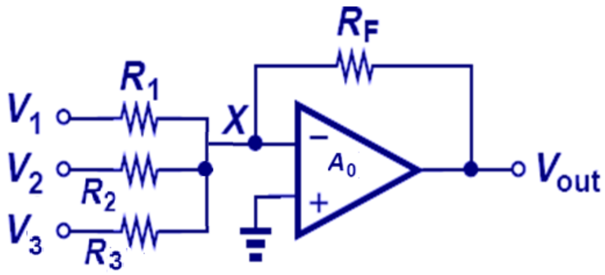
ANS:

$$\frac{V_{out}}{V_{in1}}=\frac{-R_2}{R_1}=-\frac{1}{R_1\mu_n C_{ox}\frac{W}{L}(V_{in2})}$$

$$V_{out}=-\left(\frac{V_{in1}}{V_{in2}}\right)\frac{1}{\mu_n C_{ox}\frac{W}{L}R_1}$$

output voltage is proportional to ration $\left(\frac{V_{in1}}{V_{in2}}\right)$

11. (10%) Find the output voltage of the following circuit in terms of V_1, V_2, V_3, R_1, R_2, R_3, R_F.

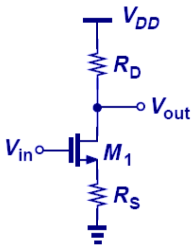


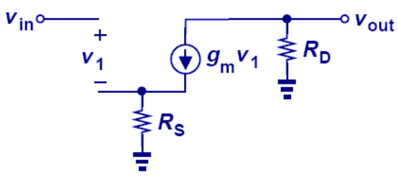
ANS:

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}=\frac{-V_{out}}{R_F}$$

$$V_{out}=-R_F\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right)$$

12. (10%) Find the small signal gain of the following circuit. (Assuming λ=0) (10%)





ANS:

$$v_{in}=v_1+g_m v_1 R_S \Rightarrow v_1=\frac{v_{in}}{1+g_m R_S}$$

$$v_{out}=-g_m v_1 R_D \quad \frac{v_{out}}{v_{in}}=-\frac{g_m R_D}{1+g_m R_S}=-\frac{R_D}{\frac{1}{g_m}+R_S}$$