HW 7 Solutions

17.2

(a)

$$\phi_F = \frac{kT}{q}\ln(N_A/n_i) = 0.0259\ln(10^{15}/10^{10}) = 0.298\text{V}$$

$$V_T = 2\phi_F + \frac{K_S x_o}{K_O}\sqrt{\frac{4qN_A}{K_S\varepsilon_0}\phi_F} \qquad \text{...(17.1a)}$$

$$= (2)(0.298) + \frac{(11.8)(5\times10^{-6})}{(3.9)}\left[\frac{(4)(1.6\times10^{-19})(10^{15})(0.298)}{(11.8)(8.85\times10^{-14})}\right]^{1/2}$$

$$\mathbf{V_T = 0.800\ V}$$

(b) In the square-law theory

$$I_{Dsat} = \frac{Z\bar{\mu}_n C_o}{2L}(V_G - V_T)^2 \qquad \text{...(17.22)}$$

$$C_o = \frac{K_O\varepsilon_0}{x_o} = \frac{(3.9)(8.85\times10^{-14})}{(5\times10^{-6})} = 6.90\times10^{-8}\ \text{F/cm}^2$$

$$I_{Dsat} = \frac{(5\times10^{-3})(800)(6.9\times10^{-8})(2-0.8)^2}{(2)(5\times10^{-4})} = \mathbf{0.397mA}$$

(c) In the bulk-charge theory we must first determine V_{Dsat} using Eq.(17.29). We know ϕ_F and V_T from part (a), but must compute V_W before substituting into the V_{Dsat} expression.

$$W_T = \left[\frac{2K_S\varepsilon_0}{qN_A}(2\phi_F)\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(2)(0.298)}{(1.6\times10^{-19})(10^{15})}\right]^{1/2} = 0.882\mu\text{m}$$

$$V_W \equiv \frac{qN_A W_T}{C_o} = \frac{(1.6\times10^{-19})(10^{15})(8.82\times10^{-5})}{(6.90\times10^{-8})} = 0.205\text{V}$$

Noting that $V_G - V_T = 1.20$V, substituting into Eq.(17.29) then gives

$$V_{Dsat} = 1.20 - 0.205\left\{\left[\frac{(1.20)}{(2)(0.298)} + \left(1 + \frac{(0.205)}{(4)(0.298)}\right)^2\right]^{1/2} - \left[1 + \frac{(0.205)}{(4)(0.298)}\right]\right\}$$

or

$$V_{Dsat} = 1.06\text{V} \qquad \text{...smaller than } V_{Dsat} \text{ of square-law theory as expected}$$

Now

$$\frac{Z\bar{\mu}_n C_o}{L} = \frac{(5\times10^{-3})(800)(6.90\times10^{-8})}{(5\times10^{-4})} = 5.52\times10^{-4} \text{ amps/V}^2$$

Finally, substituting into Eq.(17.28) gives I_{Dsat} if $V_D = V_{Dsat}$. Thus

$$I_{Dsat} = (5.52\times10^{-4})\left\{(1.20)(1.06) - \frac{(1.06)^2}{2} - \frac{4}{3}(0.205)(0.298)\left[\left(1+\frac{(1.06)}{(2)(0.298)}\right)^{3/2} - \left(1+\frac{(3)(1.06)}{(4)(0.298)}\right)\right]\right\}$$

I_{Dsat} = **0.349mA** ⇐bulk charge result (smaller than the square-law result as expected)

(d) Clearly here the device is biased below pinch-off. From Table 17.1 we note that both the square-law and bulk-charge theories reduce to the same result if $V_D = 0$.

$$g_d = \frac{Z\bar{\mu}_n C_o}{L}(V_G - V_T) = (5.52\times10^{-4})(2-0.8) = \mathbf{0.662mS}$$

(e) In the square-law theory, $V_{Dsat} = V_G - V_T$. Thus $V_{Dsat} = 1.20$V and $V_D = 2$V. Since $V_D > V_{Dsat}$, the device is saturation (above-pinch-off) biased, and from Table 17.1

$$g_m = \frac{Z\bar{\mu}_n C_o}{L}(V_G - V_T) = \mathbf{0.662mS} \qquad \text{...same as } g_d \text{ of part (d)}$$

(f) In part (c) we calculated the bulk-charge $V_{Dsat} = 1.06$V. Since $V_D > V_{Dsat}$, the device is above-pinch-off biased, and from Table 17.1

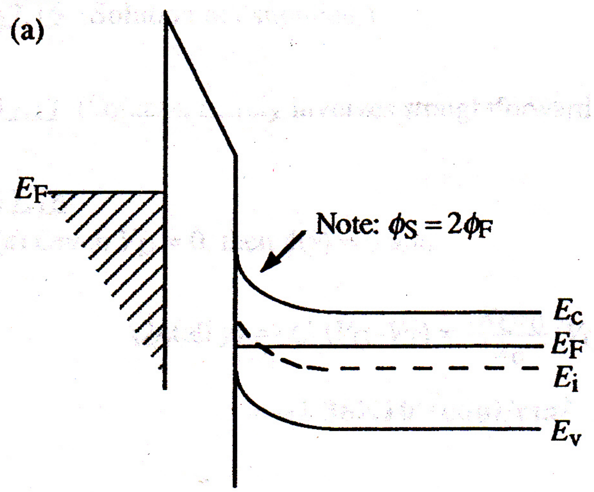
$$g_m = \frac{Z\bar{\mu}_n C_o}{L} V_{Dsat} = (5.52\times10^{-4})(1.06) = \mathbf{0.585mS}$$

(g) For the applied $V_G = 2$V, $V_{Dsat} = 1.20$V in the square-law theory and $V_{Dsat} = 1.06$V in the bulk-charge theory. Since in either case $V_D < V_{Dsat}$, we can utilize the second form of Eq.(17.37).

$$f_{max} = \frac{\bar{\mu}_n V_D}{2\pi L^2} = \frac{(800)(1)}{(2\pi)(5\times10^{-4})^2} = \mathbf{509MHz}$$

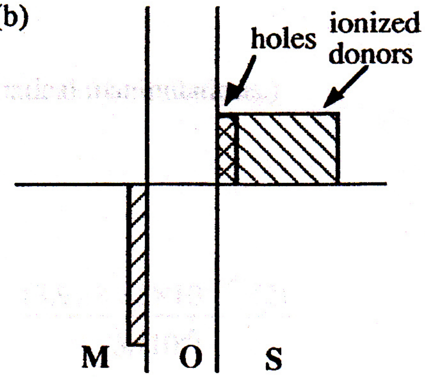
17.3

(a)



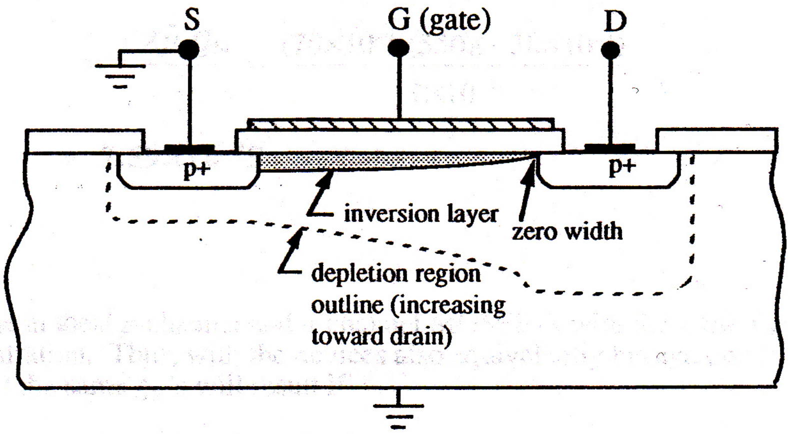
E_F
Note: $\phi_S = 2\phi_F$
E_c
E_F
E_i
E_v

(b)



holes
ionized donors
M
O
S

(c)



S
G (gate)
D
p+
p+
inversion layer
zero width
depletion region outline (increasing toward drain)

17.16 (Solution not supplied.)

17.17 (Solution merely involves straightforward mathematical manipulations.)

17.18

(a) Given $V_D = 0$, then $\phi(y) = 0$ and

$$Q_N(\text{all } y) = -C_o(V_G - V_T) = \frac{K_O\varepsilon_0}{x_o}(V_G - V_T) = \frac{(3.9)(8.85\times10^{-14})(2)}{5\times10^{-6}}$$

$$= \mathbf{-1.38\times10^{-7} coul/cm^2}$$

(b) $$g_{d\,|V_D=0} = \frac{Z\bar{\mu}_n C_o}{L}(V_G - V_T) \quad \text{...making use of Table 17.1}$$

$$= -\frac{Z\bar{\mu}_n Q_N}{L} = \frac{(70\times10^{-4})(550)(1.38\times10^{-7})}{7\times10^{-4}}$$

$$= \mathbf{7.59\times10^{-4} S}$$

17.19

$|V_T|$ is the same in ideal p-channel and n-channel MOSFETs with the same x_o and bulk doping concentration. Thus, with the devices also equivalently biased, one concludes from Table 17.1 that the same g_m's will result if

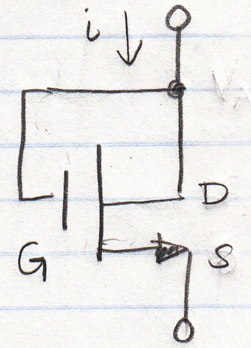
$$\frac{Z_p}{L_p}\bar{\mu}_p = \frac{Z_n}{L_n}\bar{\mu}_n$$

where the subscripts indicate the channel type. This same conclusion is reached whether one uses the square-law theory or bulk-charge theory and whether the devices are biased below or above pinch-off.

Next, examining the first form of Eq.(17.37), we again quite generally conclude that C_O(p-channel) must equal C_O(n-channel) for the f_{max} values to be the same. Since $C_O = K_O\varepsilon_0 ZL/x_o$, we therefore require

$$Z_pL_p = Z_nL_n$$

4. Diode connected load



$$I_D = \frac{1}{2} \mu \frac{W}{L} C_o (V_{GS} - V_T)^2$$

$$r = \frac{\partial V_{DS}}{\partial I_D}$$

$$\frac{\partial I_D}{\partial I_D} = \frac{1}{2} \mu \frac{W}{L} C_o \, 2(V_{GS} - V_T)\left(\frac{\partial V_{DS}}{\partial I_D}\right)$$

$\partial \rightarrow 1$

$$1 = \frac{1}{2} \mu \frac{W}{L} C_o \, 2(V_{GS} - V_T)$$

$$\frac{V_{DS}}{I_D} = \frac{1}{\underbrace{\frac{1}{2} \mu \frac{W}{L} C_o \, 2(V_{GS} - V_T)}_{g_m}}$$

$$\boxed{r = \frac{1}{g_m}}$$