习 题 3

Table 3.1

		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}
$2\lvert\phi_F\rvert$	Surface potential at strong inversion	0.9	0.8	V

3-1 Suppose the common-source stage of Fig 3.1 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 3.1.

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) While output goes from 1V to 2.5V, calculate how much the small-signal gain(g_mR_D) varies.

d) Using λ in Table 3.1 and $V_{out} = 1V$, calculate the intrinsic gain of the NMOS device.

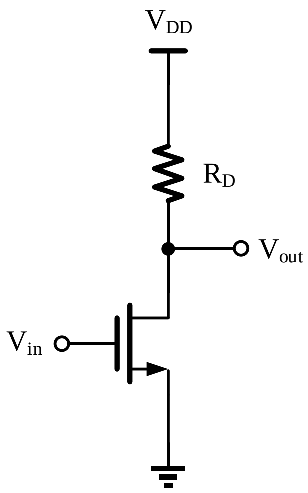


Figure 3.1

解：

a), b):

Vout=1V 时：

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

$$V_{in} = V_{TH1} + \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} = 1.086V$$

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

Vout=2.5V 时：

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

$$V_{in} = V_{TH1} + \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} = 0.893V$$

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

c)：

$$\Delta g_m R_D = 5.18$$

d):

$$r_o = \frac{1}{\lambda_n I_D} = \frac{1}{0.1 \times 1 \times 10^{-3}} = 1 \times 10^4 \Omega$$

$$g_m r_0 = 51.8$$

3-2 Consider the circuit of Fig 3.2 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 0.66V, what is the small-signal gain under this condition?

c) Calculate the maximum output voltage swing while both devices are saturated.

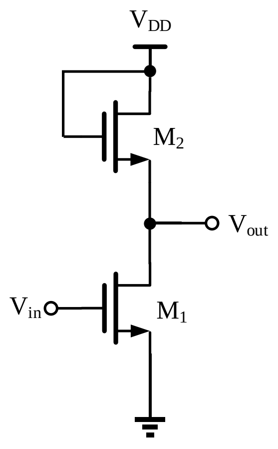


Figure 3.2

解：

a)

M_1 在临界点：

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

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

解得$V_{in}=1.41V$，此时$V_{out}=0.71V$

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

b)

由于 Vout=0.66V＜0.71V，所以 M_1 工作在三极管区

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

解得$V_{in}=1.84V$

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

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

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

c)

若 M_2 处于饱和区临界，则$V_{out}=V_{DD}-V_{TH1}=3-0.7=2.3V$

由 a）可知，最大输出摆幅为 2.3-0.71=1.59V

3-3 In the circuit of Fig 3.3, $(W/L)_1 = 20/0.5$, $I_1 = 1mA$, 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 3.1.

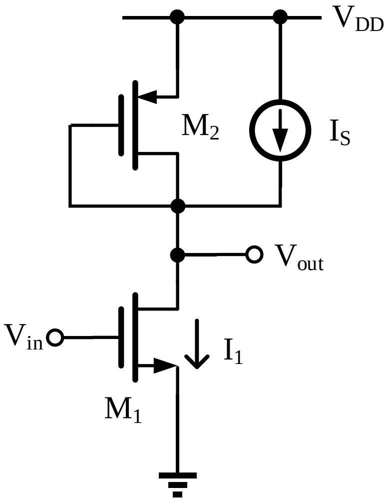


Figure 3.3

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

且：

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

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

所以：$A_V = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{\mu_n C_{ox}\left(\frac{W}{L}\right)_1 I_1}{\mu_p C_{ox}\left(\frac{W}{L}\right)_2 I_2}} = -10.4$

3-4 Consider the circuit of Fig 3.4 with $(W/L)_1 = 50/0.5$, $R_D = 2k\Omega$, and $R_S = 200\Omega$, $V_{DD} = 3V$. Use model parameters in Table 3.1.

(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?

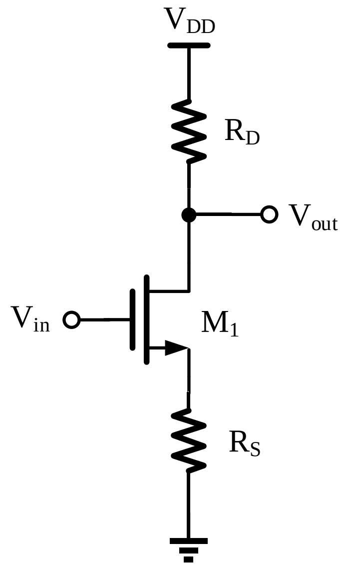


Figure 3.4

解：

a)：

$$V_S = R_S I_D = 0.1V$$

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

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

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

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

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

b):

M_1 在临界点，所以

$$V_{out} = V_{in} - V_{TH1}$$
$$V_{in} = V_{GS1} + R_S I_D$$
$$V_{DD} - R_D I_D = V_{out}$$

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

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

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

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

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

$$G_m = \frac{g_{m1}}{1 + g_{m1} R_S} = 2.642 \times 10^{-3}$$
$$A_V = -G_m R_D = -5.283$$

思考题：

3-5 Three versions of a common source amplifier are shown in Fig.3.5. Assume that the biasing currents in each circuit are equal, the capacitors of the output node in each circuit are equal, all transistor work in strong-inversion mode.

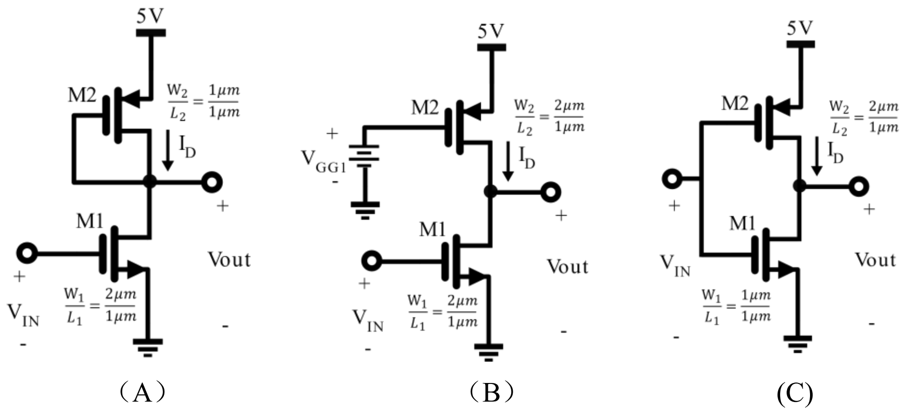
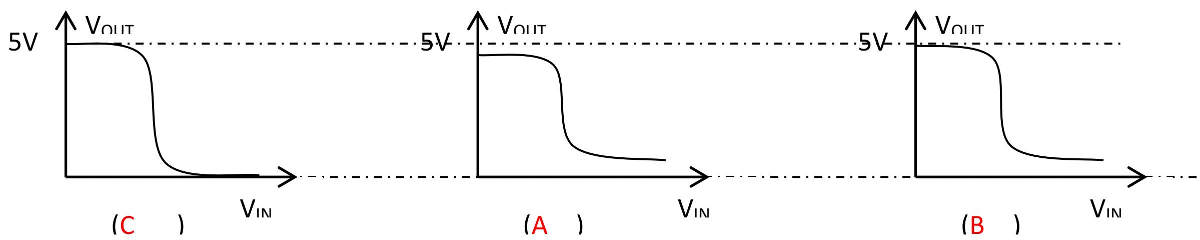


Figure 3.5

(a) Please select the corresponding voltage transfer characteristic and Bode plot in Fig 3.6.. Give your reasons.



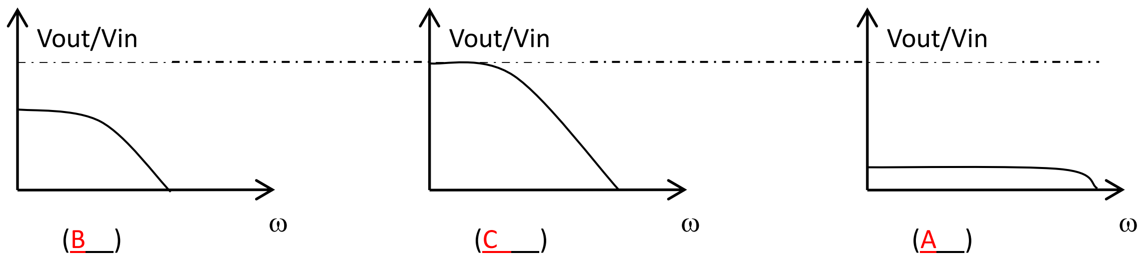


Figure 3.6

(b) If increase the W/L of M1 in circuit of Fig 3.5, how does Vout (MIN) change (decrease, increase, remain constant or be uncertain)? Give your reasons.

(c) If increase the biasing current in circuit of Fig 3.5, how does Vout/Vin change (decrease, increase, remain constant or be uncertain)? Give your reasons.

Solutions:

(b)

Increase the W/L of M1 in circuit A， Vout(MIN) _***decreases / increases / remains constant ;***

Increase the W/L of M1 in circuit B， Vout(MIN) _***decreases / increases / remains constant ;***

Increase the W/L of M1 in circuit C， Vout(MIN) _***decreases / increases / remains constant ;***

(c)

Increase the biasing current of circuit A, Vout/Vin would_***decreases / increases / remains constant;***

Increase the biasing current of circuit B, Vout/Vin would _***decreases / increases / remains constant;***

Increase the biasing current of circuit C, Vout/Vin would _***decreases / increases / remains constant;***