10.50 An n-channel MOSFET has the following parameters: $N_a = 5 \times 10^{16}$ cm^{-3}, $t_{ox} = 15$ nm $= 150$ Å, $\mu_n = 450$ cm^2/V-s, $V_{FB} = -0.5$ V, $L = 1.2$ μm, and $W = 8$ μm. (*a*) Determine the body-effect coefficient. (*b*) Plot $\sqrt{I_D(sat)}$ versus V_{GS} over the range $0 \le I_D \le 0.5$ mA for source-to-body voltages of (*i*) $V_{SB} = 0$, (*ii*) $V_{SB} = 1$ V, (*iii*) $V_{SB} = 2$ V, and (*iv*) $V_{SB} = 4$ V. (*c*) What are the threshold voltages for the conditions given in part (*b*)?

Using MathCAD

Constants

$kB := 1.380649 \cdot 10^{-23}$ J/K $\quad \varepsilon 0 := 8.8541878 \cdot 10^{-12}$ F/m $\quad qe := 1.602176634 \cdot 10^{-19}$ C

Given $\quad T := 300$ K $\quad Na := 5 \cdot 10^{22}$ m^{-3} $\quad tox := 15 \cdot 10^{-9}$ m

$VFB := -0.5$ V $\quad \mu n := 450 \cdot 10^{-4}$ m^2/V-s $\quad W := 8 \cdot 10^{-6}$ m $\quad L := 1.2 \cdot 10^{-6}$ m

Table B.4 Si at 300 K $\quad ni := 1.5 \cdot 10^{16}$ m^{-3} $\quad \varepsilon r := 11.7$

Table B.6 SiO_2 at 300 K $\quad \varepsilon rox := 3.9$

(10.35) $\quad Cox := \dfrac{\varepsilon rox \cdot \varepsilon 0}{tox}$ $\quad Cox = 2.302089 \times 10^{-3}$ F/m^2

a) Per (10.82) $\quad \gamma := \dfrac{\sqrt{2 \cdot qe \cdot \varepsilon r \cdot \varepsilon 0 \cdot Na}}{Cox}$ $\quad \boxed{\gamma = 0.559629}$ V$^{0.5}$

b) (7.10) $\quad Vt := \dfrac{kB \cdot T}{qe}$ $\quad Vt = 0.025852$ V

(10.4) $\quad \phi fp := Vt \cdot \ln\left(\dfrac{Na}{ni}\right)$ $\quad \phi fp = 0.388284$ V

(10.6) $\quad xdT := \sqrt{\dfrac{4 \cdot \varepsilon r \cdot \varepsilon 0 \cdot \phi fp}{qe \cdot Na}}$ $\quad xdT = 1.417202 \times 10^{-7}$ m

(10.27) $\quad QSD\_max := qe \cdot Na \cdot xdT$ $\quad QSD\_max = 1.135304 \times 10^{-3}$ C/m^2

(10.31c) $\quad VTN := \dfrac{QSD\_max}{Cox} + VFB + 2 \cdot \phi fp$ $\quad VT0 := VTN$

Find ΔV_T & V_T using (10.83) for

(*i*) $V_{SB} = 0$ $\quad \Delta VT0 := \gamma \cdot \left(\sqrt{2 \cdot \phi fp + 0} - \sqrt{2 \cdot \phi fp}\right)$ $\quad \Delta VT0 = 0$ V

$VT0 := VT0 + \Delta VT0$

(*ii*) $V_{SB} = 1$ V $\quad \Delta VT1 := \gamma \cdot \left(\sqrt{2\cdot\phi fp + 1} - \sqrt{2\cdot\phi fp}\right)$ $\quad \Delta VT1 = 0.25276$ V

$VT1 := VT0 + \Delta VT1$

(*iii*) $V_{SB} = 2$ V $\quad \Delta VT2 := \gamma \cdot \left(\sqrt{2\cdot\phi fp + 2} - \sqrt{2\cdot\phi fp}\right)$ $\quad \Delta VT2 = 0.43935$ V

$VT2 := VT0 + \Delta VT2$

(*iv*) $V_{SB} = 4$ V $\quad \Delta VT4 := \gamma \cdot \left(\sqrt{2\cdot\phi fp + 4} - \sqrt{2\cdot\phi fp}\right)$ $\quad \Delta VT4 = 0.72993$ V

$VT4 := VT0 + \Delta VT4$

Use above threshold voltages and (10.69) to calculate the square root of I_D (sat) versus V_{GS} for the ranges of V_{GS} where $0 < I_D < 0.5$ mA for the various V_{SB}

When $\boldsymbol{V_{SB} = 0}$, find V_{GS} range for $0 < I_D < 0.5$ mA using (10.45a)

For $I_D = 0$ $\quad VGS0 := VT0$ $\quad VGS0 = 0.76973$ V

For $I_D = 0.5$ mA $\quad VGS05 := VT0 + \sqrt{\frac{0.5\cdot 10^{-3}\cdot 2\cdot L}{W\cdot \mu n\cdot Cox}}$ $\quad VGS05 = 1.973042$ V

When V_{SB} changes, add the appropriate constant ΔV_T offset to the above range

$n := 0..50$ $\quad VGS0_n := VGS0 + \frac{VGS05 - VGS0}{50}\cdot n$ $\quad VGS1_n := VGS0_n + \Delta VT1$

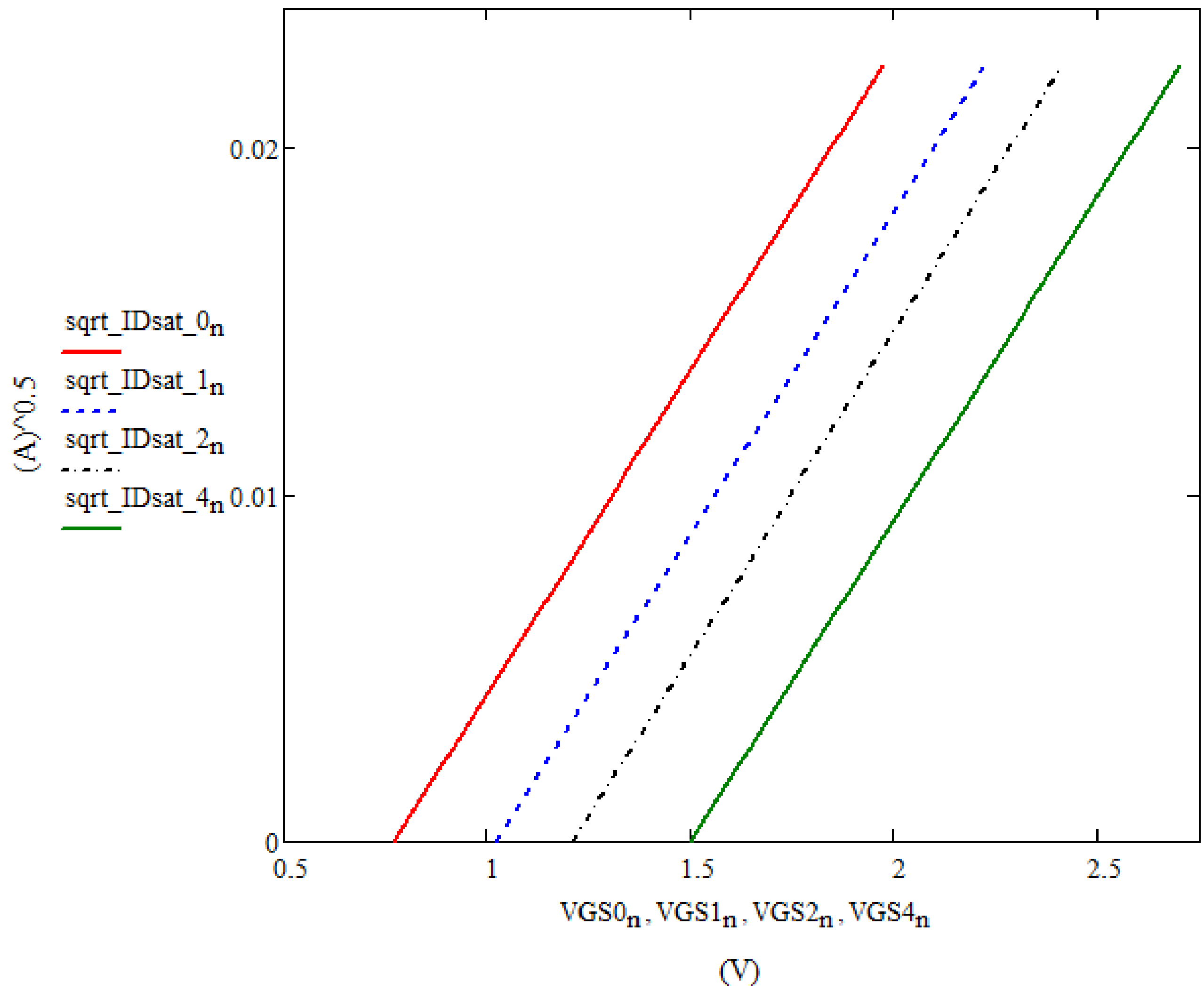
$VGS2_n := VGS0_n + \Delta VT2$ $\quad VGS4_n := VGS0_n + \Delta VT4$

(*i*) $V_{SB} = 0$ $\quad sqrt\_IDsat\_0_n := \sqrt{\frac{W\cdot \mu n\cdot Cox}{2\cdot L}}\cdot\left(VGS0_n - VT0\right)$

(*ii*) $V_{SB} = 1$ V $\quad sqrt\_IDsat\_1_n := \sqrt{\frac{W\cdot \mu n\cdot Cox}{2\cdot L}}\cdot\left(VGS1_n - VT1\right)$

(*iii*) $V_{SB} = 2$ V $\quad sqrt\_IDsat\_2_n := \sqrt{\frac{W\cdot \mu n\cdot Cox}{2\cdot L}}\cdot\left(VGS2_n - VT2\right)$

(*iv*) $V_{SB} = 4$ V $\quad sqrt\_IDsat\_4_n := \sqrt{\frac{W\cdot \mu n\cdot Cox}{2\cdot L}}\cdot\left(VGS4_n - VT4\right)$



c)

(*i*) $V_{SB} = 0$ — VT0 = 0.76973 V

(*ii*) $V_{SB} = 1$ V — VT1 = 1.022486 V

(*iii*) $V_{SB} = 2$ V — VT2 = 1.20908 V

(*iv*) $V_{SB} = 4$ V — VT4 = 1.499657 V