

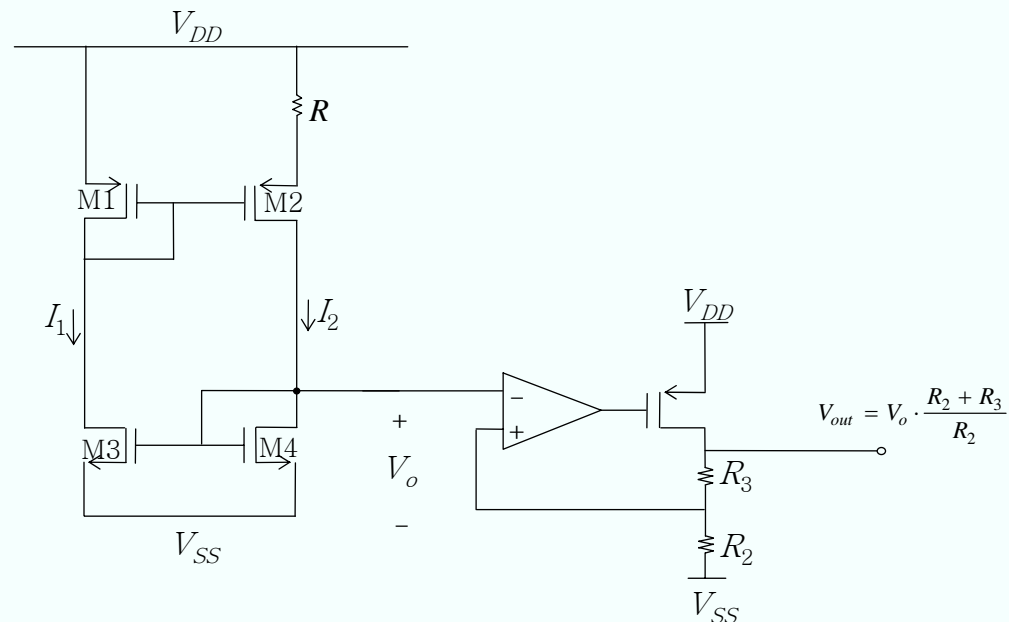
1. Simple voltage source circuit
2. Constant G_m bias circuit
3. Constant G_m bias circuit using cascode
4. Self-biased CMOS diff amp

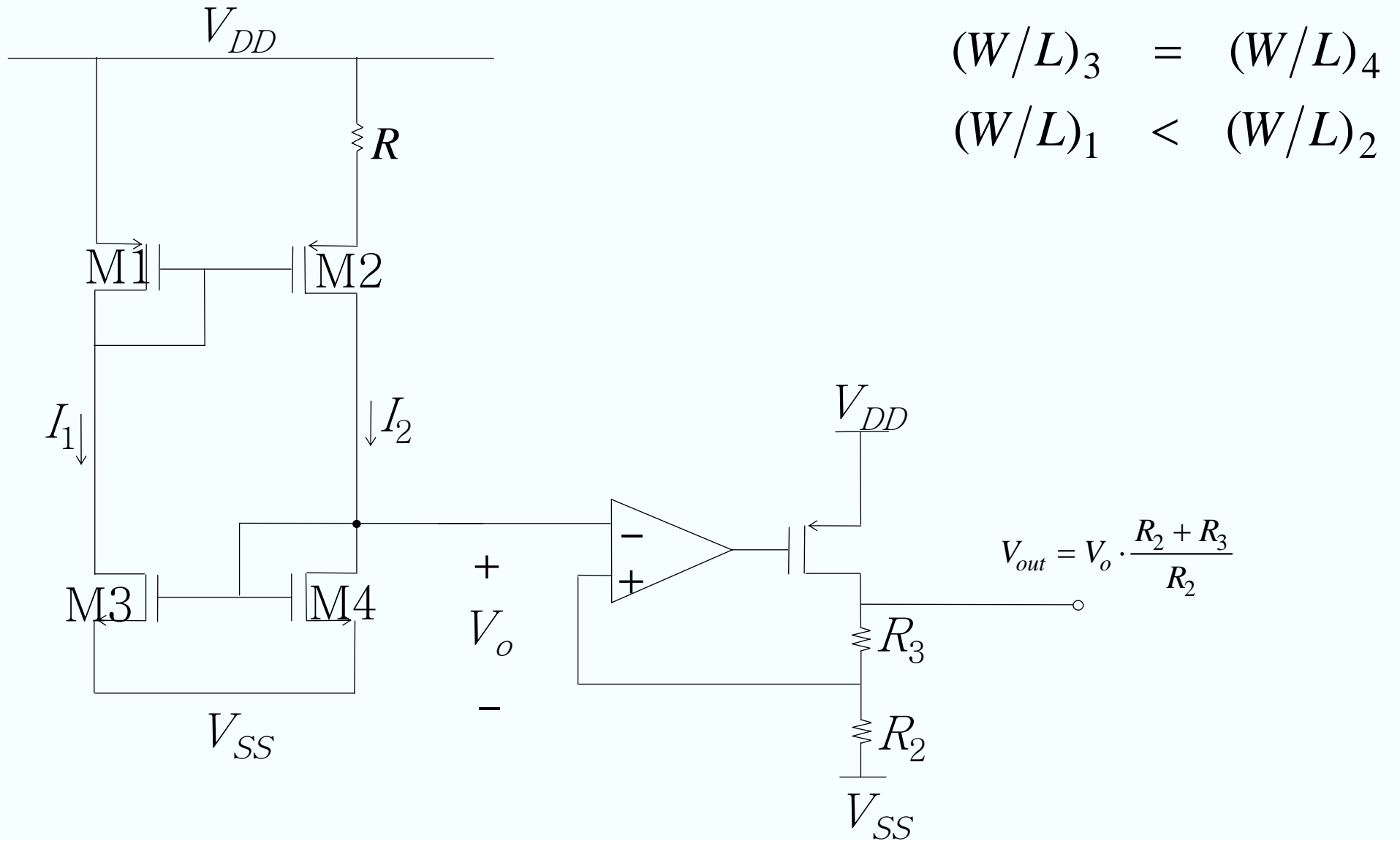
Bandgap reference:

- large current through PN junction,
- used for precision purpose
(eg. Reference voltage of high precision ADC)

5V-to-3.3V converter:

- high precision not required,
- must be insensitive to supply noise
- MOS-R self bias circuit used





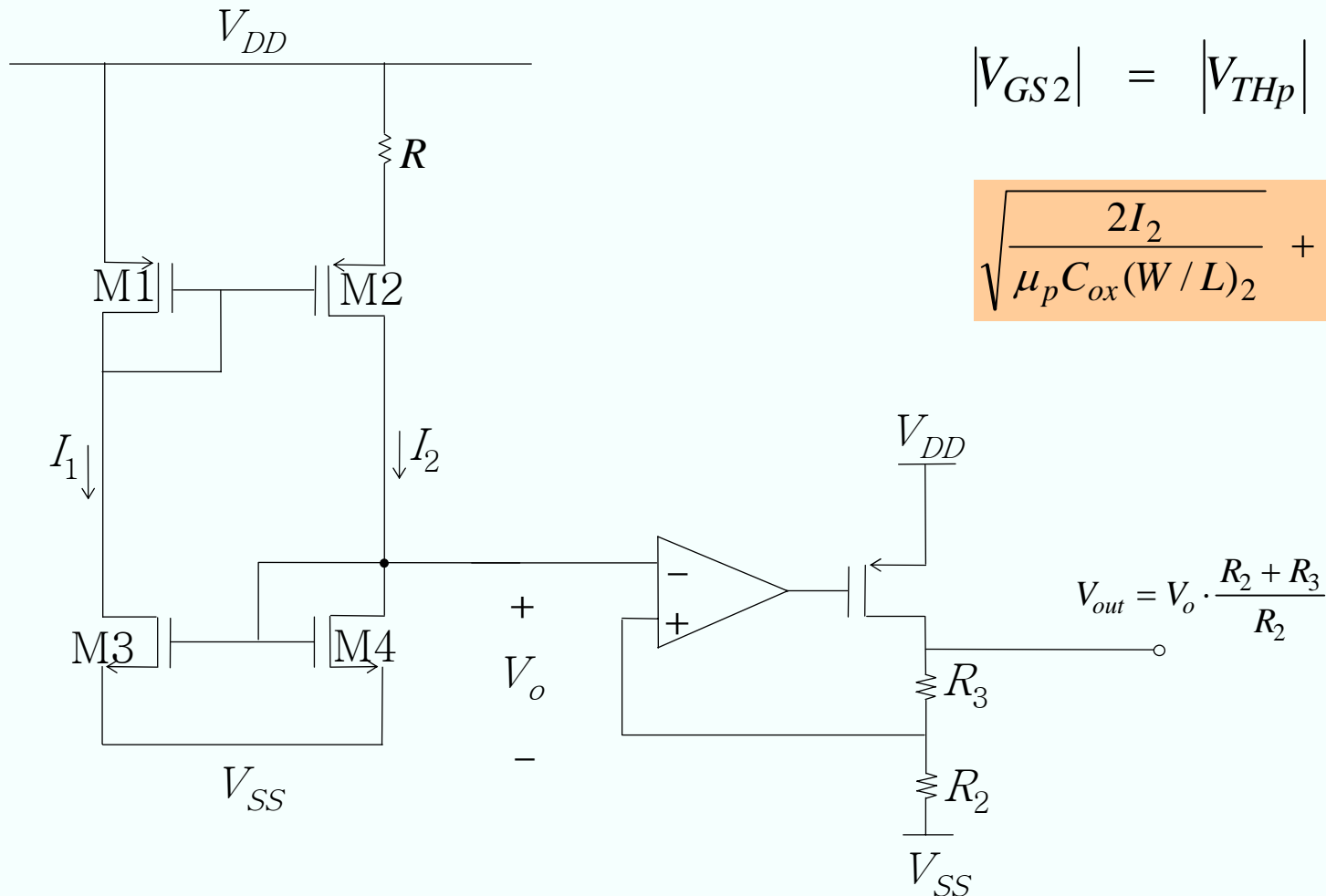
$$I_1 = I_2$$

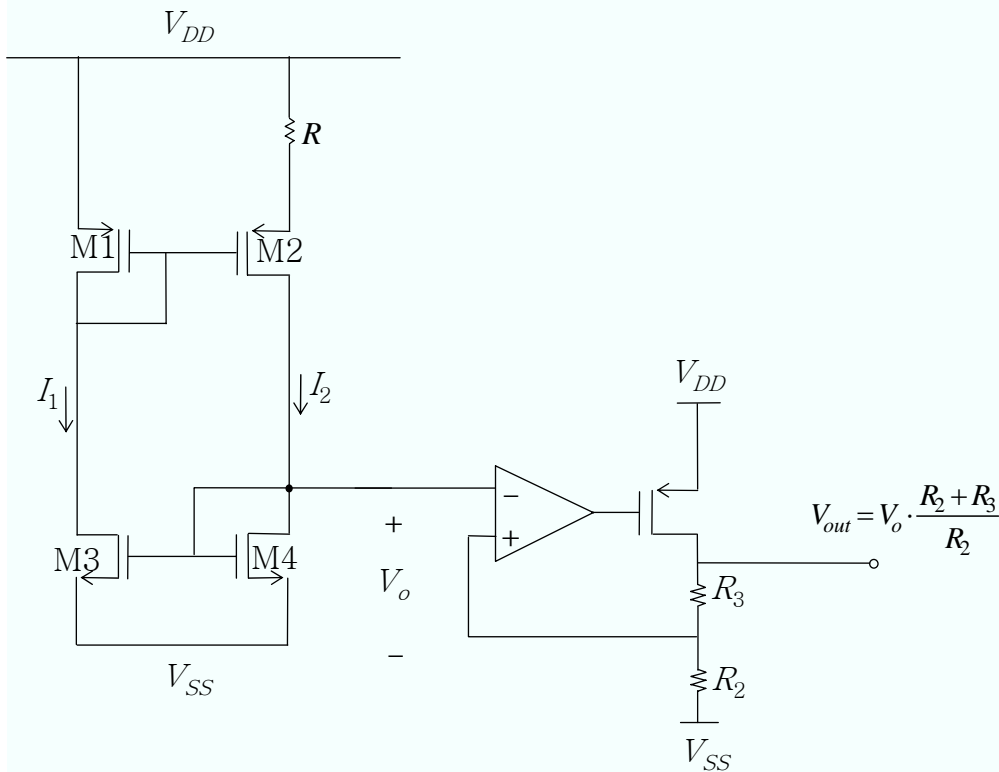
$$|V_{GS1}| = |V_{GS2}| + I_2 \cdot R$$

$$|V_{GS1}| = |V_{THp}| + \sqrt{2I_1 / \{\mu_p C_{ox} (W/L)_1\}}$$

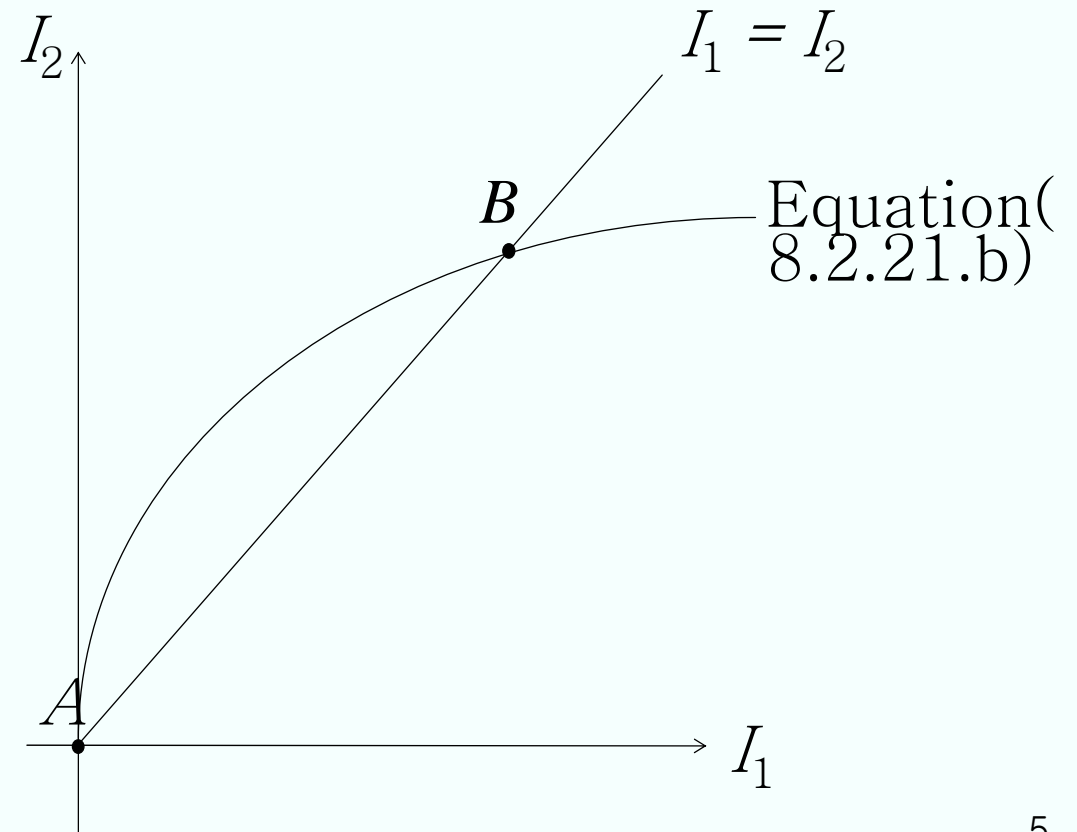
$$|V_{GS2}| = |V_{THp}| + \sqrt{2I_2 / \{\mu_p C_{ox} (W/L)_2\}}$$

$$\sqrt{\frac{2I_2}{\mu_p C_{ox} (W/L)_2}} + I_2 \cdot R = \sqrt{\frac{2I_1}{\mu_p C_{ox} (W/L)_1}}$$





$$\sqrt{\frac{2I_2}{\mu_p C_{ox} (W/L)_2}} + I_2 \cdot R = \sqrt{\frac{2I_1}{\mu_p C_{ox} (W/L)_1}}$$

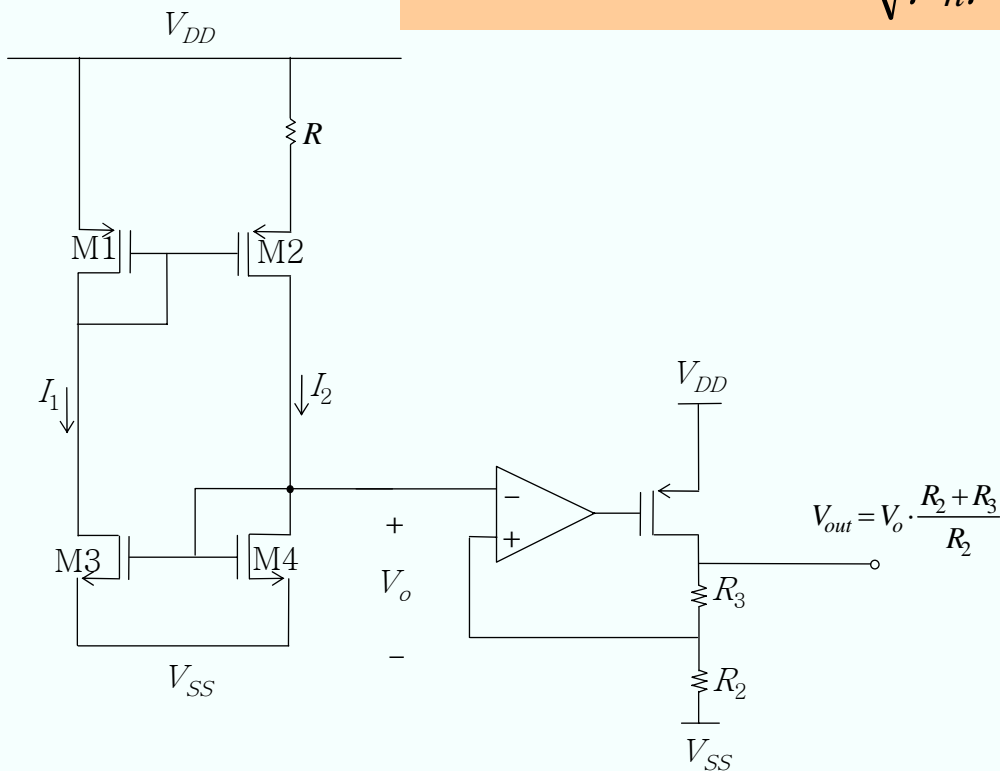


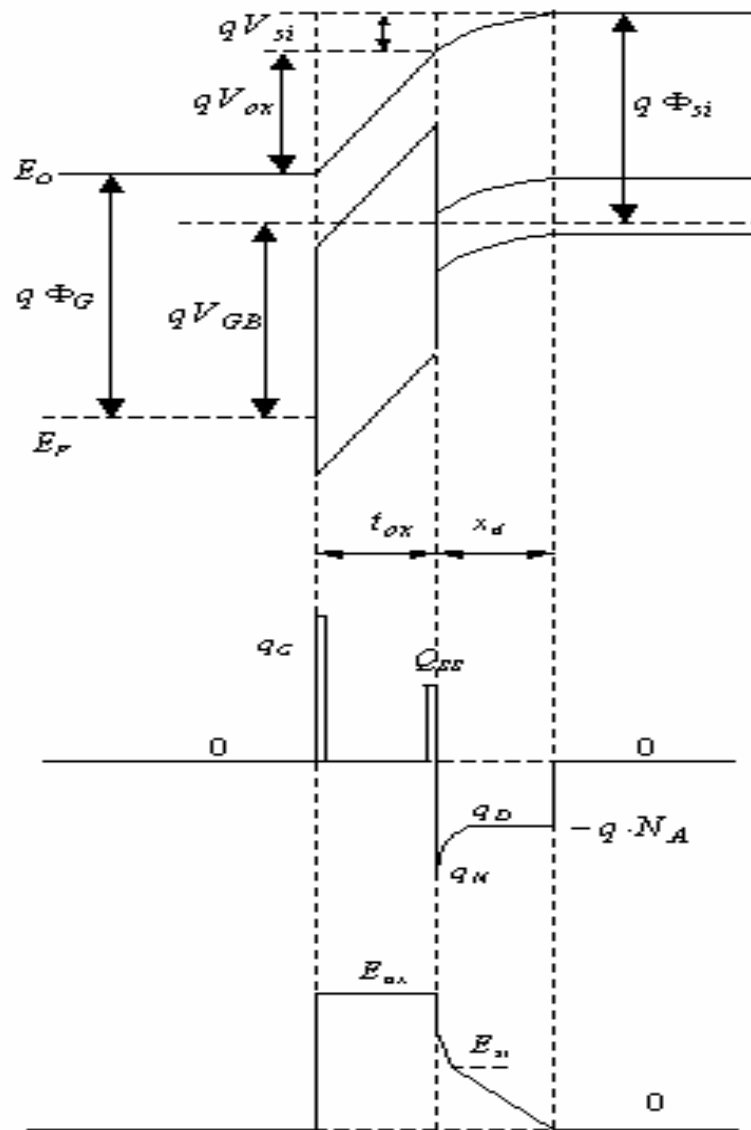
$$I_1 = I_2 = \frac{2}{R^2 \cdot \mu_p C_{ox}} \cdot \left\{ \frac{1}{\sqrt{(W/L)_1}} - \frac{1}{\sqrt{(W/L)_2}} \right\}^2$$

TC > 0

$$V_o = V_{THn} + \frac{2}{R \cdot \sqrt{\mu_n \mu_p} \cdot C_{ox} \sqrt{(W/L)_4}} \cdot \left\{ \frac{1}{\sqrt{(W/L)_1}} - \frac{1}{\sqrt{(W/L)_2}} \right\}$$

(- TC) + (+ TC)





$$V_{THno} = \Phi_G - \Phi_{si} + 2\phi_F + \gamma\sqrt{2\phi_F}$$

at $V_{BS}=0$

$$\Phi_G = \frac{\chi_{si}}{q}$$

(a)

$$\Phi_{si} = \frac{\chi_{si}}{q} + \frac{E_G}{2q} + \phi_F$$

(b)

$$V_{THno} = -\frac{E_G}{2q} + \phi_F + \gamma\sqrt{2\phi_F}$$

(c)

$$V_{THno} = -\frac{E_G}{2q} + \phi_F + \gamma\sqrt{2\phi_F}$$

$$\frac{dV_{THno}}{dT} = -\frac{1}{2q} \cdot \frac{dE_G}{dT} + \left(1 + \frac{\gamma}{\sqrt{2\phi_F}} \right) \cdot \frac{d\phi_F}{dT}$$

$$\phi_F = V_T \cdot \ln \frac{N_A}{n_i}$$

$$\frac{d\phi_F}{dT} = \frac{\phi_F}{T} - V_T \cdot \frac{dn_i}{n_i dT}$$

$$n_i = 3.88 \times 10^{16} \cdot T^{1.5} \cdot e^{-\frac{E_{GO}}{2kT}}$$

$$\frac{1}{q} \cdot \frac{dE_G}{dT} = -0.28 \quad [mV/^\circ K]$$

$$\frac{dn_i}{dT} = \frac{1}{T} \left(\frac{3}{2} + \frac{E_{GO}}{2kT} \right)$$

$$d\phi_F/dT = -0.98 \text{ mV}/^\circ K$$

$$\frac{dV_{THno}}{dT} = -\frac{1}{2q} \cdot \frac{dE_G}{dT} + \left(1 + \frac{\gamma}{\sqrt{2\phi_F}} \right) \cdot \frac{d\phi_F}{dT}$$

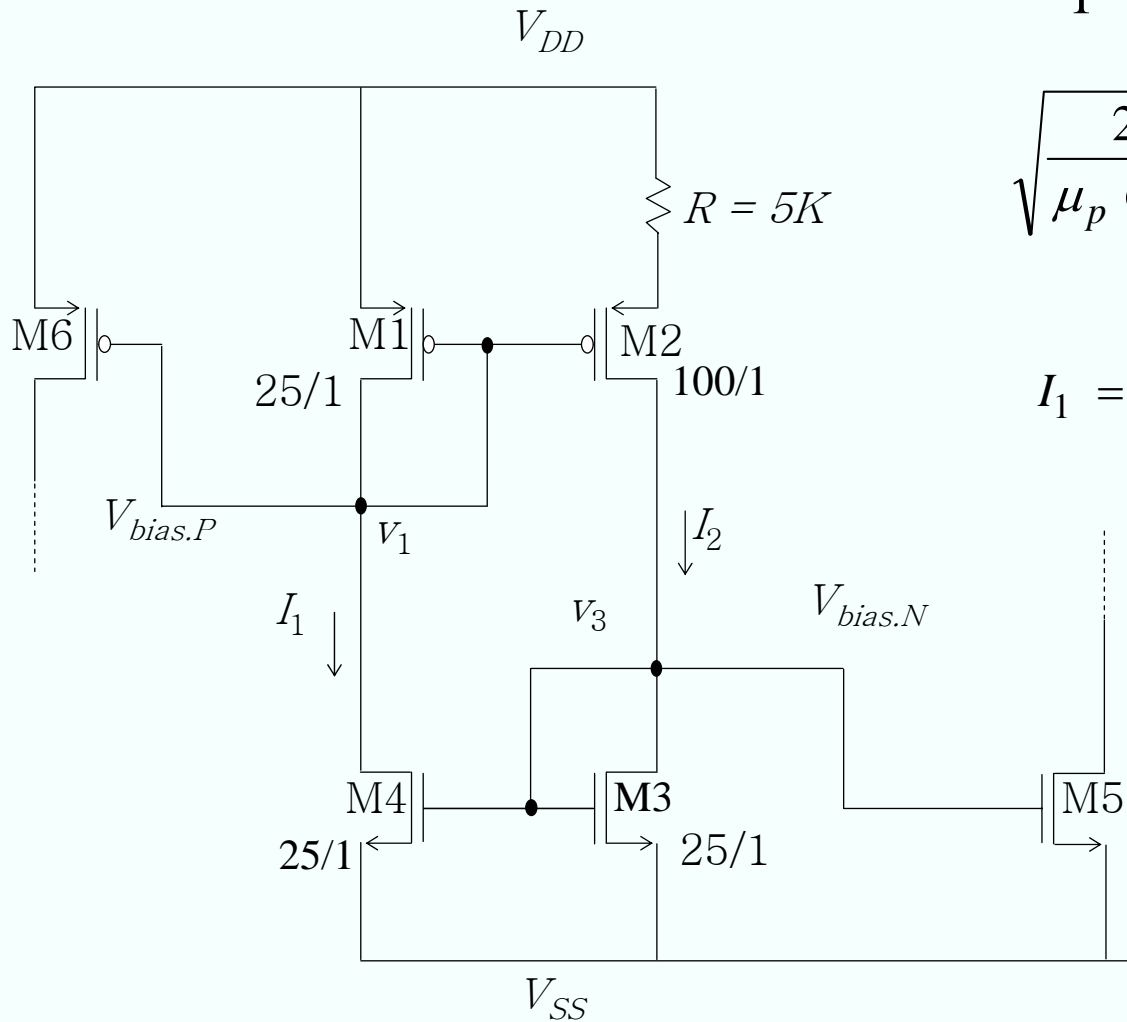
$$dV_{THno}/dT = -2.0 \text{ mV}/^\circ K$$

$$V_{THpo} = \Phi_G - \Phi_{si} - 2\phi_F - \gamma \sqrt{2\phi_F}$$

$$V_{THpo} = -\frac{E_G}{2q} - \phi_F - \gamma \sqrt{2\phi_F}$$

$$\frac{dV_{THpo}}{dT} = -\frac{1}{2q} \cdot \frac{dE_G}{dT} - \left(1 + \frac{\gamma}{\sqrt{2\phi_F}}\right) \cdot \frac{d\phi_F}{dT}$$

$$dV_{THpo} / dT = +2.3 \text{ mV} / ^\circ \text{K}$$



$$I_1 = I_2$$

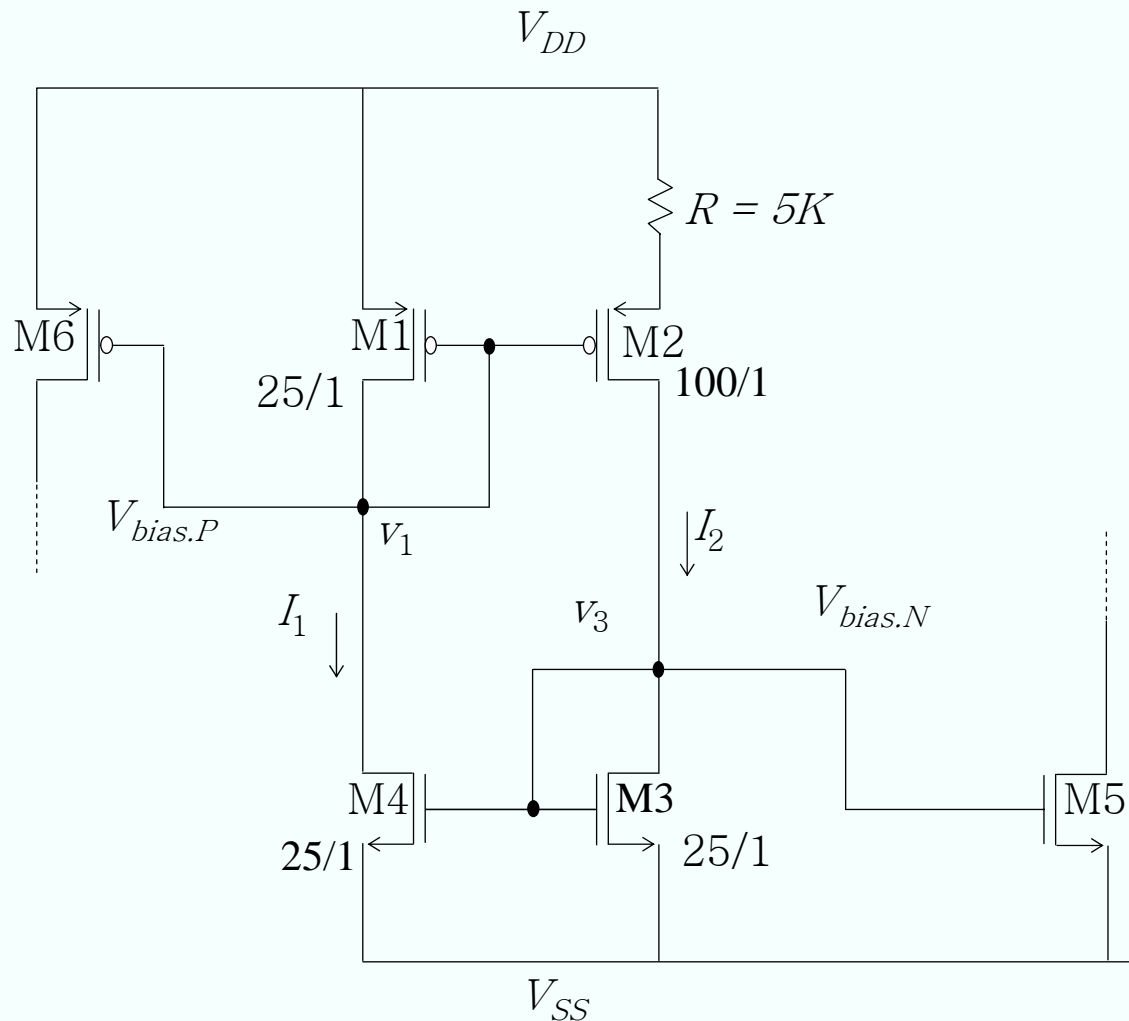
$$\sqrt{\frac{2}{\mu_p C_{ox}}} \cdot \left\{ \sqrt{\frac{I_1}{(W/L)_1}} - \sqrt{\frac{I_2}{(W/L)_2}} \right\} = I_2 \cdot R$$

$$I_1 = I_2 = \frac{2}{\mu_p C_{ox} \cdot R^2} \cdot \left\{ \frac{1}{\sqrt{(W/L)_1}} - \frac{1}{\sqrt{(W/L)_2}} \right\}^2$$

$$g_{m1} = \frac{2}{R} \cdot \left(1 - \sqrt{\frac{(W/L)_1}{(W/L)_2}} \right)$$

$$g_{m3} = g_{m1} \cdot \sqrt{\frac{\mu_n}{\mu_p} \cdot \frac{(W/L)_3}{(W/L)_1}}$$

gm1, gm3 : constant, supply-insensitive



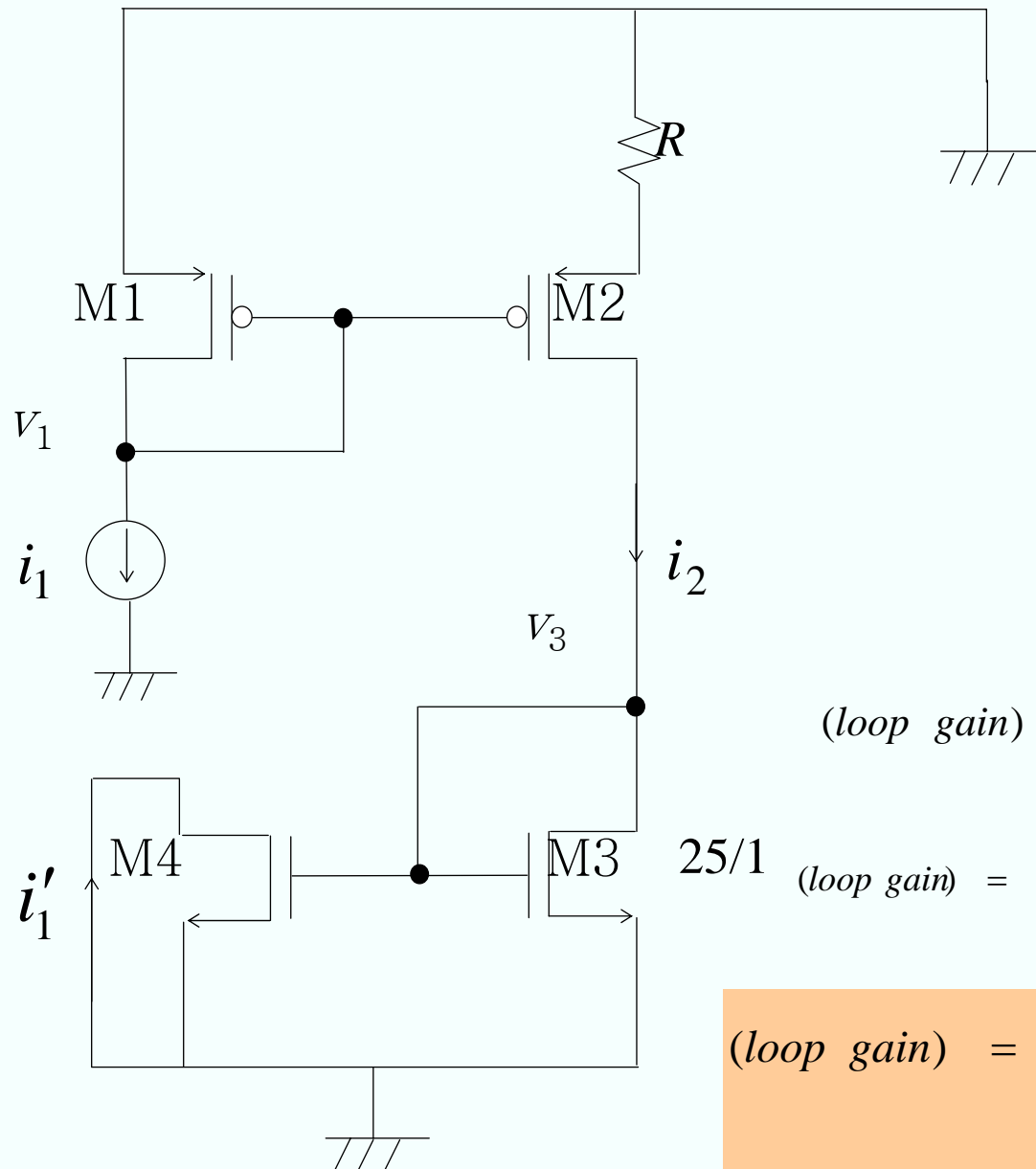
$$g_{m1} = \frac{2}{R} \cdot \left(1 - \sqrt{\frac{(W/L)_1}{(W/L)_2}} \right)$$

$$g_{m3} = g_{m1} \cdot \sqrt{\frac{\mu_n}{\mu_p} \cdot \frac{(W/L)_3}{(W/L)_1}}$$

$$g_{m5} = g_{m3} \cdot \frac{(W/L)_5}{(W/L)_3}$$

$$g_{m6} = g_{m1} \cdot \frac{(W/L)_6}{(W/L)_1}$$

gm5, gm6 : constant, supply-insensitive



Loop gain calculation

$$\frac{v_1}{i_1} = r_{s1} = \frac{1}{g_{m1}}$$

$$\frac{i_2}{v_1} = \frac{1}{r_{s2} + R} = \frac{g_{m2}}{1 + g_{m2}R}$$

$$\frac{v_3}{i_2} = r_{s3} = \frac{1}{g_{m3}}$$

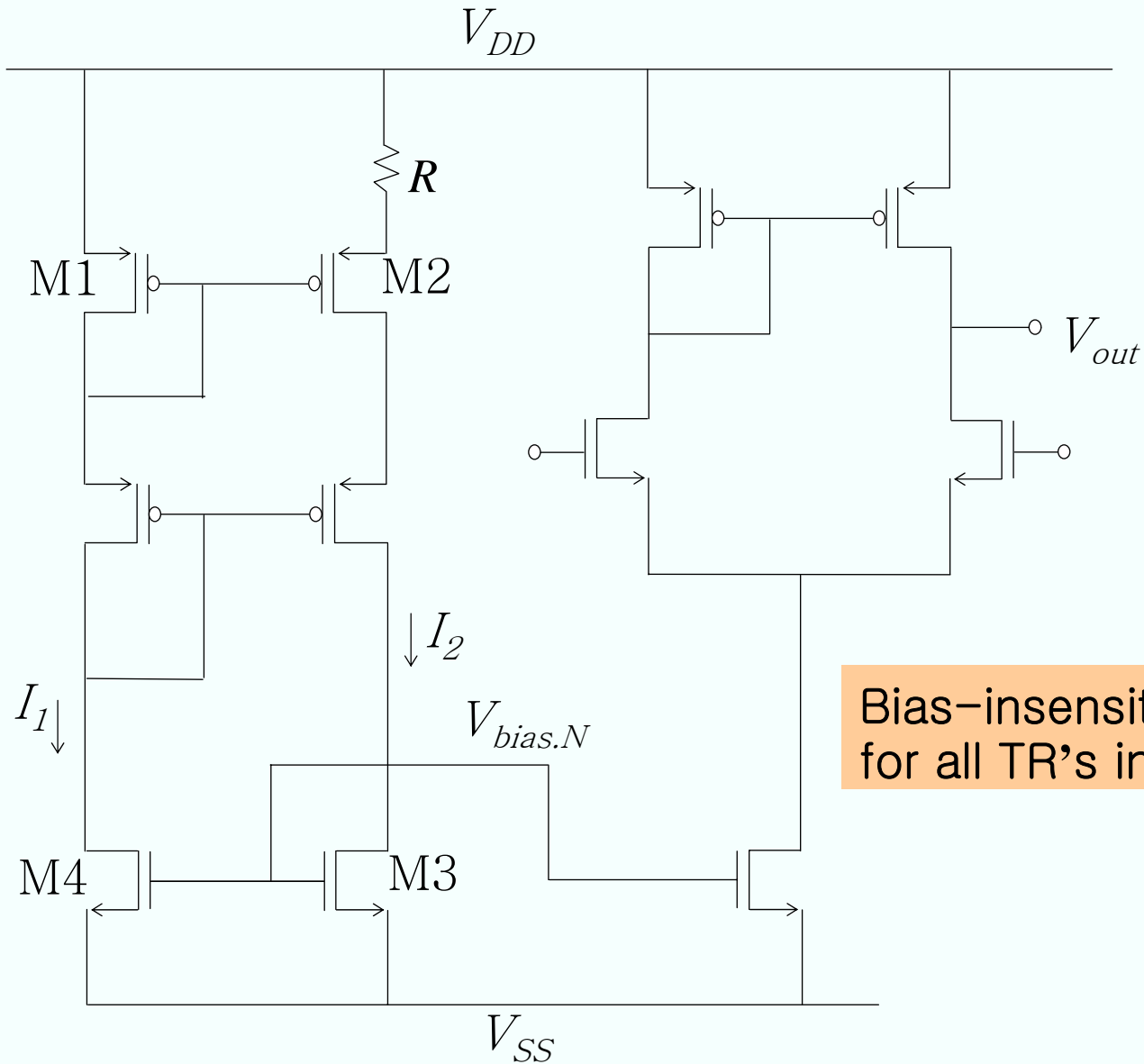
$$\frac{i_1'}{v_3} = g_{m4}$$

$$(\text{loop gain}) = \frac{i_1'}{i_1} = \frac{v_1}{i_1} \cdot \frac{i_2}{v_1} \cdot \frac{v_3}{i_2} \cdot \frac{i_1'}{v_3}$$

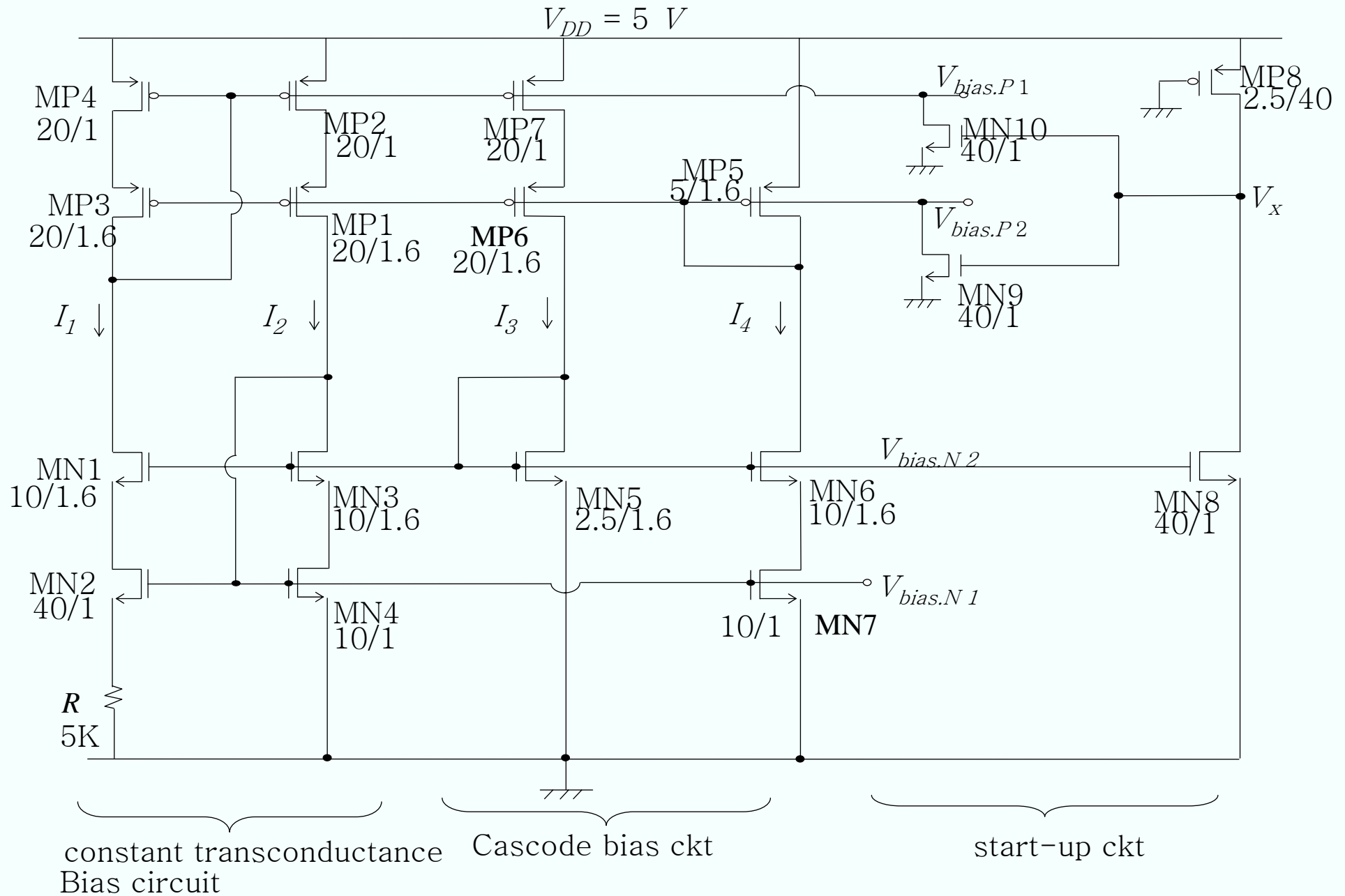
$$\frac{25}{1} (\text{loop gain}) = \frac{g_{m2}}{g_{m1}} \cdot \frac{1}{1 + g_{m2}R} = \frac{1}{\frac{g_{m1}}{g_{m2}} + g_{m1}R} = \frac{1}{\sqrt{\frac{(W/L)_1}{(W/L)_2}} + g_{m1}R}$$

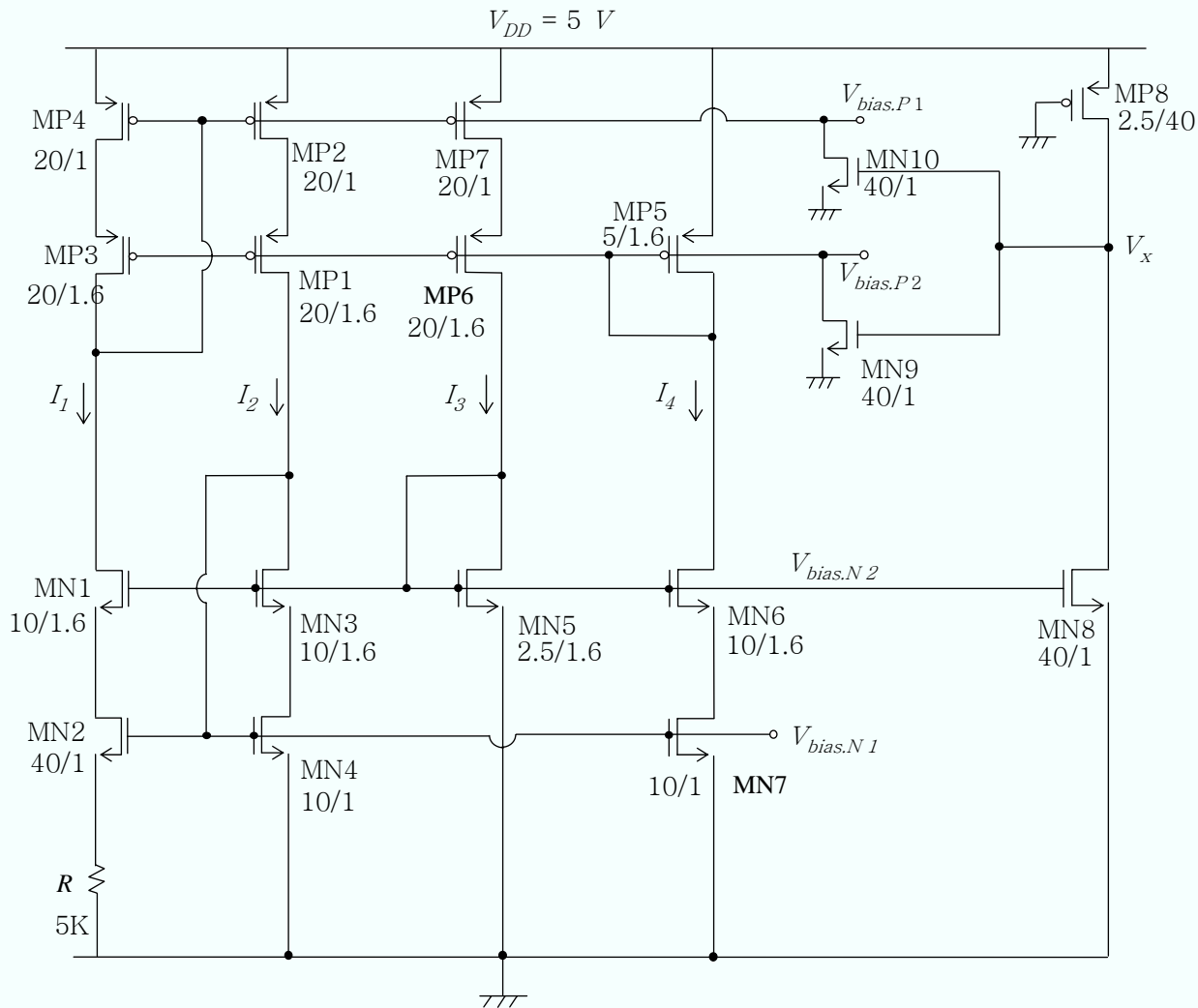
$$(\text{loop gain}) = \frac{1}{2 - \sqrt{\frac{(W/L)_1}{(W/L)_2}}} < 1$$

$$(W/L)_1 < (W/L)_2$$



Bias-insensitive constant Gm guaranteed for all TR's in diff amp





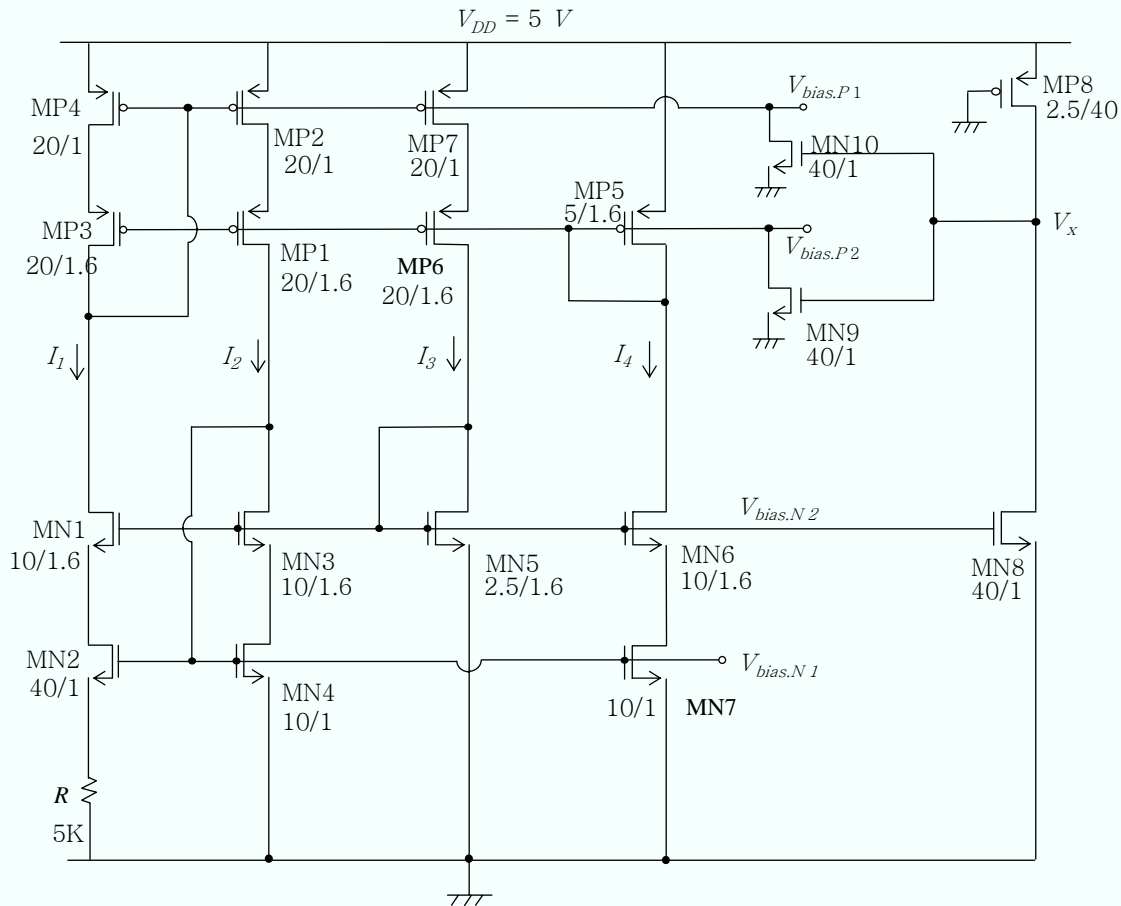
$$I_1 = I_2 = \frac{1}{2\mu_n C_{ox} \cdot R^2 \cdot (W/L)_{MN4}}$$

$$g_{MN4} = \frac{1}{R}$$

$$g_{MP4} = \frac{1}{R} \cdot \sqrt{\frac{\mu_p}{\mu_n} \cdot \frac{(W/L)_{MP4}}{(W/L)_{MN4}}}$$

$$V_{DSAT.MN4} = \frac{1}{R \cdot \mu_n C_{ox} \cdot (W/L)_{MN4}}$$

$$|V_{DSAT.MP4}| = \frac{1}{R \cdot \sqrt{\mu_n \mu_p} \cdot C_{ox} \cdot \sqrt{(W/L)_{MN4} \cdot (W/L)_{MP4}}}$$



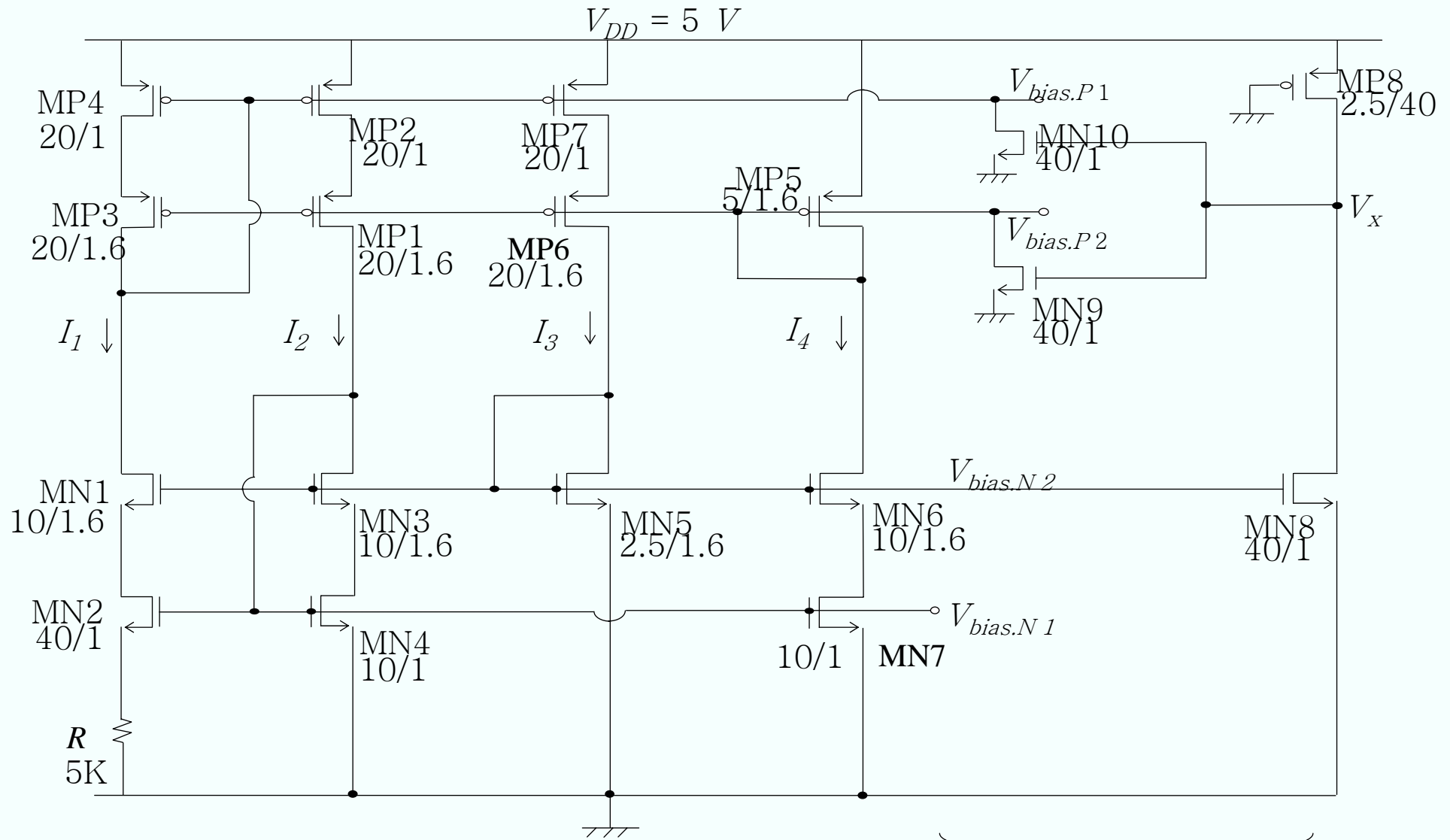
$$|V_{DSAT.MP4}| = \frac{1}{R \cdot \sqrt{\mu_n \mu_p} \cdot C_{ox} \cdot \sqrt{(W/L)_{MN4} \cdot (W/L)_{MP4}}}$$

$$V_{bias.N1} = V_{SS} + V_{THn} + V_{DSAT.MN4}$$

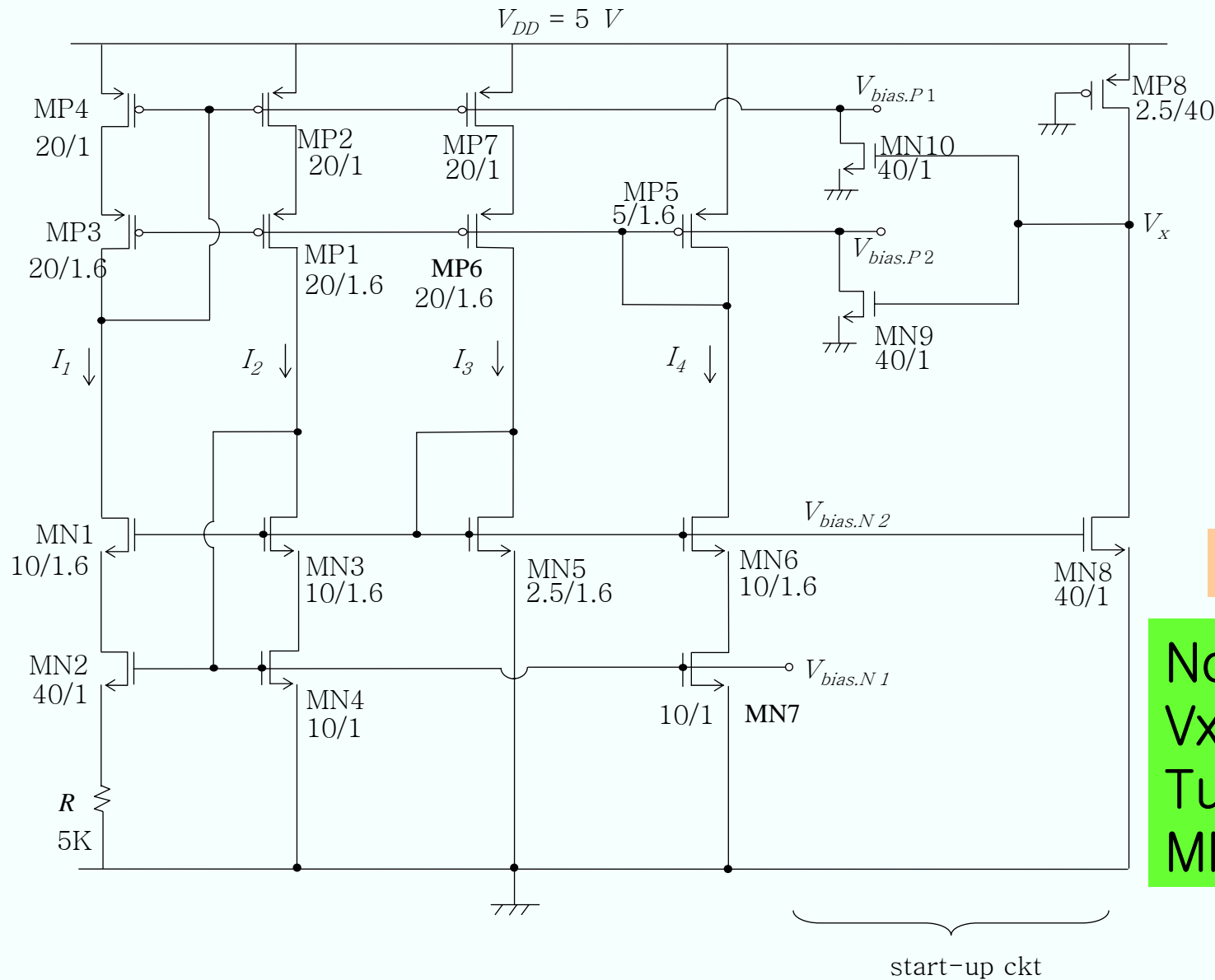
$$V_{bias.N2} = V_{SS} + V_{THn} + 2 V_{DSAT.MN4}$$

$$V_{bias.P1} = V_{DD} - |V_{THp}| - |V_{DSAT.MP4}|$$

$$V_{bias.P2} = V_{DD} - |V_{THp}| - 2 |V_{DSAT.MP4}|$$



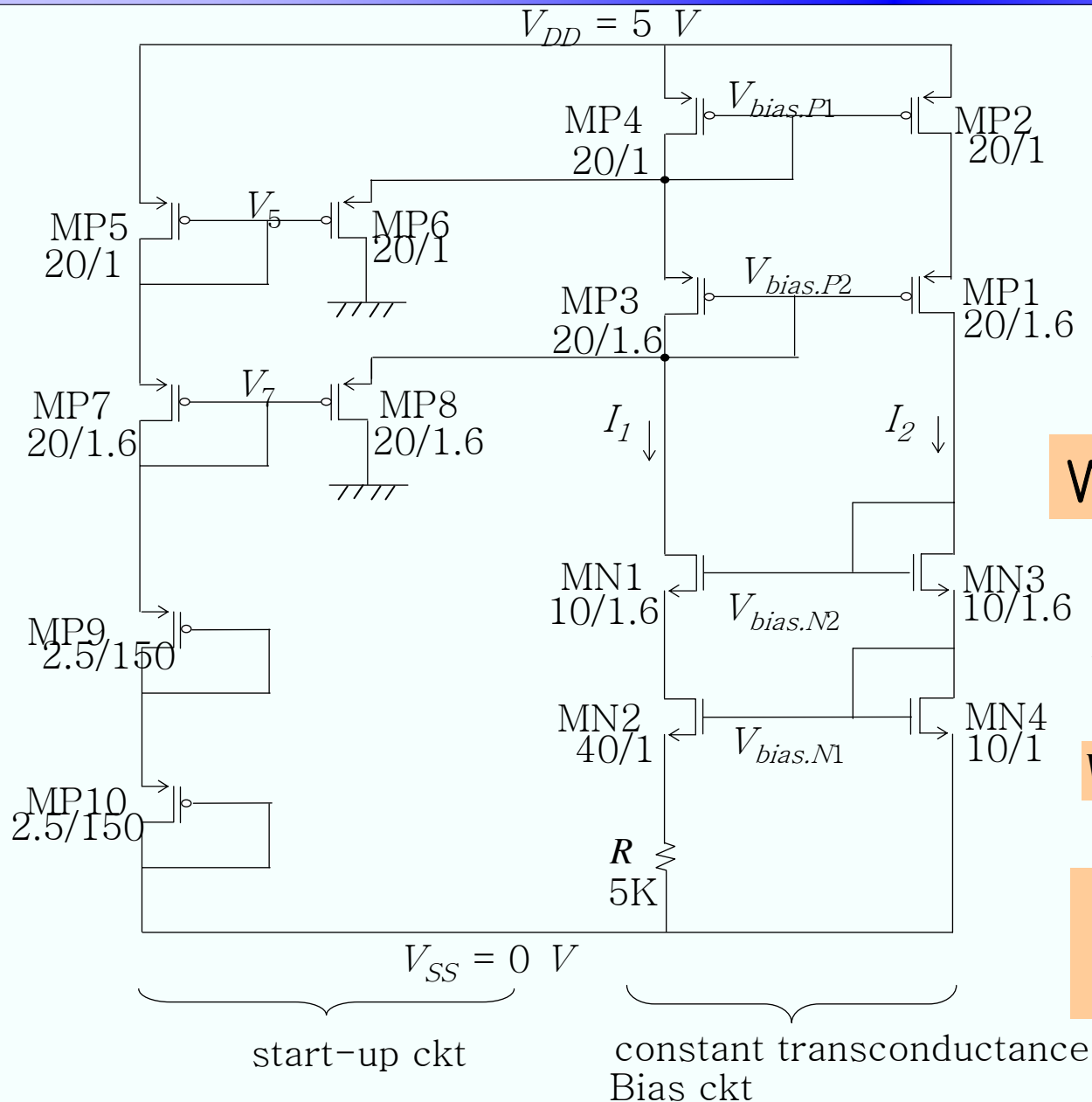
start-up circuit



Start-up ckt (*)

$$(W/L)_{MP8} \ll (W/L)_{MN8}$$

Normal operation:
 V_x close to 0
 Turns off MN9, MN10
 MN8, MP8: on, small I



$$V_5 = V_{DD} - |V_{THp}| - \Delta$$

$$V_7 = V_{DD} - 2|V_{THp}| - 2\Delta$$

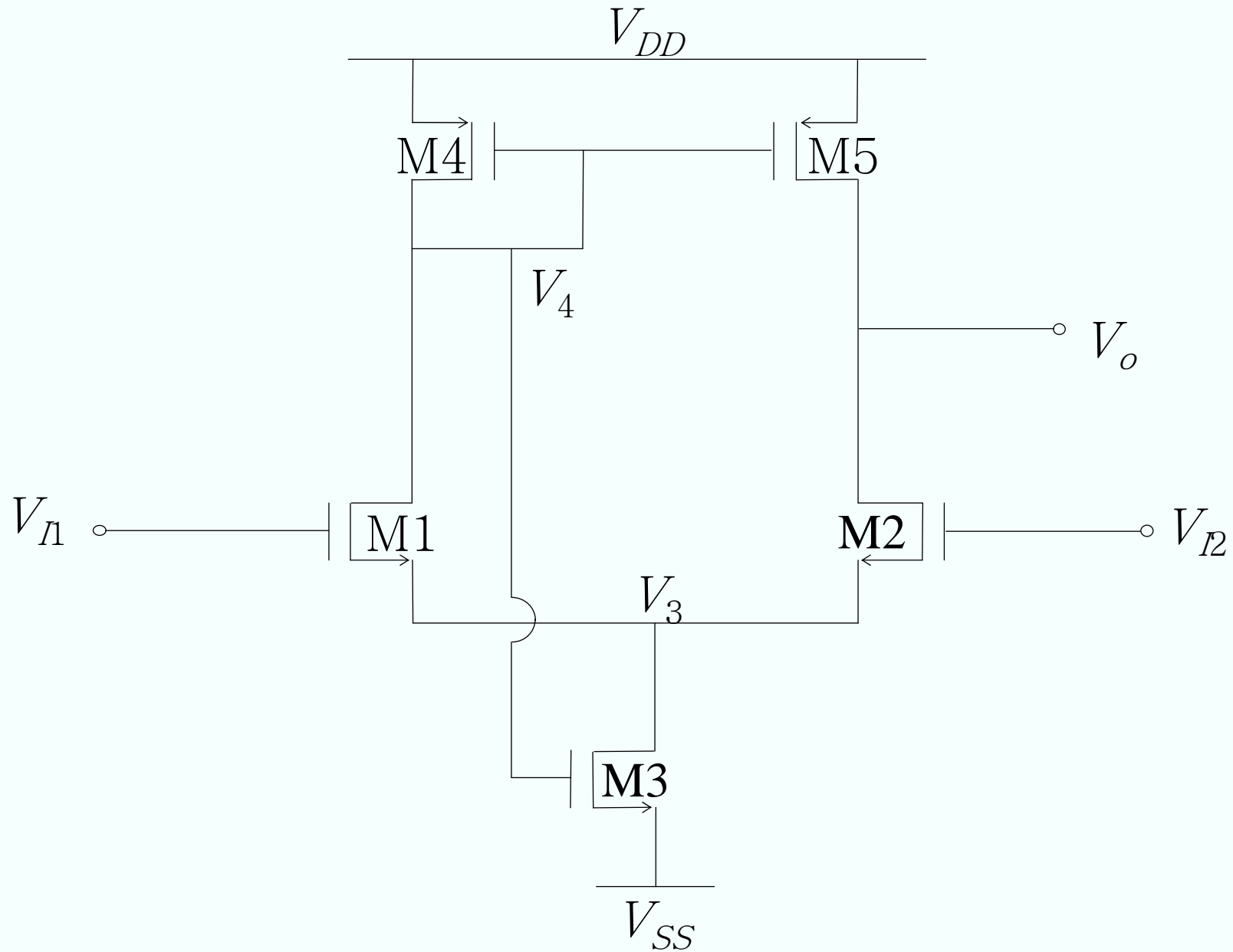
When no current flows

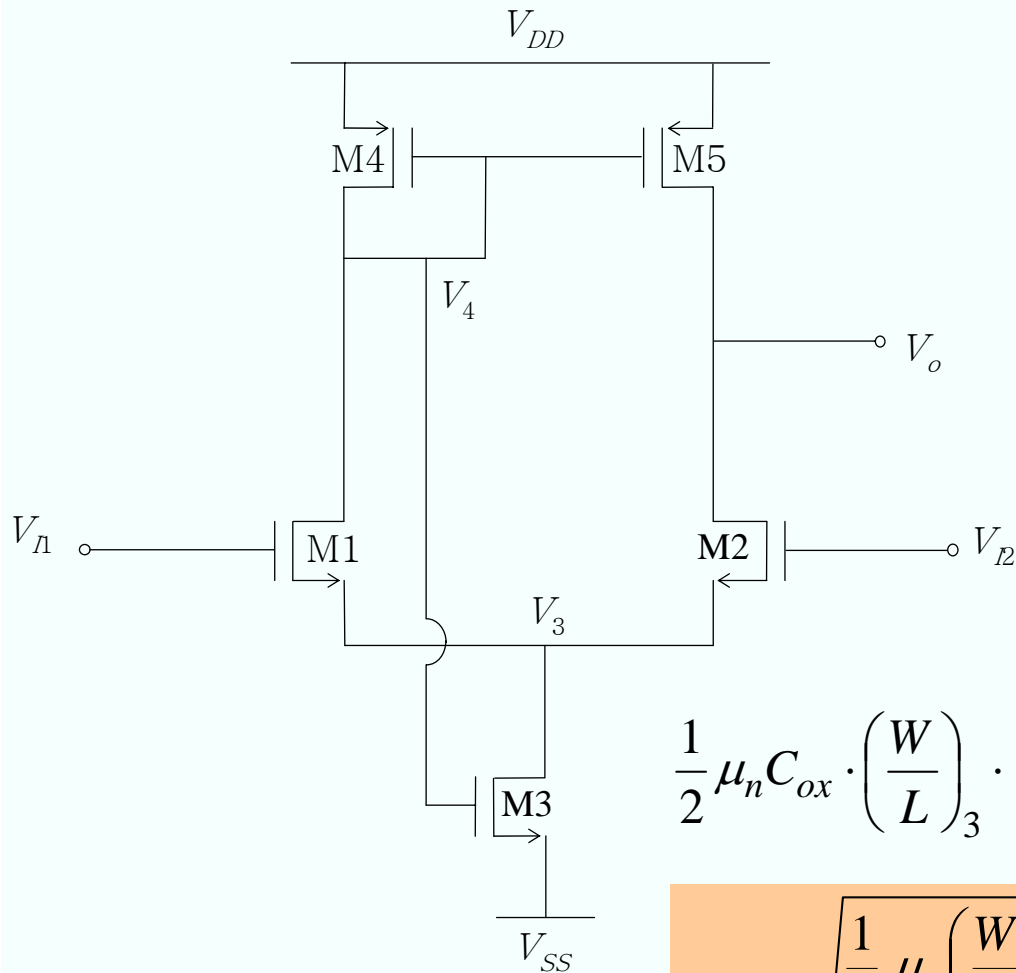
$$V_{bias.P1} = V_5 + |V_{THp}| = V_{DD} - \Delta$$

$$V_{bias.P2} = V_7 + |V_{THp}| = V_{DD} - |V_{THp}| - 2\Delta$$

$$V_{GS3} = V_{bias.P2} - V_{bias.P1} = -|V_{THp}| - \Delta$$

→ Turns on MP3
→ starts self-bias circuit



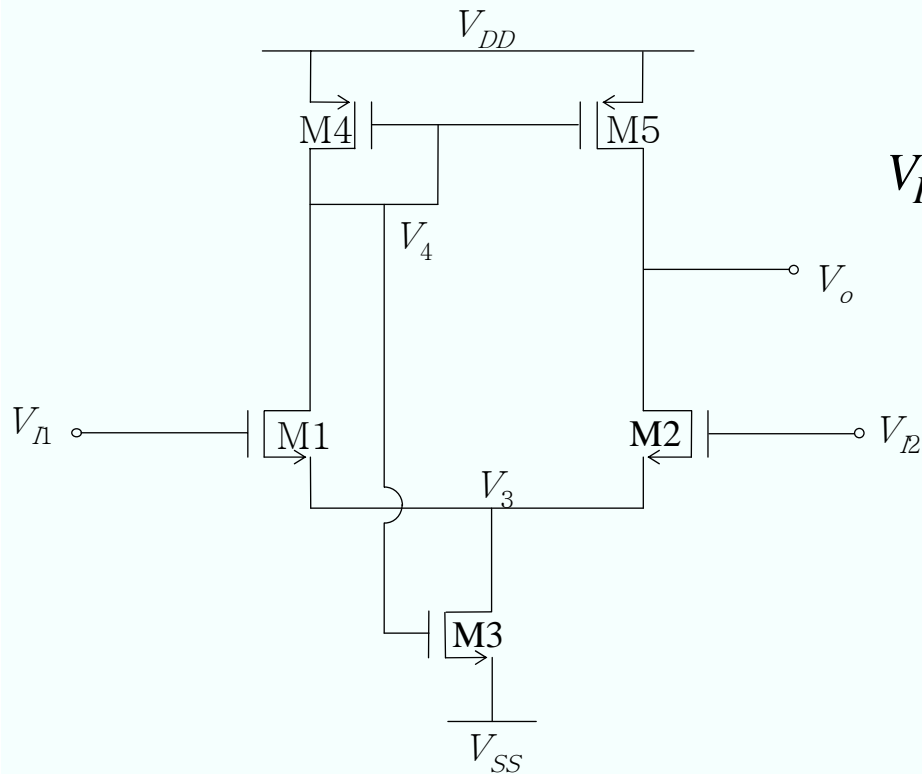


$$V_{GS3} + |V_{GS4}| = V_{DD} - V_{SS}$$

$$I_{D3} = 2I_{D4}$$

$$\frac{1}{2} \mu_n C_{ox} \cdot \left(\frac{W}{L}\right)_3 \cdot (V_{GS3} - V_{THn})^2 = \mu_p C_{ox} \cdot \left(\frac{W}{L}\right)_4 \cdot (|V_{GS4}| - |V_{THp}|)^2$$

$$V_4 = \frac{\sqrt{\frac{1}{2} \mu_n \left(\frac{W}{L}\right)_3 \cdot (V_{THn} + V_{SS})} + \sqrt{\mu_p \left(\frac{W}{L}\right)_4 \cdot (V_{DD} - |V_{THp}|)}}{\sqrt{\frac{1}{2} \mu_n \left(\frac{W}{L}\right)_3} + \sqrt{\mu_p \left(\frac{W}{L}\right)_4}}$$



$$V_{I1} \leq V_4 + V_{THn1}$$

$$V_{I1} \geq (V_{GS1} - V_{THn}) + V_4 = (V_{GS1} - V_{THn1}) + V_4 + (V_{THn1} - V_{THn})$$

$$V_{THn1} = V_{THn} + \gamma \cdot (\sqrt{2\phi_F + V_3} - \sqrt{2\phi_F})$$

$$V_{GS1} - V_{THn1} = \sqrt{\frac{2 \cdot I_{D4}}{\mu_n C_{ox} \cdot (W/L)_1}}$$

$$V_4 + \sqrt{\frac{2I_{D4}}{\mu_n C_{ox} (W/L)_1}} + \gamma \cdot (\sqrt{2\phi_F + V_4 - V_{THn}} - \sqrt{2\phi_F}) \leq V_{I1} \leq V_4 + V_{THn1}$$

$$V_4 + \sqrt{\frac{2I_{D4}}{\mu_n C_{ox} (W/L)_1}} + \gamma \cdot (\sqrt{2\phi_F + V_4 - V_{THn}} - \sqrt{2\phi_F}) \leq V_{I2} \leq V_4 + V_{THn1} + |V_{THp}|$$

GTL(Gunning Transceiver Logic) receiver circuit