电子学基础——第八次作业

LXQ

2019.11.27

6.38 Construct the small-signal model of the circuits dipicted in Fig. 6-50. Assume all transistors operate in saturation and $\lambda \neq 0$

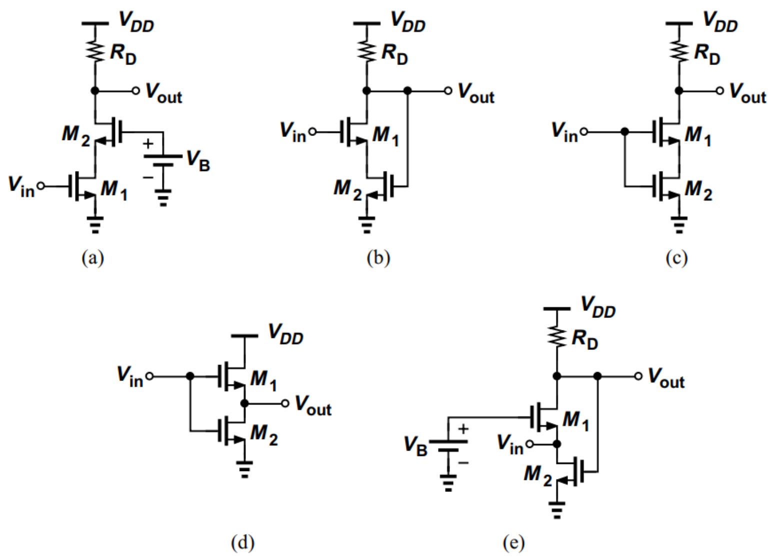

Figure 6-50

解 如图 p6-38 所示。

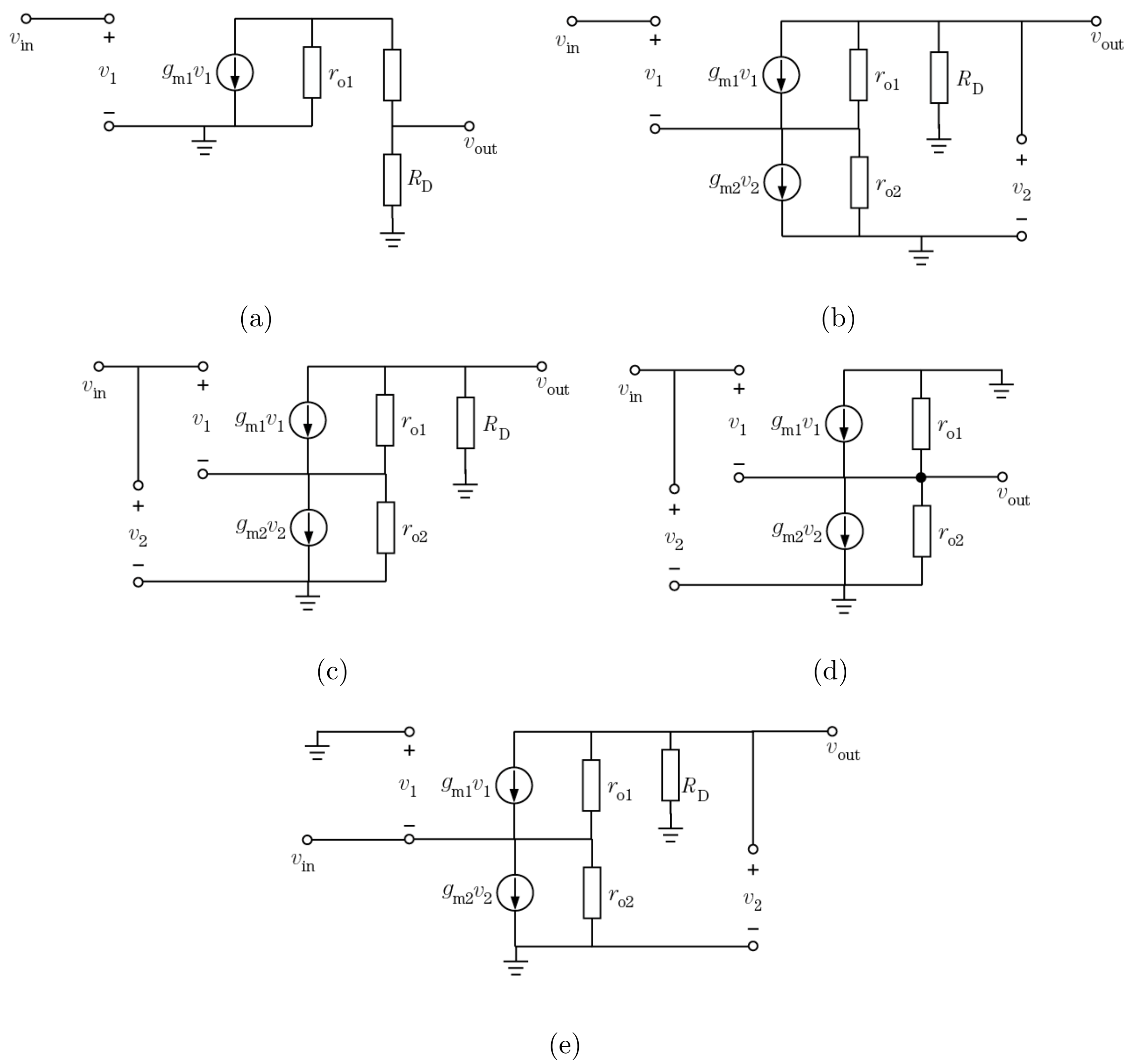

Figure p6-38

6.46 Consider the circuit depicted in Fig. 6-57, where M_1 and M_2 operate in saturation and exhibit channel-length modulation coefficients λ_n and λ_p, respectively.

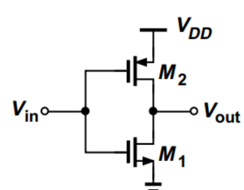

Figure 6-57

(a) Construct the small-signal equivalent circuit and explain why M_1 and M_2 appear in "parallel."
(b) Determine the small-signal voltage gain of the circuit.

解 (a) 小信号电路图如图 p6-46 所示。由于两个MOSFET管的D端即v_{out}，而S端接地，从而在小信号电路中表现为并联。

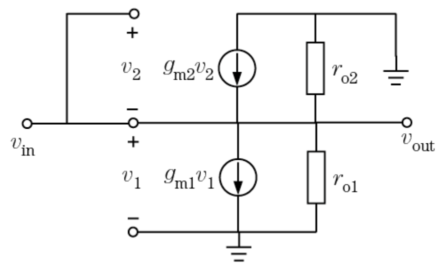

Figure p6-46

(b) 可列得以下方程

$$\begin{cases} \dfrac{v_{out}}{r_{o1}} + \dfrac{v_{out}}{r_{o2}} = g_{m2}v_2 + g_{m2}v_1 \\ v_2 = v_{in} - v_{out} \\ v_1 = v_{in} \end{cases}$$

$$\therefore A_v = \frac{v_{out}}{v_{in}} = \frac{g_{m1} + g_{m2}}{\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}}$$

7.28 If $\lambda \neq 0$, determine the voltage gain of the stages shown in Fig. 7-60.

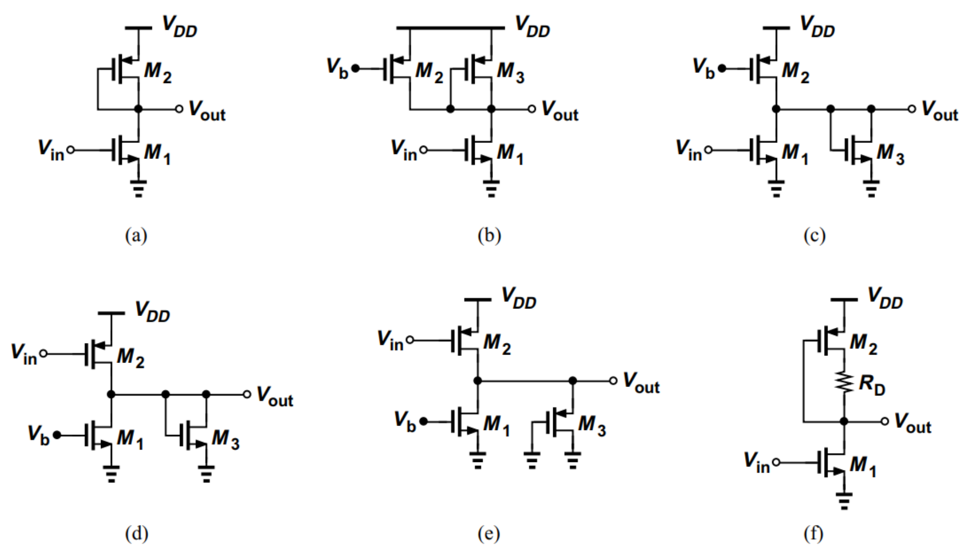

Figure 7-60

解 (a)M_2为二极管接法，可看作电阻$\frac{1}{g_m2}//r_{o2}$，则M_1为共源放大器，

$$A_v = -g_{m1}(r_{o1}//r_{o2}//\frac{1}{g_m2})$$

(b)M_2可视为r_{o2}，M_3为二极管接法，可视为$\frac{1}{g_{m3}}//r_{o3}$，则M_1为共源接法，

$$A_v = -g_{m1}(r_{o1}//r_{o2}//r_{o3}//\frac{1}{g_{m3}})$$

(c)M_2可视为r_{o2}，M_3为二极管接法，可视为$\frac{1}{g_{m3}}//r_{o3}$，则M_1为共源接法，

$$A_v = -g_{m1}(r_{o1}//r_{o2}//r_{o3}//\frac{1}{g_{m3}})$$

(d)M_1可视为r_{o1}，M_3可视为$\frac{1}{g_{m3}}//r_{o3}$，M_2为共源接法，

$$A_v = -g_{m2}(r_{o2}//r_{o1}//r_{o3}//\frac{1}{g_{m3}})$$

(e)M_1可视为r_{o1}，M_3D,G端接地，是为二极管接法，可视为$\frac{1}{g_{m3}}//r_{o3}$，M_2为共源放大器，

$$A_v = -g_{m2}(r_{o2}//r_{o1}//r_{o3}//\frac{1}{g_{m3}})$$

(f)首先考察从M_1的漏端向上看的输出电阻，其小信号电路如图 p7-28-f 所示。可设输入信号为v，产生i的电流。

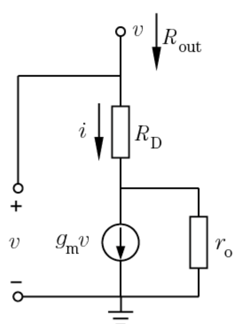

Figure p7-28-f

则

$$iR_D + (i - vg_m)r_o = v$$

$$\therefore R_{out} = \frac{v}{i} = \frac{R_D + r_o}{1 + g_m r_o}$$

从而M_2等效为$r_2 = \frac{v}{i} = \frac{R_D + r_o}{1 + g_m r_o}$，$M_1$为共源接法，则

$$A_v = -g_{m1}(r_{o1}//r_2) = -g_{m1}(r_{o1}//\frac{R_D + r_o}{1 + g_m r_o})$$

7.46 Consider the circuit of Fig. 7-73, where a common-source stage (M_1 and R_{D1}) is followed by a common-gate stage (M_2 and M_{D2}).

(a) Writing $v_{out}/v_{in} = (v_X/v_{in})(v_{out}/v_X)$ and assuming $\lambda = 0$, compute the overall voltage gain.

(b) Simplify the result obtained in (a) if $R_{D1} \to \infty$. Explain why this result is to be expected.

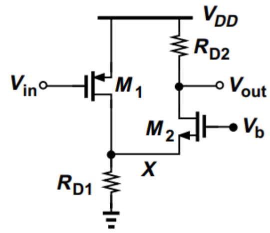

Figure 7-73

解 (a) M_1放大器为共源放大器，负载$R_1 = R_{D1}//\frac{1}{g_{m2}}$则

$$\frac{v_x}{v_{in}} = -g_{m1}(R_{D1}//\frac{1}{g_{m2}})$$

而M_2为共栅放大器，则

$$\frac{v_{out}}{v_x} = g_{m2}R_{D2}$$

从而$\frac{v_{out}}{v_{in}} = -g_{m1}g_{m2}R_{D2}(R_{D1}//\frac{1}{g_{m2}})$

(b)

$$R_{D1} \to \infty, \frac{v_{out}}{v_{in}} \to -g_{m1}R_{D2}$$

$R_{D1} \to \infty$时，原电路中可视R_{D1}为断路，而M_2共栅，可视为导线，则原电路简化为仅有M_1作为共源放大器负载R_{D2}的电路，则$A_v = -g_{m1}R_{D2}$。

7.47 Assuming $\lambda = 0$, calculate the voltage gain of the circuit shown in Fig. 7-74. Explain why this stage is *not* a common-gate amplifier.

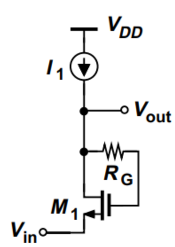

Figure 7-74

解 小信号电路如图 p7-47 所示

$$\begin{cases} v_{in} + v_1 = v_{out} \\ g_m v_1 = 0 \end{cases}$$

$$\therefore v_{in} = v_{out}, A_v = 1$$

该电路不是共栅放大器的原因是栅端和漏端并非直接相连而是通过电阻。

7.55 Determine the voltage gain of the stages shown in Fig. 7-80. Assume $\lambda \neq 0$.

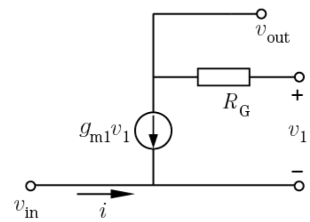

Figure p7-47

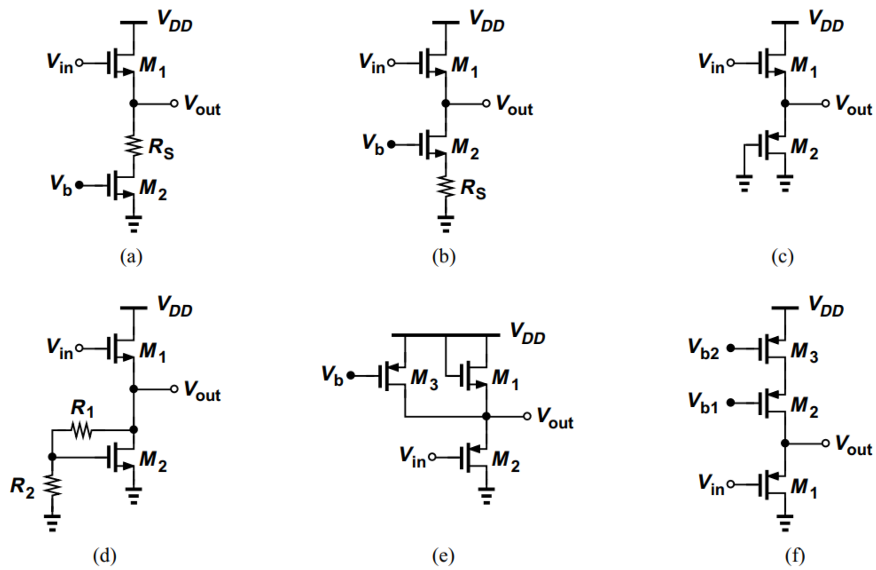

Figure 7-80

解 (a) M_2可视作r_{o2}，M_1为源极跟随器，则

$$A_v = \frac{g_{m1}[r_{o1}//(R_S + r_{o2})]}{1 + g_{m1}[r_{o1}//(R_S + r_{o2})]}$$

(b) M_2与R_S构成源简并放大器，可等效为$(1 + g_{m2}r_{o2})R_S + r_{o2}$，$M_1$为源极跟随器，则

$$A_v = \frac{g_{m1}[r_{o1}//((1 + g_{m2}r_{o2})R_S + r_{o2})]}{1 + g_{m1}[r_{o1}//((1 + g_{m2}r_{o2})R_S + r_{o2})]}$$

(c) M_2为二极管接法，等效于$\frac{1}{g_{m2}}//r_{o2}$，M_1为源极跟随器，则

$$A_v = \frac{g_{m1}(r_{o1}//\frac{1}{g_{m2}}//r_{o2})}{1 + g_{m1}(r_{o1}//\frac{1}{g_{m2}}//r_{o2})}$$

(d) 可先求v_{out}以下部分的等效电阻r_{out}，小信号电路如图 p7-55-d 所示。

$$\begin{cases} v = [i_1 - g_m(v - (i - i_1)R_1)]r_o \\ v = (i - i_1)(R_1 + R_2) \end{cases}$$

$$\therefore r_{out} = \frac{v}{i} = \frac{r_o(R_1 + R_2)}{R_1 + R_2 + r_o + g_m r_o R_2}$$

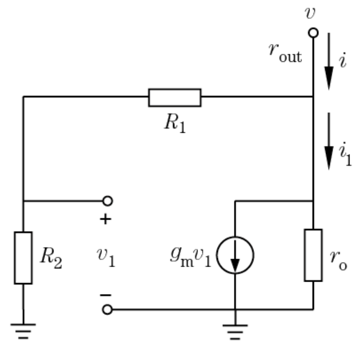

Figure 1

而M_1为源极跟随器，从而

$$A_v = \frac{g_{m1}(r_{o1}//\frac{r_{o2}(R_1+R_2)}{R_1+R_2+r_{o2}+g_{m2}r_{o2}R_2})}{1+g_{m1}(r_{o1}//\frac{r_{o2}(R_1+R_2)}{R_1+R_2+r_{o2}+g_{m2}r_{o2}R_2})}$$

(e) M_3可视作r_{o3}，M_1可视作$\frac{1}{g_{m1}}//r_{o1}$，M_2为源极跟随器，则

$$A_v = \frac{g_{m2}(r_{o2}//r_{o1}//r_{o3}//\frac{1}{g_{m1}})}{1+g_{m2}(r_{o2}//r_{o1}//r_{o3}//\frac{1}{g_{m1}})}$$

(f) M_2, M_3可视为电阻$r=(1+g_{m2}r_{o2})r_{o3}+r_{o2}$，而$M_1$为源极跟随器，则

$$A_v = \frac{g_{m1}[r_{o1}//((1+g_{m2}r_{o2})r_{o3}+r_{o2})]}{1+g_{m1}[r_{o1}//((1+g_{m2}r_{o2})r_{o3}+r_{o2})]}$$

7.56 Consider the circuit of Fig. 7-81, where a source follower (M_1 and I_1) precedes a common-gate stage (M_2 and M_D).

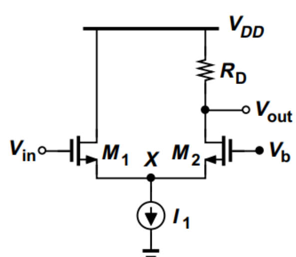

Figure 7-81

(a) Writing $v_{out}/v_{in} = (v_X/v_{in})(v_{out}/v_X)$, compute the overall voltage gain.
(b) Simplify the result obtained in (a) if $g_{m1} = g_{m2}$.

解 (a) M_1为源极跟随器，$R_L = R_{2in} = \frac{1}{g_{m2}}$

$$\therefore \frac{v_x}{v_{in}} = \frac{g_{m1}\cdot\frac{1}{g_{m2}}}{1+g_{m1}\cdot\frac{1}{g_{m2}}} = \frac{g_{m1}}{g_{m1}+g_{m2}}$$

M_2为共栅放大器，则

$$\frac{v_{out}}{v_x} = g_{m2}R_D$$

$$\therefore \frac{v_{out}}{v_{in}} = \frac{g_{m1}g_{m2}R_D}{g_{m1}+g_{m2}}$$

(b) $g_{m1} = g_{m2} = g_m$时

$$\frac{v_{out}}{v_{in}} = \frac{g_m R_D}{2}$$

9.19 Determine the output impedance of the stages shown in Fig. 9-52. Assume all of the transistors operate in saturation and $g_m r_O >> 1$.

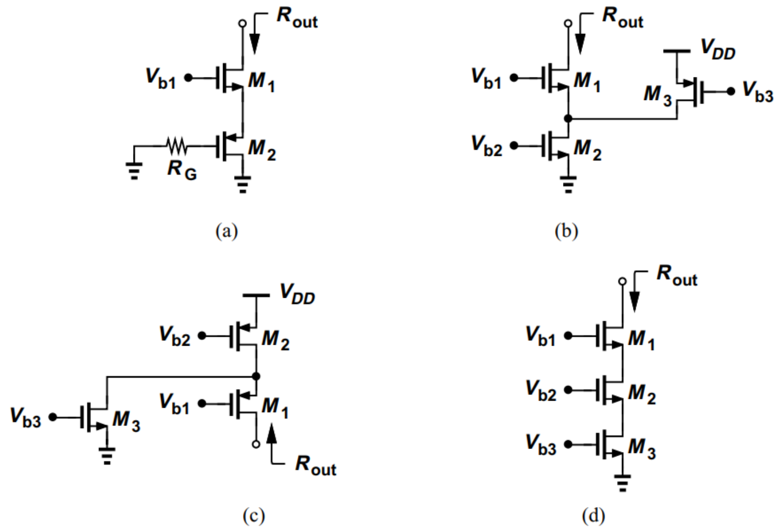

Figure 9-52

解 (a) R_G上无电流，则M_2为二极管接法，可视为$r = \frac{1}{g_{m2}}//r_{o2}$，而$M_1$为源简并放大器，则

$$r_{out} = (1+g_{m1}r_{o1})(\frac{1}{g_{m2}}//r_{o2}) + r_{o1} \approx r_{o1}(\frac{g_m1}{g_m2}+1)$$

(b) M_2, M_3均共源，则可分别视为r_{o2}, r_{o3}，而M_1为源简并放大器，则

$$r_{out} = (1+g_{m1}r_{o1})(r_{o2}//r_{o3}) + r_{o1} \approx g_{m1}r_{o1}(r_{o2}//r_{o3}) + r_{o1}$$

(c) M_2, M_3均共源，则可分别视为r_{o2}, r_{o3}，而M_1为源简并放大器，则

$$r_{out} = (1+g_{m1}r_{o1})(r_{o2}//r_{o3}) + r_{o1} \approx g_{m1}r_{o1}(r_{o2}//r_{o3}) + r_{o1}$$

(d) M_3共源，可视为r_{o3}，M_2为源简并放大器，可视为

$$r_2 = (1+g_{m2}r_{o2})r_{o3} + r_{o2} \approx g_{m2}r_{o2}r_{o3}$$

M_1亦为源简并放大器，则

$$r_{out} = (1+g_{m1}r_{o1})g_{m2}r_{o2}r_{o3} + r_{o1} \approx g_{m1}g_{m2}r_{o1}r_{o2}r_{o3}$$

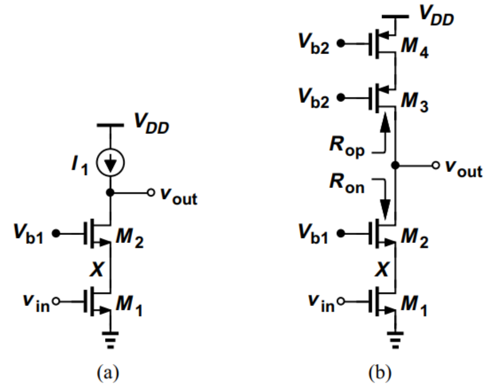

Figure 9-20

9.32 In the cascode stage of Fig. 9-20(b), $(W/L)_1 = \cdots = (W/L)_4 = 20/0.18$. If $\mu_n C_{ox} = 100\mu\text{A/V}^2$, and $\mu_p C_{ox} = 50\mu\text{A/V}^2$, $\lambda_n = 0.1\text{V}^{-1}$, and $\lambda_p = 0.15\text{V}^{-1}$, calculate the bias current such that the circuit achieves a voltage gain of 500.

解

$$
\begin{aligned}
g_{m1} = g_{m2} &= \sqrt{2\mu_n C_{ox}(W/L)I_D} = 149\sqrt{I_D} \\
g_{m3} = g_{m4} &= \sqrt{2\mu_p C_{ox}(W/L)I_D} = 105\sqrt{I_D} \\
r_{o1} = r_{o2} &= \frac{1}{\lambda_n I_D} = \frac{10}{I_D} \\
r_{o3} = r_{o4} &= \frac{1}{\lambda_p I_D} = \frac{6.67}{I_D} \\
A_v &\approx -g_{m1}(((1+g_{m3}r_{o3})r_{o4} + r_{o3})//((1+g_{m2}r_{o2})r_{o1} + r_{o2})) \\
&\approx -g_{m1}[(g_{m3}r_{o3}r_{o4})//(g_{m2}r_{o2}r_{o1})] \\
&= -531400/I_D
\end{aligned}
$$

上式中I_D以μA为单位。

欲使增益达到500，则$I_D = 1.06\text{mA}$。

9.34 Determine the voltage gain of each circuit in Fig. 9-59. Assume $g_m r_O >> 1$.

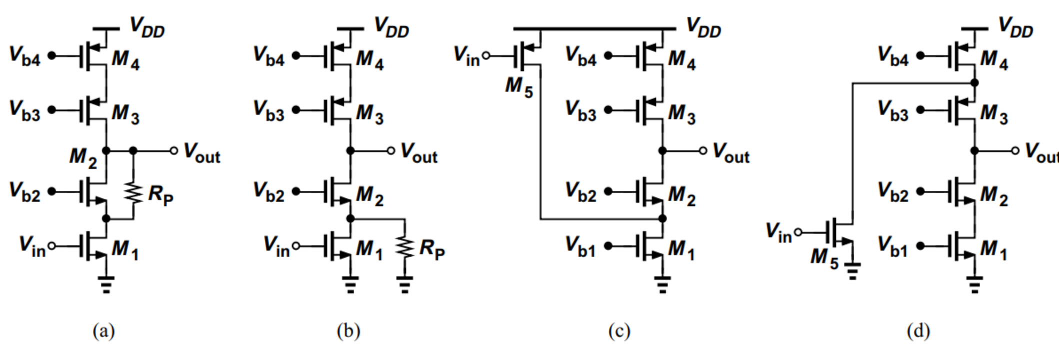

Figure 9-59

解 (a)

$$
\begin{aligned}
G_m &= g_{m1}\cdot\frac{r_{o1}}{r_{o1}+\frac{1}{g_{m2}//r_{o2}//R_P}}\\
&\approx \frac{g_{m1}r_{o1}}{r_{o1}+\frac{1}{g_{m2}}//R_P}
\end{aligned}
$$

$$
\begin{aligned}
R_{out} &= [(1+g_{m3})r_{o4}+r_{o3}]//[(1+g_{m2}(r_{o2}//R_P))r_{o1}+r_{o2}//R_P]\\
&\approx [g_{m3}r_{o3}r_{o4}]//[g_{m2}r_{o1}(r_{o2}//R_P)]
\end{aligned}
$$

$$
\begin{aligned}
A_v &= -G_mR_{out}\\
&= -\frac{g_{m1}r_{o1}}{r_{o1}+\frac{1}{g_{m2}}//R_P}\cdot[(g_{m3}r_{o3}r_{o4})//(g_{m2}r_{o1}(r_{o2}//R_P))]
\end{aligned}
$$

(b)

$$
G_m = g_{m1}\cdot\frac{r_{o1}//R_P}{r_{o1}//R_P+\frac{1}{g_{m2}}//r_{o2}}\approx g_{m1}
$$

$$
\begin{aligned}
R_{out} &= [(1+g_{m3})r_{o4}+r_{o3}]//[(1+g_{m2}r_{o2})(r_{o1}//R_P)+r_{o2}]\\
&\approx [g_{m3}r_{o3}r_{o4}]//[g_{m2}r_{o2}(r_{o1}//R_P)]
\end{aligned}
$$

$$
\begin{aligned}
A_v &= -G_mR_{out}\\
&= -g_{m1}[(g_{m3}r_{o3}r_{o4})//(g_{m2}r_{o2}(r_{o1}//R_P))]
\end{aligned}
$$

(c) 设M_5漏端电压为v_x

$$
\begin{aligned}
\frac{v_x}{v_{in}} &= -g_{m5}(r_{o5}//r_{out1}//r_{in2})\\
&= -g_{m5}(r_{o5}//r_{o1}//\frac{1}{g_{m2}}//r_{o2})\\
&\approx -g_{m5}(r_{o1}//r_{o5}//\frac{1}{g_{m2}})
\end{aligned}
$$

对于从v_x到v_{out}的放大器

$$
G_m = \frac{1}{r_{in2}}\approx g_{m2}
$$

$$
\begin{aligned}
R_{out} &= [(1+g_{m3})r_{o4}+r_{o3}]//[(1+g_{m2}r_{o2})(r_{o1}//r_{o5})+r_{o2}]\\
&\approx [g_{m3}r_{o3}r_{o4}]//[g_{m2}r_{o2}(r_{o1}//r_{o5})]\\
\therefore \frac{v_{out}}{v_x} &= -g_{m1}[(g_{m3}r_{o3}r_{o4})//(g_{m2}r_{o2}(r_{o1}//r_{o5}))]\\
\therefore \frac{v_{out}}{v_{in}} &= g_{m1}g_{m5}(r_{o1}//r_{o5}//\frac{1}{g_{m2}})[(g_{m3}r_{o3}r_{o4})//(g_{m2}r_{o2}(r_{o1}//r_{o5}))]
\end{aligned}
$$

(d) 设M_5漏端电压为v_x

$$
\begin{aligned}
\frac{v_x}{v_{in}} &= -g_{m5}(r_{o5}//r_{out4}//r_{in3})\\
&= -g_{m5}(r_{o5}//r_{o4}//\frac{1}{g_{m3}}//r_{o3})\\
&\approx -g_{m5}(r_{o4}//r_{o5}//\frac{1}{g_{m3}})
\end{aligned}
$$

对于从v_x到v_{out}的放大器

$$G_m = \frac{1}{r_{in3}} \approx g_{m3}$$

$$R_{out} \approx [g_{m2}r_{o2}r_{o1}]//[g_{m3}r_{o3}(r_{o4}//r_{o5})]$$

$$\therefore \frac{v_{out}}{v_x} = -g_{m3}[(g_{m2}r_{o2}r_{o1})//(g_{m3}r_{o3}(r_{o4}//r_{o5}))]$$

$$\therefore \frac{v_{out}}{v_{in}} = g_{m3}g_{m5}(r_{o4}//r_{o5}//\frac{1}{g_{m3}})[(g_{m2}r_{o2}r_{o1})//(g_{m3}r_{o3}(r_{o4}//r_{o5}))]$$