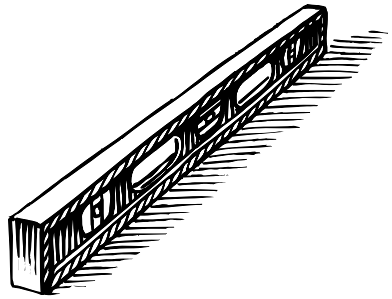
ECEN 607 (ESS)

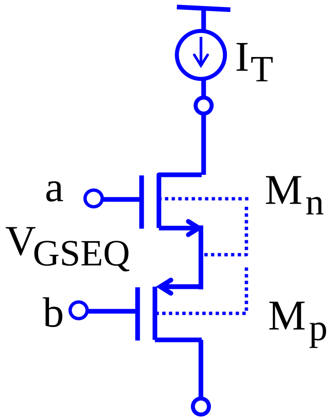


DC Level Shifters and applications

Ref- *Low-Voltage Low Power Integrated Circuits*, E. Sánchez-Sinencio, A. Andreou, IEEE Press, Chapter 7, 1999.

DC Level Shifters

Composed Transistor Type:

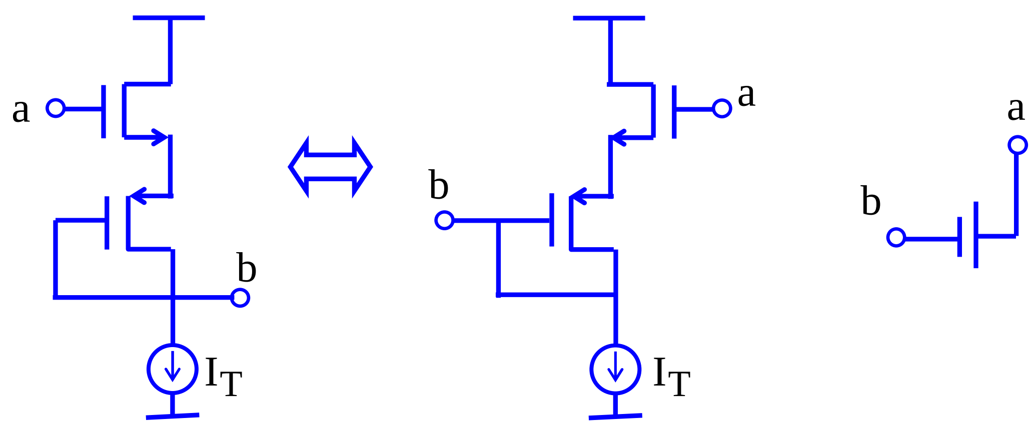


$$V_{GSEQ} = V_{GSn} + V_{SGp} = \sqrt{\frac{I_T}{K_n}} - V_{Tn} + \sqrt{\frac{I_T}{K_p}} - V_{Tp}$$

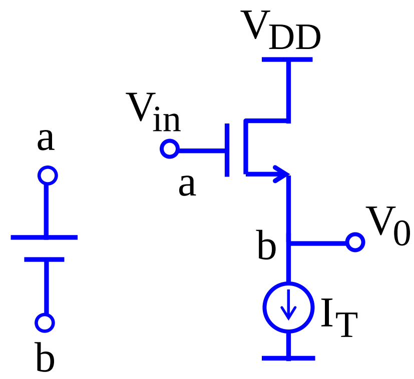
$$V_{GSEQ} = \sqrt{I_T}\left(\frac{1}{\sqrt{K_n}} + \frac{1}{\sqrt{K_p}}\right) - (V_{Tn} + V_{Tp}) = \sqrt{\frac{I_T}{K_{eq}}} - V_{Teq}$$

$$V_{ab} = \sqrt{\frac{I_T}{K_{eq}}} - V_{Teq}$$

A typical use of this (composed transistor) circuit is the following:



Source Follower Type



$$I_T = K'\frac{W}{L}(V_{GS} - V_T)^2$$

$$I_T = K'\frac{W}{L}(V_{in} - V_0 - V_T)^2$$

$$V_{in} - V_0 = \sqrt{\frac{I_T}{K'\frac{W}{L}}} + V_T$$

$$V_{in} - \left\{\sqrt{\frac{I_T}{K'\frac{W}{L}}} + V_T\right\} = V_0$$

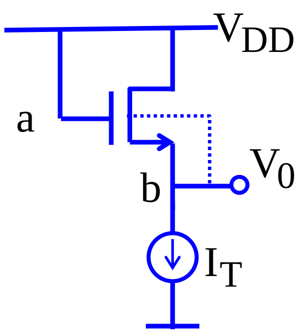
$$V_{DS} > V_{GS} - V_T$$

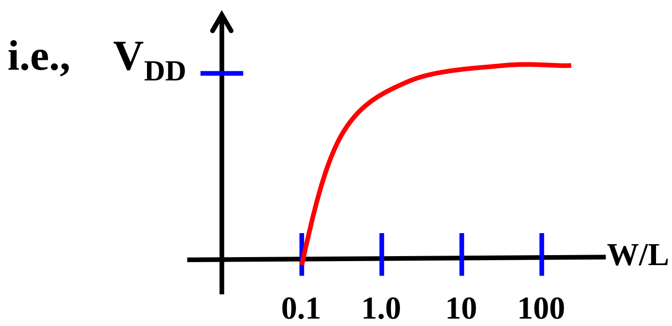
$$V_D > V_G - V_T$$

$$V_{DD} > V_G - V_T$$

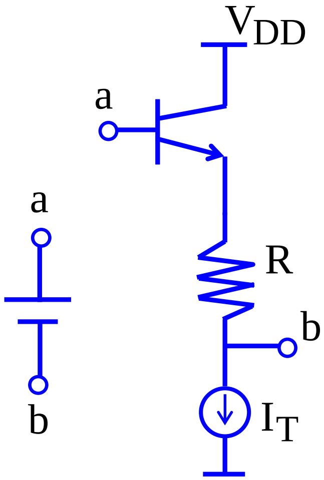
i.e., $V_{in} = V_{DD}$, Then

$$V_0 = V_{DD} - \left\{\sqrt{\frac{I_T}{K'W/L}} + V_{T0}\right\}$$



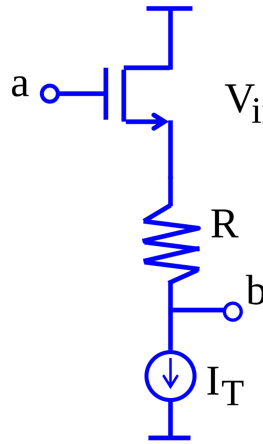


$$V_{ab} = V_{DD} - V_0 = \sqrt{\frac{I_T}{K'W/L}} + V_{T0}$$



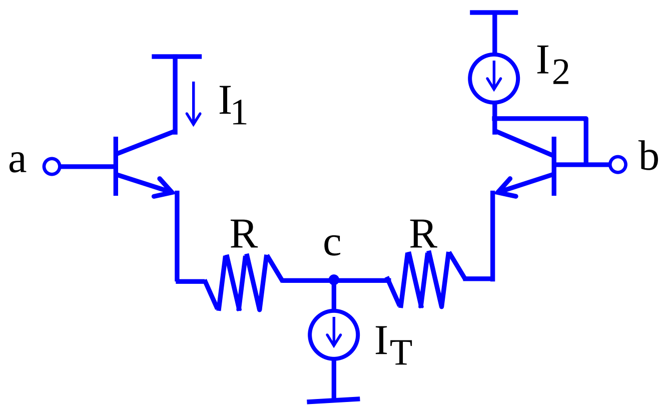
$$V_{ab} \cong 0.6 + RI_T$$

Single Ended BJT Implementation



$$V_{in} - V_0 = V_{ab} = \sqrt{\frac{I_T}{K'W/L}} + V_{T0} + I_T R$$

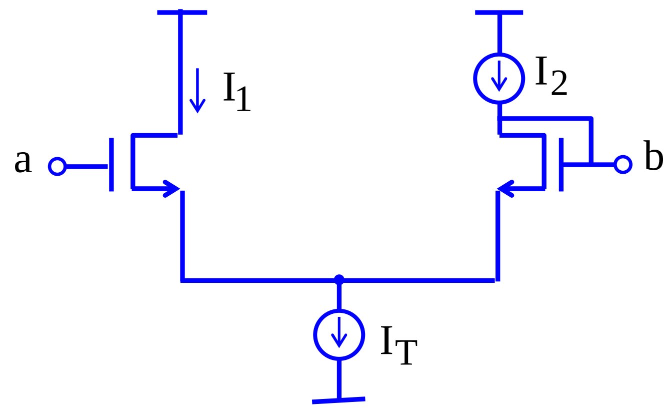
Single Ended MOSFET Implementation



$$V_{ab} = V_{ac} + V_{cb} = V_{ac} - V_{bc}$$

$$V_{ab} = (I_2 - I_1)R$$

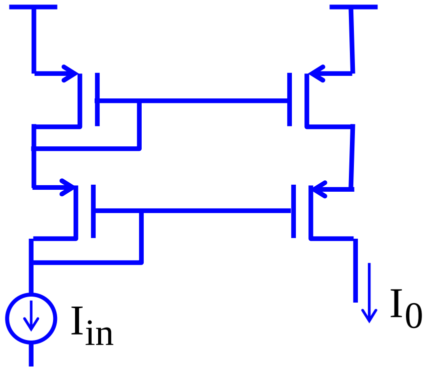
Differential Bipolar Level Shifter



$$V_{ab} = \sqrt{\frac{I_1}{K'W/L}} - \sqrt{\frac{I_2}{K'W/L}} + (V_{T1} - V_{T2})$$

Note: Terminal ⓑ must be tied to high-impedance terminal of the circuit where it is used

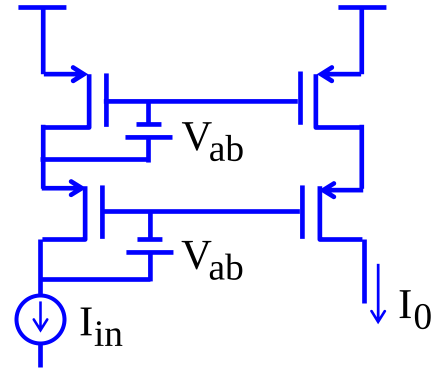
Application of DC Level Shifters



Conventional Cascode CM

$\min V_{in} = 2V_{SG} \sim 4.2V$

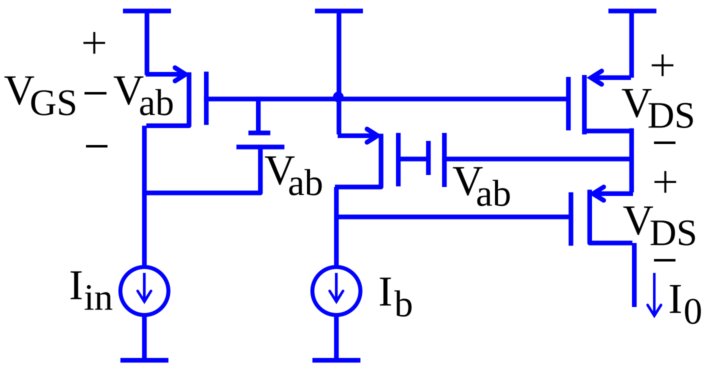
$\min V_0 = V_{GS} + V_{DSAT} \sim 3.3V$

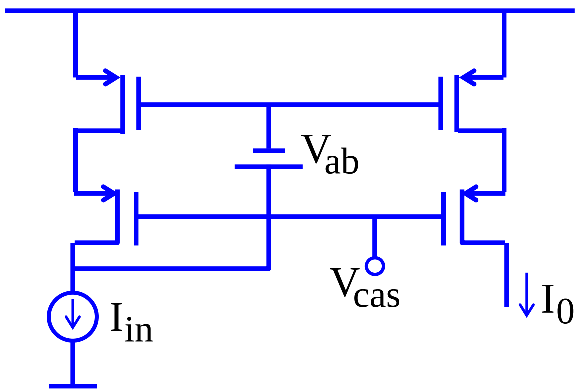


Conventional Cascode with Level Shifter

$\min V_{in} = 2V_{SG} - 2V_{ab}$

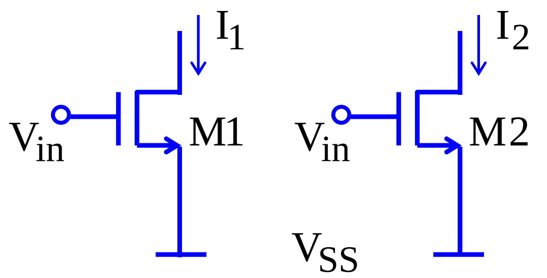
$\min V_0 = V_{GS} + V_{DSAT} - V_{ab}$





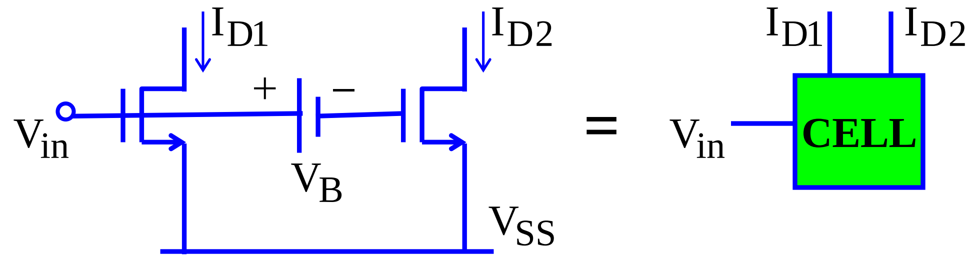
Linearization Technique Using Floating Voltage Sources

$(a+b)^2 - (a-b)^2 = 4ab$ principle



$$I_{D1} = \frac{K}{2}(V_{in} - V_{SS} - V_T)^2 \sim (a+b)^2$$

How to obtain the $(a - b)^2$ type term?



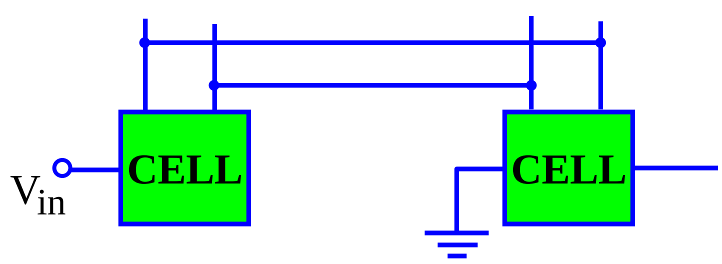
$$I_{D1} = \frac{K}{2}(V_{in} - V_{SS} - V_T)^2$$

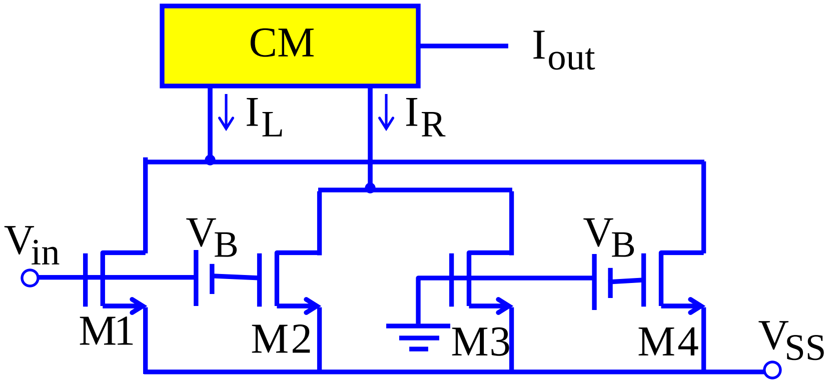
$$I_{D2} = \frac{K}{2}(V_{in} - V_{ab} - V_{SS} - V_T)^2$$

$$I_{out} = I_{D1} - I_{D2} = KV_B V_{in} + I_{off}$$

$$I_{off} = -KV_B\left(V_{SS} + V_T + \frac{V_B}{2}\right)$$

Next we consider an approach to practically eliminate I_{off}.





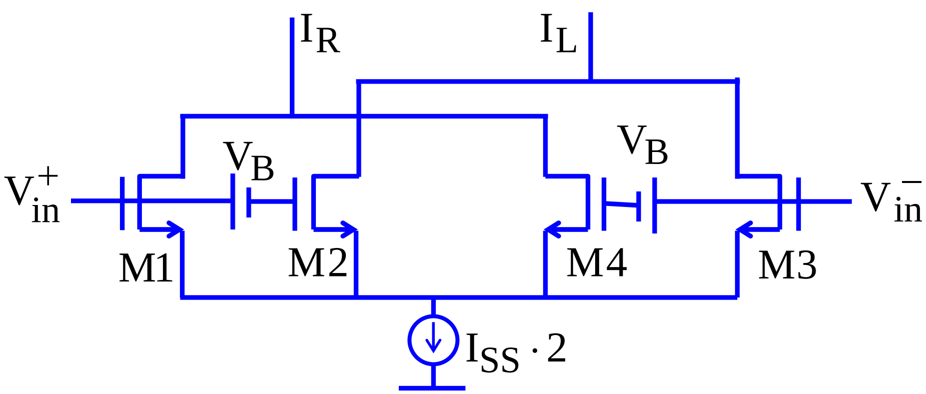
Offset cancellation by connecting two cells.

$$I_{out} = I_L - I_R = (I_{D1} - I_{D2}) - I_{off} = KV_BV_{in}$$

$$\min V_{in} \geq V_{SS} + V_T$$

Power consumption is as large as $4\left(\frac{K}{2}\right)\left(|V_{SS}| - V_T\right)^2$ for $V_B = 0$

A differential version could alliviate this problem.



$$I_L + I_R = 2I_{SS}$$

$$\left.\begin{aligned} I_L &= I_{SS} + \frac{K}{2}V_BV_{in} \\ I_R &= I_{SS} - \frac{K}{2}V_BV_{in} \end{aligned}\right\} I_{out} = I_L - I_R = KV_BV_{in}$$