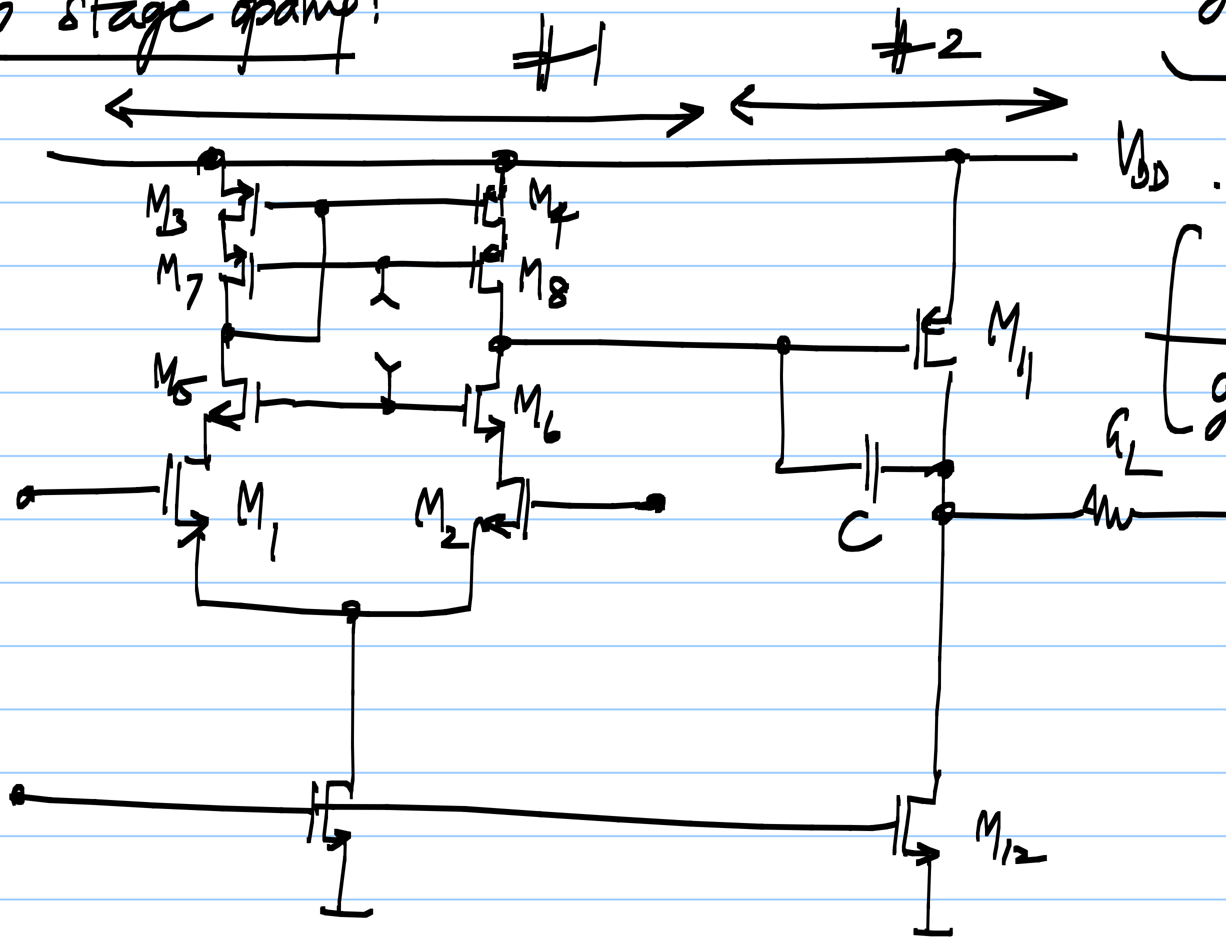
# Lecture 38

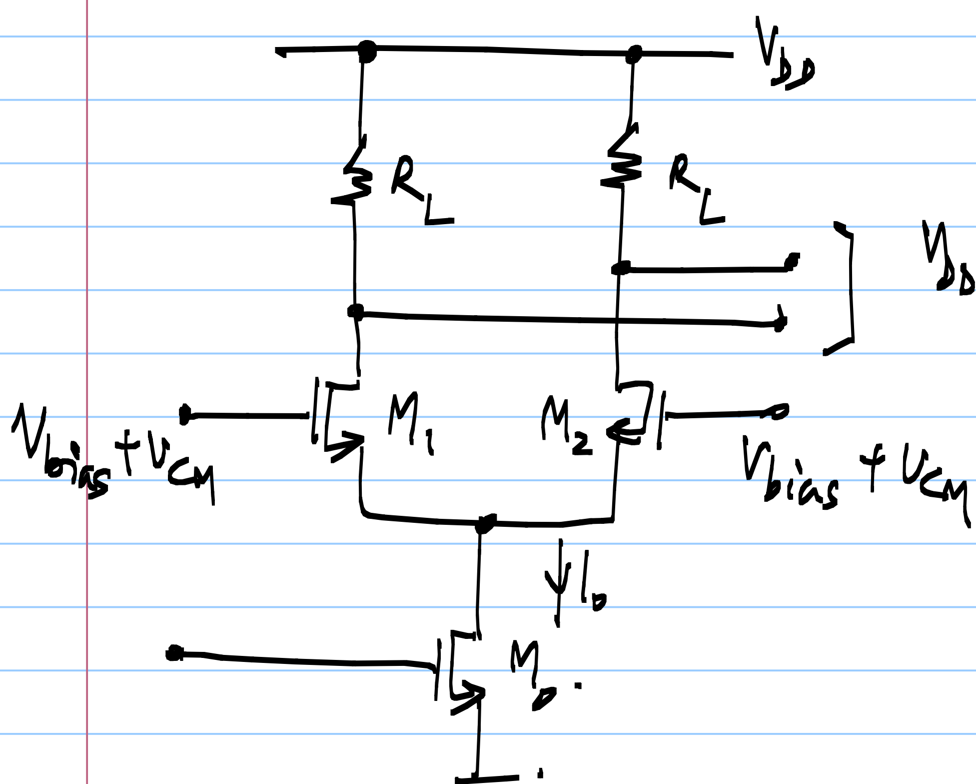
Two stage opamp:




$$\left(\frac{g_{m1}}{g_{ds1}+g_{ds3}}\right)\cdot\frac{g_{m11}}{g_{ds11}+g_{ds12}+G_L}$$

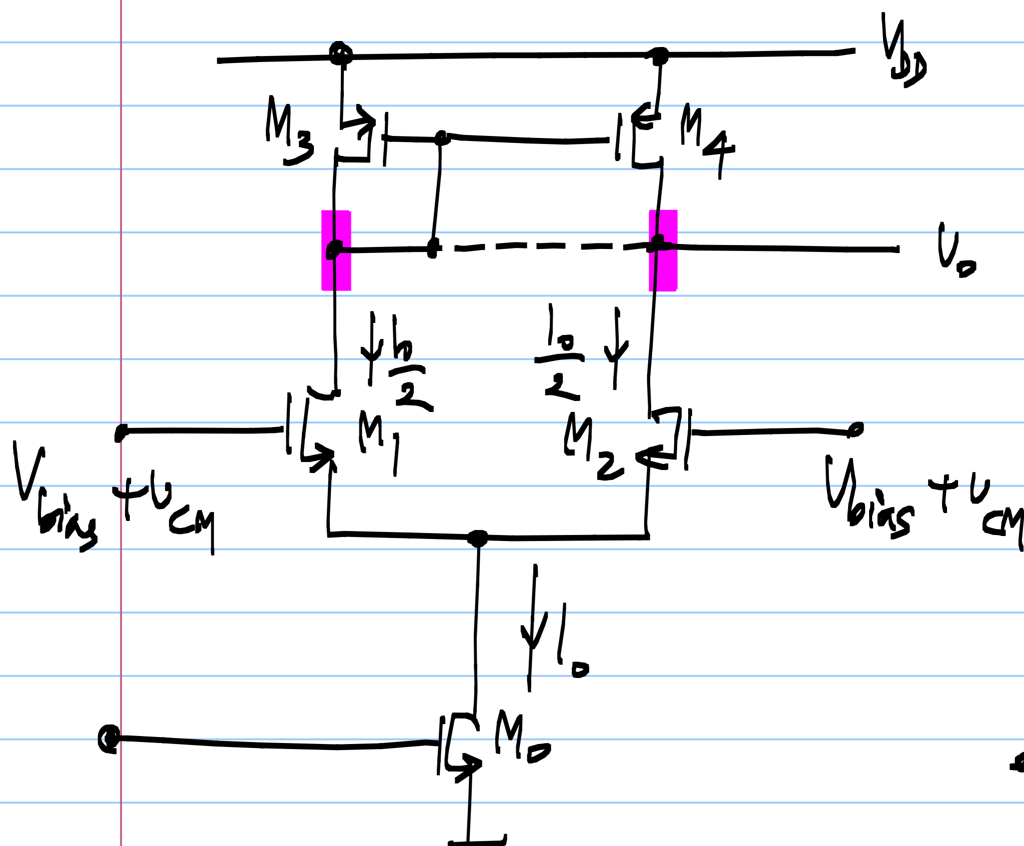
$$\left[\frac{g_{m1}}{g_{ds1}\cdot\frac{g_{ds6}}{g_{m6}}+g_{ds3}\cdot\frac{g_{ds7}}{g_{m7}}\right]$$

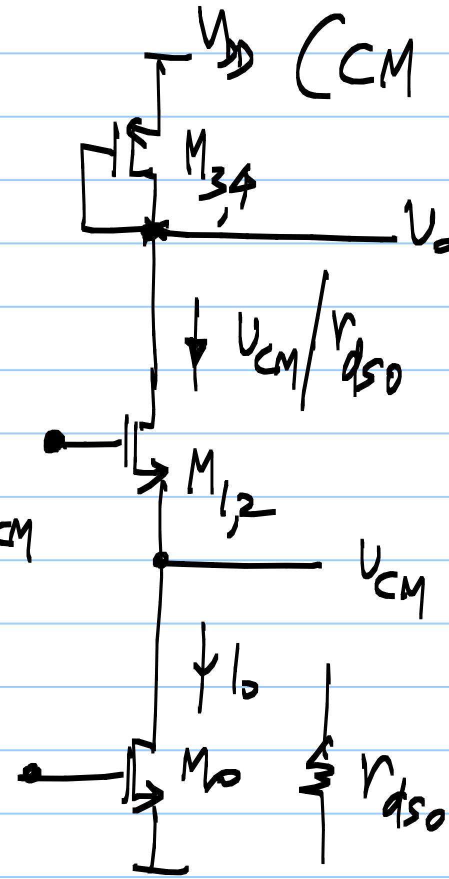
# Common mode gain:




$$V_{DD} - \frac{I_0 R_L}{2} - v_{CM} \cdot \left( \frac{R_L}{2 \cdot r_{ds0}} \right)$$

# Single stage opamp:



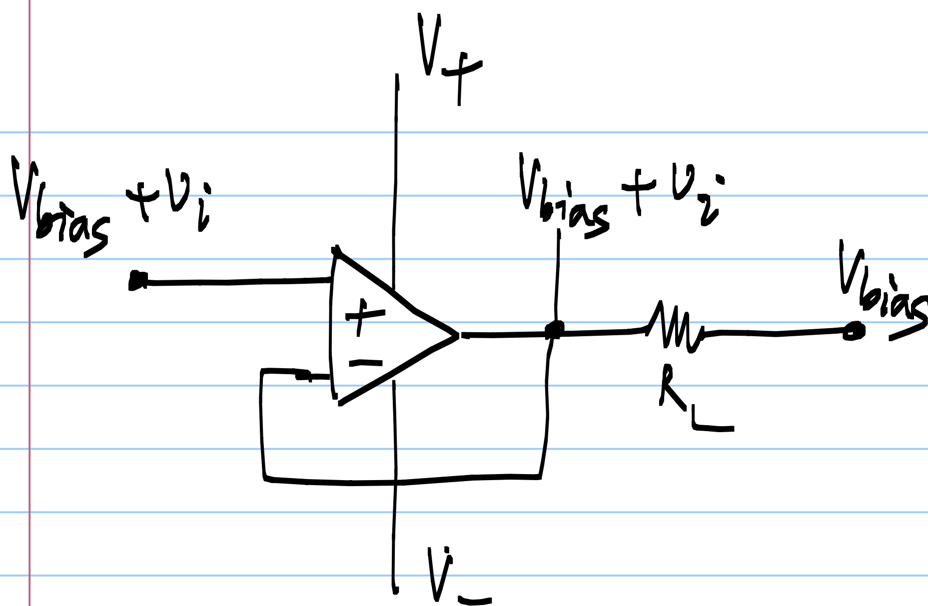



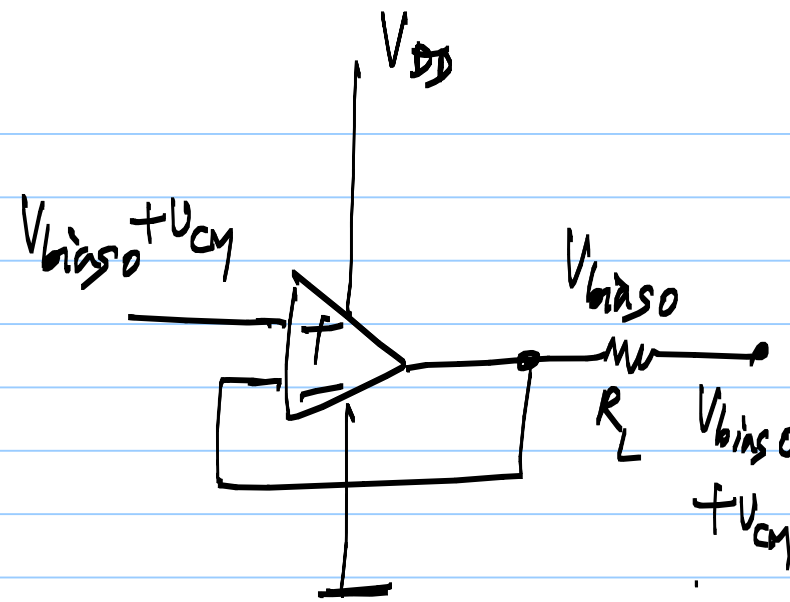

$r_{ds0} = \infty, \quad v_o = 0$ (CM gain $= 0$)

$$v_o = -\frac{v_{CM}}{r_{ds0}} \cdot \frac{1}{2 g_{m3}}$$

$$\boxed{\frac{v_o}{v_{CM}} = -\frac{1}{2 g_{m3} r_{ds0}}}$$

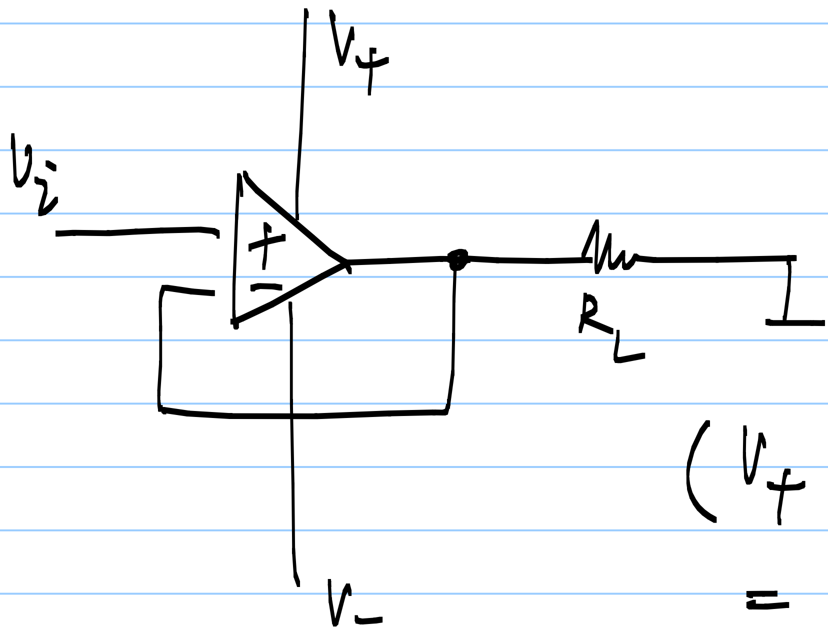
| | Differential gain | Common mode gain | $\lvert CMRR \rvert$ |
|---|---|---|---|
| Resistive load, o/p taken from one side | $\frac{g_{m_1} \cdot R_L}{2}$ | $-\frac{R_L}{2 r_{ds0}}$ | $g_{m_1} \cdot r_{ds0}$ |
| Current mirror load. | $\frac{g_{m_1}}{g_{ds_1} + g_{ds_3}}$ | $-\frac{1}{2 \cdot r_{ds0} \cdot g_{m_3}}$ | $\frac{2 g_{m_1} \cdot g_{m_3} \cdot r_{ds0}}{g_{ds_1} + g_{ds_3}}$ |



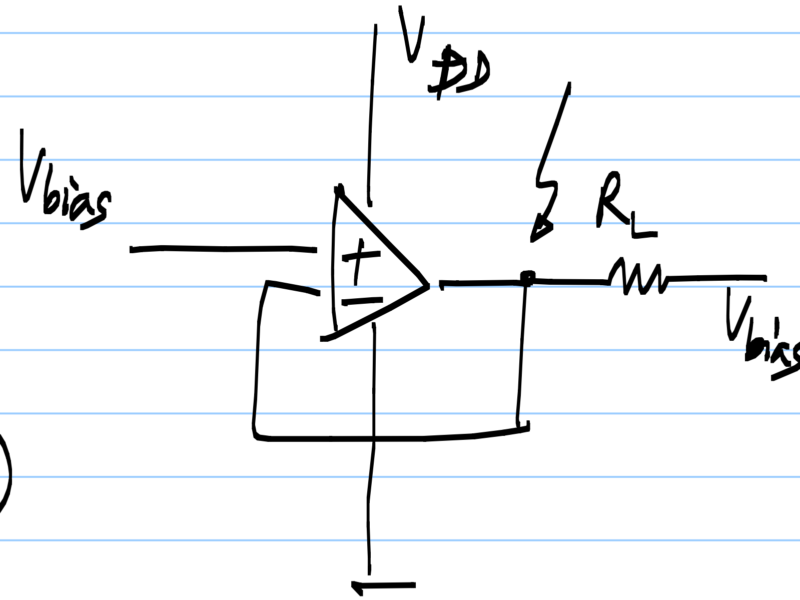




Voltage follower.

# Single & dual supply operation:

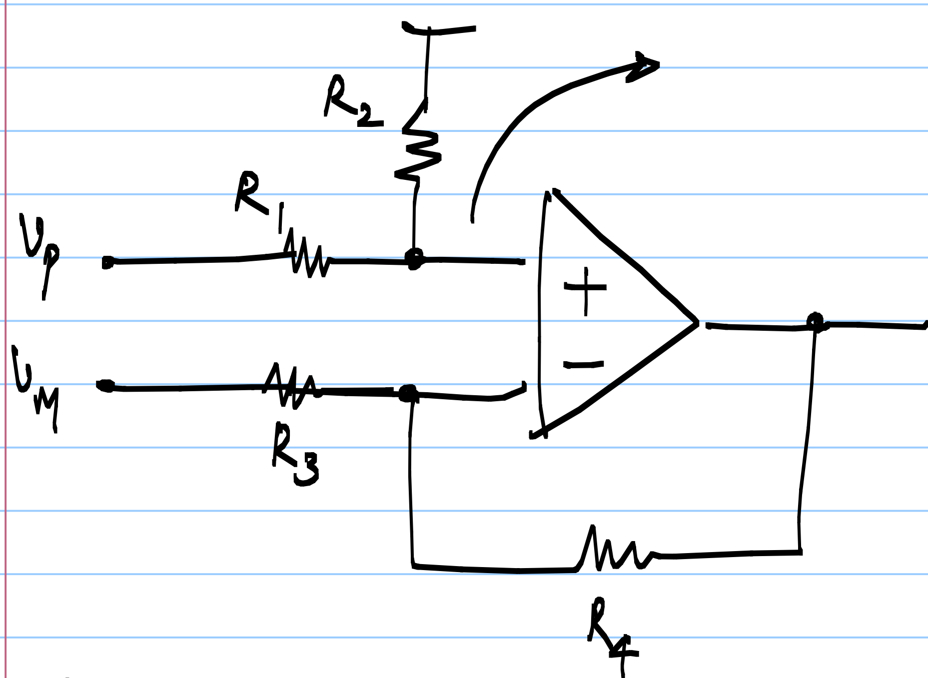



$$(V_+ - V_-) = V_{DD}$$




$V_i = 0 \rightarrow V_{bias} + V_{off}$

# Differential to single ended converter:




$$v_p \cdot \frac{R_2}{R_1 + R_2}\left(1 + \frac{R_4}{R_3}\right) - v_M \cdot \left(\frac{R_4}{R_3}\right)$$

$$\frac{R_4}{R_3} = \frac{R + \Delta R_4}{R + \Delta R_3}$$

$$= \frac{R\left(1 + \frac{\Delta R_4}{R}\right)}{R\left(1 + \frac{\Delta R_3}{R}\right)}$$

$$= 1 + \frac{\Delta R_4 - \Delta R_3}{R}$$

$R_1 = R + \Delta R_1$

$R_2 = R + \Delta R_2$

$$V_o = \frac{1+\frac{R_4}{R_3}}{1+\frac{R_1}{R_2}} \cdot V_P - \frac{R_4}{R_3} \cdot V_M \qquad \frac{R_4}{R_3} = 1 + \frac{\Delta R_{34}}{R} \qquad \frac{R_1}{R_2} = 1 + \frac{\Delta R_{12}}{R}$$

$$= \left(1 + \frac{\Delta R_{34}}{R} - \frac{\Delta R_{12}}{R}\right) \cdot V_P - \left(1 + \frac{\Delta R_{34}}{R}\right) \cdot V_M$$

$$= \alpha_P \cdot V_P - \alpha_M \cdot V_M = \alpha_P \left(\frac{V_P + V_M}{2} + \frac{V_P - V_M}{2}\right) - \alpha_M \left(\frac{V_P + V_M}{2} - \frac{V_P - V_M}{2}\right)$$

$$= (\alpha_P - \alpha_M) \frac{V_P + V_M}{2} + (\alpha_P + \alpha_M) \cdot \left(\frac{V_P - V_M}{2}\right)$$

Common mode gain:

$$\alpha_p - \alpha_m = \left(1 + \frac{\Delta R_{34}}{R} - \frac{\Delta R_{12}}{R}\right) - \left(1 + \frac{\Delta R_{34}}{R}\right)$$

$$= -\frac{\Delta R_{12}}{R}$$

Differential gain:

$$\frac{\alpha_p + \alpha_m}{2} = 1 + \frac{\Delta R_{34}}{R} - \frac{1}{2} \cdot \frac{\Delta R_{12}}{R} \simeq 1$$

$v_p = 1V$

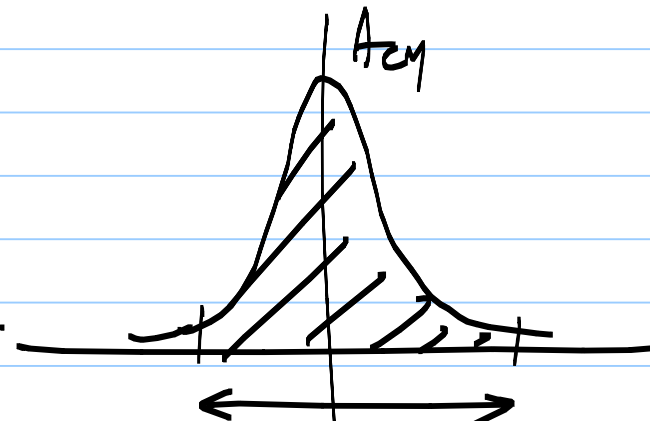
$v_M = 1.001V$

$(v_p - v_M) \cdot 1$ — $-1mV$

$-\frac{\Delta R_{12}}{R} \cdot \left(\frac{v_p + v_M}{2}\right)$

$(-0.01) \cdot (1.0005V) \simeq -10mV$

$$\sigma_{A_{CM}} = \sigma\left(-\frac{\Delta R_{12}}{R}\right) = \sigma_R$$




$\sigma_R = 0.1\%$

$|A_{CM}| < 0.3\%$

99.9% of the amps will have

Minimum difference: 1mV

$\sigma_{A_{CM}} = 0.1\%$  $|A_{cm}| < 0.3\%$

$V_{CM} \cdot A_{CM} << 1mV$

$V_{CM} \cdot 0.003 \leq 0.1mV$

$V_{CM} \leq \frac{0.1mV}{0.003} = \frac{10^{-4}V}{3 \cdot 10^{-3}V} = \boxed{33mV}$

Would like to tolerate

$V_{CM} \leq 3.3V$

$\sigma_{A_{cm}} = 0.001\%$

$\sigma_R = 0.001\%$