Digital Electronics Spring 2014 Midterm Exam 05/02/2014

Name: ID#

1. (10%) A cellphone incorporates a 2.4GHz oscillator whose frequency is defined by the resonance frequency of an *LC* tank If the tank capacitance is realized as the *pn* junction of Example 2.15, calculate the change in the oscillation frequency while the reverse voltage goes from 0 to 1.5 V. Assume the circuit operates at 2.4 GHz at a reverse voltage of 0 V, and the junction area is 2500 μm^2.

$$f_{res} = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}, C_j = 0.265 fF/\mu m^2, \quad C_{j,tot} = \frac{C_{j0}}{\sqrt{1+\frac{V_R}{V_0}}}, \quad V_0 = 0.73V$$

Ans:

$$jL\omega_{res} = -(jC\omega_{res})^{-1} \qquad f_{res} = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

at $V_R = 0V$ and $C_j = 0.265fF/\mu m^2$

$$C_{j,tot} = (V_R = 0) = (0.265fF/\mu m^2)\times(2500\mu m^2) = 662.5fF$$

$$f_{res} = 2.4GHz = \frac{1}{2\pi}\frac{1}{\sqrt{L\times 662.5fF}}, \quad L = 6.64nH$$

if $V_R = 1.5V \quad C_{j,tot} = \frac{C_{j0}}{\sqrt{1+\frac{1.5}{0.73}}}\times 2500\mu m^2 = 379fF$

$$f_{res}(V_R = 1.5) = \frac{1}{2\pi}\frac{1}{\sqrt{L\times 379fF}} = 3.17GHz$$

2. (10%). An NMOS device with λ=0.1V^{-1} must provide a $g_m r_o$ of 20 with V_{DS}=1.5V. Determine the required value of W/L if I_D=0.5mA. Assume $\mu_n C_{ox}$=200uA/V^2, and V_{TH}=0.4V. $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$,

$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} \qquad r_o = \frac{1}{\lambda I_D}$$

Ans:

3b. Given NMOS with $\lambda = 0.1\ V^{-1}$ $g_m r_o = 20$ $V_{DS} = 1.5V$

determine W/L if $I_D = 0.5mA$.

$$r_0 = \frac{1}{\lambda I_D} = \frac{1}{(0.1V^{-1})(0.5mA)} = 20\ k\Omega$$

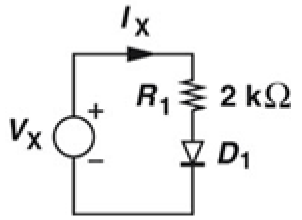
$$\Rightarrow g_m = \frac{20}{20k\Omega} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$$

$$\therefore \frac{W}{L} = \left(\frac{20}{20k\Omega}\right)^2\frac{1}{2\mu_n C_{ox} I_D}$$

$$= \left(\frac{1}{1k\Omega}\right)^2 \cdot \frac{1}{2\left(\frac{200\mu A}{V^2}\right)(0.5mA)} \approx 5.$$

3. (10%) Suppose D_1 must sustain a voltage 850 mV for $V_X = 2.0$ V. $R_1 = 2.0$ kΩ. Calculate the required I_S.

$V_T = 26\text{mV}$, $I_D = I_S \exp^{\frac{V_D}{V_T}}$



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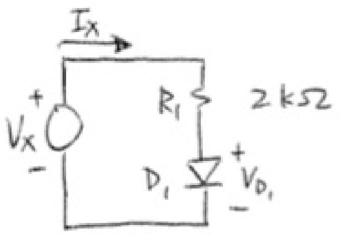


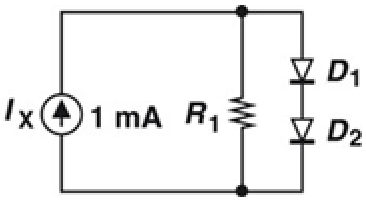
Given: @ $V_X = 2V$, $V_{D_1} = 850mV$

$$\Rightarrow I_X = \frac{V_X - V_{D_1}}{R_1} = 0.58\ mA$$

$$\therefore I_S = \frac{I_X}{(e^{V_D/V_T} - 1)} \approx I_X \exp[-V_{D_1}/V_T]$$

$$= (0.58\ mA) \exp[-0.85/0.026] \approx 3.64 \cdot 10^{-18} A$$

4. (10%) In the following circuit, determine the value of R_1 such that this resistor carries 0.5 mA. Assume $I_S = 5 \times 10^{-16}$ A for each diode. $V_T = 26\text{mV}$, $I_D = I_S \exp^{\frac{V_D}{V_T}}$



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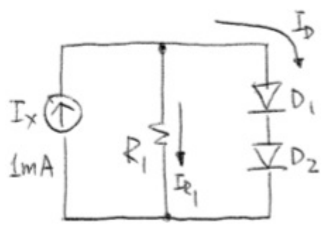


Given $I_{R_1} = 0.5\ mA$, $I_S = 5 \cdot 10^{-16} A$ for each diode.

Find R_1.

By KCL, $I_D = I_X - I_{R_1} = 0.5\ mA$

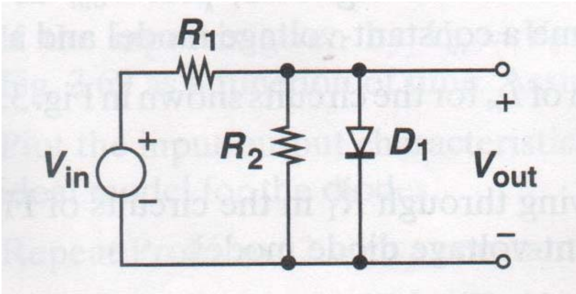
$$\Rightarrow V_{D_1} = V_{D_2} = V_T \ln\left(\frac{I_D}{I_S}\right) = 0.026 \ln\left(\frac{0.5mA}{5 \cdot 10^{-16} A}\right)$$

$$\approx 0.718\ V$$

$$\therefore R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{2 V_{D_1}}{I_{R_1}} = \frac{2(0.718V)}{0.5mA} = 2.87\ k\Omega$$

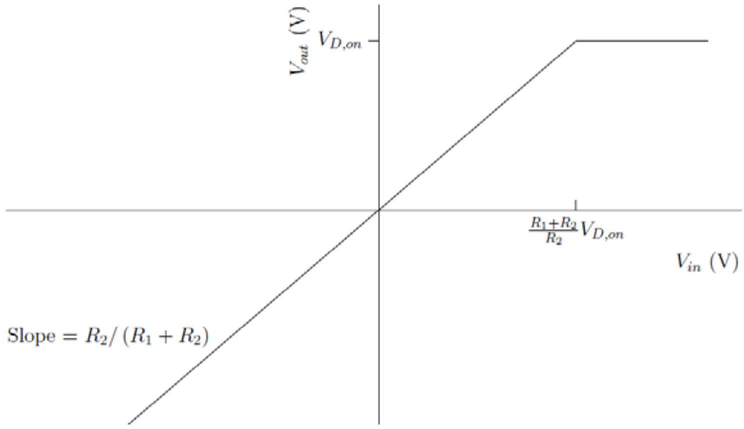
5. (10%) Please plot the input/output characteristic of the circuit assuming a constant voltage model ($V_{D,on}$).

Ans:

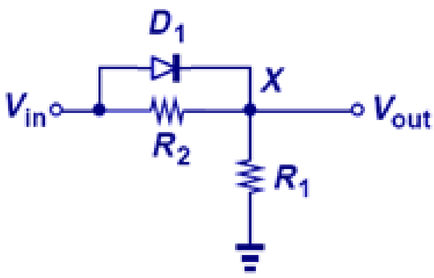


3.23 (a)

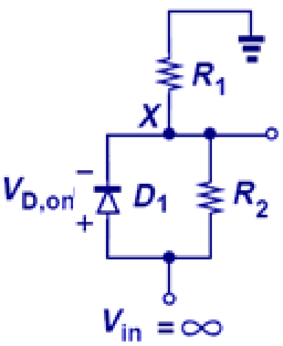
$$V_{out} = \begin{cases} \frac{R_2}{R_1+R_2} V_{in} & V_{in} < \frac{R_1+R_2}{R_2} V_{D,on} \\ V_{D,on} & V_{in} > \frac{R_1+R_2}{R_2} V_{D,on} \end{cases}$$

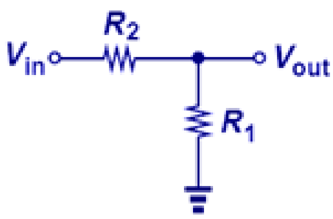


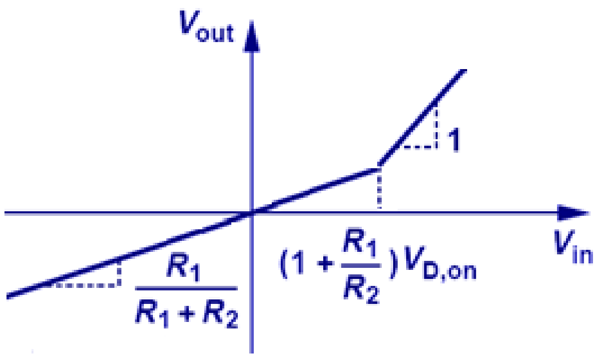
6. (10%) Using the constant voltage mode, plot the input/output characteristic of the following circuit.



Ans:



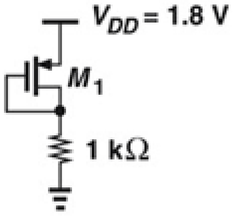




$$V_{in} = V_{D,on} + V_{out} \qquad I_{R2} = \frac{V_{D,on}}{R_2} \qquad I_{R1} = \frac{V_X - 0}{R_1} = \frac{(V_{in} - V_{D,on})}{R_1}$$

$$\frac{V_{D,on}}{R_2} = \frac{(V_{in} + V_{D,on})}{R_1} \qquad V_{in} = (1+\frac{R_1}{R_2})V_{D,on} \qquad V_{out} = \frac{R_1}{R_1+R_2} V_{in}$$

7. (10%) If W/L =10/0.18 and λ=0, determine the operating point of M_1 in the following circuit. $\mu_p C_{ox}$=100uA/V^2, and V_{TH}=-0.4V. $I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(|V_{GS}|-|V_{TH}|)^2$



Ans:

(b) Since M_1 is diode-connected, we know it is operating in saturation.

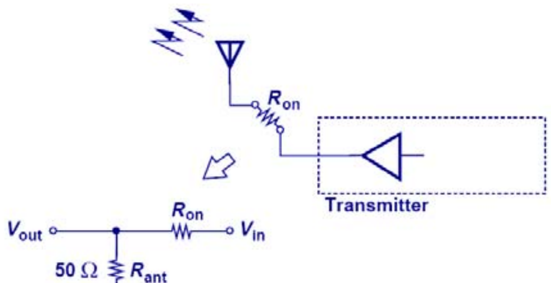
$$|V_{GS}| = |V_{DS}|$$

$$V_{DD} - |V_{GS}| = |I_D|(1\ \mathrm{k}\Omega) = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}\left(|V_{GS}| - |V_{TH}|\right)^2 (1\ \mathrm{k}\Omega)$$

$$|V_{GS}| = |V_{DS}| = \boxed{0.952\ \mathrm{V}}$$

$$|I_D| = \boxed{848\ \mu\mathrm{A}}$$

8. (5%) The switch connecting the transmitter to the antenna attenuates the signal by no more than 10%. If $\mu_n C_{ox}$=200uA/V^2, and V_{TH}=0.4V, and the W/L is 1500, determine the minimum required V_{GS} of the switch. Assume the antenna can be model as a 50Ω resistor. $R_{on} = \frac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})}$



$$V_{out}/V_{in} = 0.9$$

Ans:

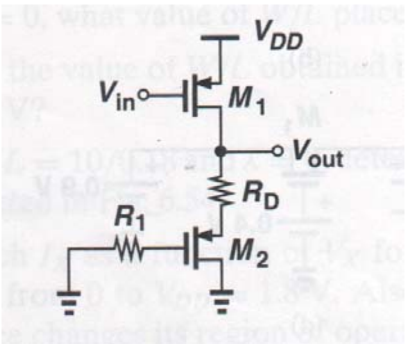
$$V_{out} = \frac{R_{ant}}{R_{ant}+R_{on}} = \frac{50}{50+R_{on}} = 0.90, R_{on} = 5.6$$

$$R_{on} = \frac{1}{\mu_n C_{ox}(W/L)(V_{GS}-V_{TH})} = 5.6 = \frac{1}{200\times 10^{-6}\times 1500\times(V_{GS}-0.4)}$$

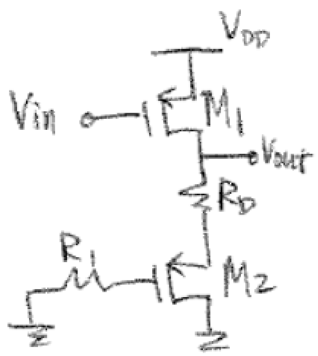
$$V_{GS} = 0.995V$$

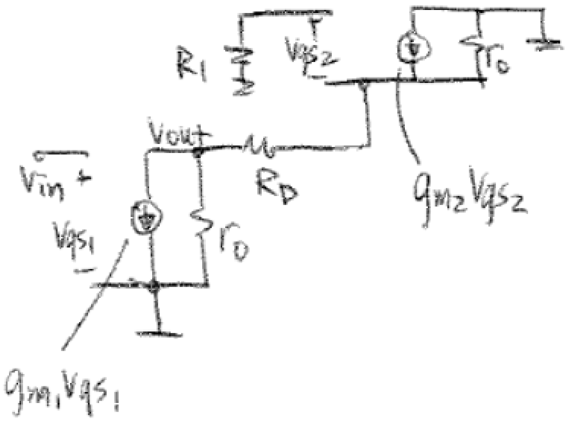
9.

10. (5%) Construct the small signal model of circuit, if all transistor operate in saturation and $\lambda \neq 0$.

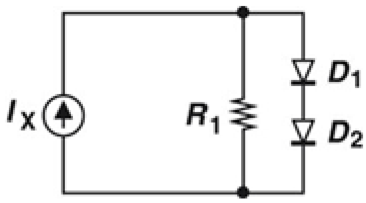


Ans:





11.(10%) This circuit employs two identical diodes with $I_S = 5 \times 10^{-16}$ A. Calculate the voltage across R_1 for $I_X = 2$mA. Assume $R_1 = 2.0$ kΩ.



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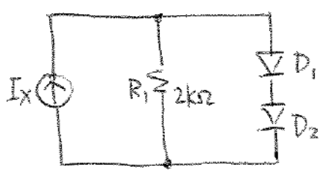

Given $D_1 = D_2$ with
$I_S = 5 \cdot 10^{-16} A$

Find V_{R_1} for $I_X = 2mA$.

Current through the diodes $= I_D$
$= I_X - \dfrac{V_{R_1}}{R_1}$ where V_{R_1} = voltage across R_1

$$\Rightarrow V_{R_1} = 2 \cdot V_T \ln\left(\frac{I_D}{I_S}\right) = 2\left[V_T \ln\left(\frac{I_X}{I_S} - \frac{V_{R_1}}{I_S R_1}\right)\right]$$

$$V_{R_1} = 1.4\ V \Rightarrow I_D = I_X - \frac{V_{R_1}}{R_1} = 2mA - \frac{1.4V}{2k\Omega} = 1.3mA$$

$$\Rightarrow V_{R_1} = 2V_T \ln\left(\frac{I_D}{I_S}\right)$$

$$= 2(0.026V)\ln\left(\frac{1.3mA}{5\times10^{-16}A}\right) \approx 1.49\ V$$

$$V_{R_1} = 1.49V \Rightarrow I_D = 2mA - \frac{1.49}{2k\Omega} = 1.26\ mA$$

$$\Rightarrow V_{R_1} = 2(0.026V)\ln\left(\frac{1.26\ mA}{5\cdot10^{-16}A}\right) \approx 1.48V$$

$$V_{R_1} = 1.48V \Rightarrow I_D = 2mA - \frac{1.48V}{2k\Omega} = 1.26\ mA$$

$$\Rightarrow V_{R_1} = 1.48V$$

$\therefore$ voltage across $R_1 = 1.48\ V$