Table 5.1

		Typical Parameter Value		
Parameter Symbol	Parameter Description	n-Channel	p-Channel	Units
V_{T0}	Threshold voltage(V_{BS}=0)	0.7	-0.8	V
K	Transconductance parameter(in saturation)	134	50	$\mu A/V^2$
γ	Bulk threshold parameter	0.45	0.4	$V^{1/2}$
λ	Channel length modulation parameter	0.1	0.2	V^{-1}
2|ϕ_F|	Surface potential at strong inversion	0.9	0.8	V

$K = \mu C_{OX}$

5.1 Assume that W/L ratios of Figure 5.1 are $(W/L)_1$ = 2μm/1μm and $(W/L)_2 = (W/L)_3 = (W/L)_4$ =1μm/1μm. Find the dc value of v_{IN} that will give a dc current in M1 of 110μA. Calculate the small signal voltage gain and output resistance using the parameters of Table 5.1. Assume λ=γ=0.

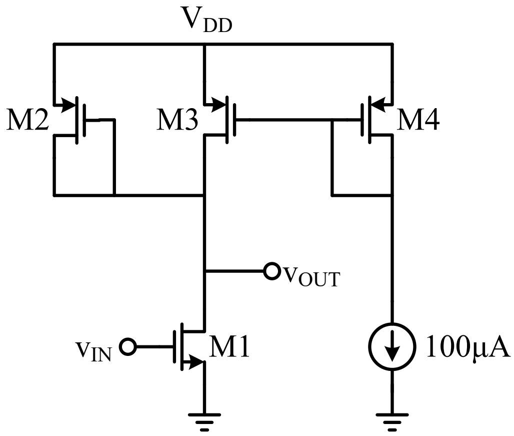

Figure 5.1

Answer:

$$I_{D1} = \frac{1}{2} K_N (\frac{W}{L})_1 (V_{in} - V_{TH1})^2$$

$$110\mu = \frac{1}{2} \times (134\mu) \times \frac{2}{1} \times (V_{in} - 0.7)^2$$

$V_{in} = 1.61V$

$I_{D3} = I_{D4} = 100\mu A$

$I_{D2} = I_{D1} - I_{D3} = 10\mu A$

$$A_v \cong -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{K_N}{K_P}\frac{(W/L)_1}{(W/L)_2}\frac{I_{D1}}{I_{D2}}} = -\sqrt{\frac{134\mu}{50\mu}\times\frac{2}{1}\times\frac{110\mu}{10\mu}} = -7.68$$

$$R_{out} \cong \frac{1}{g_{m2}} = \frac{1}{\sqrt{2K_P(W/L)_2 I_{D2}}} = \frac{1}{\sqrt{2\times 50\times 10^{-6}\times 1\times 10\times 10^{-6}}} = 31.6K\Omega$$

5.2 Suppose the common-source stage of Fig 5.2 is to provide an output swing from 1V to 2.5V. Assume that $(W/L)_1 = 50/0.5$, $R_D = 2k\Omega$, $V_{DD} = 3V$ and $\lambda = 0$. Use model parameters in Table 5.1.

a) Calculate the input voltages that yield $V_{out} = 1V$ and $V_{out} = 2.5V$.

b) Calculate the drain current and the transconductance of M_1 for both cases.

c) How much does the small-signal gain, $g_m R_D$, vary as the output goes from 1V to 2.5V?

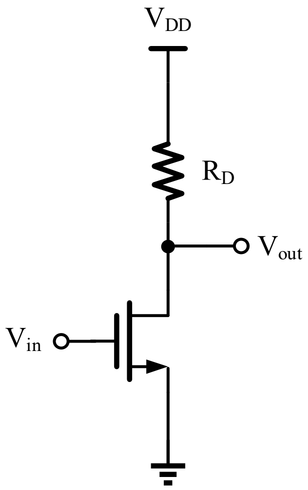

Figure 5.2

Answer:

a), b):

Vout=1V 时：

$$I_{D1} = \frac{V_{DD} - V_{out}}{R_D} = 1mA$$

$$V_{in} = V_{THN0} + \sqrt{\frac{2I_{D1}}{K_N\left(\frac{W}{L}\right)_1}} = 1.086V$$

$$g_{m1} = \sqrt{2K_N\left(\frac{W}{L}\right)_1 I_D} = 5.18\times 10^{-3}\mathrm{S}$$

Vout=2.5V 时：

$$I_{D1} = \frac{V_{DD} - V_{out}}{R_D} = 0.25mA$$

$$V_{in} = V_{THN0} + \sqrt{\frac{2I_{D1}}{K_N\left(\frac{W}{L}\right)_1}} = 0.893V$$

$$g_{m1} = \sqrt{2K_N\left(\frac{W}{L}\right)_1 I_D} = 2.588 \times 10^{-3}\mathrm{S}$$

c):

$$\Delta g_m R_D = 5.18$$

5.3 Consider the circuit of Fig 5.3 with $(W/L)_1 = 50/0.5$ and $(W/L)_2 = 10/0.5$. Assume that $\lambda = \gamma = 0$, $V_{DD} = 3V$.

a) At what input voltage is M_1 at the edge of the triode region? What is the small-signal gain under this condition?

b) When V_{out} is 0.66 V, what is the small-signal gain under this condition?

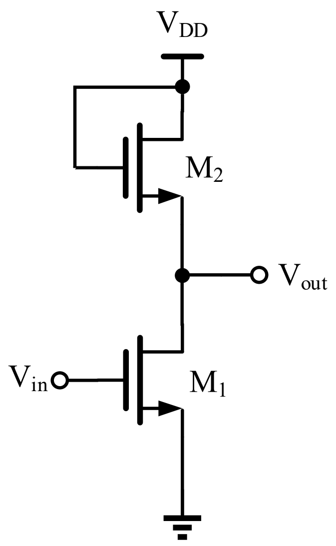

Figure 5.3

Answer:

a)

M_1 at the edge of the triode region:

$$V_{out} = V_{in} - V_{TH1}$$

$$I_{D1} = I_{D2} = \frac{1}{2}K_N\left(\frac{W}{L}\right)_1 (V_{in} - V_{TH1})^2 = \frac{1}{2}K_N\left(\frac{W}{L}\right)_2 (V_{DD} - V_{out} - V_{TH2})^2$$

$$V_{in} = 1.41V, \quad V_{out} = 0.71V$$

$$A_V = -\sqrt{\frac{2K_N\left(\frac{W}{L}\right)_1 I_{D1}}{2K_N\left(\frac{W}{L}\right)_2 I_{D2}}} = -2.236$$

b)

Vout=0.66V<0.71V, M_1 is working in the triode region

$$\frac{1}{2}K_N\left(\frac{W}{L}\right)_2 (V_{DD} - V_{out} - V_{TH2})^2 = K_N\left(\frac{W}{L}\right)_1 \left[(V_{in} - V_{TH1})V_{out} - \frac{V_{out}^2}{2}\right]$$

$$V_{in} = 1.84V$$

$$I_D = K_N\left(\frac{W}{L}\right)_1\left[(V_{in} - V_{TH1})V_{out} - \frac{V_{out}^2}{2}\right]$$

$$\frac{\partial I_D}{\partial V_{in}} = K_N\left(\frac{W}{L}\right)_1 V_{out}$$

$$A_V = -\frac{g_{m1}}{g_{m2}} = -\frac{K_N\left(\frac{W}{L}\right)_1 V_{out}}{K_N\left(\frac{W}{L}\right)_2 (V_{DD} - V_{out} - V_{TH2})} = -2.015$$

5.4 In the circuit of Fig 5.4, $(W/L)_1 = 20/0.5$, $I_1 = 1mA$, and $I_S = 0.75mA$. Assuming $\lambda = 0$, $V_{DD} = 3V$, calculate $(W/L)_2$ such that M_1 is at the edge of triode region. What is the small-signal voltage gain under this condition? Use model parameters in Table 5.1.

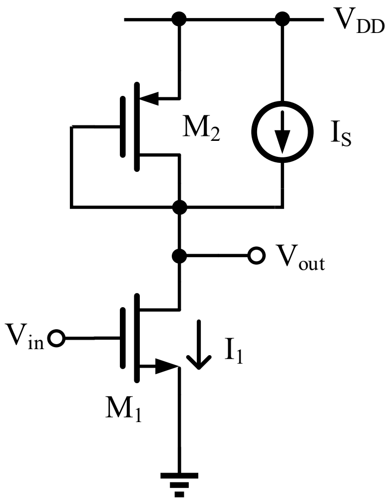

Figure 5.4

Answer:

M_1 at the edge of the triode region：

$$V_{out} = V_{in} - V_{TH1}$$

$$\frac{1}{2}K_P\left(\frac{W}{L}\right)_2 (V_{DD} - V_{out} - |V_{TH2}|)^2 + I_S = \frac{1}{2}K_N\left(\frac{W}{L}\right)_1 (V_{in} - V_{TH1})^2 = 10^{-3}$$

$$V_{in} = 1.311, \ \left(\frac{W}{L}\right)_2 = 3.961$$

$$A_V = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{K_N\left(\frac{W}{L}\right)_1 I_1}{K_P\left(\frac{W}{L}\right)_2 I_2}} = -10.4$$

5.5 Consider the circuit of Fig 5.5 with $(W/L)_1 = 50/0.5$, $R_D = 2k\Omega$, and $R_S = 200\Omega$, $V_{DD} = 3V$. Use model parameters in Table 5.1.

a) Calculate the small-signal voltage gain if $I_D = 0.5mA$.

b) Assuming that $\lambda = \gamma = 0$, calculate the input voltage that places M1 at the edge of the triode region. What is the gain under this condition?

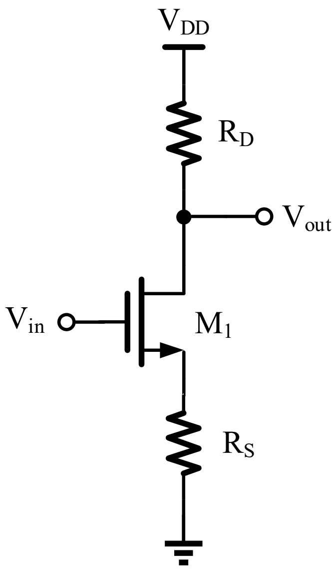

Figure 5.5

Answer:

a):

$$V_S = R_S I_D = 0.1V$$

$$V_{TH1} = V_{TH1,0} + \gamma\left(\sqrt{2|\varphi_F| + V_{SB}} - \sqrt{2|\varphi_F|}\right) = 0.7 + 0.45\left(\sqrt{0.9+0.1} - \sqrt{0.9}\right) = 0.723$$

$$V_{out} = V_{DD} - R_D I_D = 2V$$

$$V_{DS} = 2 - 0.1 = 1.9V$$

$$g_m = \sqrt{2K_N\left(\frac{W}{L}\right)_1 (1+\lambda V_{DS}) I_D} = 3.993 \times 10^{-3}$$

$$A_V = -\frac{g_m R_D}{1 + g_m R_S} = -4.44$$

b):

M1 at the edge of the triode region

$$V_{out} = V_{in} - V_{TH1}$$

$$V_{in} = V_{GS1} + R_S I_D$$

$$V_{DD} - R_D I_D = V_{out}$$

$$V_{DD} - (R_S + R_D) I_D = V_{GS1} - V_{TH1}$$

$$I_D = \frac{1}{2} K_N \left(\frac{W}{L}\right)_1 (V_{GS1} - V_{TH1})^2 = \frac{1}{2} K_N \left(\frac{W}{L}\right)_1 [V_{DD} - (R_S + R_D) I_D]^2$$

$I_{D1} = 1.58mA$（$V_{GS} < V_{TH}$，eliminate），$I_{D2} = 1.17mA$

$$V_{in} = V_{DD} - R_D I_D + V_{TH1} = 1.36V$$

$$g_{m1} = \sqrt{2K_N\left(\frac{W}{L}\right)_1 I_D} = 5.60 \times 10^{-3}$$

$$G_m = \frac{g_{m1}}{1 + g_{m1}R_S} = 2.642 \times 10^{-3}$$

$$A_V = -G_m R_D = -5.283$$