Logic Circuit Design
NOR-1

20170829

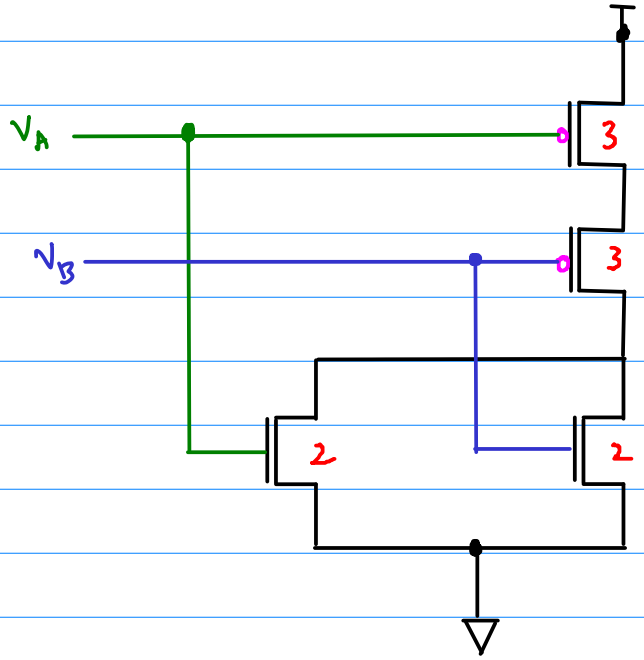
References

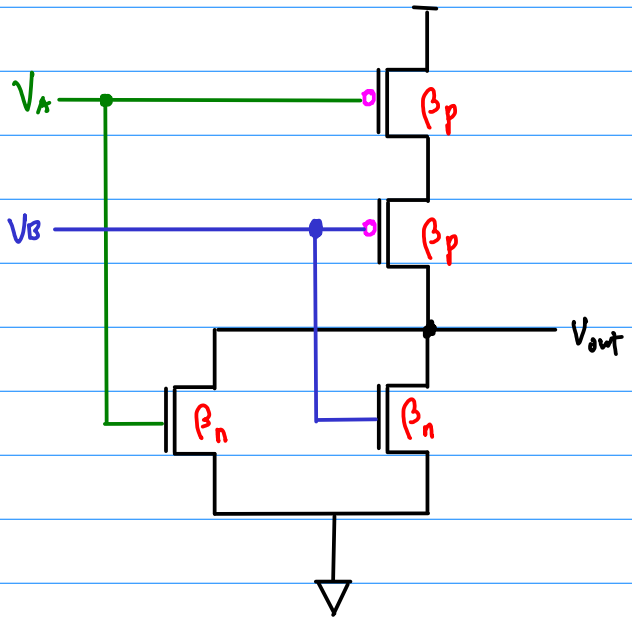
Some Figures from the following sites

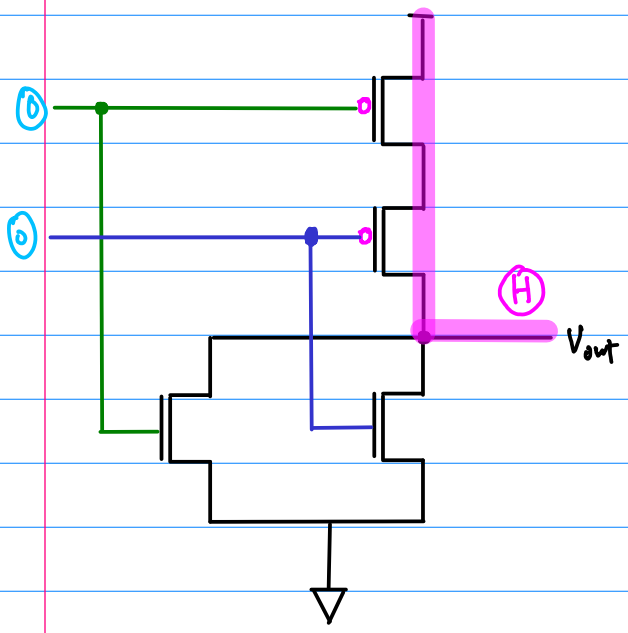
[1] http://pages.hmc.edu/harris/cmosvlsi/4e/index.html
Weste & Harris Book Site

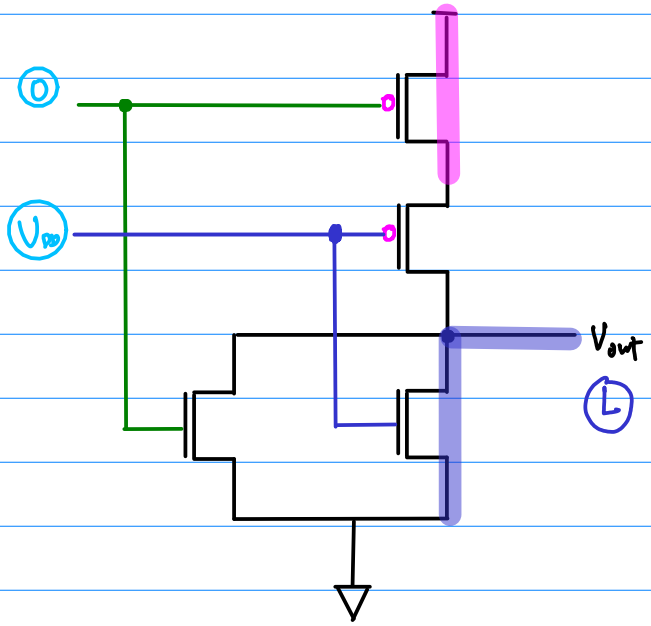
[2] Introduction to VLSI Circuits and Systems, Uyemura

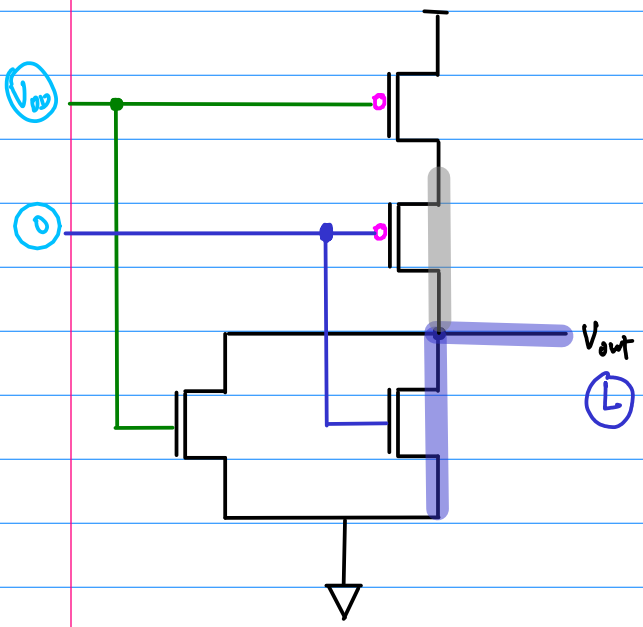
[2] en.wikipedia.org

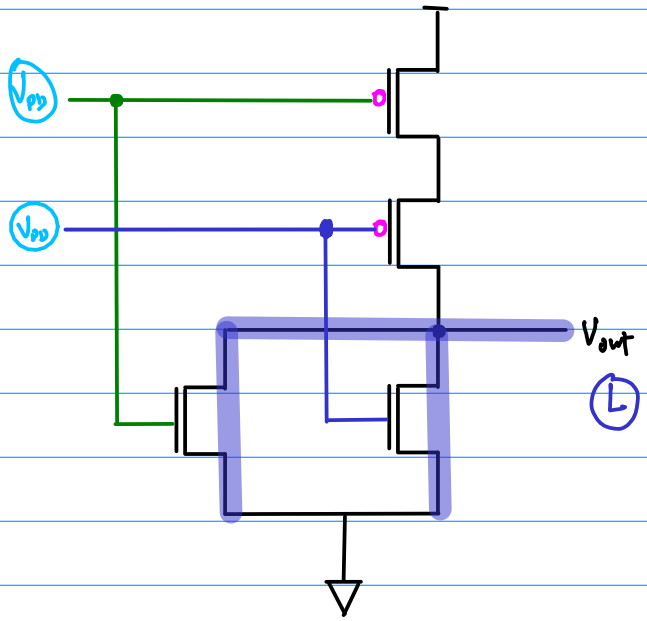

V_A
V_B
3
3
2
2

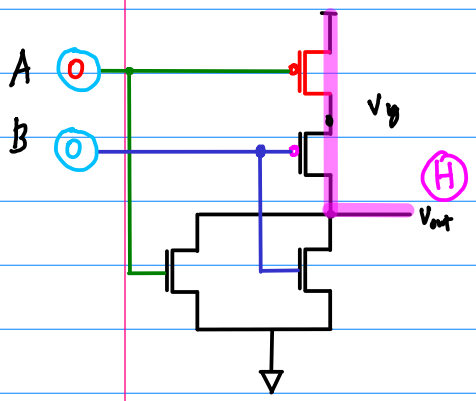

V_A
V_B
β_p
β_p
V_{out}
β_n
β_n

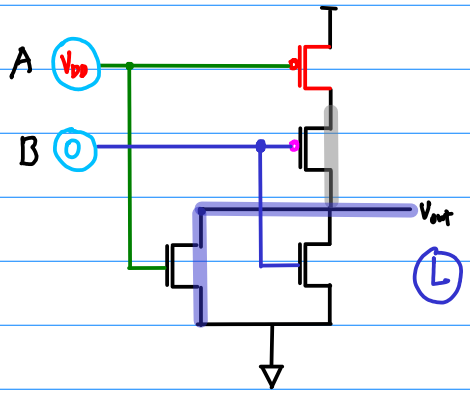

0
0
H
V_{out}

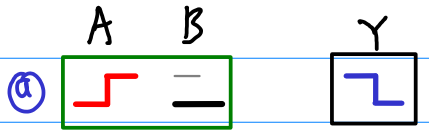

0
V_{DD}
V_{out}
L


V_{DD}
0
V_{out}
L


V_{DD}
V_{DD}
V_{out}
L



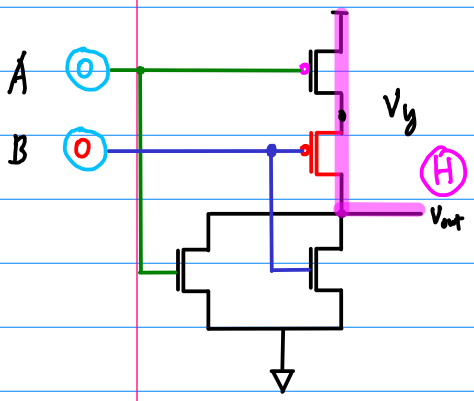


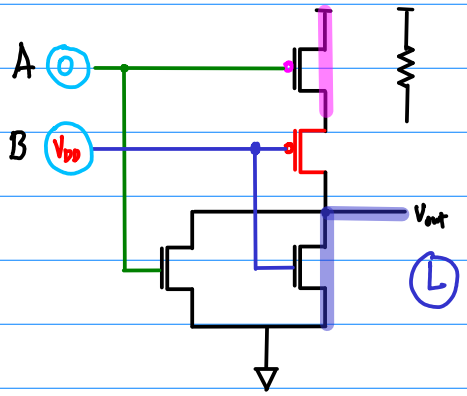


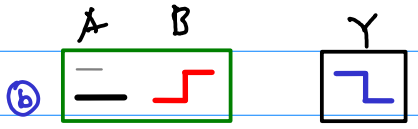
Weak PDN

pMA : resistor

pMB : ~~Body effect~~







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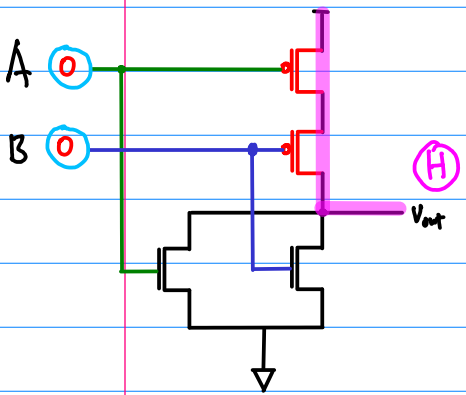
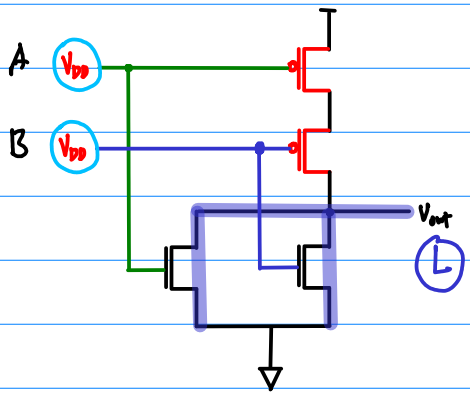
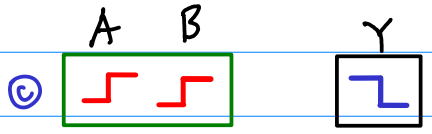
pMB : Body Effect





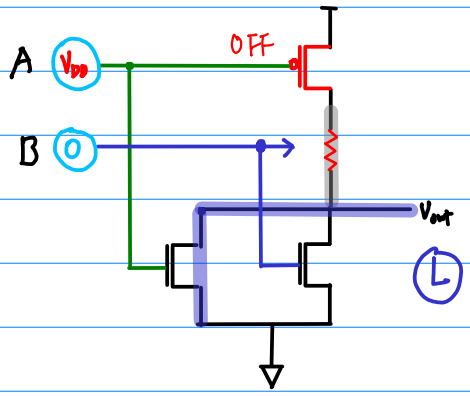


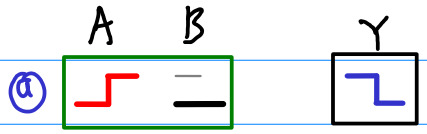
Strong PDN

{ small R
  large C (load)

{ small voltage drop
  slow change

small effect on VTC

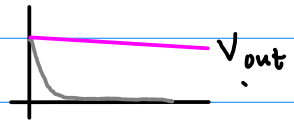




weak PDN

pMA : resistor

pMB : ~~Body effect~~



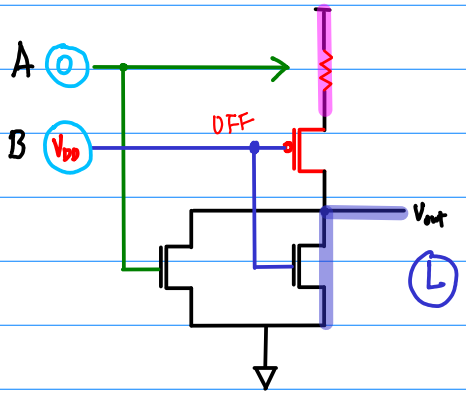
{ small R
  small C (load)

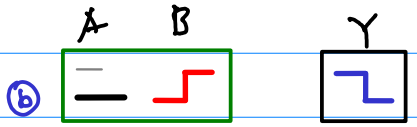
{ large voltage drop
  immediate change

increase V_T

→ hard to turn ON nMB

→ VTC shifted to the right

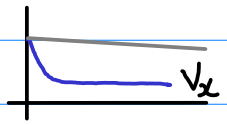


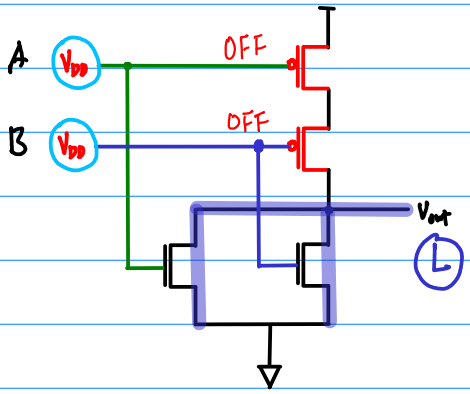


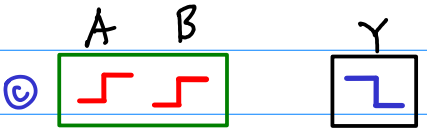
weak PDN

pMA : resistor

pMB : Body Effect

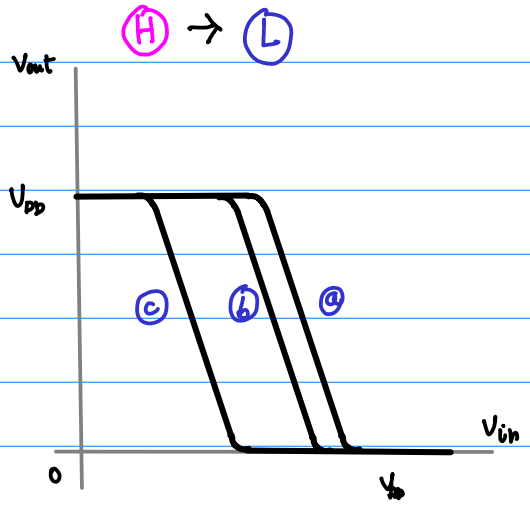


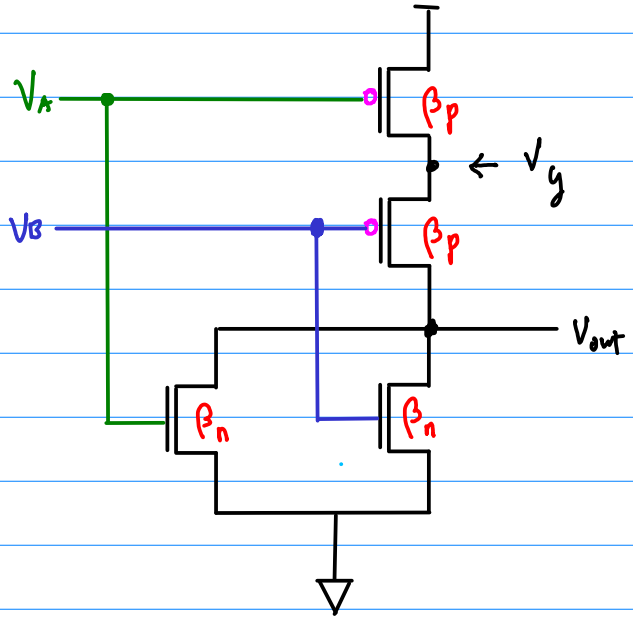


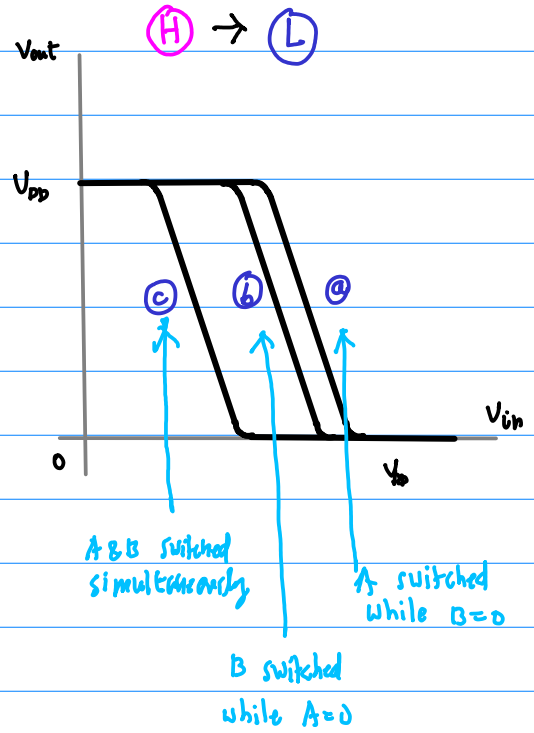


Strong PDN

	V_A	V_B	V_{out}
	0	0	V_{DD}
ⓑ	0	V_{DD}	0
ⓐ	V_{DD}	0	0
ⓒ	V_{DD}	V_{DD}	0





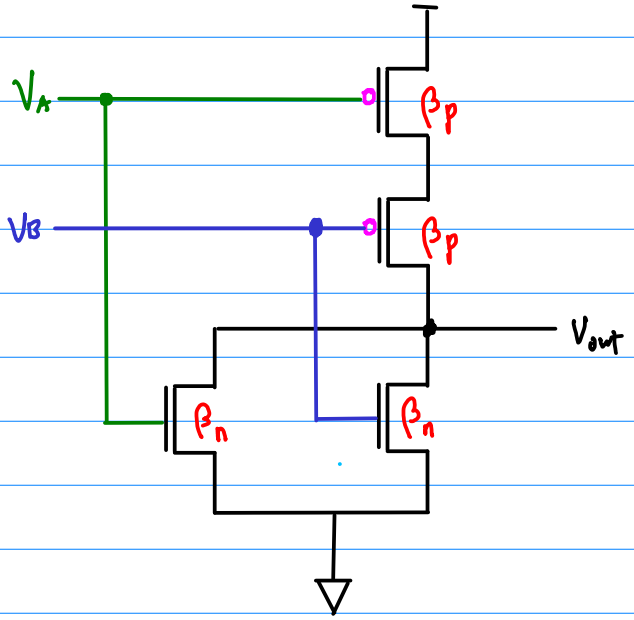


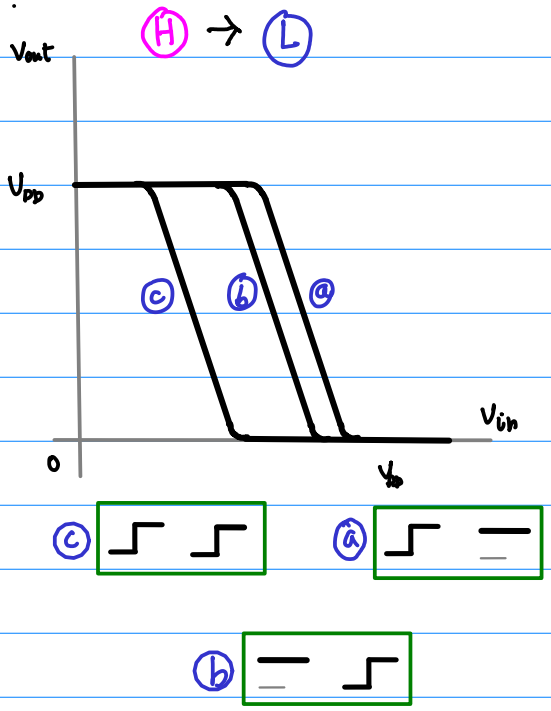
Body Effect

B is more difficult to be turned on than A

	V_A	V_B	V_{out}
	0	0	V_{DD}
ⓑ	0	V_{DD}	0
ⓐ	V_{DD}	0	0
ⓒ	V_{DD}	V_{DD}	0

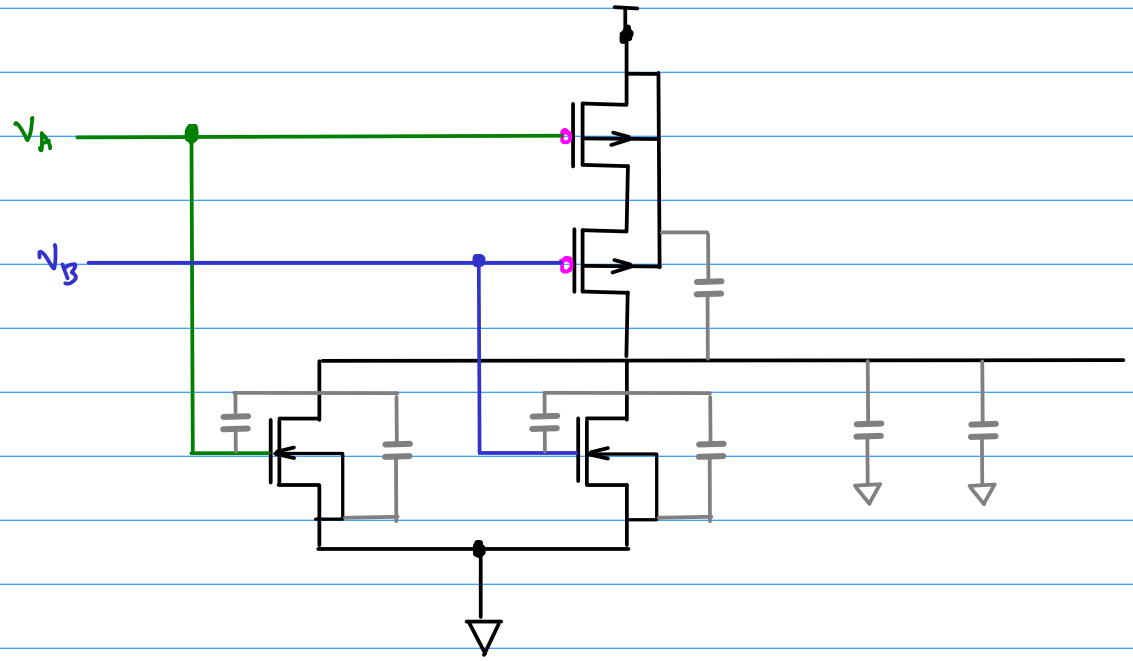
	V_A	V_B	V_{out}
ⓐ	⌐¯	¯	⌐¯
ⓑ	¯	⌐¯	⌐¯
ⓒ	⌐¯	⌐¯	⌐¯

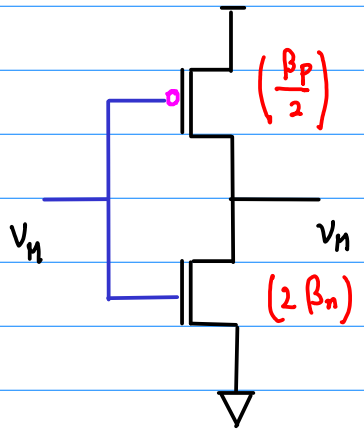


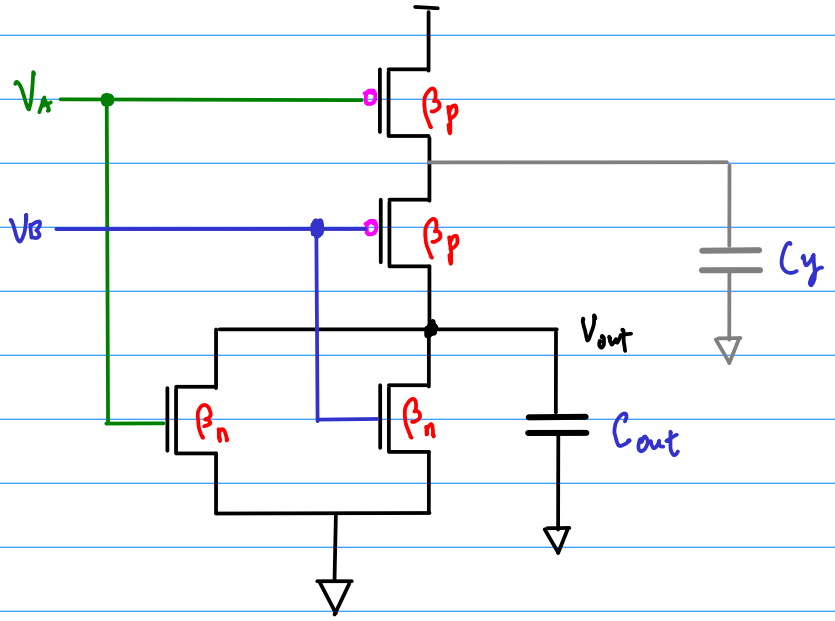


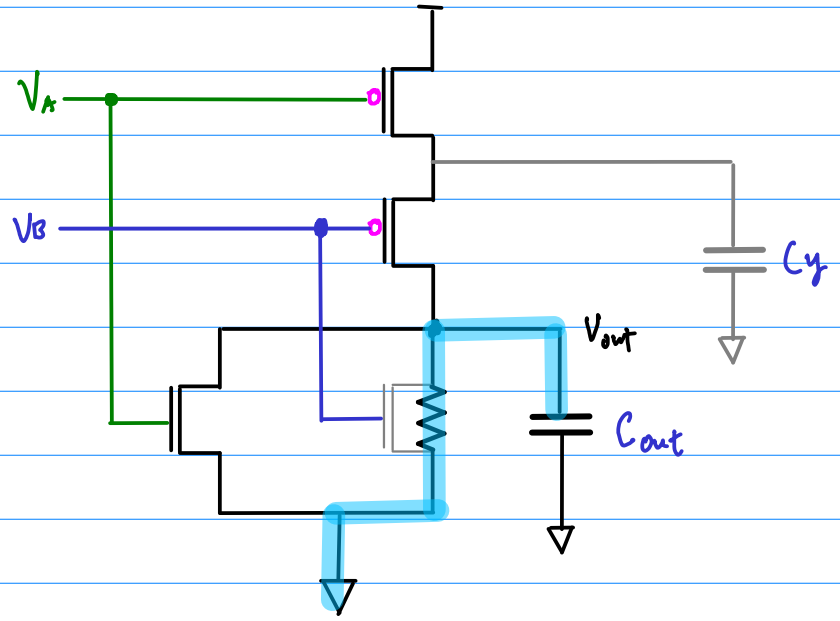
ⓒ ⌐¯ ⌐¯ ⓐ ⌐¯ ¯

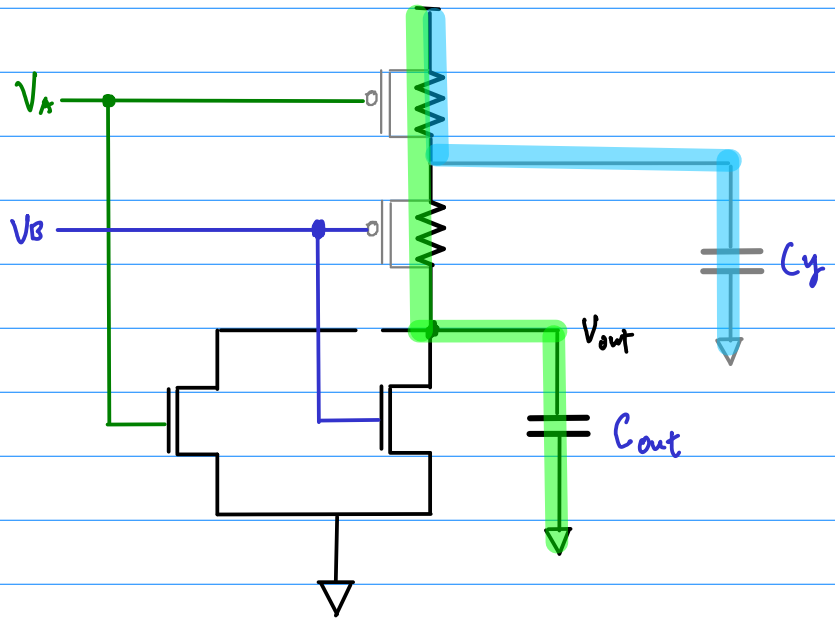
ⓑ ¯ ⌐¯


V_A
V_B


$\left(\frac{\beta_p}{2}\right)$
V_M
V_M
$(2\beta_n)$


V_A
V_B
β_p
β_p
C_y
V_{out}
β_n
β_n
C_{out}


V_A
V_B
C_y
V_{out}
C_{out}


V_A
V_B
C_y
V_{out}
C_{out}

$$C_{out} = C_{FET} + C_L$$

$$C_{FET} = 2C_{Dn} + C_{Dp}$$

$$R_p = \frac{1}{\beta_p (V_{DD} - |V_{Tp}|)} \qquad R_n = \frac{1}{\beta_n (V_{DD} - V_{Tn})}$$

Simultaneous Switching

$$V_{GS,1} = V_{GS,2} = V_{th} = V_{DS,1} = V_{DS,2}$$

$$I_D = I_{D,1} + I_{D,2}$$
$$= \beta_n (V_{th} - V_{Ton})^2$$

$$V_{th} - V_{Ton} = \sqrt{\frac{I_D}{\beta_n}}$$

$$V_{SG,3} = V_{DD} - V_{th}$$
$$V_{SG,4} = V_{DD} - V_{th} - V_{SD,3}$$

$$V_{DD} - V_{th} = V_{SD,3} + V_{SD,4}$$

$$I_D = \frac{\beta_p}{2} \left(2(V_{DD} - V_{th} - |V_{Ton}|) V_{SD,3} - V_{SD,3}^2 \right)$$

$$= \frac{\beta_p}{2} (V_{DD} - V_{th} - |V_{Ton}| - V_{SD,3})^2$$

$$\sqrt{\frac{2I_D}{\beta_p}} = V_{DD} - V_{th} - |V_{Ton}|$$

$$V_{th} = \frac{V_{Ton} + \frac{1}{2}\sqrt{\frac{\beta_p}{\beta_n}} (V_{DD} - |V_{Top}|)}{1 + \frac{1}{2}\sqrt{\frac{\beta_p}{\beta_n}}}$$

$$V_{th} = \frac{V_{DD} + V_{TO}}{3}$$

Single Switching

$$I_D = I_{D,S} = \frac{\beta_n}{2}(V_{th} - V_{TOn})^2$$

$$V_{SG,3} = V_{DD}$$
$$V_{SG,4} = V_{DD} - V_{th} - V_{SD,3}$$

$$V_{DD} - V_{th} = V_{SD,3} + V_{SD,4}$$

$$I_D = \frac{\beta_p}{2}\left[2(V_{DD} - |V_{TOp}|)V_{SD,3} - V_{SD,3}^2\right]$$

$$= \frac{\beta_p}{2}(V_{DD} - V_{th} - |V_{Top}| - V_{SD,3})^2$$

$$V_{SD,3} = (V_{DD} - |V_{TOn}| - V_{th}) - \sqrt{\frac{2I_D}{\beta_p}}$$

$$2\left(\frac{2I_D}{\beta_p}\right) = (V_{DD} - |V_{TOn}|)^2 - V_{th}^2 - 2\sqrt{\frac{2I_D}{\beta_p}}V_{th}$$

$$\left[1 + 2\left(\frac{\beta_n}{\beta_p} + \sqrt{\frac{\beta_n}{\beta_p}}\right)\right]V_{th}^2 - 2V_{TOn}\left[2\left(\frac{\beta_n}{\beta_p}\right) + \sqrt{\frac{\beta_n}{\beta_p}}\right]V_{th}$$
$$- \left[(V_{DD} - |V_{Top}|)^2 - 2\left(\frac{\beta_n}{\beta_p}\right)V_{TOn}^2\right] = 0$$

$$V_{th} = 0.6\,V_{TO} + 0.2\sqrt{5V_{DD}^2 - 10V_{DD}V_{TO} + 4V_{TO}^2}$$