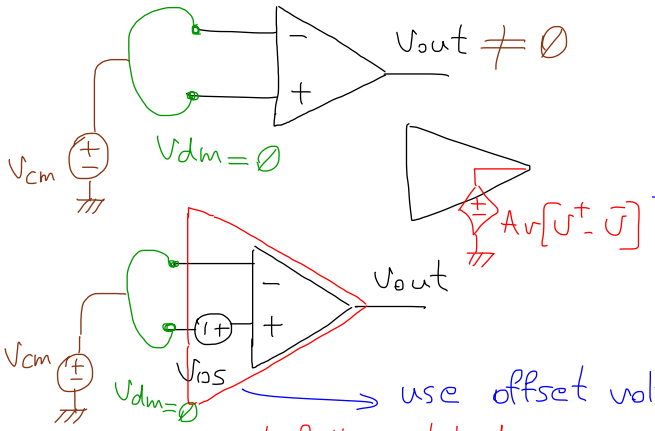
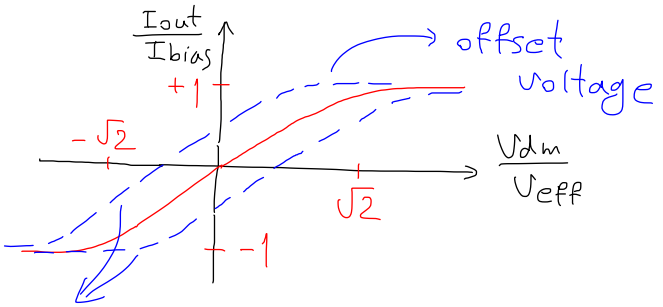
* offset voltage :

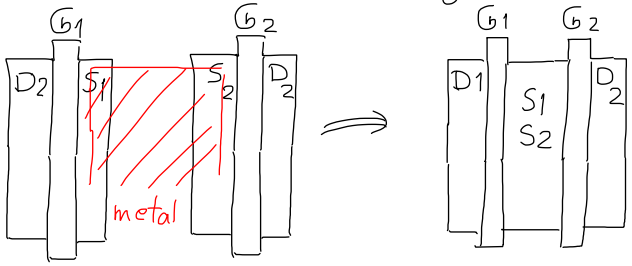


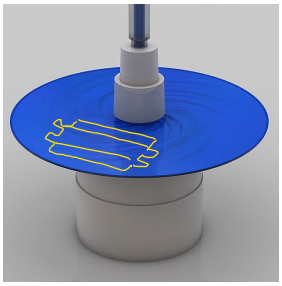



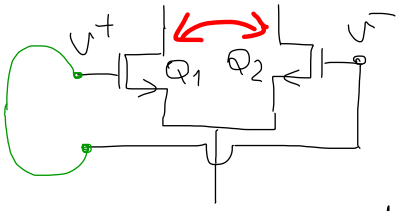

use offset voltage model to create practical response

not fully matched because of process variation

* use common centroid layout to minimize mismatch effect :




$$V_{OS} = V^+ - V^- = V_{G1} - V_{G2} \underbrace{- V_{S1} + V_{S2}}_{V_{S1} = V_{S2}}$$

$$V_{OS} = V_{GS1} - V_{GS2} \quad \text{EQ.1}$$

$Q_1$ (active) : $I_{DS1} = \frac{1}{2}\mu_{n_1} C_{ox_1} \frac{W_1}{L} (V_{GS1} - V_{th})^2$ EQ.2

$Q_2$ (active) : $I_{DS2} = \frac{1}{2}\mu_{n_2} C_{ox_2} \frac{W_2}{L} (V_{GS2} - V_{th})^2$ EQ.3

$$\begin{cases} \mu_{n1} = \mu_n \pm \Delta\mu_n \\ \mu_{n2} = \mu_n \mp \Delta\mu_n \end{cases}, \quad \begin{cases} t_{ox2} = t_{ox} \pm \Delta t_{ox} \\ t_{ox1} = t_{ox} \mp \Delta t_{ox} \end{cases}, \quad \begin{cases} W_1 = W \pm \Delta W \\ W_2 = W \mp \Delta W \end{cases}$$

| | |
|---|---|
| $x_1$ | 5 |
| $x_2$ | 6 |

$x_1 = 5.5 - 0.5$

$x_2 = 5.5 + 0.5$

$\Rightarrow x_{1,2} = x \pm \Delta x$

$V_{th1} = V_{th} \pm \Delta V_{th}$

$V_{th2} = V_{th} \mp \Delta V_{th}$

EQ.1, 2, 3:

$$V_{OS} = \underbrace{\sqrt{\frac{2I_{DS1}}{\mu_{n1}C_{ox1}\frac{W1}{L}}}}_{V_{GS1}} + V_{th1} - \left(\underbrace{\sqrt{\frac{2I_{DS2}}{\mu_{n2}C_{ox2}\frac{W2}{L_2}}}}_{V_{GS2}} + V_{th2}\right)$$

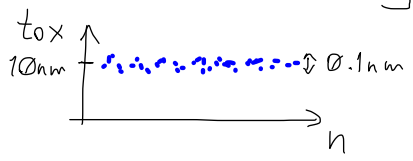
$$V_{OS} = \sqrt{\frac{2(I_{DS} \pm \Delta I_{DS})}{(\mu_n \pm \Delta\mu)\left(\frac{\varepsilon_0\varepsilon_{ox}}{t_{ox} \pm \Delta t_{ox}}\right)\left(\frac{W \pm \Delta W}{L \pm \Delta L}\right)}} - \sqrt{\frac{2(I_{DS} \mp \Delta I_{DS})}{(\mu_n \mp \Delta\mu)\left(\frac{\varepsilon_0\varepsilon_{ox}}{t_{ox} \mp \Delta t_{ox}}\right)\left(\frac{W \mp \Delta W}{L \mp \Delta L}\right)}} \pm 2\Delta V_{th}$$

$$\lim_{n\to 0}\sqrt{1+n} = 1 + \frac{n}{2}, \quad \lim_{n\to 0}\sqrt{1-n} = 1 - \frac{n}{2}, \quad \lim_{n\to 0}\frac{1}{\sqrt{1+n}} = 1 - \frac{n}{2}, \quad \lim_{n\to 0}\frac{1}{\sqrt{1-n}} = 1 + \frac{n}{2}$$

$$V_{OS} = \underbrace{\sqrt{\frac{2I_{DS}}{\mu_n\frac{\varepsilon_0\varepsilon_r}{t_{ox}}\frac{W}{L}}}}_{V_{eff}}\left[\sqrt{\frac{\left(1 \pm \frac{\Delta I_{DS}}{I_{DS}}\right)\left(1 \pm \frac{\Delta t_{ox}}{t_{ox}}\right)\left(1 \pm \frac{\Delta L}{L}\right)}{\left(1 \pm \frac{\Delta\mu}{\mu_n}\right)\left(1 \pm \frac{\Delta W}{W}\right)}} - \sqrt{\frac{\left(1 \mp \frac{\Delta I_{DS}}{I_{DS}}\right)\left(1 \mp \frac{\Delta t_{ox}}{t_{ox}}\right)\left(1 \mp \frac{\Delta L}{L}\right)}{\left(1 \mp \frac{\Delta\mu}{\mu}\right)\left(1 \mp \frac{\Delta W}{W}\right)}}\right] - 2\Delta V_{th}$$

$$V_{OS} = V_{eff}\left[\left(1 \pm \frac{\Delta I_{DS}}{2I_{DS}}\right)\left(1 \pm \frac{\Delta t_{ox}}{2t_{ox}}\right)\left(1 \pm \frac{\Delta L}{2L}\right)\left(1 \mp \frac{\Delta\mu}{2\mu_n}\right)\left(1 \mp \frac{\Delta W}{2W}\right) - \left(1 \mp \frac{\Delta I_{DS}}{2I_{DS}}\right)\left(1 \mp \frac{\Delta t_{ox}}{2t_{ox}}\right)\left(1 \mp \frac{\Delta L}{2L}\right)\left(1 \pm \frac{\Delta\mu}{2\mu_n}\right)\left(1 \pm \frac{\Delta W}{2W}\right)\right] - 2\Delta V_{th}$$

$$V_{OS} = V_{eff}\left[\pm\frac{\Delta I_{DS}}{I_{DS}} \pm \frac{\Delta t_{ox}}{t_{ox}} \pm \frac{\Delta L}{L} \mp \frac{\Delta\mu}{\mu} \mp \frac{\Delta W}{W}\right] - 2\Delta V_{th}$$




worst-case $V_{OS}$:

$$V_{OS} = V_{eff}\sqrt{\left(\frac{\Delta I_{DS}}{I_{DS}}\right)^2 + \underbrace{\left(\frac{\Delta t_{ox}}{t_{ox}}\right)^2}_{1\%} + \underbrace{\left(\frac{\Delta L}{L}\right)^2}_{3\%} + \underbrace{\left(\frac{\Delta\mu}{\mu}\right)^2}_{2\%} + \left(\frac{\Delta W}{W}\right)^2} + 2\underbrace{|\Delta V_{th}|}_{0.1V}$$