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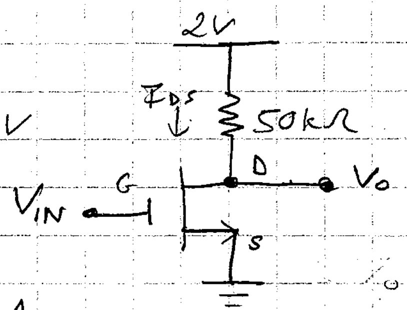
(3.3) $k'_n = 75\mu A/V^2$

$\frac{W}{L} = 4$

$V_o = 1.2V,\ V_T = 0.5V$

$V_{Tn} = 0.5V$



$$I_{DS} = \frac{2V - 1.2V}{50k\Omega} = 16\mu A$$

$$I_{DS} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(V_{IN} - V_{Tn})^2$$

$$V_{IN} = \sqrt{\frac{2I_{DS}}{k'_n\left(\frac{W}{L}\right)}} + V_{Tn} = \sqrt{\frac{2(16\mu A)}{(75\mu A/V^2)(4)}} + 0.5V = \boxed{0.826V}$$

$V_{IN} > V_{Tn} \Rightarrow$ channel exists ; $V_{DS} = 2V - (50k\Omega)(16\mu A) = 1.2V$

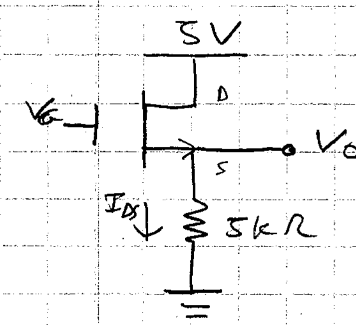
$V_{DS} > V_{IN} - V_{Tn} \Rightarrow$ saturation verified

(3.4) $V_{Tn} = 0.8V$

$k'_n = 100\mu A/V^2$

$W/L = 4$

$I_{DS} = 200\mu A$



$V_o = (200\mu A)(5k\Omega) = 1V$

Assume saturation:

$$I_{DS} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{Tn})^2$$

$$V_{GS} = \sqrt{\frac{2I_{DS}}{k'_n(W/L)}} + V_{Tn} = \sqrt{\frac{2(200\mu A)}{(100\mu A/V^2)(4)}} + 0.8V = 1.8V$$

$$V_G = V_o + V_{GS} = 1.8V + 1V = \boxed{2.8V}$$

$V_{DS} > V_{GS} - V_{Tn}$ ∴ transistor is in saturation.

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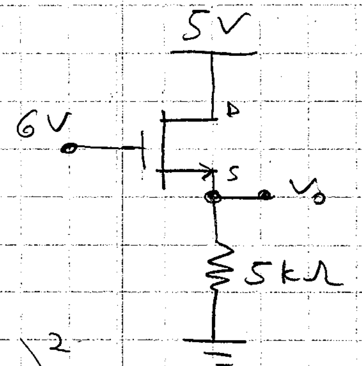
(3.6) $V_{Tn} = 0.8V$
$k'_n = 200\mu A/V^2$
$\frac{W}{L} = 4$



Assume Saturation:

$$I_{DS} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(V_{GS}-V_{Tn})^2$$

$$I_{DS} = \frac{V_o}{5k\Omega} \; ; \quad V_{GS} = 6V - V_o$$

$$\frac{V_o}{5k\Omega} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(6V - V_o - V_{Tn})^2$$

$$V_o = (2.5k\Omega)(200\mu A/V^2)(4)(5.2 - V_o)^2$$

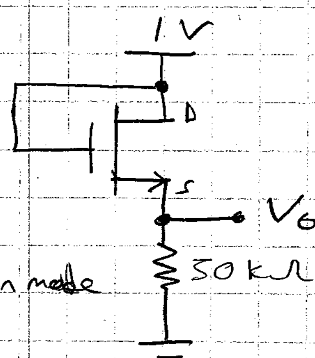
$$V_o = 2(V_o^2 - 10.4V_o + 27.04)$$

$$2V_o^2 - 21.8V_o + 54.08 = 0$$

$$V_o = \frac{21.8 \pm \sqrt{(21.8)^2 - 4(2)(54.08)}}{2(2)} = (3.818, 7.082)$$

$$V_o \neq 7.082 > V_{DD} \quad \therefore \quad V_o = \boxed{3.818V}$$

(3.8) $\frac{W}{L} = 5$
$V_{Tn} = 0.25V$
$k'_n = 110\mu A/V^2$



$V_{GS} = V_{DD} > V_{GS} - V_{Tn}$
$\therefore$ saturation mode

$$I_{DS} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(V_{GS}-V_{Tn})^2$$

$$I_{DS} = \frac{V_o}{50k\Omega} \; ; \quad V_{GS} = 1V - V_o$$

$$\frac{V_o}{50k\Omega} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(1V - V_o - V_{Tn})^2$$

$$V_o = (25k\Omega)(110\mu A/V^2)(5)(0.75 - V_o)^2$$

$$V_o = 13.75(V_o^2 - 1.5V_o + 0.5625)$$

$$13.75V_o^2 - 21.625V_o + 7.73 = 0$$

$$V_o = \frac{21.625 \pm \sqrt{(21.625)^2 - 4(13.75)(7.73)}}{2(13.75)} = (0.550, 1.023)$$

(continued next page)

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(3.8 - continued)

Let $V_o = 0.550$

$V_{GS} = 1V - 0.550V = 0.450V$

$V_{GS} - V_{Tn} = 0.450V - 0.25V = 0.2V$

Let $V_o = 1.023$

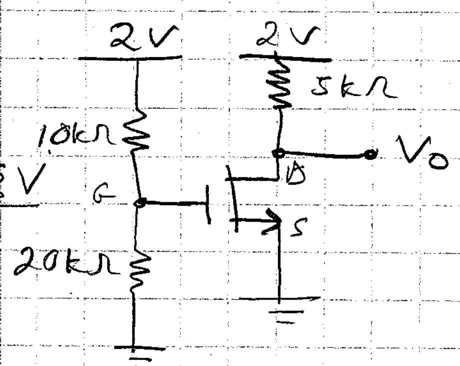
$V_{GS} = 1V - 1.023V = -0.23V < V_{Tn}$

$\therefore$ transistor would be in cutoff

$\therefore V_o = \boxed{0.550V}$

$I_{DS} = \frac{0.550}{50k\Omega} = \boxed{11\mu A}$

(3.9) $\frac{W}{L} = 20$
$V_{Tn} = 0.5V$
$K'_n = 120\mu A/V^2$



$V_G = V_{GS} = \left(\frac{20k}{30k}\right)2V \cdot \underline{1.3\bar{3}V}$

Assume Saturation:

$I_{DS} = \frac{K'_n}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{Tn})^2$

$I_{DS} = \frac{120\mu A/V^2}{2}(20)(1.3\bar{3}V - 0.5V)^2$

$I_{DS} = \boxed{83\bar{3}\mu A}$ $\quad V_o = 2V - (83\bar{3}\mu A)(5k\Omega) = -2.1\bar{6}V$

$\therefore$ transistor is not in saturation

Linear:

$I_{DS} = K'_n\left(\frac{W}{L}\right)\left[(V_{GS} - V_{Tn})V_{DS} - \frac{V_{DS}^2}{2}\right]$

$I_{DS} = \frac{2 - V_o}{5k\Omega}$; $V_{DS} = V_o$

$\frac{2 - V_o}{5k\Omega} = (120\mu A/V^2)(20)\left[(0.83\bar{3}V)V_o - \frac{V_o^2}{2}\right]$

$V_o = (0.204, 1.628) \Rightarrow$ Let $V_o = 1.628V \Rightarrow V_o = V_{DS} > V_{GS} - V_T$

Let $V_o = 0.205 \Rightarrow V_o = V_{DS} < V_{GS} - V_T$ $\therefore$ transistor is in Linear rg

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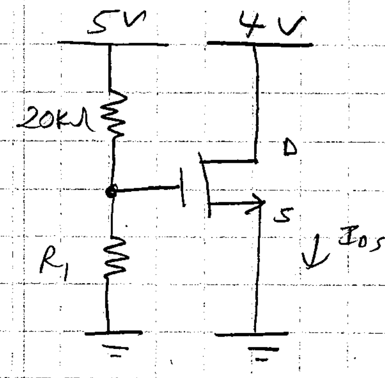
(3.9 - continued)

$V_o = \boxed{0.205}$ $\quad I_{DS} = \frac{2 - V_o}{5k\Omega} = \boxed{359.1\mu A}$

(3.13) $V_{Tn} = 0.5V$



sat/non-sat border:

$V_{DS} = V_{GS} - V_{Tn}$

$4V = V_{GS} - 0.5V$

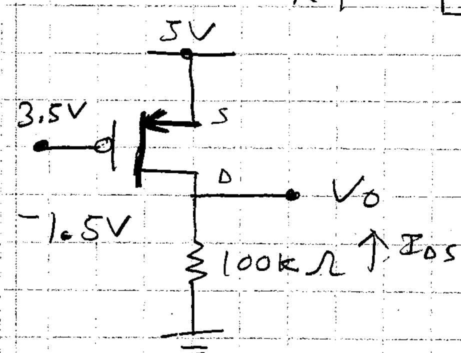
$V_{GS} = 4.5V = V_G$

$\left(\frac{R_1}{20k + R_1}\right)(5V) = 4.5V \Rightarrow (5V)R_1 = 4.5V(20k + R_1)$

$(0.5V)R_1 = 90k\Omega \cdot V$

$R_1 = \boxed{180k\Omega}$

(3.16) $V_{Tp} = -0.8V$
$K'_p = 30\mu A/V^2$
$\frac{W}{L} = 2$



$V_{GS} = -1.5V$

$|I_{DS}| = \frac{K'_p}{2}\left(\frac{W}{L}\right)\left(|V_{GS}| - |V_{Tp}|\right)^2$

$|I_{DS}| = \frac{30\mu A/V^2}{2}(2)(1.5V - 0.8V)^2 = 14.7\mu A \Rightarrow I_{DS} = \boxed{-14.7\mu A}$

$V_o = (100k\Omega)(14.7\mu A) = \boxed{1.47V}$

$|V_{DS}| = 3.53V > |V_{GS}| - |V_{Tp}| \therefore$ transistor is in saturation region

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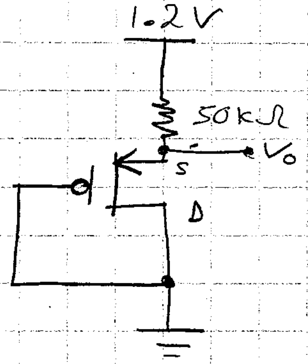

(3.21) $\frac{W}{L} = 6$
$V_{Tp} = -0.3V$
$K'_p = 40\mu A/V^2$

Assume saturation:

$|I_{DS}| = \frac{K'_p}{2}\left(\frac{W}{L}\right)\left(|V_{GS}| - |V_{Tp}|\right)^2$ $\quad |I_{DS}| = \frac{1.2 - V_o}{50k\Omega}$; $|V_{GS}| = |V_o| = |V_{DS}|$

$\frac{1.2 - V_o}{50k\Omega} = \frac{40\mu A/V^2}{2}(6)\left(|V_o| + 0.3V\right)^2$

$1.2 - V_o = (150k)(40\mu A/V^2)\left(V_o^2 + .6V_o + .09\right)$

$-V_o = 6V_o^2 + 3.6V_o - 0.66$

$6V_o^2 + 4.6V_o - 0.66 = 0$

$V_o = (-0.890, 0.124)$ $\quad V_o \neq -0.890 < 0$

$V_{DS} = 0.124V < V_{GS} - V_{Tp} = 0.124 + 0.3V = 0.424V$

$\therefore$ transistor is in saturation

$V_o = \boxed{0.124V}$; $I_{DS} = \frac{0.124V - 1.2V}{50k\Omega} = \boxed{-21.53\mu A}$

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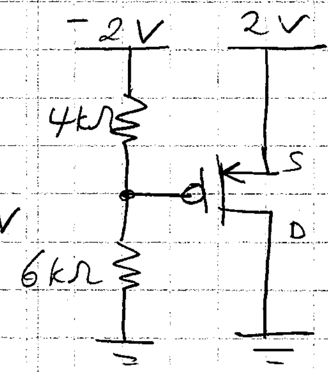
(3.22) $V_{Tp} = -0.4V$
$\frac{W}{L} = 4$
$k'_p = 100\mu A/V^2$

$V_G = V_{GS} = \left(\frac{6k\Omega}{10k\Omega}\right)2V = -1.2V$



a) Bias State:

$V_{DS} = -2V$, $V_{GS} = -1.2V - 2V = -3.2V$

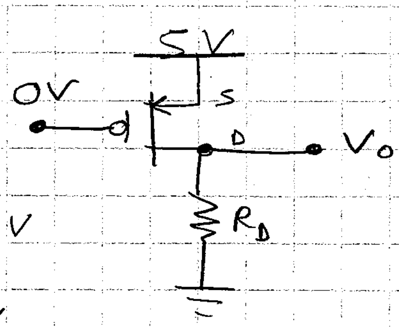
$V_{DS} > V_{GS} - V_{Tp}$ ∴ transistor is in $\boxed{\text{linear}}$ region

b) $I_{SD} = k'_p\left(\frac{W}{L}\right)\left[(V_{GS} - V_{Tp})V_{DS} - \frac{V_{DS}^2}{2}\right]$

$I_{SD} = (100\mu A/V^2)(4)\left[(-3.2V+0.4V)(-2) - \frac{(-2)^2}{2}\right]$

$I_{SD} = \boxed{1.44mA}$

(3.23) $V_{Tp} = -0.8V$
$K'_p = 75\mu A/V^2$
$I_{DS} = 0.25A$
$V_{SD} < 0.2V$
$V_{GS} = -5V$



Let $V_{DS} = -0.2V$

$V_{DS} > V_{GS} - V_{Tp}$ ∴ transistor is in cutoff

$I_{SD} = k'_p\left(\frac{W}{L}\right)\left[(V_{GS} - V_{Tp})V_{DS} - \frac{V_{DS}^2}{2}\right]$

$0.25 = (75\mu A/V^2)\left(\frac{W}{L}\right)\left[(-5+0.8)(-0.2) - \frac{(-0.2)^2}{2}\right]$

$\frac{W}{L} = \boxed{4,065}$

$R_D = \frac{5 - V_{SD}}{0.25A} = \frac{5-0.2}{0.25A} = \boxed{19.2\Omega}$

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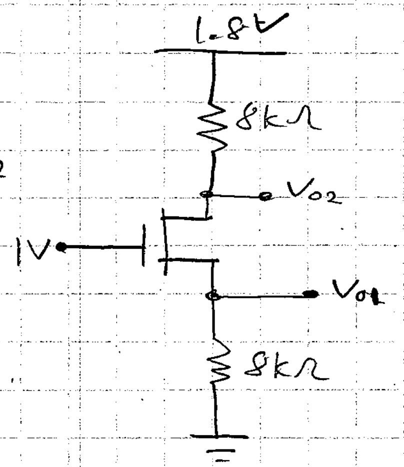
(3.27) $\frac{W}{L} = 4$
$V_{Tn} = 0.4V$
$k'_n = 95\mu A/V^2$



$I_{DS} = \frac{V_{o1}}{8k\Omega}$

$V_{GS} = 1V - V_{o1}$

Assume Saturation:

$I_{DS} = \frac{k'_n}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{Tn})^2$

$\frac{V_{o1}}{8k\Omega} = \frac{95\mu A/V^2}{2}(4)\left[(1V - V_{o1}) - 0.4V\right]^2$

$V_{o1} = 1.52(V_{o1}^2 - 1.2V_{o1} + 0.36)$

$1.52V_{o1}^2 - 2.824V_{o1} + 0.5472V = 0$

$V_{o1} = (0.2198V, 1.638V)$

$V_{o1} \neq 1.638V \Rightarrow V_{GS} = 1V - V_{o1} = -0.638V < 0$

$\underline{V_{o1}} = \boxed{0.2198V}$

$V_{GS} = 1 - 0.2198V = 0.780V$

$V_{GS} > V_{Tn}$ $\therefore$ channel is created

$\underline{I_{DS}} = \frac{V_{o1}}{8k\Omega} = \boxed{27.47\mu A}$

$V_{o2} = 1.8V - (8k\Omega)(27.47\mu A)$

$\underline{V_{o2}} = 1.8 - 0.2198V = \boxed{1.58V}$

$V_{DS} = V_{o2} - V_{o1} = 1.36V$

$V_{DS} > V_{GS} - V_{Tn}$ $\therefore$ Saturation is verified

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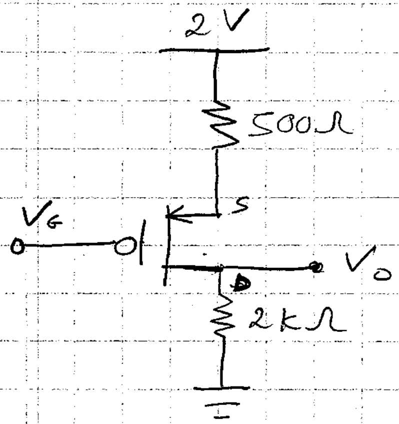
(3.31) $V_{Tp} = -0.5V$

$\frac{W}{L} = 5$

$K'_p = 50\mu A/V^2$

$V_o = 0.3V$



$I_{SD} = \frac{V_o}{2k\Omega} = 150\mu A$

$V_{SD} = [2V - (150\mu A)(500\Omega)] - (0.3V)$

$V_{SD} = 1.625V$

For saturation:

$I_{SD} = \frac{K'_p}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{Tp})^2$

$150\mu A = \frac{50\mu A/V^2}{2}(5)(V_{GS} - (-0.5))^2$

$V_{GS} = (-1.5954V,\ 0.5954V)$

$V_{GS} \neq 0.5954V$ because $I_{SD} = 0$ for $V_{GS} > V_{Tp}$

$V_{GS} = -1.5954V$

$V_G = V_S - 1.5954V \Rightarrow V_S = V_o + V_{DS}$

$V_S = 0.3V + 1.625V = 1.925V$

$V_G = 1.995V - 1.5954V = \boxed{329.6\ mV}$