1.

(a) $I_D = \frac{k_p'}{2}\cdot\frac{W}{L}\left[2(V_{SG}+V_T)V_{SD}-V_{SD}^2\right]$

$$=\left(\frac{0.10}{2}\right)(15)\left[2(0.8-0.4)(0.25)-(0.25)^2\right]$$

$I_D = 0.103$ mA

(b) $I_D = \frac{k_p'}{2}\cdot\frac{W}{L}(V_{SG}+V_T)^2$

$$=\left(\frac{0.10}{2}\right)(15)(0.8-0.4)^2$$

$= 0.12$ mA

(c) $I_D = \frac{k_p'}{2}\cdot\frac{W}{L}(V_{SG}+V_T)^2$

$$=\left(\frac{0.10}{2}\right)(15)(1.2-0.4)^2$$

$= 0.48$ mA

(d) Same as (c), $I_D = 0.48$ mA

2.

(a) Assume biased in saturation region

$$I_D = \frac{k_p'}{2}\cdot\frac{W}{L}(V_{SG}+V_T)^2$$

$$0.10 = \left(\frac{0.12}{2}\right)(20)(0+V_T)^2$$

$\Rightarrow V_T = +0.289$ V

Note: $V_{SD} = 1.0\text{ V} > V_{SG}+V_T = 0+0.289\text{ V}$

So the transistor is biased in the saturation region.

(b) $I_D = \left(\frac{0.12}{2}\right)(20)(0.4+0.289)^2$

$= 0.570$ mA

(c) $I_D = \left(\frac{0.12}{2}\right)(20)\left[2(0.6+0.289)(0.15)-(0.15)^2\right]$

or

$I_D = 0.293$ mA

3.

(a) n^+ poly-to-p-type $\Rightarrow \phi_{ms} = -1.0\text{ V}$

$$\phi_{fp} = (0.0259)\ln\left(\frac{10^{15}}{1.5\times10^{10}}\right) = 0.288\text{ V}$$

also

$$x_{dT} = \left[\frac{4\in_s \phi_{fp}}{eN_a}\right]^{1/2}$$

$$= \left[\frac{4(11.7)(8.85\times10^{-14})(0.288)}{(1.6\times10^{-19})(10^{15})}\right]^{1/2}$$

or

$$x_{dT} = 0.863\times10^{-4}\text{ cm}$$

Now

$$|Q'_{SD}(\max)| = (1.6\times10^{-19})(10^{15})(0.863\times10^{-4})$$

or

$$|Q'_{SD}(\max)| = 1.38\times10^{-8}\text{ C/cm}^2$$

Also

$$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{(3.9)(8.85\times10^{-14})}{400\times10^{-8}}$$

or

$$C_{ox} = 8.63\times10^{-8}\text{ F/cm}^2$$

We find

$$Q'_{ss} = (1.6\times10^{-19})(5\times10^{10}) = 8\times10^{-9}\text{ C/cm}^2$$

Then

$$V_T = \frac{|Q'_{SD}(\max)| - Q'_{ss}}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$

$$= \left(\frac{1.38\times10^{-8} - 8\times10^{-9}}{8.63\times10^{-8}}\right) - 1.0 + 2(0.288)$$

or

$$V_T = -0.357\text{ V}$$

(b) For NMOS, apply V_{SB} and V_T shifts in a positive direction, so for $V_T = 0$, we want $\Delta V_T = +0.357\text{ V}$.

So

$$\Delta V_T = \frac{\sqrt{2e\in_s N_a}}{C_{ox}}\left[\sqrt{2\phi_{fp} + V_{SB}} - \sqrt{2\phi_{fp}}\right]$$

or

$$+0.357 = \frac{\sqrt{2(1.6\times10^{-19})(11.7)(8.85\times10^{-14})(10^{15})}}{8.63\times10^{-8}} \times\left[\sqrt{2(0.288)+V_{SB}} - \sqrt{2(0.288)}\right]$$

or

$$0.357 = 0.211\left[\sqrt{0.576+V_{SB}} - \sqrt{0.576}\right]$$

which yields

$$V_{SB} = 5.43\text{ V}$$

4.

(a)

$$g_m = \frac{W\mu_n C_{ox}}{L}(V_{GS} - V_T)$$

$$= \frac{W\mu_n \in_{ox}}{Lt_{ox}}(V_{GS} - V_T)$$

$$= \frac{(10)(400)(3.9)(8.85\times10^{-14})}{475\times10^{-8}}(5 - 0.65)$$

or

$$g_m = 1.26\text{ mS}$$

Now

$$g'_m = \frac{g_m}{1 + g_m r_s} \Rightarrow \frac{g'_m}{g_m} = 0.8 = \frac{1}{1 + g_m r_s}$$

which yields

$$r_s = \frac{1}{g_m}\left(\frac{1}{0.8} - 1\right) = \frac{1}{1.26}\left(\frac{1}{0.8} - 1\right)$$

or

$$r_s = 0.198\text{ k}\Omega$$

(b) For $V_{GS} = 3\text{ V}$, $g_m = 0.683\text{ mS}$

Then

$$g'_m = \frac{0.683}{1 + (0.683)(0.198)} = 0.602\text{ mS}$$

or

$$\frac{g'_m}{g_m} = \frac{0.602}{0.683} = 0.88$$

which is a 12% reduction.

5.

(a)

$$I_D = 10^{-15} \exp\left(\frac{V_{GS}}{(2.1)V_t}\right)$$

For $V_{GS} = 0.5\,\text{V}$,

$$I_D = 10^{-15} \exp\left[\frac{0.5}{(2.1)(0.0259)}\right] \Rightarrow$$

$$I_D = 9.83 \times 10^{-12}\,\text{A}$$

For $V_{GS} = 0.7\,\text{V}$,

$$I_D = 3.88 \times 10^{-10}\,\text{A}$$

For $V_{GS} = 0.9\,\text{V}$,

$$I_D = 1.54 \times 10^{-8}\,\text{A}$$

Then the total current is:

$$I_T = I_D\left(10^6\right)$$

For $V_{GS} = 0.5\,\text{V}$, $I_T = 9.83\,\mu\text{A}$

For $V_{GS} = 0.7\,\text{V}$, $I_T = 0.388\,\text{mA}$

For $V_{GS} = 0.9\,\text{V}$, $I_T = 15.4\,\text{mA}$

(b)

Power: $P = I_T \cdot V_{DD}$

Then

For $V_{GS} = 0.5\,\text{V}$, $P = 49.2\,\mu\text{W}$

For $V_{GS} = 0.7\,\text{V}$, $P = 1.94\,\text{mW}$

For $V_{GS} = 0.9\,\text{V}$, $P = 77\,\text{mW}$

6.

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.85\times10^{-14})}{120\times10^{-8}}$$
$$= 2.876\times10^{-7}\ \text{F/cm}^2$$
$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$$
$$= -0.5 - \frac{(4\times10^{10})(1.6\times10^{-19})}{2.876\times10^{-7}}$$
$$V_{FB} = -0.5223\ \text{V}$$

Now

$$V_T = \frac{|Q'_{SD}(\max)|}{C_{ox}} + V_{FB} + 2\phi_{fp}$$

We find

$$\phi_{fp} = (0.0259)\ln\left(\frac{4\times10^{16}}{1.5\times10^{10}}\right) = 0.3832\ \text{V}$$
$$x_{dT} = \left[\frac{4(11.7)(8.85\times10^{-14})(0.3832)}{(1.6\times10^{-19})(4\times10^{16})}\right]^{1/2}$$
$$= 1.575\times10^{-5}\ \text{cm}$$
$$|Q'_{SD}(\max)|$$
$$= (1.6\times10^{-19})(4\times10^{16})(1.575\times10^{-5})$$
$$= 1.008\times10^{-7}\ \text{C/cm}^2$$

So

$$V_T = \frac{1.008\times10^{-7}}{2.876\times10^{-7}} - 0.5223 + 2(0.3832)$$
$$= 0.595\ \text{V}$$
$$V_{DS}(sat) = V_{GS} - V_T = 1.25 - 0.595 = 0.655\ \text{V}$$

$$\sqrt{\frac{2\epsilon_s}{eN_a}} = \sqrt{\frac{2(11.7)(8.85\times10^{-14})}{(1.6\times10^{-19})(4\times10^{16})}}$$
$$= 1.799\times10^{-5}\ \text{cm/V}^{1/2}$$

(a) $$\Delta L = \sqrt{\frac{2\epsilon_s}{eN_a}}\left[\sqrt{\phi_{fp} + V_{DS}(sat) + \Delta V_{DS}} - \sqrt{\phi_{fp} + V_{DS}(sat)}\right]$$

(i) $$\Delta L = (1.799\times10^{-5}) \times\left[\sqrt{0.3832 + 0.655 + 1} - \sqrt{0.3832 + 0.655}\right]$$
$$\Delta L = 7.35\times10^{-6}\ \text{cm} = 0.0735\ \mu\text{m}$$

(ii) $$\Delta L = (1.799\times10^{-5}) \times\left[\sqrt{0.3832 + 0.655 + 2} - \sqrt{0.3832 + 0.655}\right]$$
$$\Delta L = 1.303\times10^{-5}\ \text{cm} = 0.1303\ \mu\text{m}$$

(iii) $$\Delta L = (1.799\times10^{-5}) \times\left[\sqrt{0.3832 + 0.655 + 4} - \sqrt{0.3832 + 0.655}\right]$$
$$\Delta L = 2.205\times10^{-5}\ \text{cm} = 0.2205\ \mu\text{m}$$

(b) $$\frac{\Delta L}{L} = 0.12 = \frac{0.2205}{L}$$
$$L = 1.84\ \mu\text{m}$$

7.

(a)

(i) $I_D = \frac{k_n'}{2} \cdot \frac{W}{L}(V_{GS} - V_T)^2$

$= \left(\frac{0.075}{2}\right)(10)(0.8 - 0.35)^2$

$= 0.07594\,\text{mA} = 75.94\,\mu\text{A}$

(ii) $I_D' = I_D(1 + \lambda V_{DS})$

$= (75.9375)[1 + (0.02)(1.5)]$

$= 78.22\,\mu\text{A}$

(iii) $r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.02)(75.94)}$

$= 0.658\,\text{M}\Omega = 658\,\text{k}\Omega$

(b)

(i) $I_D = \left(\frac{0.075}{2}\right)(10)(1.25 - 0.35)^2$

$= 0.30375\,\text{mA}$

(ii) $I_D' = (0.30375)[1 + (0.02)(1.5)]$

$= 0.3129\,\text{mA}$

(iii) $r_o = \frac{1}{(0.02)(0.30375)} = 165\,\text{k}\Omega$

8.

(a)

(i) $I_D(\max) = \frac{k_n'}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_T)^2$

$= \left(\frac{0.15}{2}\right)\left(\frac{6}{1.2}\right)(3 - 0.45)^2$

$2.438\,\text{mA}$

(ii) Scaled device:

$V_D = V_{GS} = k(3) = (0.65)(3) = 1.95\,\text{V}$

$k_n' = \left(\frac{0.15}{k}\right) = \left(\frac{0.15}{0.65}\right) = 0.2308\,\text{mA/V}^2$

$L = k(1.2) = (0.65)(1.2) = 0.78\,\mu\text{m}$

$W = k(6) = (0.65)(6) = 3.90\,\mu\text{m}$

Then

$I_D(\max) = \left(\frac{0.2308}{2}\right)\left(\frac{3.9}{0.78}\right)(1.95 - 0.45)^2$

$= 1.298\,\text{mA}$

(b) (i) $P(\max) = I_D(\max)V_D = (2.438)(3)$

$= 7.314\,\text{mW}$

(ii) $P(\max) = (1.298)(1.95)$

$= 2.531\,\text{mW}$

9.

$$C_{ox} = \frac{(3.9)(8.85\times10^{-14})}{80\times10^{-8}}$$

$$= 4.314\times10^{-7}\ \mathrm{F/cm^2}$$

$$\phi_{fp} = (0.0259)\ln\left(\frac{2\times10^{16}}{1.5\times10^{10}}\right) = 0.3653\ \mathrm{V}$$

$$x_{dT} = \left[\frac{4(11.7)(8.85\times10^{-14})(0.3653)}{(1.6\times10^{-19})(2\times10^{16})}\right]^{1/2}$$

$$= 2.174\times10^{-5}\ \mathrm{cm}$$

$$\Delta V_T = -\frac{(1.6\times10^{-19})(2\times10^{16})(2.174\times10^{-5})}{4.314\times10^{-7}}$$

$$\times\left[\frac{0.30}{0.70}\left(\sqrt{1+\frac{2(0.2174)}{0.30}}-1\right)\right]$$

$$\Delta V_T = -0.0391\ \mathrm{V}$$

$$V_T = V_{TO} + \Delta V_T$$

$$0.35 = V_{TO} - 0.0391$$

$$\Rightarrow V_{TO} = 0.389\ \mathrm{V}$$