Digital Electronics Spring 2012 Midterm Exam 04/25/2012

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.

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

Ans:

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

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

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

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

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

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

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.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 \;, \; g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$$

Ans:

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

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

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

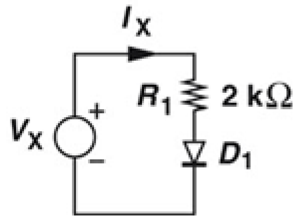
$$\Rightarrow g_m = \frac{20}{20k\Omega} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$$

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

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

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



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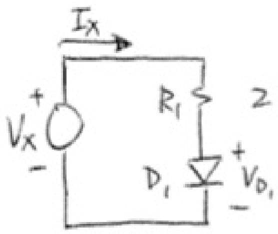


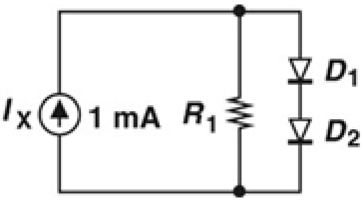
Given: @ $V_X = 2V$, $V_{D_1} = 850mV$

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

$$\therefore I_S = \frac{I_X}{(e^{V_{D}/V_T} - 1)} \approx I_X \exp[-V_{D1}/V_T]$$

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

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



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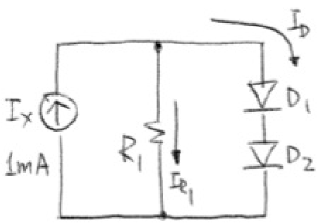


Given $I_{R_1} = 0.5\ mA$, $I_S = 5 \cdot 10^{-16} A$ for each diode.

Find R_1.

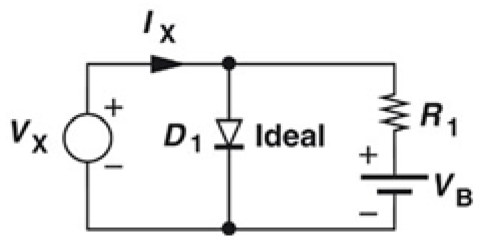
By KCL, $I_D = I_X - I_{R_1} = 0.5 mA$

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

$$\approx 0.718\ V$$

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

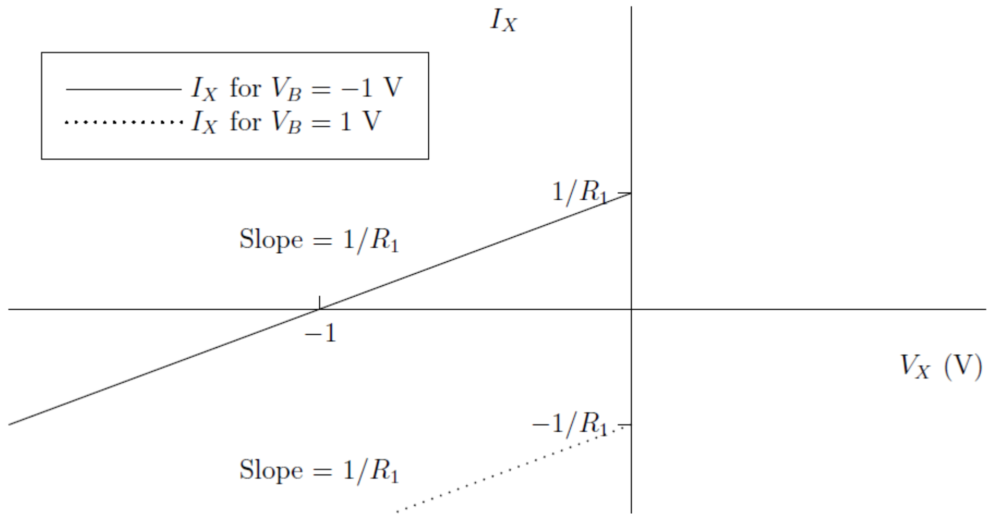
5. (10%) For the circuits shown below, choose the correct Ix/Vx characteristic for V_B=+1V and V_B= −1V



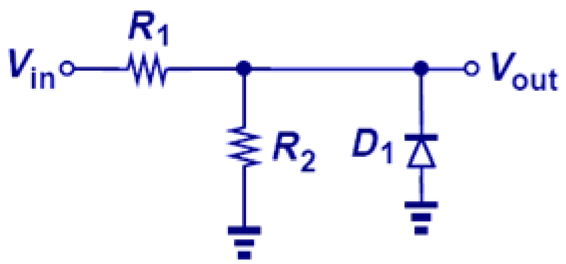
Ans:

$$I_X = \begin{cases} \frac{V_X - V_B}{R_1} & V_X < 0 \\ \infty & V_X > 0 \end{cases}$$

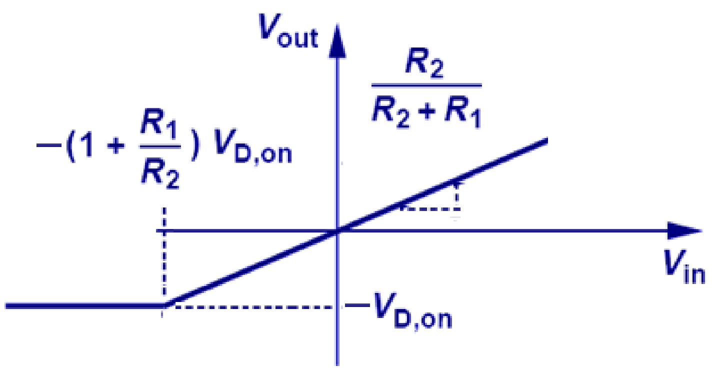
Plotting I_X vs. V_X for $V_B = -1$ V and $V_B = 1$ V, we get:



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

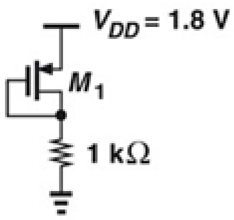


Ans:



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

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. $I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(|V_{GS}|-|V_{TH}|)^2$

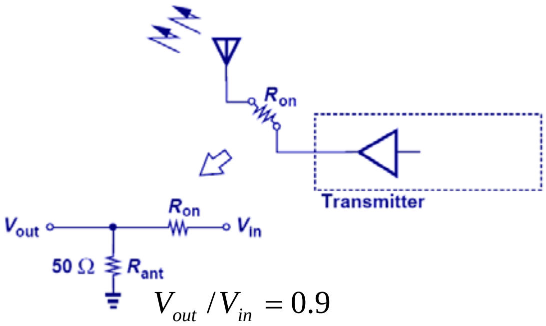


Ans:

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

$$|V_{GS}| = |V_{DS}|$$
$$V_{DD} - |V_{GS}| = |I_D|(1\ \text{k}\Omega) = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}\left(|V_{GS}| - |V_{TH}|\right)^2 (1\ \text{k}\Omega)$$
$$|V_{GS}| = |V_{DS}| = \boxed{0.952\ \text{V}}$$
$$|I_D| = \boxed{848\ \mu\text{A}}$$

8. (10%) 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. $R_{on} = \dfrac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})}$

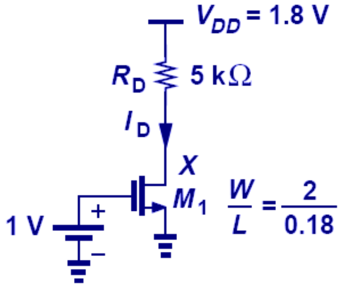


$$V_{out}/V_{in} = 0.9$$

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%) Determine the W/L of the above figure that place the M_1 at the edge of saturation. Assume $\mu_n C_{ox}$=200uA/V^2, and V_{TH}=0.5V. $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$



Ans:

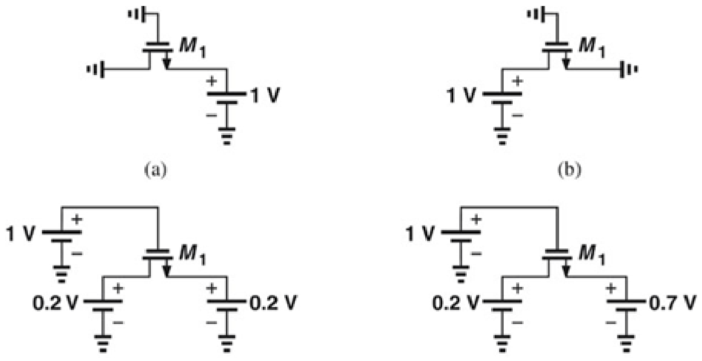
$V_{GS} = +1V$, drain voltage must fall to $V_{GS} - V_{TH} = 0.5V$ for M_1 enter triode region.

$$I_D = \frac{V_{DD} - V_{DS}}{R_D} = 260uA = I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$$

$$260uA = \frac{1}{2}\times 200uA/V^2 \times \frac{\mathrm{W}}{\mathrm{L}}(1-0.5)^2$$

$$\frac{\mathrm{W}}{\mathrm{L}} == \frac{260}{100\times 0.25} = \frac{1.872}{0.18}$$

10. (10%) Please determine the region of M1 in each circuit. Assume V_{TH}=0.4V, ($V_{GS}< V_{TH}$, MOS is at OFF region, $V_{DS}> V_{GS} - V_{TH}$ MOS at saturation region, $V_{DS}< V_{GS} - V_{TH}$,MOS at triode region)



(a) (b) (c) (d)

Ans:

20. (a) OFF ∵ $V_{GS} = 0$ ($V_{GS} < V_{TH}$)

(b) OFF ∵ $V_{GS} = 0$ ($V_{GS} < V_{TH}$)

(c) TRIODE (LINEAR) ∵ $V_{GS} > V_{TH}$ &

$V_{DS} \ll 2(V_{GS} - V_{TH})$

(d) SATURATION ∵ $V_{GS} > V_{TH}$ & $V_{DS} > V_{GS} - V_{TH}$