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Q3- Figure-1a shows an amplifier circuit employing a MOSFET. For the MOSFET, β=2mA/V^2 and V_{TH}=2V are given.

a) V_{DQ} is required to be 0V at the operating point. Find I_{DQ} and R_S. (10Points)

b) Find the DC power dissipated on the MOSFET. (10Points)

c) Find ac input and output resistances of the circuit (ri and ro). (10Points)

d) Draw the ac output voltage vo(t) for the ac input voltage vi(t) given in Figure-1b. (10Points)

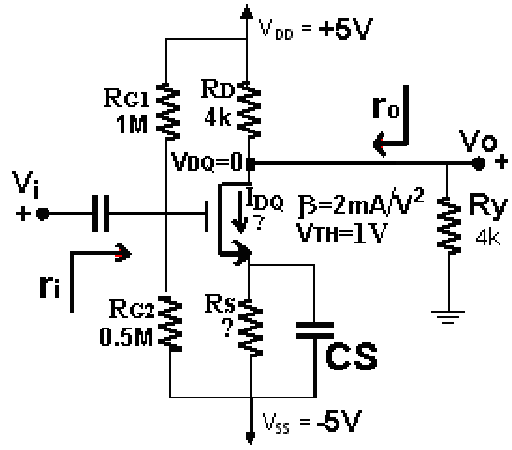

Figure-1a

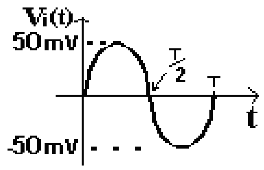

Figure-1b

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Q4- For the MOS transistors given in Figure-2a, $\beta_1=\beta_2=\beta_3$=1mA/V^2, $V_{TH1}=V_{TH2}$= -1V and V_{TH3}=1V are given.

a) Find drain currents of the transistors for Vi=0V. (10Points)

b) Find ac gain (vo/vi) of the circuit. (10Points)

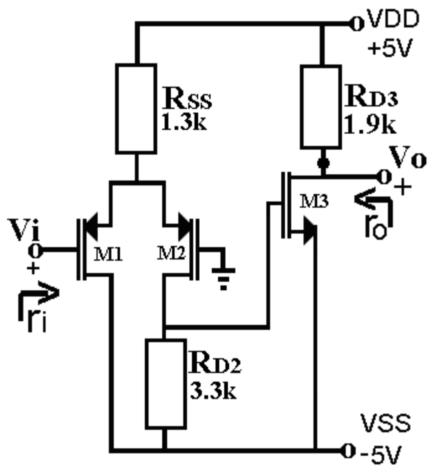


Figure-2a

c) A PMOS transistor will be used in place of R_{SS} (Figure-2b). DC values of the circuit (the values found in a) are required not to change. Find the gate bias voltage (V_{GB}) of the transistor (β_4=2mA/V^2, V_{TH4}= -1V and V_{A4}=100V) . (10Points)

d) Find the ac gain for the new case. (10Points)

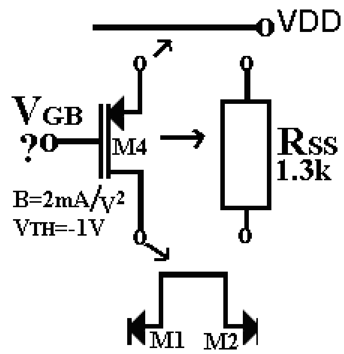


Figure-2b

C-3-

a) $V_{RD} = V_{DD} - V_{DQ} = 5 - 0 = 5V$

Voltage accross R_D

$$I_{RD} = \frac{V_{RD}}{R_D} = \frac{5V}{4k} = 1{,}25\,mA$$

$I_D = I_{RD} = 1{,}25\,mA$ (from the circuit topology)

Transistor is probably in the saturation mode.

Thus, $I_D = \frac{\beta}{2}(V_{GS} - V_{Th})^2 = 1{,}25\,mA$

$$V_{GS} = +\sqrt{\frac{2I_D}{\beta}} + V_{Th} \cong 3{,}12V$$

$$V_G = \frac{R_{G2}}{R_{G1}+R_{G2}}(V_{DD} - V_{SS}) + V_{SS} = \frac{0{,}5}{1{,}5}10 - 5$$

$$V_G \cong -1{,}67V$$

$$V_S = V_G - V_{GS} = -1{,}67 - 3{,}12 \cong -4{,}8V$$

$$I_{RS} = I_D = 1{,}25\,mA \Rightarrow R_S = \frac{V_{RS}}{I_{RS}} = \frac{-4{,}8+5V}{1{,}25mA}$$

$$R_S \cong 160\Omega$$

b) $V_{DQ} = 0V \quad V_{SQ} = -4{,}8V \rightarrow V_{DS} = 4{,}8V$

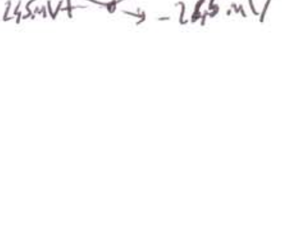
$$P_{Tr} = I_D \cdot V_{DS} = 1{,}25mA \cdot 4{,}8V \cong 6mW$$

c) $r_i = R_{G1} // R_{G2} = 1M // 0{,}5M \cong 333k$

$r_o \cong R_D = 4k$

d) $\frac{v_o}{v_i} = \frac{v_d}{v_g} = \frac{-g_m R_d}{1+g_m R_S}$ $\quad R_d = R_D // R_Y$, $R_S = 0$, $g_m = \sqrt{2\beta I_D} \cong 2{,}45mS$

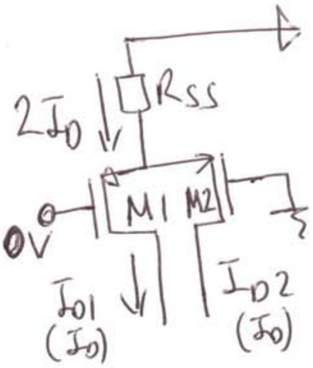
$\rightarrow \frac{v_o}{v_i} \cong -4{,}9 \rightarrow v_o = -4{,}9 \cdot v_i$



C-4- a) M1 is in the saturation mode, since its drain is at the lowest potential.

M2 is probably in the saturation mode.

Thus, $I_{D1} = I_{D2}$ (probably)



$$V_{GS1} = V_{G1} - V_{S1}$$

$$= 0 - (V_{DD} - 2I_D \cdot R_{SS})$$

$$I_D = \frac{\beta}{2}\left(V_{GS} - V_{Th}\right)^2$$

$$= \frac{1mA/V^2}{2}\Big(\underbrace{-5+2I_D \cdot R_{SS}}_{V_{GS}} - (-1)\Big)^2$$

$$I_D = \frac{1m}{2}\left(16 - 20{,}8\overset{10^3}{k} \cdot I_D + 6{,}76\overset{10^6}{M} \cdot I_D^2\right)$$

$$\Delta = 21{,}84 \qquad I_{D1,2} = \frac{-b \mp \sqrt{\Delta}}{2a} = \frac{11{,}4 \mp \sqrt{21{,}84}}{2 \times 3{,}38k}$$

1mA — M2 is in the saturation mode for $I_D = 1mA$

~~2,38mA~~ — $V_{S1} < V_{G1}$, $V_{GS} > V_T$, Cut-off mode

$$I_{D1} = I_{D2} = 1mA$$

M3 is probably in the saturation mode.

$$V_{G3} = V_{RD2} + V_{SS} = I_{D2} \cdot R_{D2} + V_{SS}$$
$$\cong 1mA \cdot 3{,}3k - 5 = -1{,}7V$$

$$V_{GS3} = V_{G3} - V_{S3} = -1{,}7 + 5 = 3{,}3V$$

$$I_{D3} = \frac{\beta}{2}\left(V_{GS3} - V_{Th3}\right)^2$$
$$\cong \frac{1m}{2}\left(3{,}3 - 1\right)^2 \cong 2{,}65mA$$

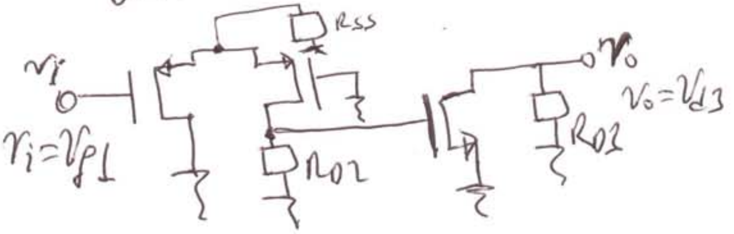
$$V_{D3} = V_{DD} - V_{RD3} = \underset{5V}{V_{DD}} - \underset{2{,}65mA}{I_{D3}} \cdot \underset{1{,}9k}{R_{D3}} \cong 0$$

(Check the condition)
$$V_{GD3} = V_{G3} - V_{D3} = -1{,}7 - 0 = -1{,}7$$
$$V_{GD3} < V_{Th3}$$
$$-1{,}7 < 1 \Rightarrow$$ M3 is in the saturation mode.
$$I_{D3} = 2{,}65mA$$

b) $g_{m1} = \sqrt{2\beta I_{D1}} \cong 1{,}41mS$

$g_{m1} = g_{m2} = 1{,}41mS$

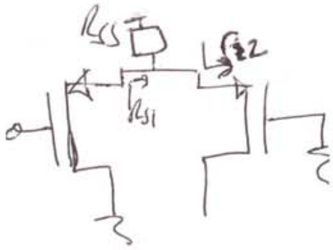
$g_{m3} = \sqrt{2\beta I_{D2}} \cong 2{,}3mS$



$$\frac{v_o}{v_i} = \frac{v_{s1}}{v_{g1}} \cdot \frac{v_{d2}}{v_{s2}} \cdot \frac{v_{d3}}{v_{g3}}$$

Source follower, Common-gate, Common-source

$$\frac{v_{s1}}{v_{g1}} = \frac{g_{m1} \cdot R_{s1}}{1 + g_{m1} R_{s1}}$$



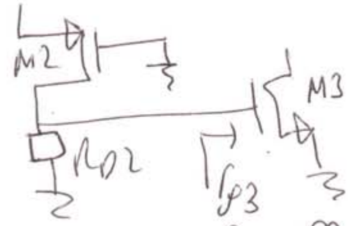
$$R_{s1} = R_{ss} // r_{i2}$$

$$r_{i2} = \frac{1}{g_{m2}} \cong 710\Omega$$

$$R_{s1} = 1{,}3k // 710\Omega \cong 460\Omega$$

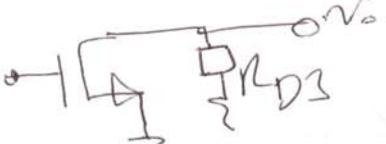
$$\frac{v_{s1}}{v_{g1}} = \frac{1{,}41m \cdot 0{,}46k}{1 + 1{,}41m \cdot 0{,}46k} \cong 0{,}39$$

$$\frac{v_{d2}}{v_{s2}} = g_{m2} \cdot R_{d2} = g_{m2} \cdot R_{D2} = 1{,}41m \cdot 3{,}3k = 4{,}65$$



$r_{g3} = \infty$

$$\frac{v_{d3}}{v_{g3}} = \frac{-g_{m3} \cdot R_{d3}}{1 + g_{m3} R_{s3}}$$



$R_{d3} = R_{D3}$

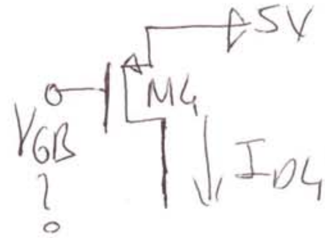
$R_{s3} = 0$

$$\frac{v_{d3}}{v_{g3}} = \frac{-2{,}3m \cdot 1{,}9k}{1 + 0} = -4{,}37$$

$$\frac{v_o}{v_i} = 0{,}39 \times 4{,}65 \times (-4{,}37) \cong -7{,}9$$

This transistor is not a amplification transistor. It is used as a DC current source the output resistance of which is not infinite. .

4 c)



$I_{D4} = I_{D1} + I_{D2} = 2mA$

M4 should be in the saturation mode.

$$I_{D4} = \frac{\beta_4}{2}\left(V_{GS4} - V_{Th4}\right)^2$$

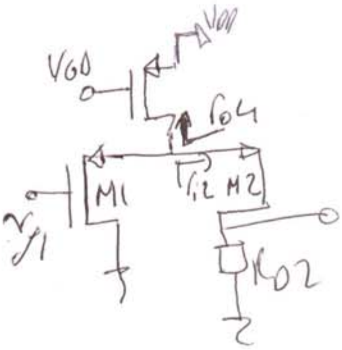
$$V_{GS4} = -\sqrt{\frac{2I_{D4}}{\beta_4}} + V_{Th4} = -2{,}41V$$

$$V_{GS4} = V_{G4} - V_{S4} = V_{GB} - V_{DD} = -2{,}41V$$

$$V_{GB} = -2{,}41 + V_{DD}$$

$$V_{GB} = 2{,}59\,V$$

d) Only $\frac{v_{s1}}{v_{g1}}$ changes, the others does not change.



$$\frac{v_{s1}}{v_{g1}} = \frac{g_{m1}R_{S1}}{1+g_{m1}R_{S1}} \qquad R_{S1} = r_{o4} // r_{i2}$$

$$r_{o4} = \frac{V_{A4}}{I_{D4}} = \frac{100V}{2mA} = 50k$$

$$R_{S1} = r_{o4} // r_{i2} = 50k // 710\Omega \cong 710\Omega$$

$$\frac{v_{s1}}{v_{g1}} = \frac{1{,}41m \cdot 0{,}71k}{1 + 1{,}41m \cdot 0{,}71k} \cong 0{,}5$$

$$\frac{v_o}{v_i} = 0{,}5 \times 4{,}65 \times (-4{,}37) \cong -10$$