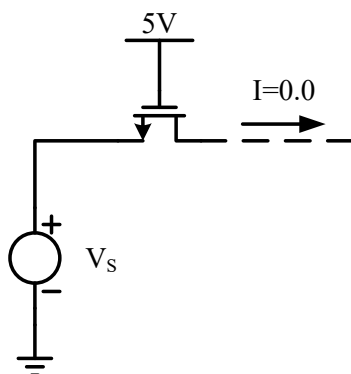




## Exercise 2

2-1 The circuit shown in Fig.2.1 illustrates a single-channel MOS resistor with a W/L of  $2\mu\text{m}/2\mu\text{m}$ . Using Table.2.1 model parameters calculate the small-signal on resistance of the MOS transistor at various values for  $V_S$  and fill in the table below. (Note that the transistor was in linear region,  $V_B=0$ ,  $I_{DS}=0$ )



$V_S(\text{V})$	$R(\Omega)$
0.0	
1.0	
2.0	
3.0	
4.0	
5.0	

Fig.2. 1

### Answer

The equation for threshold voltage is represented with absolute values so that it can be applied to n-channel or p-channel transistors without confusion.

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}]$$

$$r_{on} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)}$$

For n-channel device

$$V_{T0} = 0.7 \quad \gamma = 0.45 \quad 2|\Phi_F| = 0.9 \quad K = 134$$

(1) When  $V_S = 0, V_{GS} = 5$  and  $V_{SB} = 0$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 0.7$$

$$r_{on} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 1.736K\Omega$$

(2) When  $V_S = 1, V_{GS} = 4$  and  $V_{SB} = 1$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 0.893$$

$$r_{on} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 2.402K\Omega$$

(3) When  $V_S = 2, V_{GS} = 3$  and  $V_{SB} = 2$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.039$$

$$r_{on} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 3.806K\Omega$$

(4) When  $V_S = 3, V_{GS} = 2$  and  $V_{SB} = 3$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.162$$

$$r_{on} = \frac{1}{\partial I_D / \partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 8.905K\Omega$$

(5) When  $V_S = 4, V_{GS} = 1$  and  $V_{SB} = 4$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.269$$

$V_{GS} < V_T$  The device is cutoff, so  $r_{on} = \text{infinity}$

(6) When  $V_S = 5, V_{GS} = 0$  and  $V_{SB} = 5$

The device is cutoff, so  $r_{on} = \text{infinity}$

$V_S(V)$	$R(\Omega)$
0.0	1.736K
1.0	2.402K
2.0	3.806K
3.0	8.905K
4.0	infinity
5.0	infinity

2-2 An NMOS with  $W=50\mu m$  and  $L=0.5\mu m$  operates in the **saturated region** and its layout is folded shown as Fig2.2. Calculate the all capacitances by using the parameters in Table2.2 and  $C_{ox}=3.8 \times 10^{-3} F/m$ ,  $V_R=0.6V$ . Assume that the minimum size (lateral) of S/D region is  $1.5\mu m$

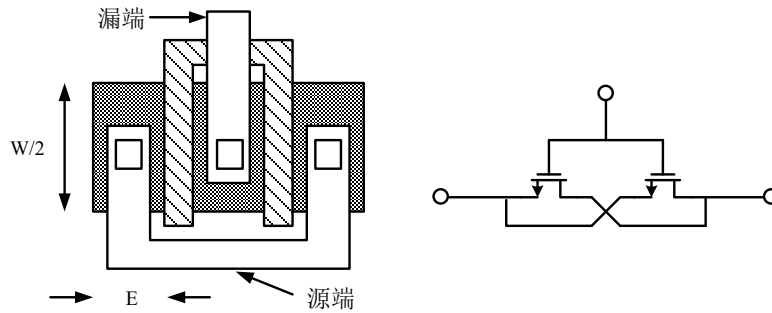


Fig.2. 2

**Answer:**

$$C_{j0} = 0.56 \times \frac{10^{-3}F}{m^2}, C_{jsw0} = 0.35 \times \frac{10^{-11}F}{m}, m_j = 0.45, m_{jsw} = 0.2$$

$$C_{ov} = 0.4 \times \frac{10^{-9}F}{m}, W = 50\mu m, L = 0.5\mu m, L_D = 0.08\mu m, E = 1.5\mu m$$

$$V_R = 0.6V, 2\Phi_F = 0.9V, C_{ox} = 3.8 \times 10^{-3}F/m^2, P_{SUB} = 9 \times 10^8 m^{-3}$$

$$\epsilon_{si} = 11.7 \times 8.85 \times 10^{-12} F/m, q = 1.6 \times 10^{-19} C$$

$$C_j = \frac{C_{j0}}{(1 + V_R/2\Phi_F)^{m_j}} = 0.445 \text{ fF}/\mu m^2 \quad C_{jsw} = \frac{C_{jsw0}}{(1 + V_R/2\Phi_F)^{m_{jsw}}} = 3.16 \times \frac{10^{-3} \text{ fF}}{\mu m}$$

$$L_{eff} = L - 2L_D = 0.34 \mu m \quad C_d = WL_{eff} \sqrt{q\epsilon_{si}P_{SUB}/4\Phi_F} = 1.55 \times 10^{-6} \text{ fF}$$

$$C_{DB} = \frac{W}{2} EC_j + 2\left(\frac{W}{2} + E\right)C_{jsw} = 16.85 \text{ fF}$$

$$C_{SB} = 2\left(\frac{W}{2} EC_j + 2\left(\frac{W}{2} + E\right)C_{jsw}\right) = 33.71 \text{ fF}$$

$$C_{GD} = 2\left(\frac{W}{2} C_{ov}\right) = 20.0 \text{ fF}$$

$$C_{GS} = \frac{2}{3} WL_{eff} C_{ox} + WC_{ov} = 63 \text{ fF}$$

$$C_{GB} = \frac{WL_{eff} C_{ox} C_d}{(WL_{eff} C_{ox} + C_d)} = 1.55 \times 10^{-6} \text{ fF}$$

2-3 There is an N-type current source,  $I_D$  is 0.5mA, and the drain-source voltage  $V_{DS}$  must more than 0.4V when it works as a current source. If the minimum output resistance is 20 K $\Omega$ , determine the length and width of the device by using the parameters in Table.2.2.

**Answer:**

$$\begin{cases} r_o = \frac{1}{\lambda I_D} = 20 \text{ K}\Omega \\ I_D = 0.5 \text{ mA} \end{cases} \Rightarrow \lambda = 0.1$$

From the table 3.2, L can be determined as  $L = 0.5 \mu m$ .

$$L_{eff} = L - 2L_D = 0.5 \mu m - 2 \times 0.08 \mu m = 0.34 \mu m$$

Calculating W

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH})^2, \quad V_{GS} - V_{TH} = V_{DSAT} = 0.4 \text{ V}$$

$$\frac{W}{L_{eff}} = \frac{I_D}{\frac{1}{2} \mu_n C_{ox} (V_{GS} - V_{TH})^2} = \frac{0.5 \times 10^{-3}}{\frac{1}{2} \times 134 \times 10^{-6} \times 0.4^2} = 46.64$$

$$\therefore W = 46.64 L_{eff} = 15.86 \mu m$$

2-4 A “ring” MOS structure is shown in Fig.2.3. Explain how the device operations and estimate its equivalent aspect ratio. Calculate the drain junction capacitance of the structure. (use  $C_j$  and  $C_{jsw}$ )

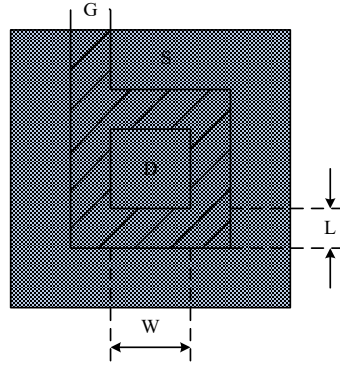


Fig.2. 3

**Answer:**

Width/length ratio is  $4W/L$

$$C_{DB} = W^2 C_j + 4WC_{jsw}$$

2-5 Find the small-signal model ( $g_m$ ,  $g_{mb}$ ,  $g_{ds}$ ) for an n-channel transistor with the drain at 4 V, gate at 4 V, source at 2 V, and the bulk at 0 V. Assume the model parameters from Table.2.1, and  $W/L = 10 \mu\text{m}/1 \mu\text{m}$ .

**Answer:**

$$V_T = V_{T0} + \gamma \left[ \sqrt{2|\Phi_F| + v_{SB}} - \sqrt{2|\Phi_F|} \right]$$

$$V_T = 0.7 + 0.45 \left[ \sqrt{0.9 + 2.0} - \sqrt{0.9} \right] = 1.04$$

$$I_D = \frac{K'W}{L} (v_{GS} - v_T)^2 (1 + \lambda v_{DS})$$

$$I_D = 110 \times 10^{-6} \times 10 \times (2 - 1.04)^2 (1 + 0.1 \times 2) = 1217 \times 10^{-6}$$

$$g_m = \sqrt{4 \frac{K'W}{L} I_D}$$

$$g_m = \sqrt{4 \times 110 \times 10^{-6} \times 10 \times 1217 \times 10^{-6}} = 2.31 \times 10^{-3}$$

$$g_{mb} = g_m \frac{\gamma}{2(2|\Phi_F| + V_{SB})^{\frac{1}{2}}}$$

$$g_{mb} = 2.31 \times 10^{-3} \frac{0.45}{2(0.9 + 2.0)^{\frac{1}{2}}} = 306 \times 10^{-6}$$

$$g_{ds} = \frac{\lambda I_D}{1 + \lambda V_{DS}}$$

$$g_{ds} = 1217 \times 10^{-6} \times 0.1 \div 1.2 = 101.38 \times 10^{-6}$$

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	$\mu A/V^2$
$\gamma$	Bulk threshold parameter	0.45	0.4	$V^{1/2}$
$\lambda$	Channel length modulation parameter	0.1	0.2	$V^{-1}$
$2 \phi_F $	Surface potential at strong inversion	0.9	0.8	V

Table.3.2

NMOS Model			
LEVEL=1	VTO=0.7	GAMMA=0.45	PHI=0.9
PSUB=9e+14	LD=0.08e-6	UO=350	LAMBDA=0.1
TOX=9e-9	PB=0.9	CJ=0.56e-3	CJSW=0.35e-11
MJ=0.45	MJSW=0.2	CGDO=0.4e-9	JS=1.0e-8
PMOS Model			
LEVEL=1	VTO=-0.8	GAMMA=0.4	PHI=0.8
PSUB=5e+14	LD=0.09e-6	UO=100	LAMBDA=0.2
TOX=9e-9	PB=0.9	CJ=0.94e-3	CJSW=0.32e-11
MJ=0.5	MJSW=0.3	CGDO=0.3e-9	JS=0.5e-8

上表给出的是 0.5 $\mu m$  工艺 level 1 MOS SPICE 模型参数的典型值，其中的参数定义如下：

VTO:	V <sub>SB</sub> =0 时的阈值电压	(单位: V)
GAMMA:	体效应系数	(单位: $V^{1/2}$ )
PHI:	$2\phi_F$	(单位: V)
TOX:	栅氧厚度	(单位: m)
NSUB:	衬底掺杂浓度	(单位: $cm^{-3}$ )

LD:	源/漏侧扩散长度	(单位: m)
UO:	沟道迁移率	(单位: $\text{cm}^2/(\text{V}/\text{s})$ )
LAMBDA:	沟道长度调制系数	(单位: $\text{V}^{-1}$ )
CJ:	单位面积的源/漏结电容	(单位: $\text{F}/\text{m}^2$ )
CJSW:	单位长度的源/漏侧壁结电容	(单位: $\text{F}/\text{m}$ )
PB:	源/漏结内建电势	(单位: V)
MJ:	CJ 公式中的幂指数	(无单位)
MJSW:	CJSW 等式中的幂指数	(无单位)
CGDO:	单位宽度的栅/漏交叠电容	(单位: $\text{F}/\text{m}$ )
CGSO:	单位宽度的栅/源交叠电容	(单位: $\text{F}/\text{m}$ )
JS:	源/漏结单位面积的漏电流	(单位: $\text{A}/\text{m}^2$ )