FET Current Sources

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Outline

1.Revision

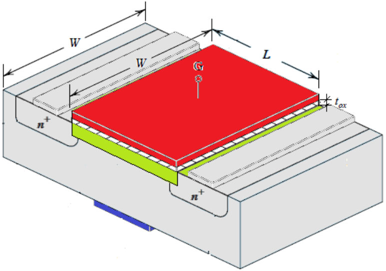
Channel Capacitance

Oxide capacitance:

$$= \frac{\text{permittivity of the silicon dioxide}(3.45 \times 10^{-11})(F/m)}{\text{thickness}(m)} = F/m^2$$

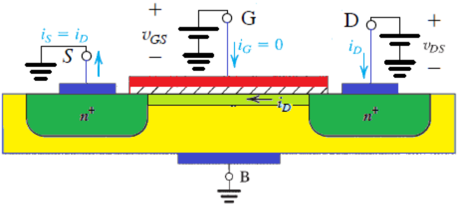
$$C_{OX} = \frac{\varepsilon_{OX}}{t_{OX}}$$

$$C = C_{OX}WL = F$$



t_{OX} of $0.13\mu m$ technology = 2.7 nm, 45nm technology = 1.4 nm.

Applying V_{DS}



Process transconductance parameter (electron mobility μ_n)

$$k'_n = \mu_n C_{OX} = (m^2/V \cdot s)(F/m^2) = A/V^2$$

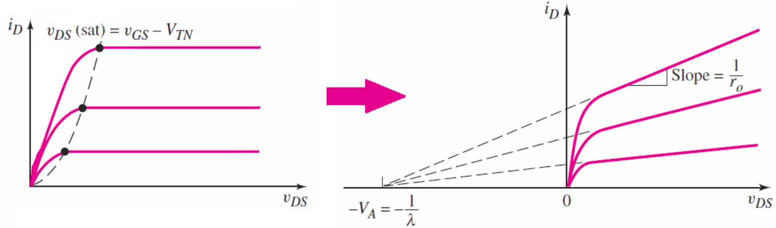
MOSFET transconductance parameter

$$K_n = k'_n \frac{W}{L} = A/V^2$$

Drain Current

$$I_D = 0.5 K_n (V_{GS} - V_t)^2$$

Finite Output Resistance



$$I_D = \frac{1}{2} K_n V_{OV}^2 (1 + \lambda V_{DS})$$

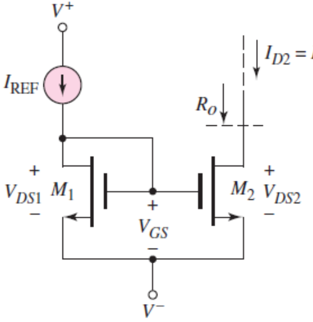
$$V_A = \frac{1}{\lambda} \quad r_o = \frac{V_A}{I_{DQ}}$$

λ : (lambda) is a positive quantity called the channel-length modulation parameter

2.Two-Tran. and current Amp.

Two-Transistor Current Source

- Identical transistors M_1 and M_2.
- $V_{TN1} = V_{TN2}$.
- $K_{n1} = K_{n2}$.
- Both tran. @ saturation.



$$I_{REF} = 0.5K_{n1}(V_{GS} - V_{TN1})^2$$

$$V_{GS} = V_{TN2} + \sqrt{\frac{2I_{REF}}{K_{n1}}}$$

Therefore

$$I_o = 0.5K_{n2}(V_{GS} - V_{TN2})^2$$

$$I_o = 0.5K_{n2}\left(\left(V_{T2} + \sqrt{\frac{2I_{REF}}{K_{n1}}}\right) - V_{T2}\right)^2$$

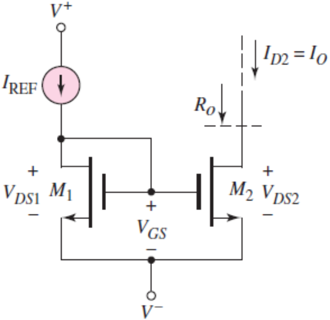
$$\therefore I_o = I_{REF}$$

Current Amplifier

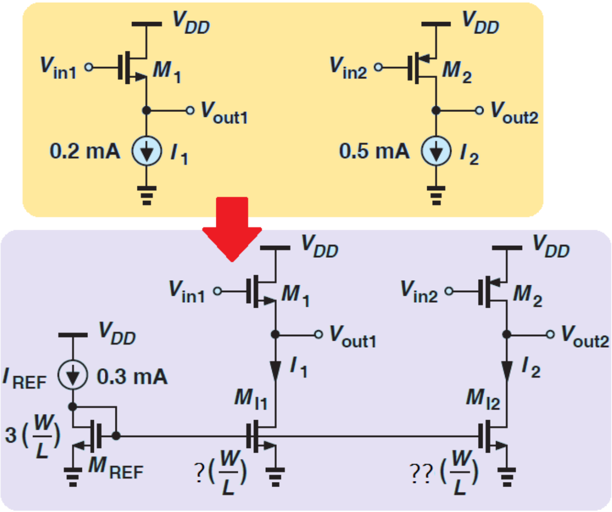
- $V_{TN1} = V_{TN2}$.
- $K_{n1} \neq K_{n2}$.
- Both tran. @ saturation.

$$I_o = K_{n2}\left(\left(V_{TN2} + \sqrt{\frac{I_{REF}}{K_{n1}}}\right) - V_{TN2}\right)^2$$

$$\therefore I_o = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1} I_{REF}$$

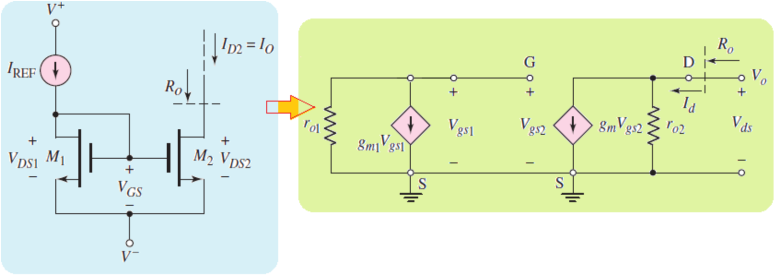


Ex:Design



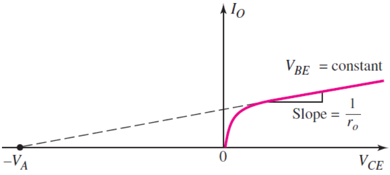
$$I_o = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1} I_{REF} \Rightarrow ? = 3\frac{I_1}{I_{REF}} = 2 \qquad ?? = 5$$

Output Resistance Two-Transistors



$$R_o = \frac{V_o}{I_o} = r_{o2}$$

$$V_A = \frac{1}{\lambda} \qquad r_o = \frac{V_A}{I_{DQ}}$$



3. No Three-Transistor Current Source

β Dependence

MOS devices draw a negligible gate current

$$I_G = 0$$

On the other hand, channel-length modulation in the current-source transistors does lead to additional errors.

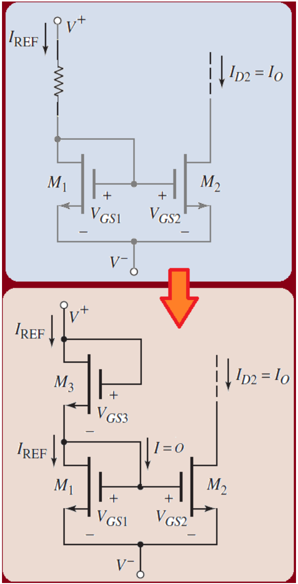
Reference Current(Reduce resistors)

Replace Resistor

$$0.5K_{n1}(V_{GS1} - V_{T1})^2 = 0.5K_{n3}(V_{GS3} - V_{T3})^2$$

$$V_{GS1} + V_{GS3} = V^+ - V^- = V$$

$$\text{Assume } K'_{n1} = K'_{n3} \quad V_{T1} = V_{T3}$$



$$\left(\frac{W}{L}\right)_1 (V_{ov1})^2 = \left(\frac{W}{L}\right)_3 (V_{ov3})^2$$

$$\left(\frac{(W/L)_3}{(W/L)_1}\right) = x$$

$$V_{ov1} = \sqrt{x}V_{ov3} \Rightarrow$$

$$V_{GS1} = \sqrt{x}V_{GS3} + V_T(1 - \sqrt{x})$$

$$V_{GS1}(1 + \sqrt{x}) = \sqrt{x}V + V_T(1 - \sqrt{x})$$

$$V_{GS1} = \frac{\sqrt{x}}{(1 + \sqrt{x})}V + \frac{(1 - \sqrt{x})}{(1 + \sqrt{x})}V_T$$

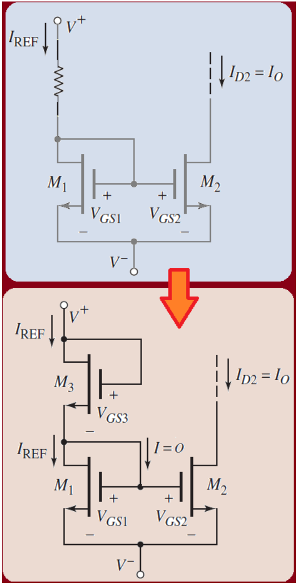
Cont.:Replace Resistor

$$V_{GS1} = \frac{\sqrt{x}}{(1+\sqrt{x})}V + \frac{(1-\sqrt{x})}{(1+\sqrt{x})}V_T = V_{GS2}$$

$$\because x = \left(\frac{(W/L)_3}{(W/L)_1}\right)$$

$$\because V = V^+ - V^-$$

$$I_O = 0.5K_{n2}(V_{GS2} - V_T)^2$$



Example:Replace Resistor

for saturation (M_2):

$$V_{DS2} \geqslant V_{GS2} - V_T \Rightarrow$$

$$V_{GS2} = V_{DS2} + V_T = 0.8V = V_{GS1}$$

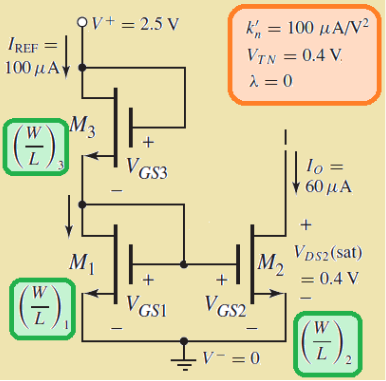
$$\left(\frac{W}{L}\right)_2 = \frac{I_O}{0.5K_{n1}(V_{GS1} - V_T)^2} = 7.5$$

$$\left(\frac{W}{L}\right)_1 = 12.5$$

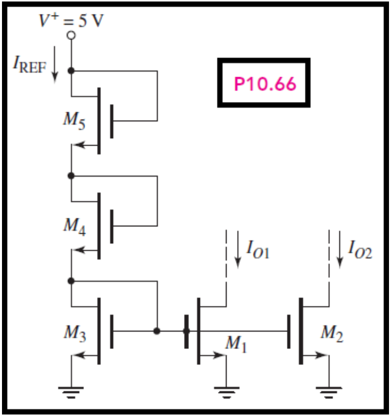
$$\because V_{GS1} + V_{GS3} = V^+ - V^- = 2.5$$

$$V_{GS3} = 1.7V$$

$$\left(\frac{W}{L}\right)_3 = 1.18$$



Example:Challenge your self



4. r_o Output Resistance

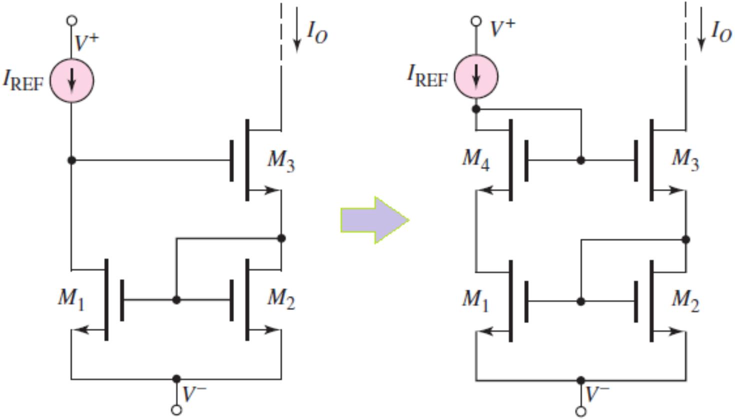
Wilson Current Mirror

Cascode

Cascode

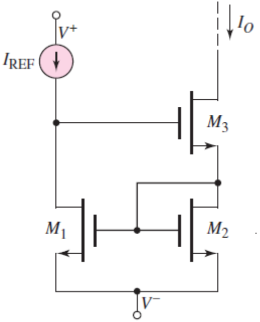
is a shortened version of "*cascaded cathode*", from the days of vacuum tubes .

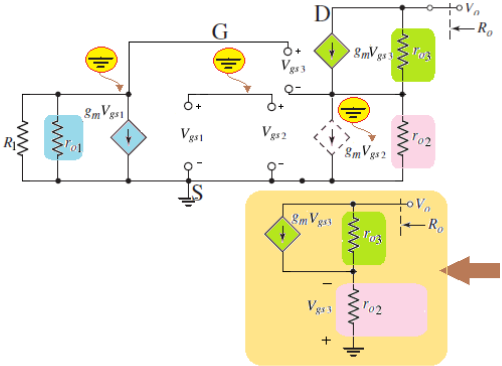
Wilson Current Source



Since λ is not zero, the ratio $\frac{I_O}{I_{REF}}$ is slightly different from the aspect ratios. This problem is solved in the **modified Wilson current source**

Wilson Output resistance





Wilson Current Mirror

$$I_o = g_m V_{gs3} + \left(\frac{V_o - I_o r_{o2}}{r_{o3}} \right)$$

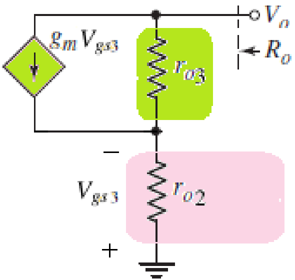
$$\because V_{gs3} = -I_o r_{o2}$$

$$r_{o3} I_o = -r_{o3} g_m I_o r_{o2} + V_o - I_o r_{o2}$$

$$\frac{V_o}{I_o} = r_{o3} + r_{o3} g_m r_{o2} + r_{o2}$$

$$\frac{V_o}{I_o} = r_{o3} + r_{o2}(g_m r_{o3} + 1)$$

normally $g_m r_{o3} \gg 1$

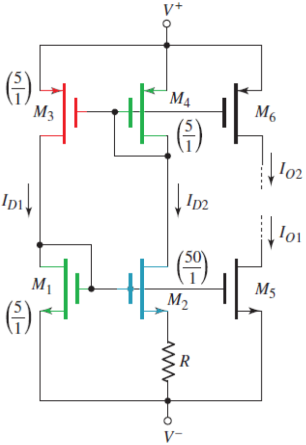


Therefore the R_O is improved.

Bias-Independent Current Source

Hum Noise Again!!

$\frac{W}{L}$ ratio of all transistors are shown:



$$V_{sg3} = V_{sg4} \Rightarrow I_{D1} = I_{D2}$$

$$V_{gs1} = V_{gs2} + I_{D2}R$$

$$I_{D2} = I_{D1}$$

$$0.5K_n(V_{gs1} - V_T)^2 = 0.5K_n(V_{gs2} - V_T)^2$$

$$X(V_{gs1} - V_T)^2 = (V_{gs1} - I_{D2}R - V_T)^2$$

$$\because X = \left(\frac{W}{L}\right)_1 / \left(\frac{W}{L}\right)_2$$

$$V_{gs1}(1 - \sqrt{X}) = I_{D2}R + V_T(1 - \sqrt{X})$$

$$(V_{gs1} - V_T)(1 - \sqrt{X}) = I_{D2}R$$

$$I_{D2}(1 - \sqrt{X})^2 = 0.5K_n(I_{D2}R)^2$$

$$R^2 = \frac{(1 - \sqrt{X})^2}{0.5K_nI_{D2}} \Rightarrow R = \frac{(1 - \sqrt{X})}{\sqrt{0.5K_nI_{D2}}}$$

Hum Noise Again!!

$$R = \frac{(1-\sqrt{X})}{\sqrt{0.5K_n I_{D2}}}$$

The currents I_{D1} and I_{D2} are independent of the supply voltages V^+ and V^- as long as M_2 and M_3 are biased in the saturation region. As the difference, $V^+ - V^-$, increases, the values of V_{DS2} and V_{SD3} increase but the currents remain essentially constant.