# Analog Integrated Circuit Design

*2nd Edition*

**Chapter 1 Solutions**

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1.1 Arsenic is an n-type dopant.

Therefore,

$$n_n = N_D = 10^{25}/m^3$$

$$P_n = \frac{n_i^2}{N_D} = \frac{\left(1.1 \times 10^{16}/m^3 \times 2^{\frac{22}{11}}\right)^2}{10^{25}/m^3} = \underline{193.6 \times 10^6/m^3}$$

$n_n > p_n$

$\therefore$ <u>the resulting material is n-type.</u>

1.2 $V_T = \frac{kT}{q} = \frac{1.38 \times 10^{-23} J/k \cdot 311k}{1.602 \times 10^{-19}} = 26.8\,mV$

The carrier concentration doubles with a 11°C Temperature increase.

$$\Phi_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$= 26.8\,mV \cdot \ln\left(\frac{10^{25} \cdot 10^{22}}{(2 \times 1.1 \times 10^{16})^2}\right)$$

$$= \underline{683\,mV}$$

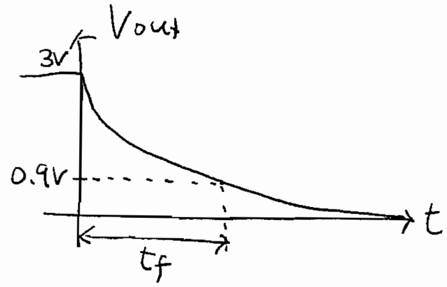
1.3 $Q^- = Q^+ \approx \left[ 2 q K_s \varepsilon_0 (\Phi_0 + V_R) N_D \right]^{\frac{1}{2}}$

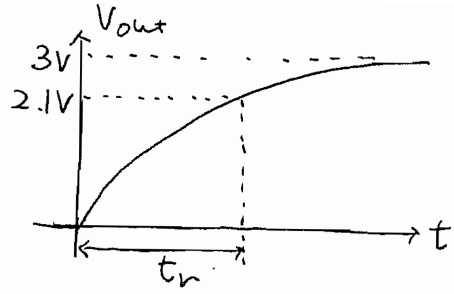
$= (2 \times 1.602 \times 10^{-19} C \cdot 11.8 \times 8.854 \times 10^{-12} F/m \; (883 mV + 3 V)$
$\times 10^{22}/m^3)^{\frac{1}{2}}$

$= 1.14 \; mC/m^2 = \underline{1.14 \; fC/\mu m^2}$

For $10 \mu m \times 10 \mu m = 100 \mu m^2$, $\underline{114 \; fC}$ would present.

1.4




For $t_f$,

$$3V \cdot e^{-\frac{t_f}{\tau_f}} = 0.9V$$

$$t_f = \tau_f \ln \frac{3V}{0.9V} \approx 1.2\tau_f$$

$$\tau_f = R C_{j\text{-}av,fall}$$

$$C_{j-av,fall} = 2C_{j0}\Phi_0 \frac{\sqrt{1+\frac{V_2}{\Phi_0}} - \sqrt{1+\frac{V_1}{\Phi_0}}}{V_2 - V_1}$$

$$= 2C_{j0}\Phi_0 \frac{\sqrt{1+\frac{3V}{0.9V}} - \sqrt{1+\frac{0.9V}{0.9V}}}{3V - 0.9V}$$

$$= 8.58fF$$

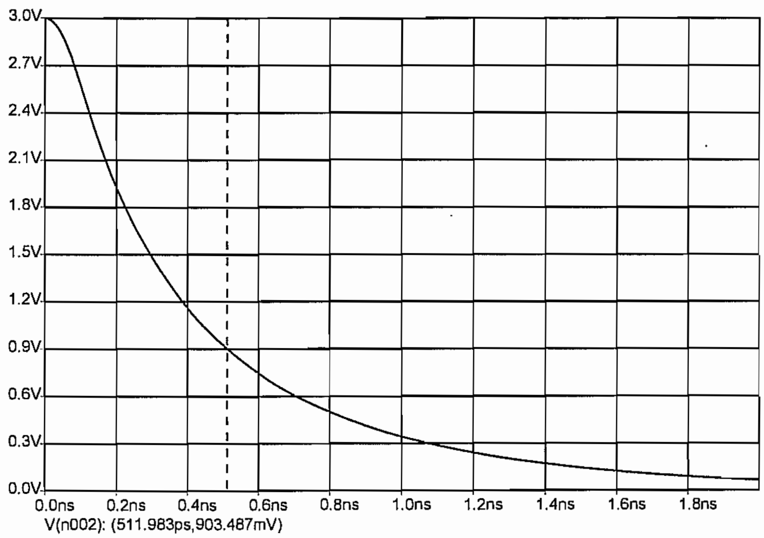
$$\tau_f = 369ps$$

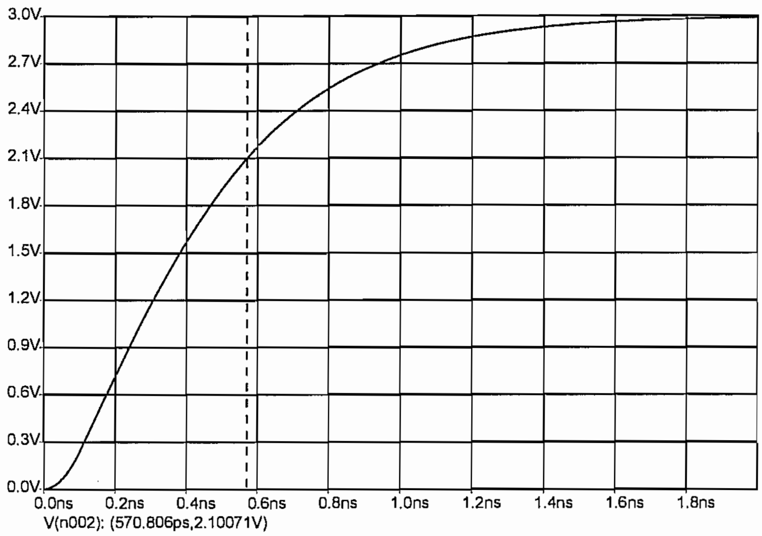
$$\underline{t_f = 443ps}$$

Similarly for $t_r$,

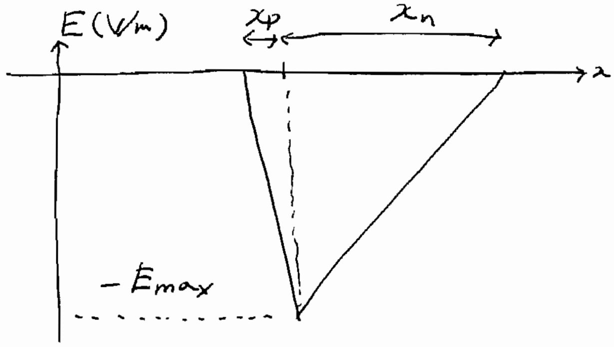
$$C_{j\_av,rise} = 10.6fF$$

$$\underline{t_f = 548ps}$$


3.0V
2.7V
2.4V
2.1V
1.8V
1.5V
1.2V
0.9V
0.6V
0.3V
0.0V
0.0ns
0.2ns
0.4ns
0.6ns
0.8ns
1.0ns
1.2ns
1.4ns
1.6ns
1.8ns
V(n002): (511.983ps,903.487mV)


3.0V
2.7V
2.4V
2.1V
1.8V
1.5V
1.2V
0.9V
0.6V
0.3V
0.0V
0.0ns
0.2ns
0.4ns
0.6ns
0.8ns
1.0ns
1.2ns
1.4ns
1.6ns
1.8ns
V(n002): (570.806ps,2.10071V)

1.5




$$\frac{E_{max}(x_p + x_n)}{2} = V_R + \Phi_0$$

$$E_{max} = \frac{2(V_R + \Phi_0)}{x_p + x_n} = \frac{2 \cdot 1.9}{0.50\times10^{-9} + 0.50\times10^{-6}}$$

$$= \underline{7.59\ \mathrm{MV/m}}$$

1.6 From 1.5,

$$E_{max} = \frac{2(V_R + \Phi_o)}{x_n + x_p} \approx \frac{2(V_R + \Phi_o)}{x_n}$$

$$= \frac{2(V_R + \Phi_o)}{\sqrt{\frac{2k_s \varepsilon_o (V_R + \Phi_o)}{qN_D}}}$$

$$= \sqrt{\frac{2qN_D}{k_s \varepsilon_o}} \cdot \sqrt{V_R + \Phi_o}$$

$$V_R = \frac{k_s \varepsilon_o E_{max}^2}{2qN_D} - \Phi_o$$

$$= \frac{11.8 \times 8.854 \times 10^{-12} \cdot (3 \times 10^7)^2}{2 \times 1.6 \times 10^{-19} \times 10^{22}} - 0.9$$

$$= \underline{28.5V}$$

1.7 For $N_A \ll N_D$,

$$C_j = \sqrt{\frac{q K_s \varepsilon_0 N_A}{2(\Phi_0 + V_R)}} = \frac{30\,fF}{40\,\mu m^2} = 750\,\mu F/m^2$$

$$N_A = \frac{2 C_j^2 (\Phi_0 + V_R)}{q K_s \varepsilon_0} = \frac{2 \cdot (750\,\mu F/m^2)(0.9V + 1V)}{1.6\times10^{-19}C \cdot 11.8 \cdot 8.854\times10^{-12} F/m}$$

$$= \underline{170 \times 10^{24}/m^3}$$

1.8 $I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{tn})V_{DS} - \frac{1}{2}V_{DS}^2\right]$ in triode

$= \mu_n C_{ox} \frac{W}{L}\left(V_{DS}^2 - \frac{1}{2}V_{DS}^2\right)$ for $V_{eff} = V_{GS} - V_{tn} = V_{DS}$.

$= \frac{1}{2}\mu_n C_{ox} \frac{W}{L} V_{DS}^2$

1.9 $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{tn})^2(1+\lambda(V_{DS}-V_{eff}))$

$$\lambda = \frac{k_{ds}}{2L\sqrt{V_{DS}-V_{eff}-\Phi_0}} \quad \text{where } k_{ds} = \sqrt{\frac{2k_s\varepsilon_0}{qN_A}}$$

$$k_{ds} = \sqrt{\frac{2\cdot 11.8\cdot 8.854\times10^{-12}}{1.6\times10^{-19}\cdot 10^{23}}} = 114.3\times10^{-9}\, m/\sqrt{V}$$

$$\lambda = \frac{114.3\times10^{-9}}{2\cdot 0.5\times10^{-6}\sqrt{0.9}} = 120.5\, mV^{-1}$$

$$I_D\Big|_{V_{DS}=V_{eff}} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{tn})^2$$

$$= \frac{1}{2}\cdot 270\times10^{-6}\cdot 10\,(1-0.45)^2$$

$$= 408.4\,\mu A$$

$$\frac{\partial I_D}{\partial V_{DS}} = \lambda\cdot\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{tn})^2$$

$$= \lambda I_D\Big|_{V_{DS}=V_{eff}} = 120.5\,mV^{-1}\cdot 408.4\,\mu A$$

$$= 49.2\,\mu A/V$$

$$\Delta V_{DS}\cdot\frac{\partial I_D}{\partial V_{DS}} = 0.3\cdot 49.2\times10^{-6} = \underline{\overset{14.8}{\cancel{1.48}}\,\mu A} = \Delta I_D$$

1.10 $\frac{\Delta V_{DS}}{r_{ds}} = \Delta I_D$

$$r_{ds} = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.5\,V}{3\,\mu A} = \underline{167\,k\Omega}$$

1.11 $\gamma = \sqrt{\dfrac{2qN_A k_s \varepsilon_0}{C_{ox}}}$

In Example 1.10, $\gamma = 0.25\sqrt{V}$ for $N_A = 5\times10^{22}/m^3$

Since $N_A = 10^{23}$ in this question, $\gamma = \sqrt{2}\cdot 0.25\sqrt{V}$

$= 0.354\sqrt{V}$.

$$\phi_F = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) = \frac{1.38\times10^{-23}\cdot 300}{1.6\times10^{-19}}\cdot\ln\left(\frac{10^{23}}{1.1\times10^{+16}}\right)$$

$= 0.415\,V$.

$$V_{tn} = V_{tn0} + \gamma\left(\sqrt{V_{SB} + |2\phi_F|} - \sqrt{|2\phi_F|}\right)$$

$$= 0.45 + \underset{0.354}{\cancel{0.415}}\left(\sqrt{1+0.829} - \sqrt{0.829}\right)$$

$= 0.606\,V$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{tn})^2\left(1 + \underbrace{\lambda(V_{DS} - V_{eff})}_{0}\right)$$

$$= \frac{1}{2}\cdot 270\times10^{-6}\cdot\frac{8}{0.6}\cdot(0.9 - 0.606)^2$$

$= 156\,\mu A$

$$g_m = \frac{2I_D}{V_{eff}} = \frac{2\cdot 156\,\mu A}{0.9 - 0.606} = \underline{1.06\,mA/V}$$

$$k_{ds} = \sqrt{\frac{2k_s\varepsilon_0}{qN_A}} = \sqrt{\frac{2\cdot 11.8\times 8.854\times10^{-12}}{1.6\times10^{-19}\cdot 10^{23}}}$$

$= 114\times10^{-9}\,m/\sqrt{V}$

$$\lambda = \frac{k_{ds}}{2L\sqrt{V_{DS} - V_{eff} + \Phi_0}} = \frac{114\times10^{-9}}{2\cdot 0.6\times10^{-6}\sqrt{0.9}}$$

$= 0.100$

$$r_{ds} = \frac{1}{\lambda I_D} = \underline{64.0\,k\Omega}$$

$$g_s = \frac{\gamma g_m}{2\sqrt{V_{SB} + |2\phi_F|}} = \frac{0.354 \cdot 1.06 \times 10^{-3}}{2 \cdot \sqrt{1 + 0.83}} = \underline{617 \mu A/V}$$

1.12 $C_{j0} = \sqrt{\frac{q k_s \varepsilon_0}{2\Phi_0} \cdot \frac{N_D N_A}{N_D + N_A}}$

$= \sqrt{\frac{1.6\times10^{-19} \cdot 11.8 \times 8.854\times10^{-12}}{2 \cdot 0.9} \cdot \frac{10^{26} \cdot 10^{23}}{10^{26} + 10^{23}}}$

$= 963.2 \mu F/m^2$

Since $V_{sb} = V_{db} = 0V$,

$C_{sb} = A_s \cdot C_{j0} = 15\times10^{-12} \cdot 963.2\times10^{-6}$

$= \underline{14.4 fF}$

$C_{db} = A_d \cdot C_{j0} = 15\times10^{-12} \cdot 963.2\times10^{-6}$

$= \underline{14.4 fF}$.

Since $V_{ds} = 0V$, the transistor is in triode assuming $V_{gs} > V_{tn}$. Then

$C_{gs} = \frac{1}{2} WLC_{ox} + WL_{ov}C_{ox} = C_{gd}$

$= \frac{1}{2} \cdot 7.5\times10^{-12} \cdot 4.5\times10^{-3} + 15\times10^{-6} \cdot 200\times10^{-12}$

$= \underline{19.9 fF}$

1.13 Ignoring the body effect, the amount of charge injection is

$$\Delta Q = \frac{(V_{GS} - V_{tn0}) WL C_{ox}}{2} = (1.8V - 1.0V - 0.45V) \cdot 4\mu m \cdot 0.2\mu m \cdot 8.5 fF/\mu m^2 / 2$$

$$= 1.19 \times 10^{-15} \ C$$

$$\Delta V = \frac{\Delta Q}{C_L} = 1.19 \ mV$$

Therefore, $V_o = 1V - \Delta V = \underline{999 \ mV}$

1.14 For $V_{in}$ $0.2V \longrightarrow 0.4V$,

$$r_{on}\Big|_{V_{DS}=0.2V} = \frac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{th}-V_{DS})}$$

$$= \frac{1}{270\times10^{-6}\cdot\frac{4}{0.2}(1.8-0.4-0.45-0.2)}$$

$$= 247\Omega$$

$$r_{on}\Big|_{V_{DS}=\cancel{0.2}\ 0V} = \frac{1}{270\times10^{-6}\cdot\frac{4}{0.2}(1.8-0.4-0.45)}$$

$$= 194\Omega$$

$$r_{on\text{-}ave} = 221\Omega$$

$$1-e^{\frac{t_r}{r_{on\text{-}ave}\cdot C_L}} = 0.99$$

$$t_r = 4.61\, r_{on\text{-}ave}\cdot C_L = 4.61\times221\times10^{-12}$$

$$= \underline{1.02\,ns}$$

For $V_{in}$ $0.6V \longrightarrow 0.8V$

$$r_{on}\Big|_{V_{DS}=0.2V} = 529\Omega$$

$$r_{on}\Big|_{V_{DS}=0.0V} = 337\Omega$$

$$r_{on\text{-}ave} = 433\Omega$$

$$t_r = 4.61\cdot r_{on\text{-}ave}\cdot C_L = \underline{2.00\,ns}$$

1.15 $\phi_F = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) = \frac{1.38\times10^{-23}\cdot300}{1.6\times10^{-19}}\ln\left(\frac{10^{23}}{1.1\times10^{16}}\right)$

$= 0.415\text{ V}$

$\gamma = \frac{\sqrt{2qN_A k_s \varepsilon_0}}{C_{ox}} = \frac{\sqrt{2\times1.6\times10^{-19}\cdot10^{23}\cdot11.8\times8.854\times10^{-12}}}{8.5\text{ mF/m}^2}$

$= 0.215\ \sqrt{V}$

$V_{tn} = V_{tn0} + \gamma\left(\sqrt{V_{SB}+2\phi_F} - \sqrt{2\phi_F}\right)$

$V_{tn}|_{V_{SB}=0.4V} = 0.45 + 0.215\left(\sqrt{0.4+0.83} - \sqrt{0.83}\right)$

$= 0.493\text{ V}$

$V_{tn}|_{V_{SB}=0.8V} = 0.529\text{ V}$

For $V_{in}$ $0.2V \rightarrow 0.4V$

$r_{on}|_{V_{DS}=0.2V} = \frac{1}{270\times10^{-6}\cdot\frac{4}{0.2}(1.8-0.4-0.493-0.2)}$

$= 262\,\Omega$

$r_{on}|_{V_{DS}=0V} = \frac{1}{270\times10^{-6}\cdot\frac{4}{0.2}(1.8-0.4-0.493)}$

$= 204\,\Omega$

$r_{on\text{-}ave} = 233\,\Omega$

$t_r = 4.61\, r_{on\text{-}ave}\cdot C_L = \underline{1.07\text{ns}}$

For $V_{in}$ $0.6V \rightarrow 0.8V$

$r_{on}|_{V_{DS}=0.2V} = 683\,\Omega$

$r_{on}|_{V_{DS}=0V} = 393\,\Omega$

$r_{on\text{-}ave} = 538\,\Omega$

$t_r = 4.61\, r_{on\text{-}ave}\cdot C_L = \underline{2.48\text{ns}}$

1.16

| Node | WL | WL Cox | ΔQ |
|---|---|---|---|
| 0.8μm | 12.8μm² | 23.04fF | 2.3 fC |
| 0.35μm | 2.45μm² | 11.03fF | 1.1 fC |
| 0.18μm | 0.648μm² | 5.508fF | 0.55fC |
| 45nm | 0.0405μm² | 1.01fF | 0.10fC |

$$\frac{W}{L} = 20 \Rightarrow WL = 20L^2$$

1.17 $r_{ds} \approx \frac{1}{\lambda I_D}$

$$\lambda = \frac{0.16\mu m/V}{0.4\mu m} = 0.4/V$$

$$g_m = \frac{2I_D}{V_{eff}}$$

$$A_i = g_m r_{ds} = \frac{2I_D}{V_{eff}} \cdot \frac{1}{\lambda I_D} = \frac{2}{\lambda V_{eff}}$$

$$V_{eff} = \frac{2}{\lambda A_i} = \frac{2}{0.4 \cdot 10} = 0.5V$$

$$g_m = \mu_n C_{ox} \frac{W}{L} V_{eff}$$

$$W = \frac{g_m \cdot L}{\mu_n C_{ox} V_{eff}} = \frac{0.5\times10^{-3} \cdot 0.4\times10^{-6}}{190\times10^{-6} \cdot 0.5}$$

$$= \underline{2.11\mu m}$$

1.18 $V_{eff} = \frac{2}{A_i \cdot \lambda}$ from 1.17.

$$\lambda = \frac{0.08}{0.2} = 0.4/V$$

$$V_{eff} = \frac{2}{10 \cdot 0.4} = 0.5\ V.$$

$$W = \frac{g_m \cdot L}{\mu_n C_{ox} \cdot V_{eff}}$$ from 1.17

$$= \frac{0.5 \times 10^{-3} \cdot 0.2 \times 10^{-6}}{270 \times 10^{-6} \cdot 0.5}$$

$$= \underline{0.74\,\mu m}$$

1.19

$$r_{ds} \approx \frac{1}{\lambda I_D} = \frac{L}{\lambda \cdot L \cdot I_D}$$

$$L = \lambda \cdot L \cdot I_D \cdot r_{ds}$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{gs}-V_{tn})^2$$

$$W = \frac{2 I_D \cdot L}{\mu_n C_{ox}(V_{gs}-V_{TH})^2}$$

For $0.35\mu m$,

$$L = 0.16\times10^{-6} \cdot 0.2\times10^{-3} \cdot 20\times10^{3}$$

$$= \underline{0.64\mu m}$$

$$W = \frac{2 \cdot 0.2\times10^{-3} \cdot 0.64\times10^{-6}}{190\times10^{-6} \cdot (0.25)^2}$$

$$= \underline{21.6\mu m}$$

For $0.18\mu m$

$$L = 0.08 \cdot 0.2\times10^{-3} \times 20\times10^{3} \times10^{-6}$$

$$= \underline{0.32\mu m}$$

$$W = \frac{2 \cdot 0.2\times10^{-3} \cdot 0.32\times10^{-6}}{270\times10^{-6} \cdot (0.25)^2}$$

$$= \underline{7.59\ \mu m}$$

1.20 Assuming the minimum L of 0.35μm,

$$\lambda = \frac{\lambda \cdot L}{L} = \frac{0.16}{0.35} = 0.457/V$$

$$r_{ds} = \frac{1}{\lambda \cdot I_D} = \frac{1}{0.35 \times 10^{-3} \cdot 0.457} = 6.25\,k\Omega$$

$$A_i = g_m r_{ds}$$

$$g_m = \frac{A_i}{r_{ds}} = 5.6\,mA/V.$$

$$g_m = \sqrt{2 I_D \mu_n C_{ox} \frac{W}{L}}$$

$$W = \frac{g_m^2 \cdot L}{2 I_D \mu_n C_{ox}} = \underline{82.5\,\mu m}$$

1.21 $g_m = \sqrt{2 I_D \mu_n C_{ox} \frac{W}{L}}$

$$\frac{W}{L} = \frac{g_m^2}{2 I_D \mu_n C_{ox}} = \frac{(2.2\times10^{-3})^2}{2\cdot 0.25\times10^{-3}\times 270\times10^{-6}}$$

$$= \underline{35.9}$$

1.22 $f_{3dB} = \dfrac{1}{2\pi r_{on} C_L}$

$$r_{on} = \frac{1}{2\pi C_L f_{3dB}} = \frac{1}{2\pi \cdot 1\times10^{-12} \times 250\times10^{6}}$$

$$= 637\Omega.$$

$$r_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{tn}-V_{DS})}$$

$$\approx \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{tn})} \quad \text{for a small } V_{DS}.$$

$$W = \frac{L}{\mu_n C_{ox}(V_{GS}-V_{tn}) r_{on}}$$

$$= \frac{0.35\times10^{-6}}{190\times10^{-6}(1.8-0.3-0.57)\cdot 637}$$

$$= \underline{3.11\,\mu m}$$

$$WLC_{ox} = 3.11\,\mu m \cdot 0.35\,\mu m \cdot 4.5\,fF/\mu m^2$$

$$= \underline{4.90\,fF}$$

If $V_{tn}$ increases by 70 mV,

$$W = \frac{0.35\times10^{-6}}{190\times10^{-6}(1.8-0.3-0.64)\cdot 637}$$

$$= \underline{3.36\,\mu m}$$

$$WLC_{ox} = 3.36\,\mu m \cdot 0.35\,\mu m \cdot 4.5\,fF/\mu m^2$$

$$= \underline{5.30\,fF}$$

1.23 From 1.22,

$$W = \frac{L}{\mu_n C_{ox} (V_{GS} - V_{tn}) r_{on}}$$

$$= \frac{0.18\,\mu m}{270 \times 10^{-6} (1.8 - 0.45 - 0.3) \cdot 637}$$

$$= \underline{0.997\,\mu m}$$

$$W L C_{ox} = 0.997\,\mu m \cdot 0.18\,\mu m \cdot 8.5\,fF/\mu m^2$$

$$= \underline{1.53\,fF}$$

If $V_{tn}$ increases by 70mV,

$$W = \frac{0.18 \times 10^{-6}}{270 \times 10^{-6} (1.8 - 0.3 - 0.52) \cdot 637}$$

$$= \underline{1.07\,\mu m}$$

$$W L C_{ox} = 1.07\,\mu m \cdot 0.18\,\mu m \cdot 8.5\,fF/\mu m^2$$

$$= \underline{1.63\,fF}$$

1.24 In strong inversion with very high $V_{GS}$,

$$I_D \approx \frac{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{eff}^2}{\theta V_{eff}} = \frac{1}{2}\frac{1}{\theta}\mu_n C_{ox}\frac{W}{L}V_{eff}$$

$$\log I_D = \log\left(\frac{1}{2}\frac{1}{\theta}\mu_n C_{ox}\frac{W}{L}\right) + \log V_{eff}$$

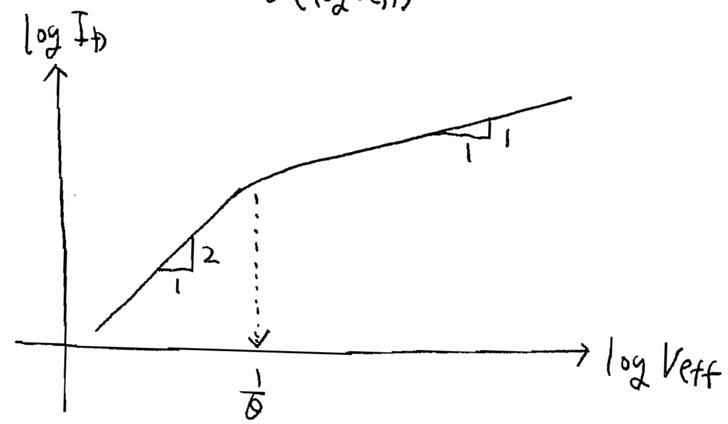
Therefore, $\underline{\dfrac{\partial(\log I_D)}{\partial(\log V_{eff})} = 1}$ in strong inversion.

Without mobility degradation,

$$I_D \approx \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{eff}^2$$

$$\log I_D = \log\left(\frac{1}{2}\mu_n C_{ox}\frac{W}{L}\right) + 2\log V_{eff}$$

Therefore, $\dfrac{\partial(\log I_D)}{\partial(\log V_{eff})} = 2$ without mobility degradation.




At $V_{eff} = \frac{1}{\theta}$, $\underline{1 < \frac{\partial I_D}{\partial V_{eff}} < 2}$.

1.25 In weak inversion,

$$g_m = \frac{q I_D}{nkT}$$

$$r_{ds} = \frac{1}{\lambda I_D}$$

$$A_i = g_m \cdot r_{ds} = \frac{q}{\lambda n k T}$$

In active mode,

$$g_m = \frac{2 I_D}{V_{eff}}$$

$$r_o = \frac{1}{\lambda I_D}$$

$$A_i = g_m \cdot r_{ds} = \frac{2}{\lambda V_{eff}}$$

In strong mobility degradation,

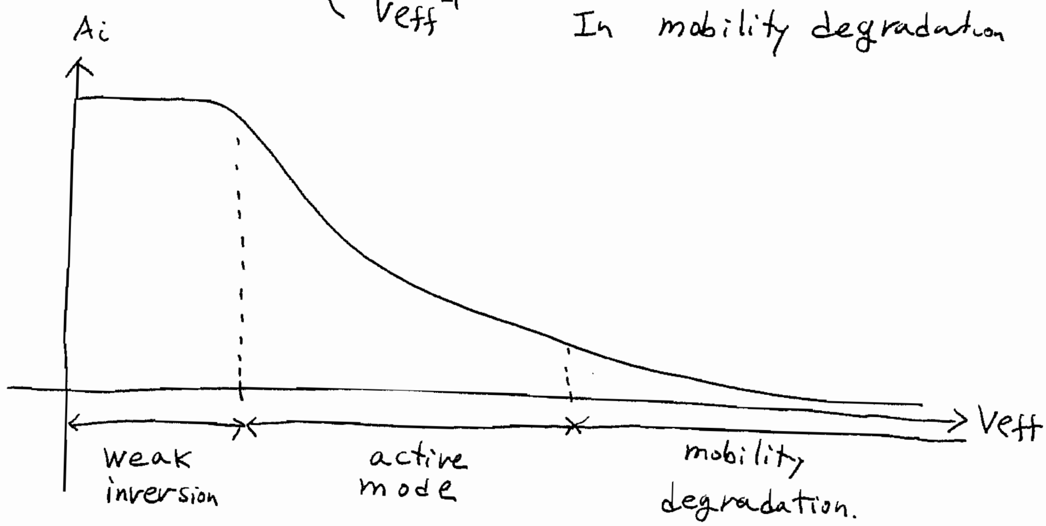
$$g_m = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \frac{1}{\theta}$$

$$r_{ds} = \frac{1}{\lambda I_D} = \frac{1}{\lambda \frac{1}{2} \mu_n C_{ox} \frac{W}{L} V_{eff} \frac{1}{\theta}}$$

$$A_i = g_m \cdot r_{ds} = \frac{1}{\lambda V_{eff}}$$

To summarize,

$$A_i \propto \begin{cases} 1 & \text{In weak inversion} \\ V_{eff}^{-1} & \text{In active mode} \\ V_{eff}^{-1} & \text{In mobility degradation} \end{cases}$$



1.26 $$f_t = \frac{g_m}{2\pi(C_{gd}+C_{gs})} \approx \frac{g_m}{2\pi C_{gs}}$$

$$= \frac{\frac{qI_D}{nkT}}{2\pi\left(\frac{2}{3}WLC_{ox}\right)} = \frac{\frac{3q}{nkT}\cdot(n-1)\mu_n C_{ox}\frac{W}{L}\left(\frac{kT}{q}\right)^2 e^{qV_{eff}/nkT}}{4\pi WLC_{ox}}$$

$$= \frac{3\frac{n-1}{n}\frac{kT}{q}e^{\frac{qV_{eff}}{nkT}}}{4\pi L^2} \quad \text{in weak inversion}$$

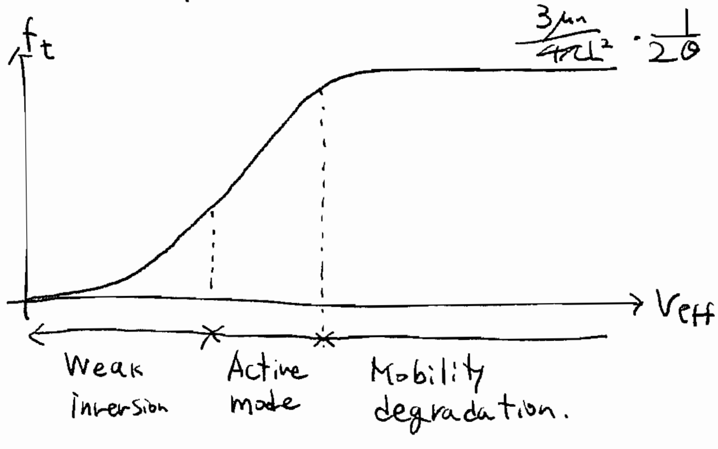
Under mobility degradation,

$$f_t = \frac{g_m}{2\pi C_{gs}} = \frac{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}\frac{1}{\theta}}{2\pi\cdot\frac{2}{3}WLC_{ox}}$$

$$= \frac{3\mu_n}{4\pi L^2}\cdot\frac{1}{2\theta}$$

In active mode,

$$f_t = \frac{3\mu_n V_{eff}}{4\pi L^2} \quad \text{as shown in (1.117).}$$



1.28 a) $30\mu m \rightarrow I_D \propto W$ if other parameters are the same

b) $10\mu m \rightarrow g_m \propto W$ if other parameters are the same

c) $3\mu m \rightarrow r_{ds} \propto \frac{1}{W}$ if other parameters are the same.

1.29 $\dfrac{4k\Omega}{1k\Omega/sq} \cdot \dfrac{1\mu m^2}{sq} \cdot \dfrac{0.4fF}{1\mu m^2} = \cancel{1.4}\ \underline{1.6fF}$

$\tau = 4k\Omega \cdot 1.6fF = 6.4ps$

$\dfrac{4k\Omega}{1k\Omega/sq} \cdot \dfrac{0.16\mu m^2}{sq} \cdot \dfrac{0.4fF}{1\mu m^2} = \underline{0.26fF}$

$\tau = 4k\Omega \cdot 0.26fF \cdot = 1.04ps$

The time constants are a lot smaller than that of Example 1.20.

1.30 $C_{j0} = \sqrt{\frac{q k_s \varepsilon_0}{2\Phi_0} \cdot \frac{N_A N_D}{N_A + N_D}}$

$= \sqrt{\frac{1.6\times10^{-19} \cdot 11.8\times8.854\times10^{-12}}{2\cdot 0.9} \cdot \frac{10^{23}\cdot10^{26}}{10^{23}+10^{26}}}$

$= 963.2\,\mu F/m^2$

If we assume $0.3\,pF = A \cdot C_{j0}$,

$A = 311.5\,\mu m^2$

For 0.2pF, we need $\frac{2}{3} = \frac{1}{\sqrt{1+\frac{V_R}{\Phi_0}}}$

$\left(\frac{2}{3}\right)^2 = \frac{1}{1+\frac{V_R}{\Phi}}$

$V_R = 1.125\,V.$

$\therefore$ $\cancel{1.125V}$ $0V < V_R < 1.125V$ with $A = 311.5\,\mu m^2$

1.31 Parallel-plate cap : $\frac{1pF}{7fF/\mu m^2} = \underline{143\,\mu m^2}$

Sidewall cap : $\frac{1pF}{10fF/\mu m^2} = \underline{100\,\mu m^2}$

MOS cap : $\frac{1pF}{25fF/\mu m^2} = \underline{40\,\mu m^2}$

1.32 $C_{MOS(ON)} = 2WL_{ov}C_{ox} + WLC_{ox}$

$C_{MOS(OFF)} = 2WL_{ov}C_{ox}$

$$\frac{C_{MOS(ON)}}{C_{MOS(OFF)}} = \frac{2WL_{ov}C_{ox} + WLC_{ox}}{2WL_{ov}C_{ox}}$$

$$= 1 + \frac{LC_{ox}}{2L_{ov}C_{ox}}$$

$$= 1 + \frac{0.18\mu m \cdot 8.5fF/\mu m^2}{2 \cdot 0.35fF/\mu m}$$

$$= 3.19$$

219% change from minimum to maximum