SANTA CLARA UNIVERSITY	ELEN 115 – Spring 2023	S. Krishnan

Homework #9 Solutions

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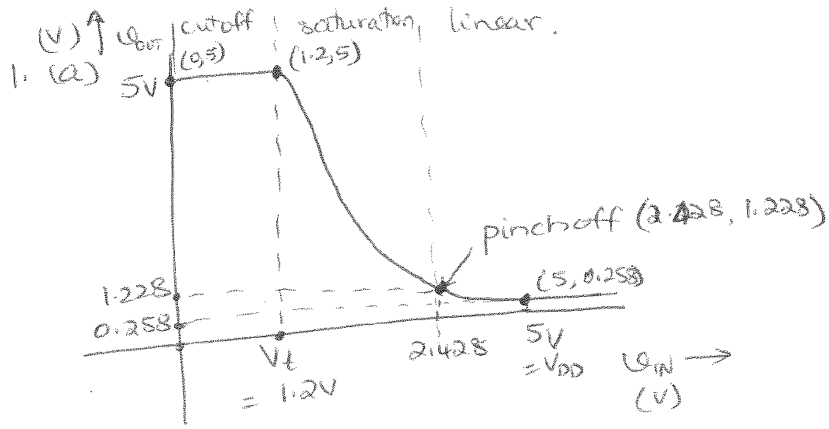
1. (a)



@ pinch off $\quad V_{DS} = V_{GS} - V_T$

$$i_D = \frac{1}{2} k' \frac{W}{L} (V_{GS} - V_T)^2 = \frac{V_{DD} - V_{DS}}{R_D}$$

$$\frac{1}{2} * 40\frac{\mu A}{V^2} * \frac{25\mu}{5\mu} * (v_{DS}^2) = \frac{5V - v_{DS}}{25K\Omega}$$

$$2.5\, v_{DS}^2 = 5 - v_{DS}$$

$$\frac{-1 \pm \sqrt{1^2 - 4*(-5)*2.5}}{2*2.5}$$

$$2.5 v_{DS}^2 + v_{DS} - 5 = 0$$

$$v_{DS} = \frac{-1 \pm \sqrt{51}}{5} \qquad v_{DS} = 1.228$$

$$v_{GS} = v_{DS} + V_T = 1.228 + 1.2 = 2.428$$

When $v_{IN} = 5V$. M1 linear region

$$\frac{V_{DD} - v_{DS}}{R_D} = k' \frac{W}{L} \left((v_{GS} - V_T) v_{DS} - \frac{v_{DS}^2}{2} \right)$$

$$\frac{5 - v_{DS}}{25K} = 40\frac{\mu A}{V^2} \frac{25}{5} \left((5 - 1.2) v_{DS} - \frac{v_{DS}^2}{2} \right)$$

$$5 - v_{DS} = 5 \left[3.8 v_{DS} - \frac{v_{DS}^2}{2} \right]$$

$$2.5 v_{DS}^2 - 19 v_{DS} - v_{DS} + 5 = 0$$

$$v_{DS}^2 - 8 v_{DS} + 2 = 0$$

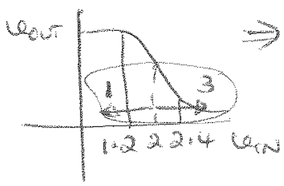
$$v_{DS} = \frac{8 \pm \sqrt{64 - 4*2}}{2} = +0.258$$

(b) (i) (ii) (iii) $V_{IN} = V_{GS} = 1V < V_T$ device off

$\Rightarrow$ cannot function as amplifier $\underline{V_{OUT} = 5V \text{ always}}$

For (iv)(v)(vi) $V_{IN} = V_{GS} = 2V$ M1 in saturation region.

(iv) $V_{GS} = 2V$ $\quad$ (iv) $v_{gs} = 1$



$\Rightarrow v_{IN}$ $\to$ 3V $(2+1)$ } goes outside saturation to linear

$\to$ 1V $(2-1)$ } goes outside saturation to cutof

So (iv) provides distorted output.

(v) $V_{GS} = 2V$ $\quad$ $v_{gs} = 0.25$ $\quad$ 2.25, 1.25 } So M1 stays saturated.

$v_{gs} \ll 2(V_{GS} - V_T)$ for small signal approximation to be true & to keep non-linear distortion low.

$0.25 \ll 2(2-1.2)$
$\frac{1}{10}$th

$0.25 \ll 1.6$ $\quad$ $0.25 \leq \frac{1}{10}\text{th } 1.6$ $\quad$ NO
$\frac{1}{10}$th

So (v) not an input to provide undistorted output.

(vi) $V_{GS} = 2 + 0.1 \cos 2\pi 10^3 t$ $\to$ M1 in saturation. small signal approx ✓

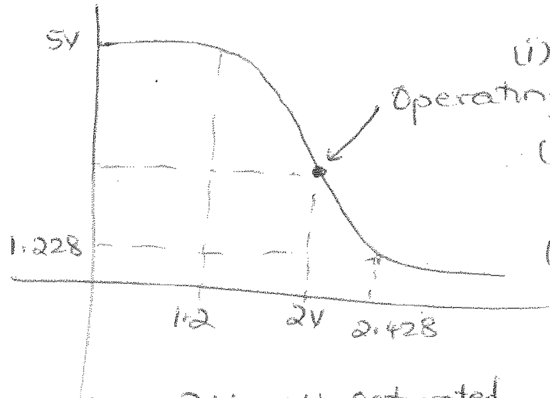
v_{IN} swings 2.1 to 1.9

$v_{gs} = 0.1 < 0.16$ ✓

So Pick $\boxed{(vi)}$.

(3)

(c)



(i) Operating point.

(ii) $V_{OV} = V_{GS} - V_T = 2 - 1.2$

$V_{OV} = 0.8V$

(iii) $g_m = k' \frac{W}{L} (V_{GS} - V_T)$

$= 40 \frac{\mu A}{V^2} * \frac{25\mu}{5\mu} (2 - 1.2)$

$g_m = 160 \frac{\mu A}{V}$

(v) @ $V_{GS} = 2V$ M1 saturated.

$I_D = \frac{1}{2} * 40\mu A * \frac{25\mu}{5\mu} (2 - 1.2)^2$

$= 64\mu A$

$V_{DS} = V_{OUT} = 5 - 64\mu A * 25K$

$= 5 - 1.6 = 3.4V$

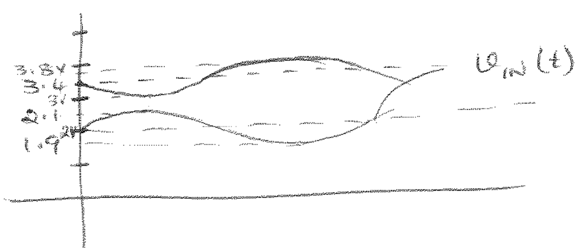
(iv) gain $= -g_m R_D$

$= -160 \frac{\mu A}{V} * 25K$

$A_v = -4 \, V/V$

$v_{out} = v_{ds} = A_v * v_{in} = -4 * 0.1 \cos\omega t = -0.4 \cos\omega t$

$\therefore v_{IN} = 2 + 0.1 \cos 2\pi 10^3 t \qquad v_{OUT} = 3.4 - 0.4 \cos\omega t$



(vi) $\frac{V_{gs}}{4 V_{OV}} * 100$

$= \frac{0.1}{4 * 0.8} * 100$

$= 3.125\%$