Homework #10

Problems 5.44, 5.48, 5.55, 5.56, 5.62, and 5.63

Problem 5.44

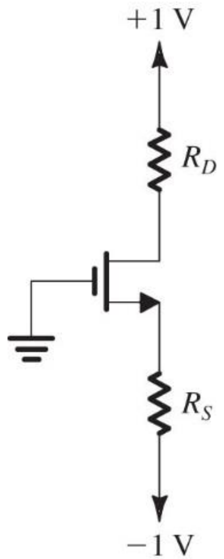


Figure P5.44

Design the circuit of Fig. P5.44 to establish a drain current of 0.1 mA and a drain voltage of +0.3 V. The MOSFET has V_t = 0.5 V, $\mu_n C_{ox}$ = 400 μA/V^2, L = 0.4 μm, and W = 5 μm. Specify the required values for R_S and R_D.

$I_D := 0.1\,mA$ $\quad V_{tn} := 0.5\,V$ $\quad k_n := \frac{400\,\mu A}{V^2} \cdot \frac{5\mu m}{0.4\,\mu m} = 5\,\frac{mA}{V^2}$

$V_{OV} := \sqrt{\frac{2 \cdot I_D}{k_n}} = 0.2\,V$ $\quad V_{GS} := V_{tn} + V_{OV} = 0.7\,V$

The gate is grounded so V_S = 0 V – V_{GS} = -0.7 V

$$R_S := \frac{-V_{GS} - -1V}{I_D} = 3\,k\Omega$$

The drain voltage is + 0.3 V

$$R_D := \frac{1V - 0.3V}{I_D} = 7\,k\Omega$$

Problem 5.48

It is required to operate the transistor in the circuit of Fig. P5.47 at the edge of saturation with I_D = 0.1 mA. If V_t = 0.4 V, find the required value of R_D.

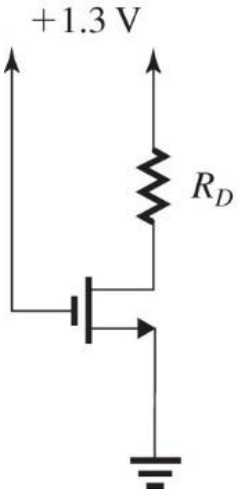


Figure P5.47

$V_{GS} = 1.3\text{V}$ Since gate is tied to V_{DD} (1.3 V) and source is grounded

$V_{GS} = V_t + V_{OV} = 1.3\text{V}$ $V_{OV} = V_{GS} - V_t = 1.3 - 0.4 = 0.9\text{V}$

Since it is operating at the edge of saturation $V_{DS} = V_{OV} = 0.9\text{V}$

$$R_D = \frac{1.3\text{V} - 0.9\text{V}}{0.1\text{mA}} = 4000\Omega$$

Problem 5.55

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.

(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix J. Find the new values of V_1 through V_7.

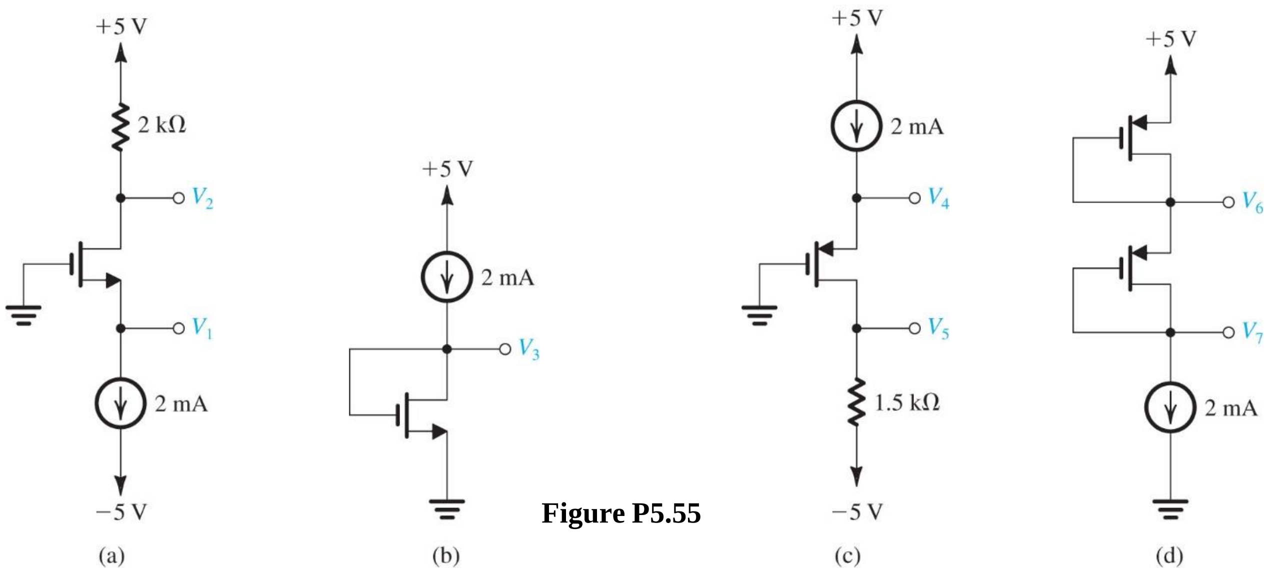


Figure P5.55

Standard Resistor Values

1% Standard Values Decade multiples are available from 10.0 Ω through 1.00 MΩ (also 1.10 MΩ, 1.20 MΩ, 1.30 MΩ, 1.50 MΩ, 1.60 MΩ, 1.80 MΩ, 2.00 MΩ and 2.20 MΩ)											
10.0	10.2	10.5	10.7	11.0	11.3	11.5	11.8	12.1	12.4	12.7	13.0
13.3	13.7	14.0	14.3	14.7	15.0	15.4	15.8	16.2	16.5	16.9	17.4
17.8	18.2	18.7	19.1	19.6	20.0	20.5	21.0	21.5	22.1	22.6	23.2
23.7	24.3	24.9	25.5	26.1	26.7	27.4	28.0	28.7	29.4	30.1	30.9
31.6	32.4	33.2	34.0	34.8	35.7	36.5	37.4	38.3	39.2	40.2	41.2
42.2	43.2	44.2	45.3	46.4	47.5	48.7	49.9	51.1	52.3	53.6	54.9
56.2	57.6	59.0	60.4	61.9	63.4	64.9	66.5	68.1	69.8	71.5	73.2
75.0	76.8	78.7	80.6	82.5	84.5	86.6	88.7	90.9	93.1	95.3	97.6

5% Standard Values Decade multiples are available from 10 Ω through 22 MΩ											
10	11	12	13	15	16	18	20	22	24	27	30
33	36	39	43	47	51	56	62	68	75	82	91

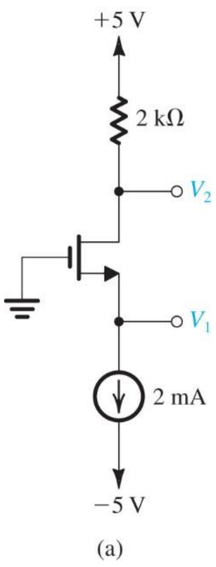
10% Standard Values Decade multiples are available from 10 Ω through 1 MΩ											
10	12	15	18	22	27	33	39	47	56	68	82

http://www.rfcafe.com/references/electrical/resistor-values.htm

Problem 5.55a (NMOS)

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.
(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix J. Find the new values of V_1 through V_7.



$$V_2 = 5 - 2\text{mA} \times 2\text{k}\Omega = 1\text{V}$$

$$v_{OV} = \sqrt{\frac{2i_D}{k_n'\left(\frac{W}{L}\right)}} = 1\text{V}$$

$$v_{GS} = V_t + v_{OV} = 1 + 1 = 2.0\text{V}$$

$V_1 = -2\text{V}$ → $v_{DS} = 3.0\text{V} > V_{OV}$ Device is in saturation

$$R_S = \frac{-2\text{V} - -5\text{V}}{2\text{mA}} = 1.5\text{k}\Omega$$ Closest 1% value is 1.50kΩ

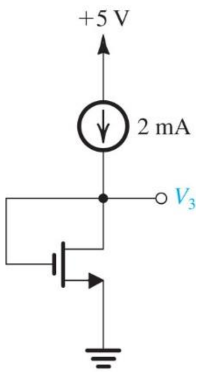
Since the resistor is exactly matched the currents and voltages don't change

Figure P5.55

Problem 5.55b (NMOS)

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.
(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix J. Find the new values of V_1 through V_7.



(b)

$$v_{OV} = \sqrt{\frac{2i_D}{k'_n\left(\frac{W}{L}\right)}} = 1.0\text{V}$$

$$v_{GS} = V_t + v_{OV} = 1 + 1 = 2\text{V}$$

$$V_3 = 2\text{V}$$

$$v_{DS} = v_{GS} = 2\text{V} > V_{OV}$$

Device is in saturation

$$R_D = \frac{5\text{V} - 2\text{V}}{3\text{mA}} = 1.5\text{k}\Omega$$

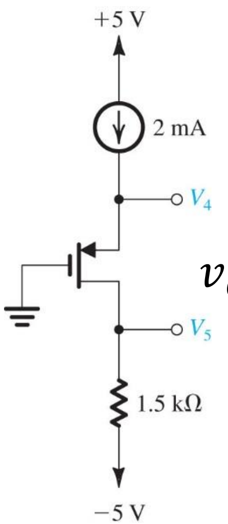
Closest 1% value is 1.5kΩ

Since the resistor is exactly matched the currents and voltages don't change

Problem 5.55c (PMOS)

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.
(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix J. Find the new values of V_1 through V_7.



(c)

$$v_{OV} = \sqrt{\frac{2i_D}{k'_n\left(\frac{W}{L}\right)}} = 1\text{V}$$

$$v_{GS} = -V_t - v_{OV} = -1 - 1 = -2\text{V}$$

$$V_4 = V_S = 2\text{V}$$

$$V_5 = -5 + 2\text{mA} \times 1.5\text{k}\Omega = -2\text{V}$$

$$R_S = \frac{5\text{V} - 2\text{V}}{2\text{mA}} = 1.5\text{k}\Omega$$

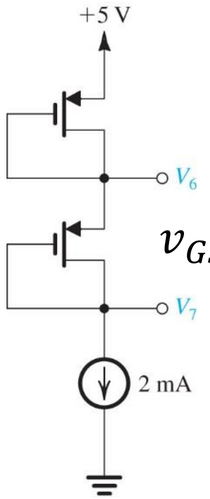
Closest 1% value is 1.50kΩ

Since the resistor is exactly matched the currents and voltages don't change

Problem 5.55d (PMOS)

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.
(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix J. Find the new values of V_1 through V_7.



(d)

$$v_{OV} = \sqrt{\frac{2i_D}{k_n'\left(\frac{W}{L}\right)}} = 1\text{V}$$

$$v_{GS} = -V_t - v_{OV} = -1 - 1 = -2\text{V}$$

$$V_6 = V_{G1} = 5\text{V - 2V} = 3\text{V}$$

$$V_7 = V_{G2} = V_{G1} - v_{GS2} = 1\text{V}$$

$$R_D = \frac{1\text{V}}{2\text{mA}} = 500\Omega$$

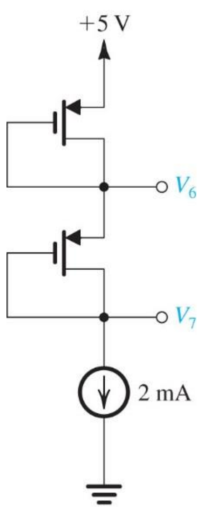
Closest 1% value is 499Ω

Problem 5.55d cont (PMOS)

In the circuits shown in Fig. P5.55, transistors are characterized by $|V_t| = 1$ V, $k'(W/L) = 4$ mA/V^2, and $\lambda = 0$.

(a) Find the labeled voltages V_1 through V_7.
(b) In each of the circuits, replace the current source with a resistor. Select the resistor value to yield a current as close to that of the current source as possible, while using resistors specified in the 1% table provided in Appendix H. Find the new values of V_1 through V_7.

With $R_D = 499\Omega$



$$I_D = \frac{5\text{V} - 2V_{SG}}{499\Omega}$$

$$I_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)(V_{SG} - V_t)^2 = \frac{1}{2}\frac{4\text{mA}}{\text{V}^2}(V_{SG} - 1\text{V})^2$$

Solving yields $V_{SG} = 2.003$V

The new current is then $I_D = 1.992$mA

Problem 5.56

For each of the circuits in Fig. P5.56, find the labeled node voltages. For all transistors, $k_n'(W/L) = 0.5\ \text{mA/V}^2$, $V_t = 0.8$ V, and $\lambda = 0$.

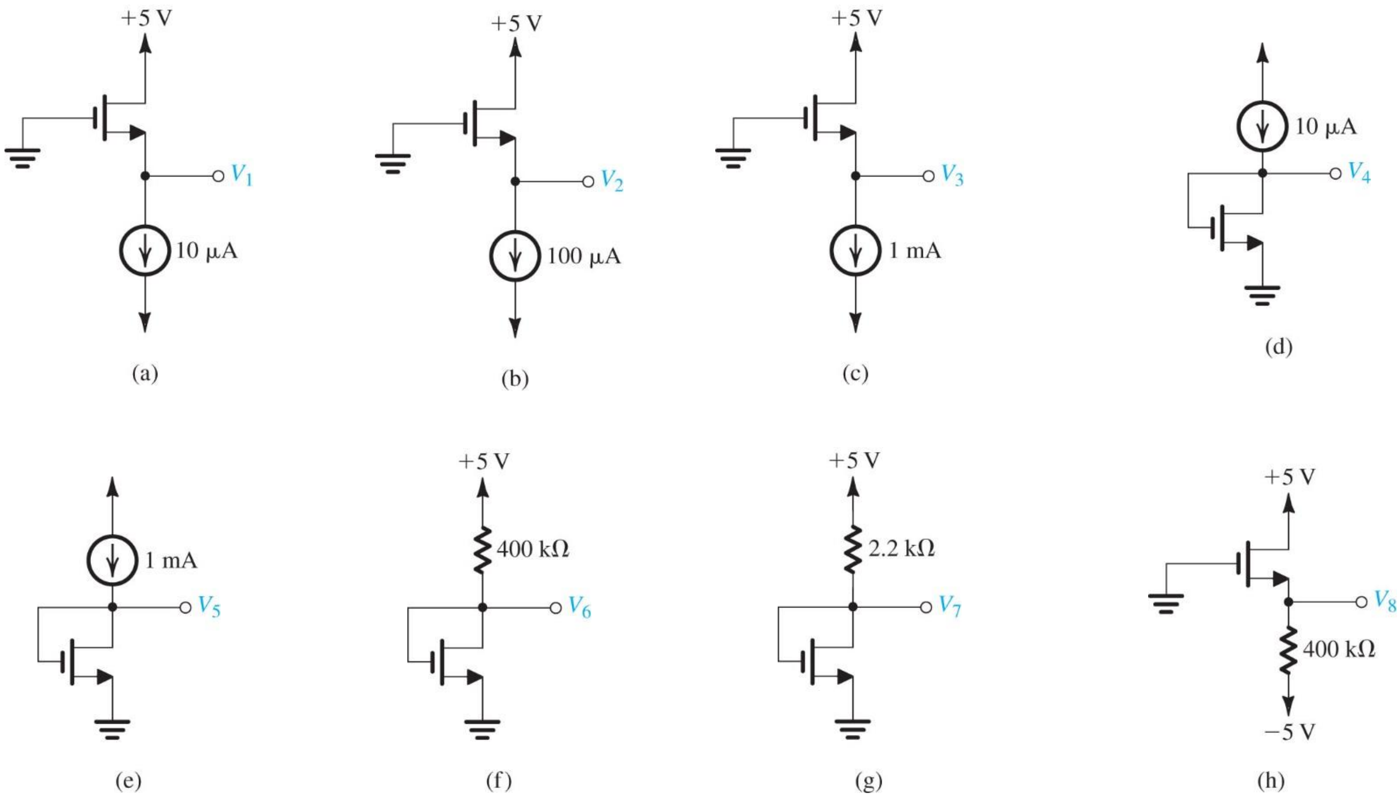
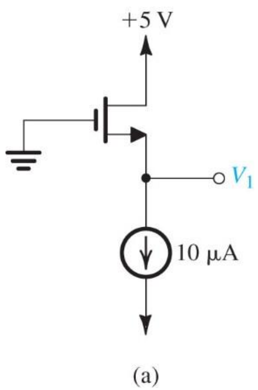


Figure P5.56

Problem 5.56a,b

For each of the circuits in Fig. P5.56, find the labeled node voltages. For all transistors, $k_n'(W/L) = 0.5\ \text{mA/V}^2$, $V_t = 0.8$ V, and $\lambda = 0$.



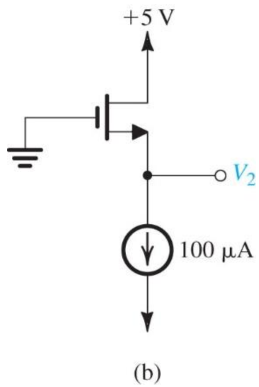
$$I_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)V_{OV}^2$$

$$V_{OV} = \sqrt{\frac{I_D}{\frac{1}{2}k_n'\left(\frac{W}{L}\right)}}$$

$$V_{OV} := \sqrt{\frac{2 \cdot 10\,\mu A}{0.5\,\frac{mA}{V^2}}} = 0.2\ V$$

$$V_{GS} = V_t + V_{OV} = 0.8 + 0.2 = 1.0\text{V}$$

$$V_1 = -1.0\text{V}$$



$$V_{OV} := \sqrt{\frac{2 \cdot 100\,\mu A}{0.5\,\frac{mA}{V^2}}} = 0.632\ V$$

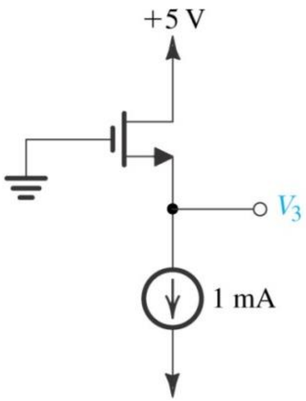
$$V_{GS} = V_t + V_{OV} = 0.8 + 0.632 = 1.432\text{V}$$

$$V_2 = -1.432\text{V}$$

Figure P5.56

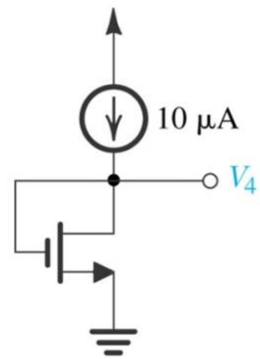
Problem 5.56c,d

For each of the circuits in Fig. P5.56, find the labeled node voltages. For all transistors, $k_n'(W/L) = 0.5$ mA/V^2, $V_t = 0.8$ V, and $\lambda = 0$.



(c)

$$V_{OV} := \sqrt{\frac{2 \cdot 1mA}{0.5 \frac{mA}{V^2}}} = 2\,V$$



(d)

$$V_{OV} := \sqrt{\frac{2 \cdot 10\mu A}{0.5 \frac{mA}{V^2}}} = 0.2\,V$$

$$V_{GS} = V_t + V_{OV} = 0.8 + 2 = 2.8\text{V}$$

$$V_3 = -2.8\text{V}$$

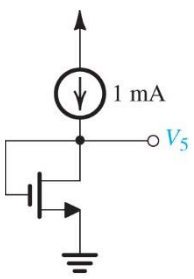
$$V_{GS} = V_t + V_{OV} = 0.8 + 0.2 = 1.0\text{V}$$

$$V_4 = 1.0\text{V}$$

Figure P5.56

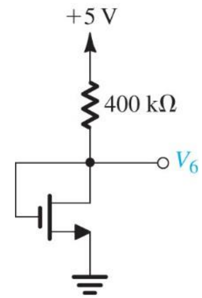
Problem 5.56e,f

For each of the circuits in Fig. P5.56, find the labeled node voltages. For all transistors, $k_n'(W/L) = 0.5$ mA/V^2, $V_t = 0.8$ V, and $\lambda = 0$.



(e)

$$V_{OV} := \sqrt{\frac{2 \cdot 1mA}{0.5\,\frac{mA}{V^2}}} = 2\,V$$



(f)

$$V_{GS} = V_t + V_{OV} = 0.8 + 2 = 2.8\text{V}$$

$$V_5 = 2.8\text{V}$$

$$V_6 = V_{GS} = 5.0\text{V} - I_D 400k\Omega$$

$$V_{OV} = V_{GS} - V_t = 5.0\text{V} - I_D 400k\Omega - 0.8\text{V}$$

$$V_{OV} = 4.2\text{V} - I_D 400k\Omega$$

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{OV}^2$$

$$I_D = \frac{1}{2} 0.5 \left(\frac{\text{mA}}{\text{V}^2}\right) (4.2\text{V} - I_D 400k\Omega\,)^2$$

From MATHCAD I_D = 10 uA or 11.025 uA

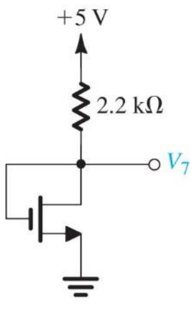
$$V_{OV} = 0.2\text{V}$$

$$V_6 = V_{GS} = 1\text{V}$$

Figure P5.56

Problem 5.56g,h

For each of the circuits in Fig. P5.56, find the labeled node voltages. For all transistors, $k_n'(W/L) = 0.5\ \text{mA/V}^2$, $V_t = 0.8$ V, and $\lambda = 0$.



(g)

$$V_7 = V_{GS} = 5.0\text{V} - I_D 2.2k\Omega$$

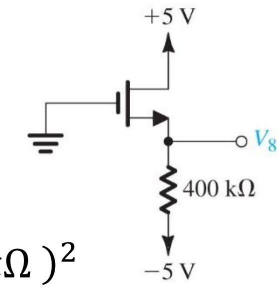
$$V_{OV} = 4.2\text{V} - I_D 2.2k\Omega$$

$$I_D = \frac{1}{2} 0.5 \left(\frac{\text{mA}}{\text{V}^2}\right)(4.2\text{V} - I_D 2.2k\Omega)^2$$

From MATHCAD $I_D = 1$ mA

$$V_{OV} := \sqrt{\frac{2 \cdot 1mA}{0.5 \frac{mA}{V^2}}} = 2\,V$$

$$V_7 = V_{GS} = 2.8\text{V}$$



(h)

$$V_8 = -V_{GS} = V_S = -(5.0\text{V} - I_D 400k\Omega)$$

$$V_{GS} = 5.0\text{V} - I_D 400k\Omega$$

$$V_{OV} = V_{GS} - V_t = 5.0\text{V} - I_D 400k\Omega - 0.8\text{V}$$

$$V_{OV} = 4.2\text{V} - I_D 400k\Omega$$

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{OV}^2$$

$$I_D = \frac{1}{2} 0.5 \left(\frac{\text{mA}}{\text{V}^2}\right)(4.2\text{V} - I_D 400k\Omega)^2$$

From MATHCAD $I_D = 10$ uA or 11.025 uA

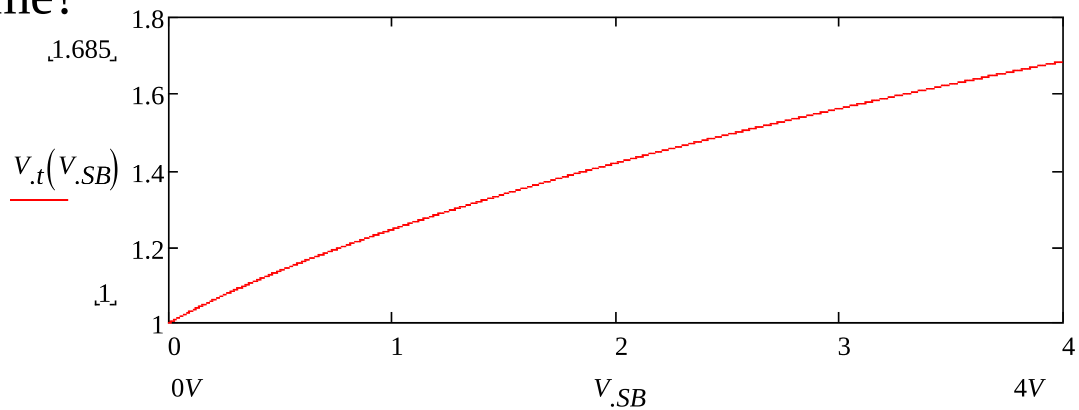
$$V_{OV} = 0.2V$$

$$V_8 = -V_{GS} = -1\text{V}$$

Problem 5.62

In a particular application, an *n*-channel MOSFET operates with V_{SB} in the range 0 V to 4 V. If V_{t0} is normally 1.0 V, find the range of V_t that results if $\gamma = 0.5\sqrt{V}$ and $2\phi_f = 0.6$ V. If the gate oxide thickness is increased by a factor of 4, what does the threshold voltage become?

$$V_t = V_{t0} + \gamma\left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right]$$



$$c_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \qquad \gamma = \frac{\sqrt{2qN_A\varepsilon_s}}{C_{ox}}$$

Increasing t_{ox} by 4x reduces C_{ox} by 4x which increases γ by 4x

$$V_t(V_{SB}) := 1V + 2\cdot\sqrt{V}\cdot\left(\sqrt{0.6V + V_{SB}} - \sqrt{0.6V}\right)$$

$$V_t(0V) = 1V$$

$$V_t(4V) = 3.74V$$

Problem 5.63

A p-channel transistor operates in saturation with its source voltage 3 V lower than its substrate. For $\gamma = 0.5\sqrt{V}$, $2\phi_f = 0.75$ V, and $V_{t0} = -0.7$ V, find V_t.

$$V_t = V_{t0} + \gamma\left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right]$$

$$V_t := -0.7V - 0.5\cdot\sqrt{V}\cdot\left(\sqrt{0.75V + 3V} - \sqrt{0.75V}\right) = -1.235V$$