EE 105 Midterm-1 Solution

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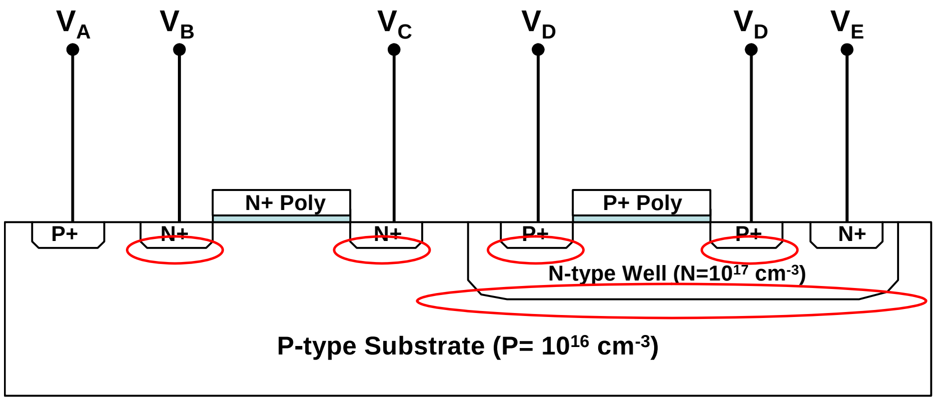
$q := 1.6\cdot 10^{-19}C$ $ni := 10^{10}cm^{-3}$ $Vth := 0.026V$

$\varepsilon0 := 8.854\cdot 10^{-14}\frac{F}{cm}$ $\varepsilon s := 11.7\cdot\varepsilon 0$ $\varepsilon ox := 3.9\cdot\varepsilon 0$

(1)(a) There are 5 PN junctions



(b) V_A should be connected to the most negative voltage, or -2V, and V_E should be connected to the most positive voltage, or 2V, so that the N-well is reverse-biased

(2) (a) $Nd := 10^{16}cm^{-3}$ $Na := Nd$

$\phi n := 60mV\cdot\log\left(\frac{Nd}{ni}\right)$ $\phi p := -60mV\cdot\log\left(\frac{Na}{ni}\right)$

$\phi bi := \phi n - \phi p$ $\phi bi = 0.72\,V$

(b)

$$xd(Vd) := \sqrt{\frac{2\cdot\varepsilon s\cdot(\phi bi - Vd)}{q}\cdot\left(\frac{1}{Na} + \frac{1}{Nd}\right)}$$ $xd(0) = 0.432\,\mu m$

(c)

$$Emax := \frac{2\cdot\phi bi}{xd(0)}$$ $Emax = 3.335\times 10^{6}\frac{V}{m}$

(d) The capacitance is inversely proportional to the depletion width:

$$C\_ratio := \frac{xd(-10V)}{xd(0)}$$ $C\_ratio = 3.859$

(3) $\varepsilon d := 20\cdot\varepsilon 0$ $\quad td := 1nm$ $\quad Nd := 10^{16}\cdot cm^{-3}$

(a) $\phi\_pp := -550mV$ $\quad \phi\_n := 60mV\cdot \log\left(\frac{Nd}{ni}\right)$ $\quad \phi\_n = 0.36\,V$

$V\_FB := -(\phi\_pp - \phi\_n)$ $\quad V\_FB = 0.91\,V$

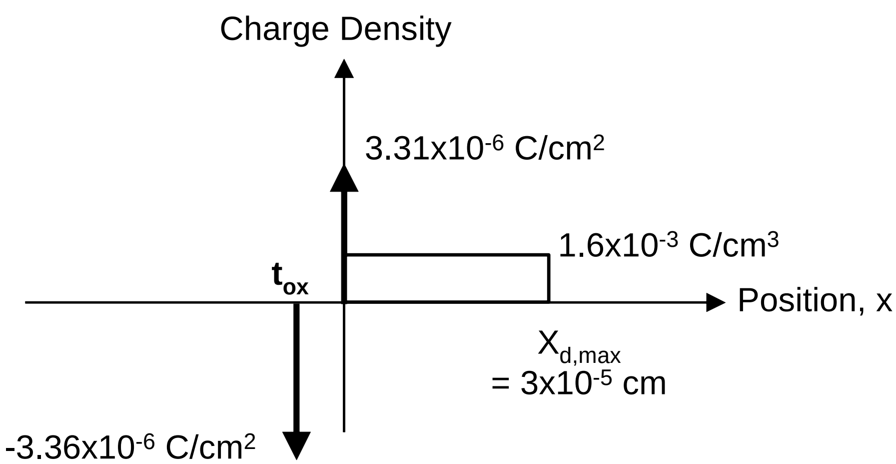
(b) $Xd\_max := \sqrt{\frac{2\cdot\varepsilon s\cdot(2\cdot\phi\_n)}{q\cdot Nd}}$ $\quad Xd\_max = 0.305\,\mu m$

$Qb\_max := q\cdot Nd\cdot Xd\_max$

$Cd := \frac{\varepsilon d}{td}$

$V\_TH := V\_FB - 2\cdot\phi\_n - \frac{Qb\_max}{Cd}$ $\quad V\_TH = 0.187\,V$

(c)



(d) Since 0V < V_TH, the PMOS is in inversion

$Qb := Qb\_max$ $\quad Qb = 4.885\times 10^{-8}\,\frac{C}{cm^2}$ $\quad \frac{Qb}{Xd\_max} = 1.6\times 10^{-3}\,\frac{C}{cm^3}$

$Qc := -(0 - V\_TH)\cdot Cd$ $\quad Qc = 3.316\times 10^{-6}\,\frac{C}{cm^2}$

$Qg := -(Qb + Qc)$ $\quad Qg = -3.365\times 10^{-6}\,\frac{C}{cm^2}$

(d) 0V is in inversion, so the capacitance is equal to the capacitance of the dielectric

$Cd = 1.771\times 10^{-5}\,\frac{F}{cm^2}$

(4) $\mu nCox := 100 \cdot \frac{\mu A}{V^2}$ $\mu pCox := 50 \cdot \frac{\mu A}{V^2}$ $\lambda n := 0.05V^{-1}$ $\lambda p := 0.01V^{-1}$

$V\_THn := 1V$ $V\_THp := -1V$ $Vdd := 5V$ $W\_over\_L := 10$

(a) $Id := 100\mu A$

$Vx := 4V$

Given

$$Id = \frac{\mu pCox}{2} \cdot W\_over\_L \cdot [(Vdd - Vx) - (|V\_THp|)]^2$$

$Vb := Find(Vx)$

$Vb = 3.368\ V$

$Vy := 2V$

Given

$$Id = \frac{\mu nCox}{2} \cdot W\_over\_L \cdot (Vy - V\_THn)^2$$

$Vg := Find(Vy)$ $Vg = 1.447\ V$

(b)

$g\_m1 := \sqrt{2 \cdot \mu pCox \cdot W\_over\_L \cdot Id}$ $g\_m1 = 3.162 \times 10^{-4} \frac{1}{\Omega}$

$r0\_1 := \frac{1}{\lambda p \cdot Id}$ $r0\_1 = 1 \times 10^{6}\ \Omega$

$g\_m2 := \sqrt{2 \cdot \mu nCox \cdot W\_over\_L \cdot Id}$ $g\_m2 = 4.472 \times 10^{-4} \frac{1}{\Omega}$

$r0\_2 := \frac{1}{\lambda n \cdot Id}$ $r0\_2 = 2 \times 10^{5}\ \Omega$

(c) $Av := -g\_m2 \cdot \left(r0\_1^{-1} + r0\_2^{-1}\right)^{-1}$ $Av = -74.536$

(d) R_in is infinity

$R\_out := \left(r0\_1^{-1} + r0\_2^{-1}\right)^{-1}$ $R\_out = 1.667 \times 10^{5}\ \Omega$

(e) Maximum output voltage is reached when M_1 is at the edge of saturation

$Vout\_max := Vb + |V\_THp|$ $Vout\_max = 4.368\ V$

Minimum output voltage is reached when M_2 is at the edge of saturation

$Vout\_min := Vg - V\_THn$ $Vout\_min = 0.447\ V$

(f) The impedance looking into M_1 becomes

$R\_L := \left(g\_m1 + r0\_1^{-1}\right)^{-1}$ $R\_L = 3.152 \times 10^{3}\ \Omega$

$Av := -g\_m2 \cdot \left(R\_L^{-1} + r0\_2^{-1}\right)^{-1}$ $Av = -1.388$

$Rout := \left(R\_L^{-1} + r0\_2^{-1}\right)^{-1}$ $Rout = 3.103 \times 10^{3}\,\Omega$

(g) $Vx := 2.5V$

Given

$$\frac{\mu pCox}{2} \cdot W\_over\_L \cdot \left[(Vdd - Vx) - \left(\left|V\_THp\right|\right)\right]^{2} \cdot \left[1 + \lambda p \cdot (Vdd - Vx)\right] = \frac{\mu nCox}{2} \cdot W\_over\_L \cdot (Vy -$$

$Vout := Find(Vx)$

$Vout = 2.518\ V$

$V\_THn)^2 \cdot (1 + \lambda n \cdot Vx)$