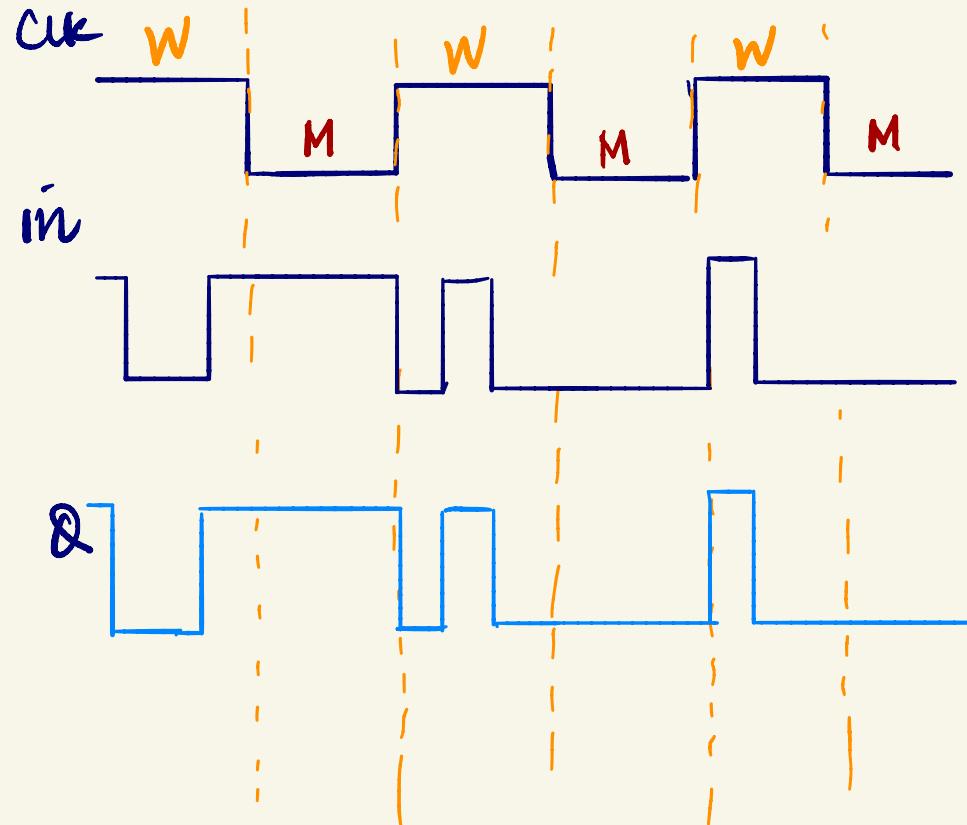
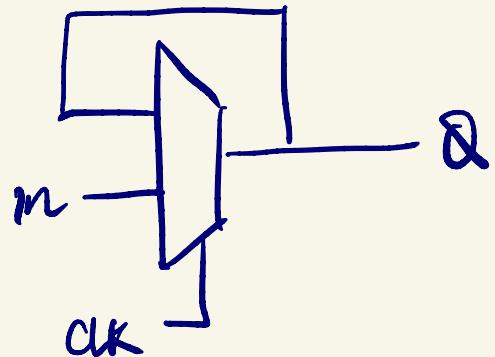


$Clk = 0$ memory mode

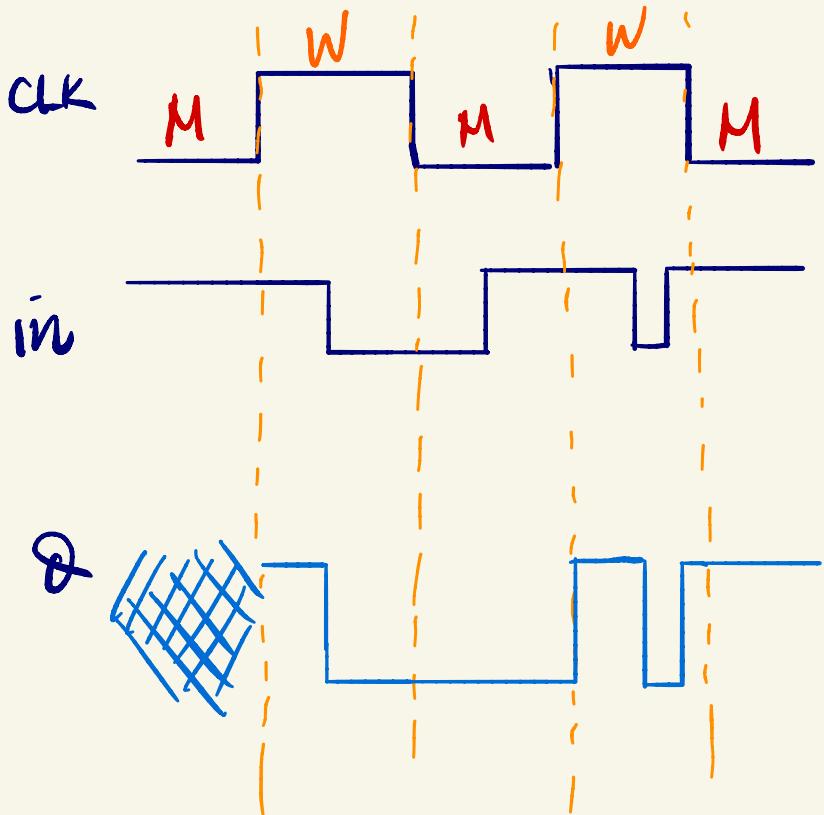
$Clk = 1$ write mode

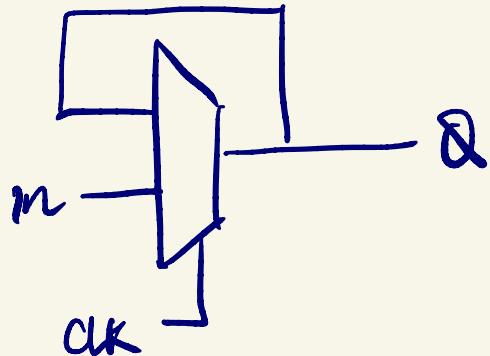




$Clk = 0$ memory mode

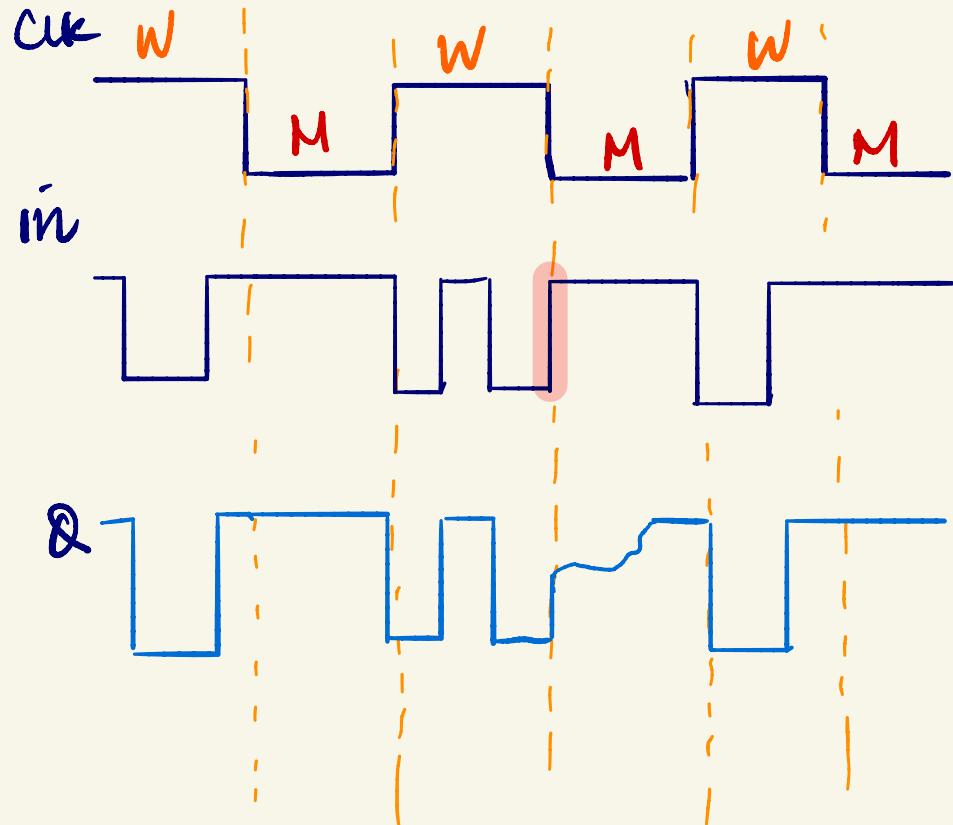
$Clk = 1$ write mode

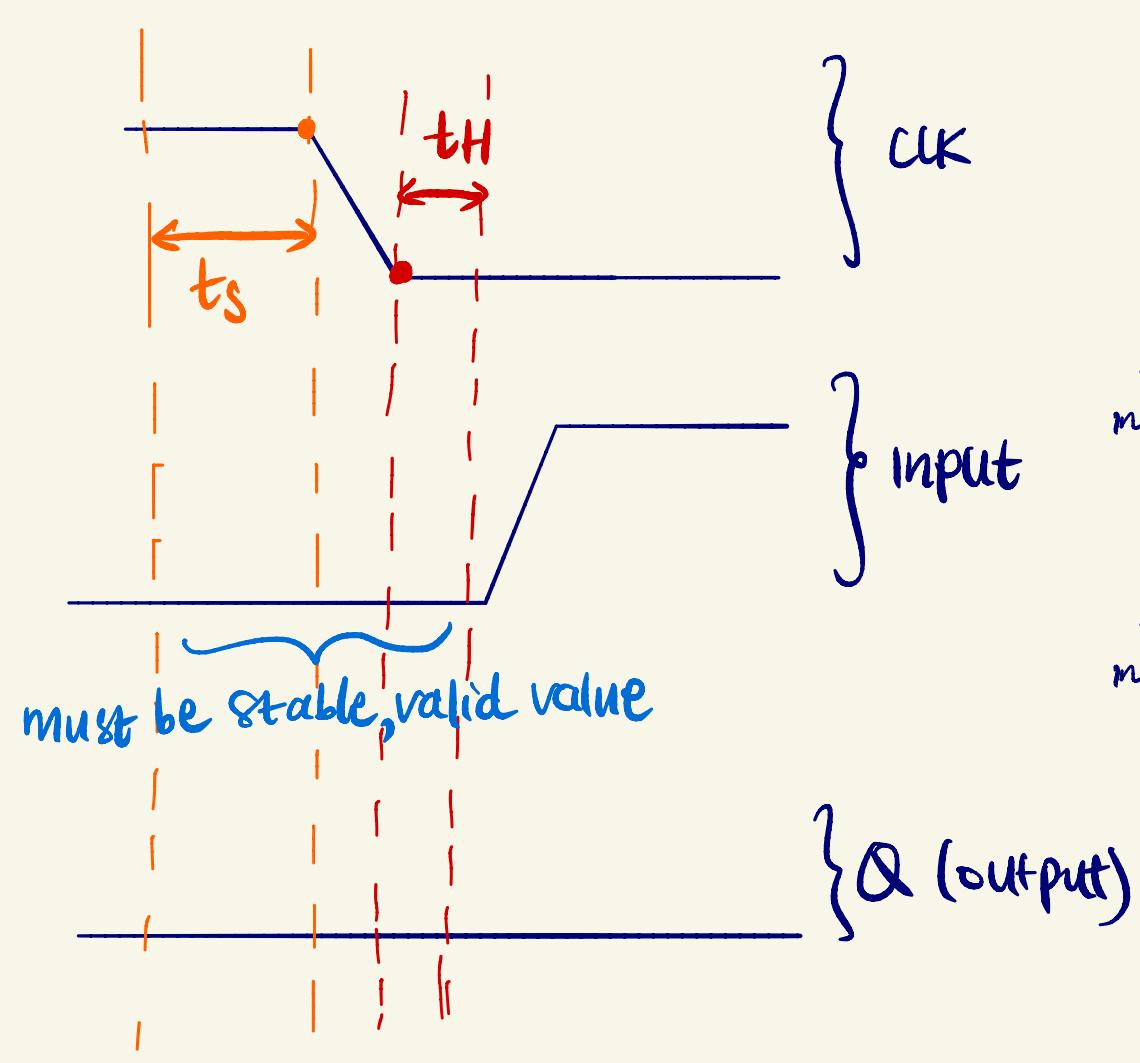




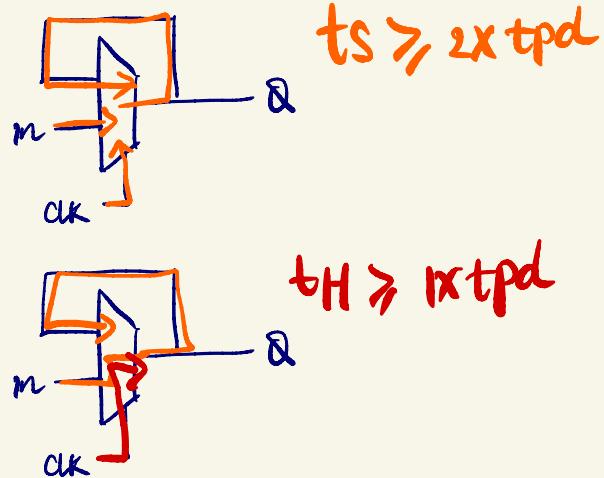
$\text{clk} = 0$ memory mode

$\text{clk} = 1$ write mode

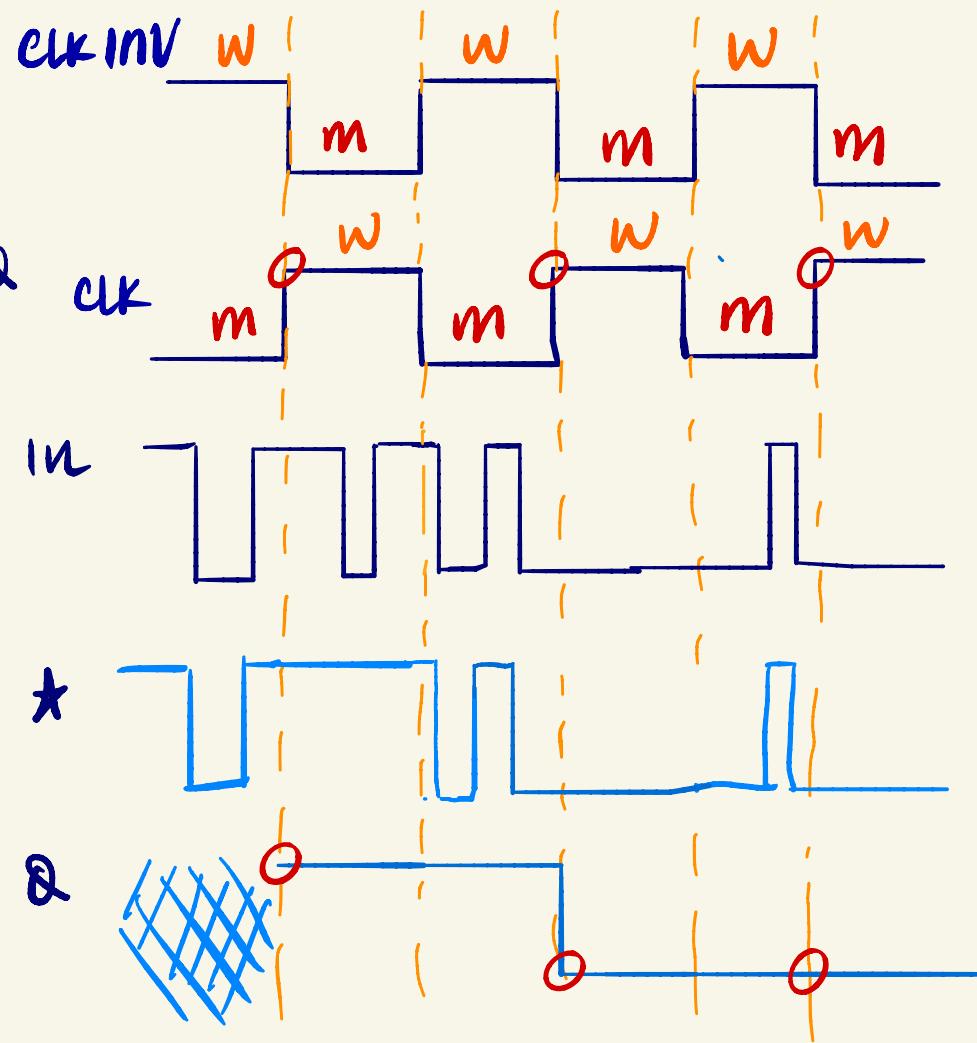
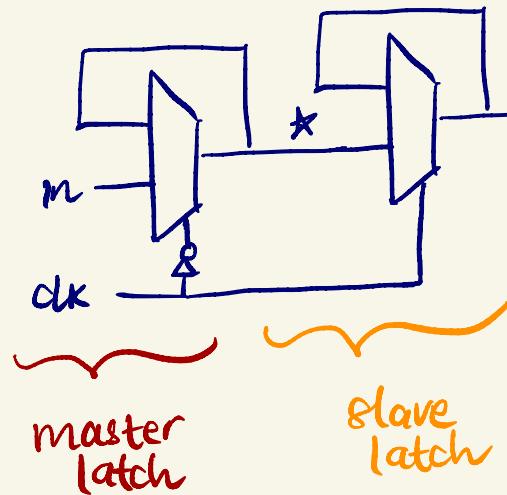


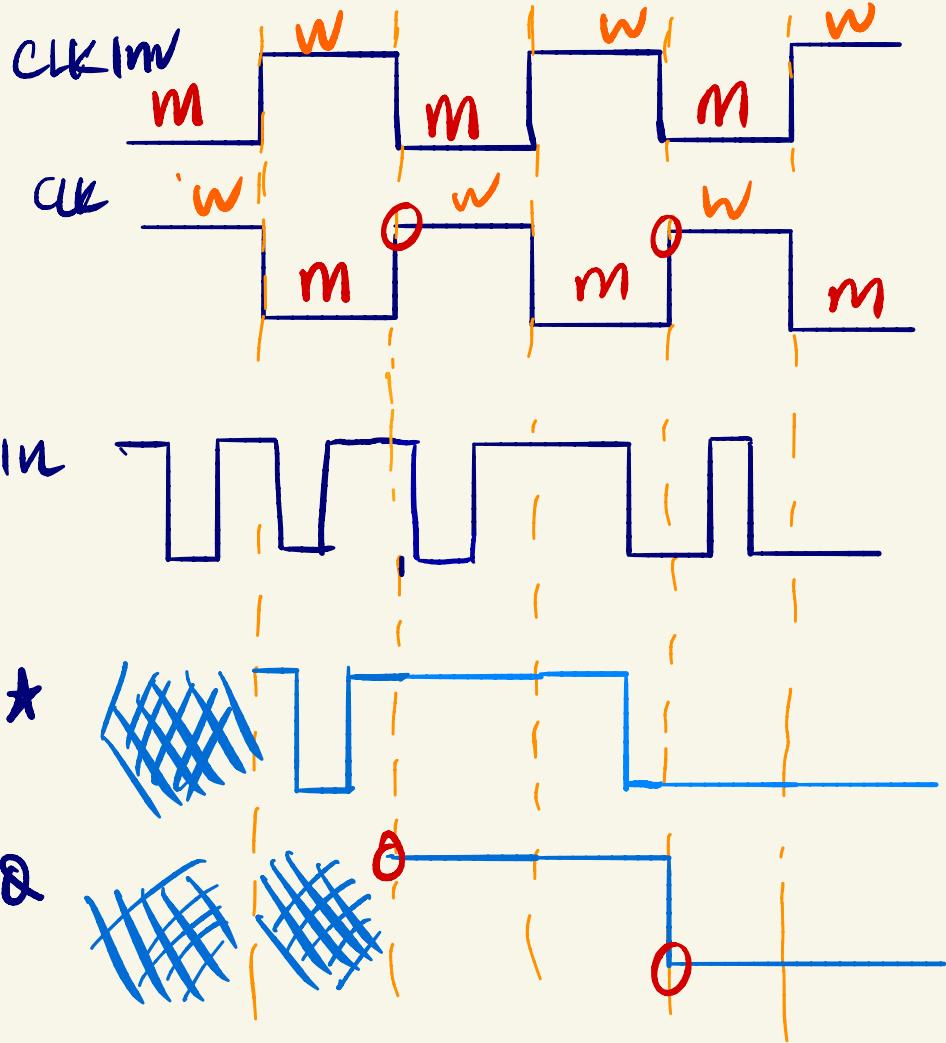
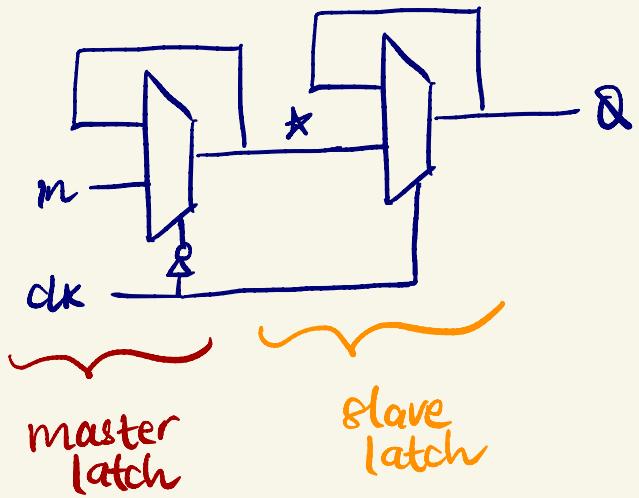


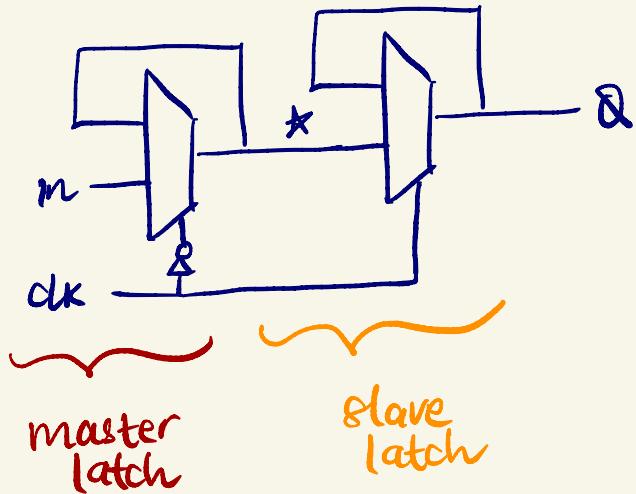
Dynamic Discipline



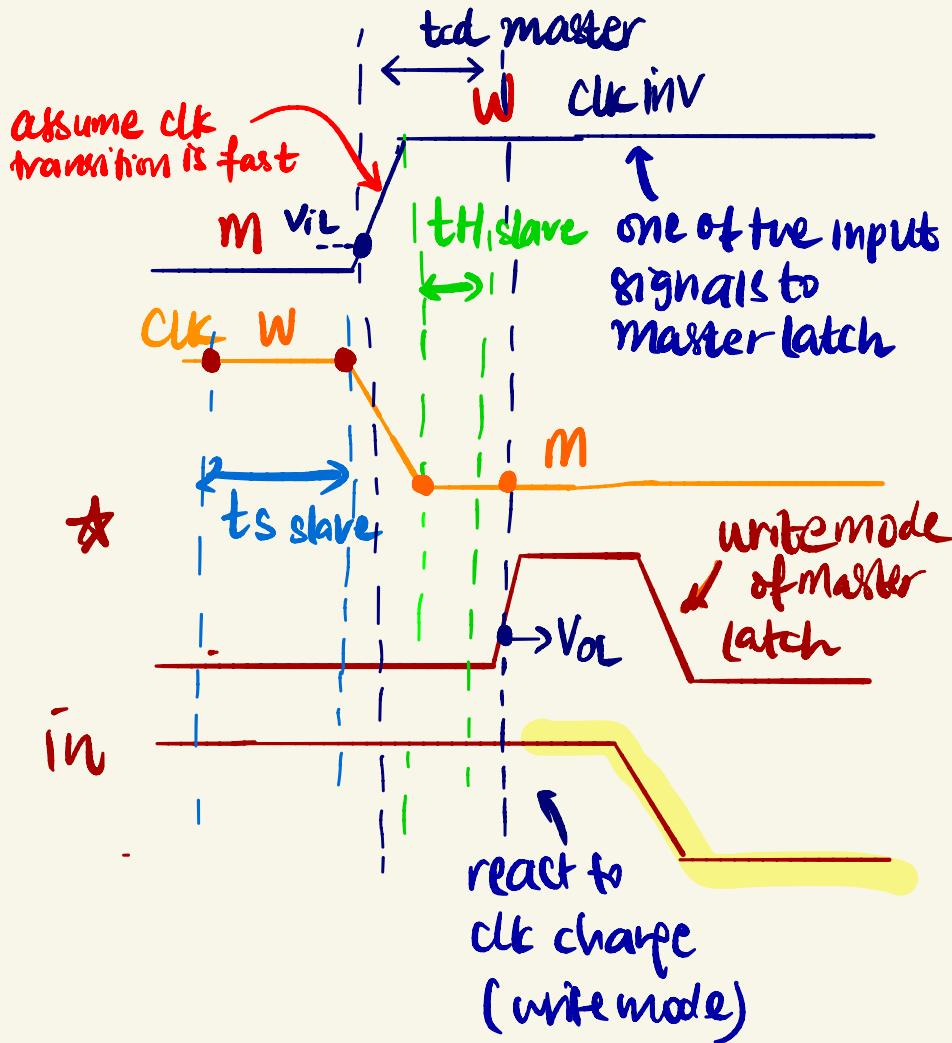
Registers



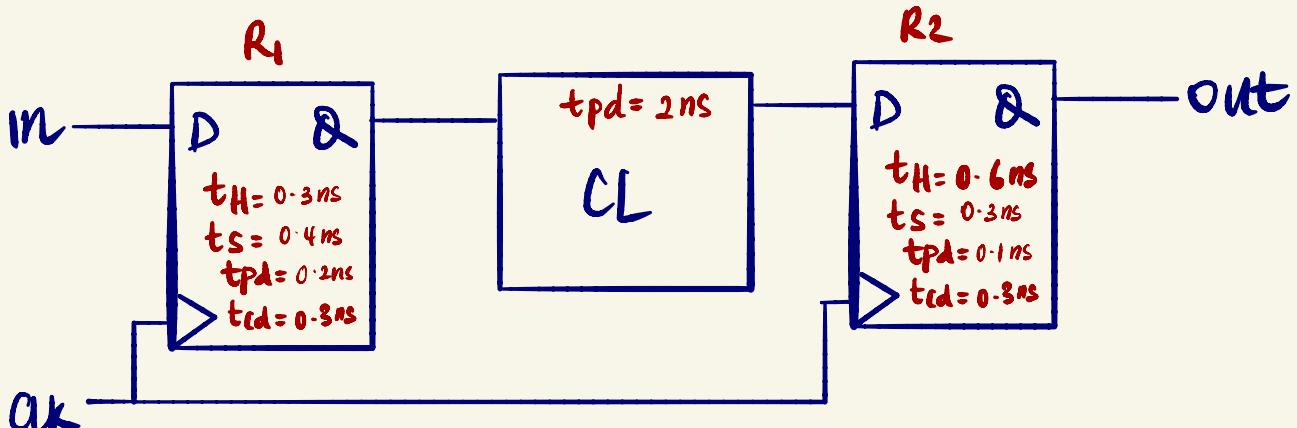




t_{CD} of master latch >
 t_{Hold} slave latch
 → for dynamic discipline
 to apply



case 1



$$\text{overall } t_{PD} = t_{PD} R_2 = 0.1 \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{sequential logic}$$

$$\text{overall } t_{CD} = t_{CD} R_2 = 0.3$$

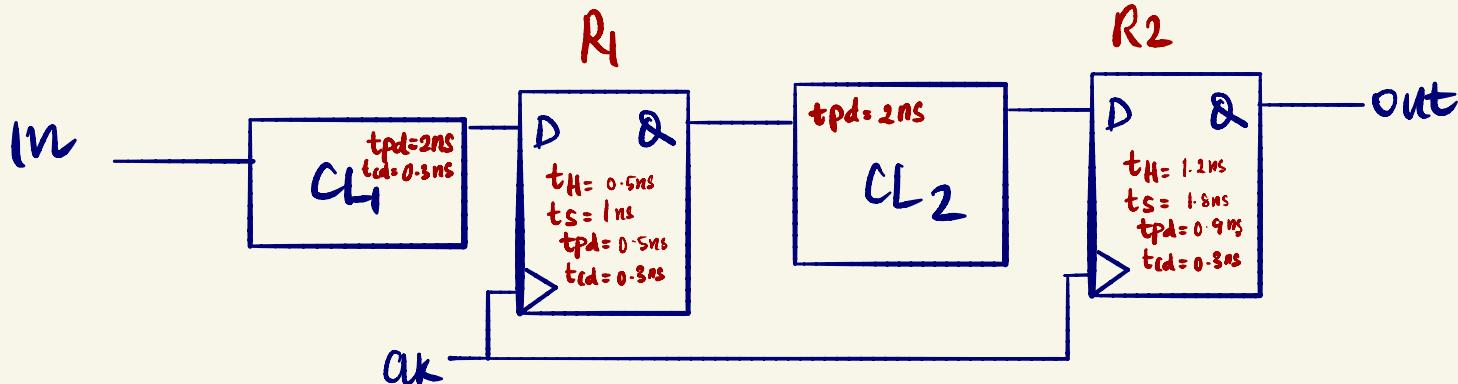
$$\min t_{CD} CL = t_H R_2 - t_{CD} R_1 = 0.6 - 0.3 = 0.3$$

$$\min \text{clk period} = t_{PD} R_1 + t_{PD} CL + t_S R_2 = 0.2 + 2 + 0.3 = 2.5$$

$$t_H \text{ input} = t_H R_1 = 0.3$$

$$t_S \text{ input} = t_S R_1 = 0.4$$

Case 2



$$\text{overall } t_{pd} = t_{pd} R_2 = 0.9 \quad \left. \right\} \text{sequential logic}$$

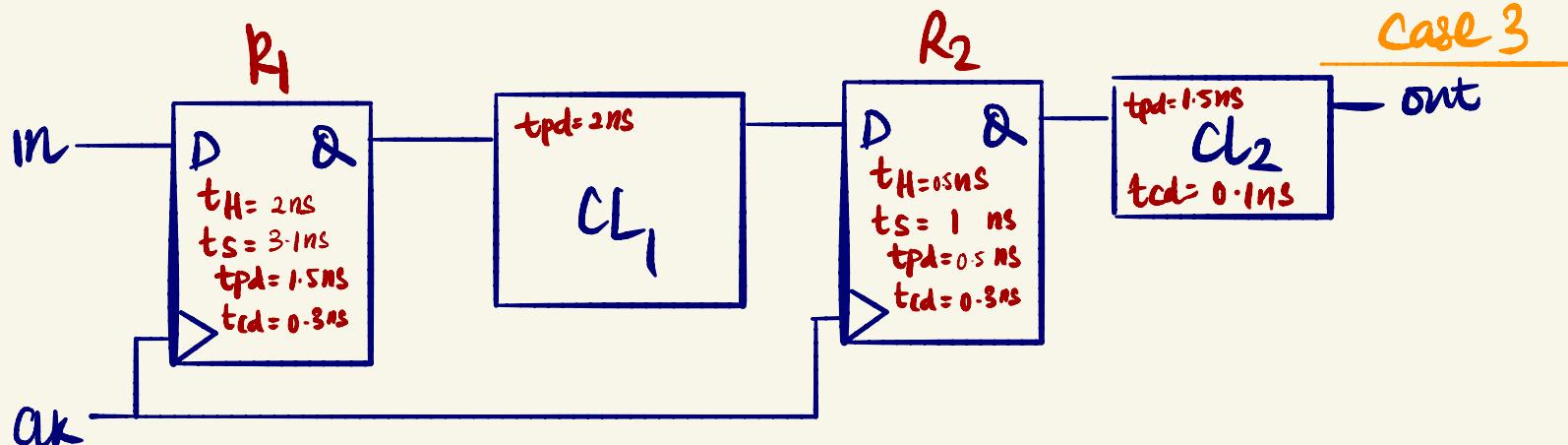
$$\text{overall } t_{cd} = t_{cd} R_2 = 0.3$$

$$\min t_{cd} CL_2 = t_H R_2 - t_{cd} R_1 = 1.2 - 0.3 = 0.9$$

$$\min \text{clk period} = t_{pd} R_1 + t_{pd} CL_2 + t_S R_2 = 0.5 + 2 + 1.8 = 4.3$$

$$t_H \text{ input} = t_H R_1 - t_{cd} CL_1 = 0.5 - 0.3 = 0.2$$

$$t_S \text{ input} = t_S R_1 + t_{pd} CL_1 = 2 + 1 = 3$$



$$\text{Overall } tpd = tpd R_2 + tpd CL_2 = 0.5 + 1.5 = 2$$

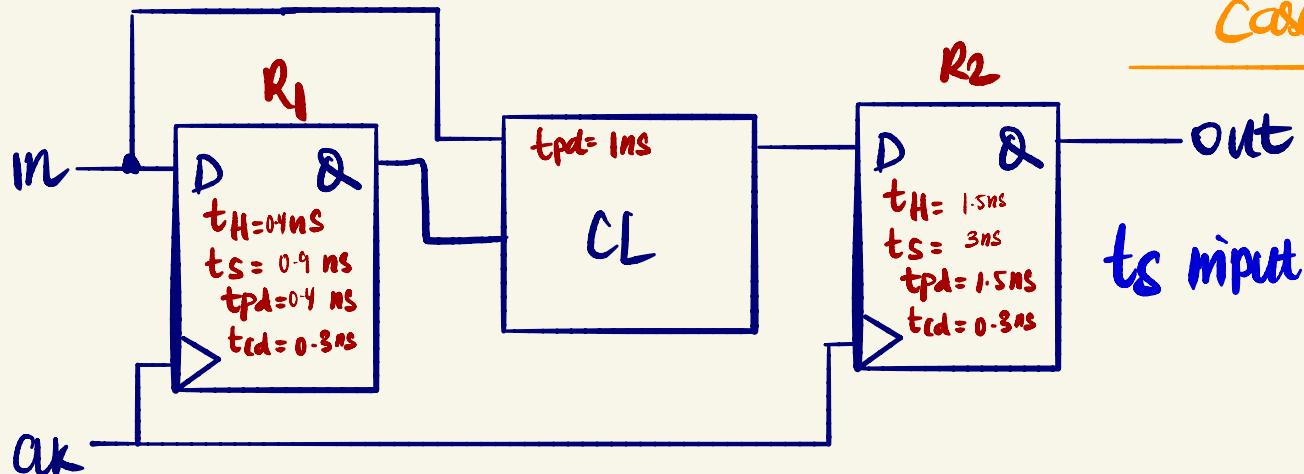
$$\text{Overall } tcd = tcd R_2 + tcd CL_2 = 0.3 + 0.1 = 0.4$$

$$\min t_{cd} CL_1 = t_{H R_2} - t_{cd R_1} = 0.5 - 0.3 = 0.2$$

$$\min \text{clk period} = tpd R_1 + tpd CL_1 + tS R_2 = 1.5 + 2 + 1 = 4.5$$

$$t_H \text{ input} = t_{H R_1} = 2$$

$$t_S \text{ input} = t_{S R_1} = 3.1$$



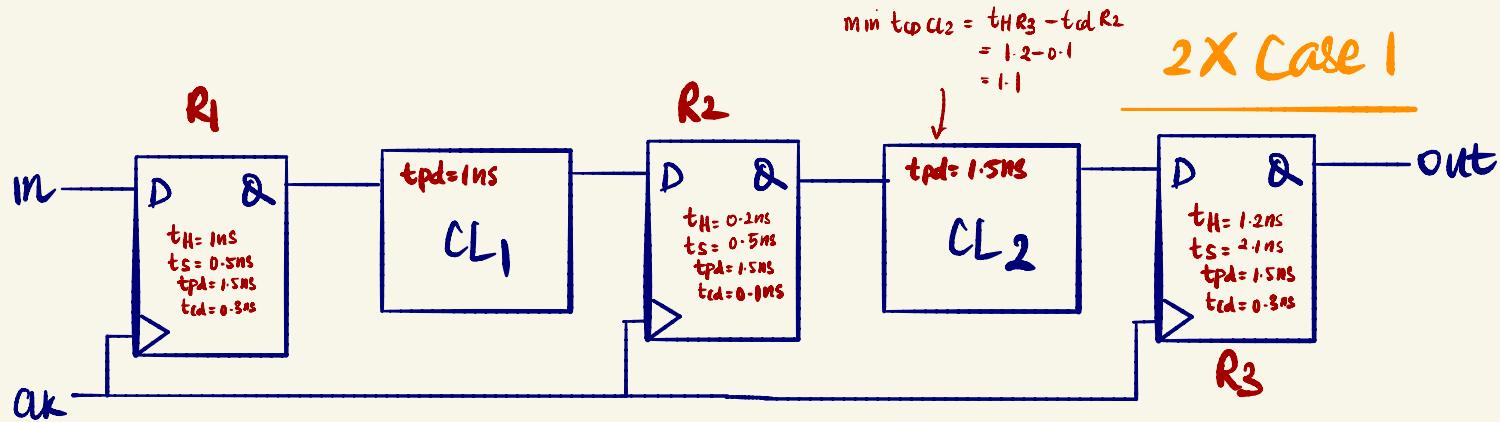
$$\text{Overall } t_{pd} = t_{pd\text{R2}} = 1.5 \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{sequential logic}$$

$$\text{Overall } t_{cd} = t_{cd\text{R2}} = 0.3$$

$$\min t_{cd\text{CL}} = t_{H\text{R2}} - t_{cd\text{R1}} = 1.5 - 0.3 = 1.2$$

$$\min \text{clk period} = t_{pd\text{R1}} + t_{pd\text{CL}} + t_{SR2} = 0.4 + 1 + 3 = 4.4$$

$$t_{H\text{ input}} = \begin{cases} t_H R_1 = 0.4 \\ t_H R_2 - t_{cd\text{CL}} = 1.5 - 1.2 = 0.3 \end{cases}$$



Overall $t_{pd} = t_{pd} R_3 = 1.5$ } sequential logic
 Overall $t_{cd} = t_{cd} R_3 = 0.3$ } time cannot be
 -ve so clamp to 0

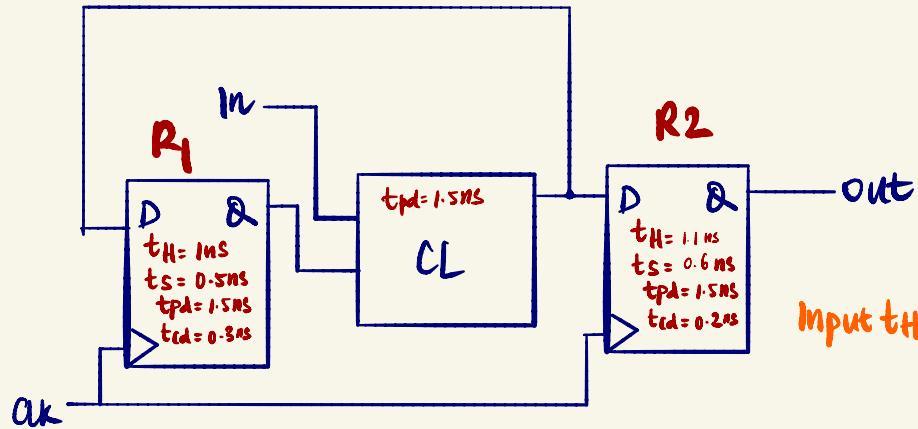
$$\min t_{CD} CL_1 = t_{HR_2} - t_{CD} R_1 = 0.2 - 0.3 = 0$$

$$\min CLK period = \max \left\{ \begin{array}{l} t_{pd} R_1 + t_{pd} CL_1 + t_S R_2 = 3 \\ t_{pd} R_2 + t_{pd} CL_2 + t_S R_3 = 5.1 \end{array} \right. = 5.1$$

$$t_H \text{ Input} = t_{HR_1} = 1$$

$$t_S \text{ Input} = t_S R_1 = 0.5$$

Case 1 + case looped



$$\begin{aligned} \text{Input } t_S &= \max \{ t_{SR2} + t_{pdCL}, \\ &\quad t_{SR1} + t_{pdCL} \} \\ &= \max \{ 0.6 + 1.5 = 2.1, \\ &\quad 0.5 + 1.5 = 2.0 \} \end{aligned}$$

$$\text{Input } t_H = \max \left\{ \begin{array}{l} t_{HR2} - t_{cdCL} = 1 - 0.8 = 0.2 \\ t_{HR2} - t_{cdCL} = 1.1 - 0.8 = 0.3 \end{array} \right\}$$

0.3

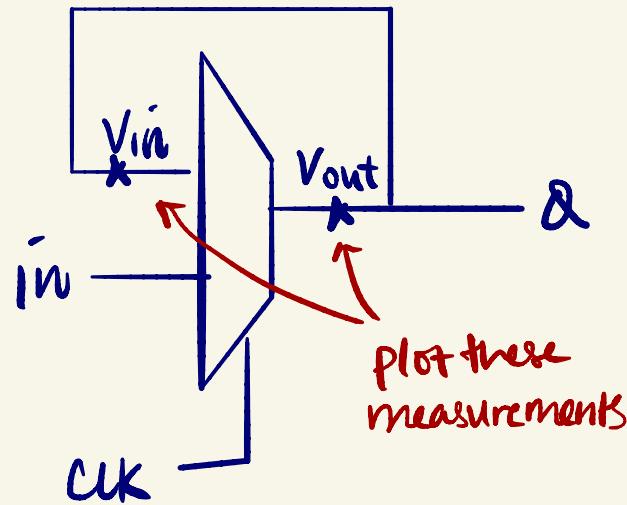
Overall $t_{pd} = t_{pdR2} = 1.5$

Overall $t_{cd} = t_{cdR2} = 0.2$

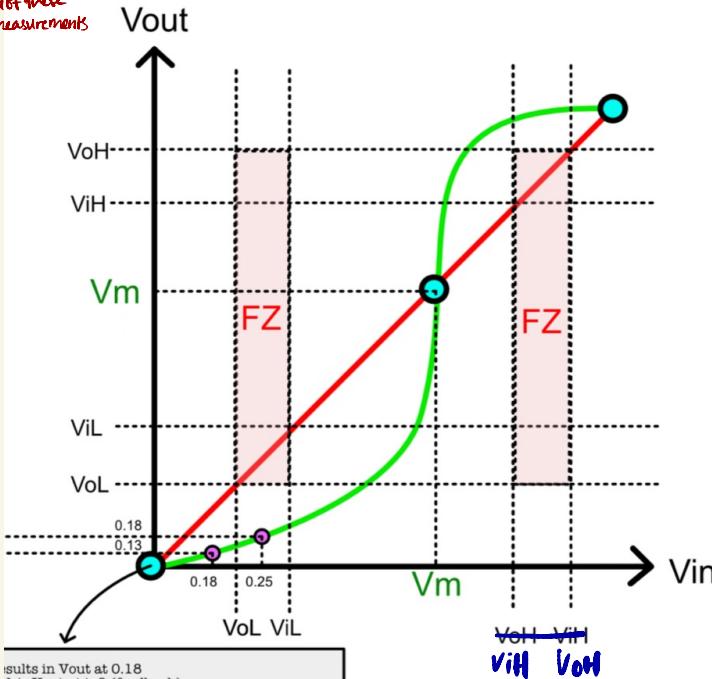
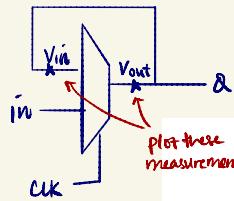
use it here

$$\min t_{cdCL} = \max \left\{ \begin{array}{l} t_{HR2} - t_{cdR1} = 1.1 - 0.3 = 0.8 \\ t_{HR1} - t_{cdR1} = 1 - 0.3 = 0.7 \end{array} \right\} = 0.8$$

$$\begin{aligned} \min CLK &= \max \left\{ \begin{array}{l} t_{pdR1} + t_{pdCL} + t_{SR2} = 1.5 + 1.5 + 0.6 = 3.6 \\ t_{pdR1} + t_{pdCL} + t_{SR1} = 1.5 + 1.5 + 0.5 = 3.5 \end{array} \right\} = 3.6 \end{aligned}$$



plot these
measurements



given:

$$\text{at } t=t_0 \rightarrow V_{in} = 0.18 \text{ V} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{first loop}$$

$$V_{out} = 0.13$$

$$\text{at } t=t_1 \rightarrow V_{in} = V_{out}(t=0) + \text{noise} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{2nd loop}$$

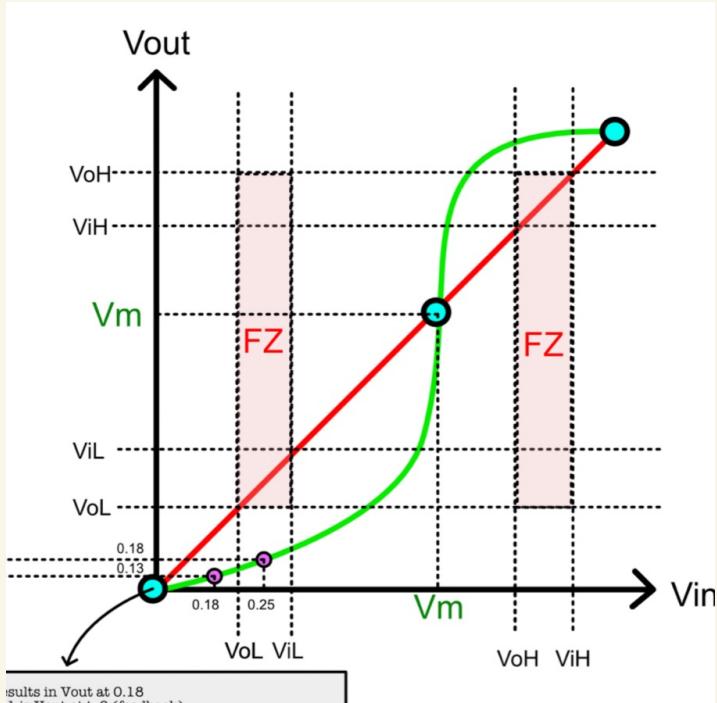
$$= 0.14$$

$$V_{out} = 0.05 - \text{noise} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{3rd loop}$$

$$\text{at } t=t_2 \rightarrow V_{in} = V_{out}(t=1) + \text{noise}$$

$$= 0.04$$

$V_{out} \approx 0$
 \curvearrowright stable



given:

$$\text{at } t=t_0 \rightarrow V_{in} = V_m$$

$$V_{out} = V_m$$

{ first loop }

$$\text{at } t=t_1 \rightarrow V_{in} = V_{out}(t=0) \stackrel{\text{+ noise}}{=} V_m + 0.01$$

{ 2nd loop }

$$V_{out} = V_m + 0.02$$

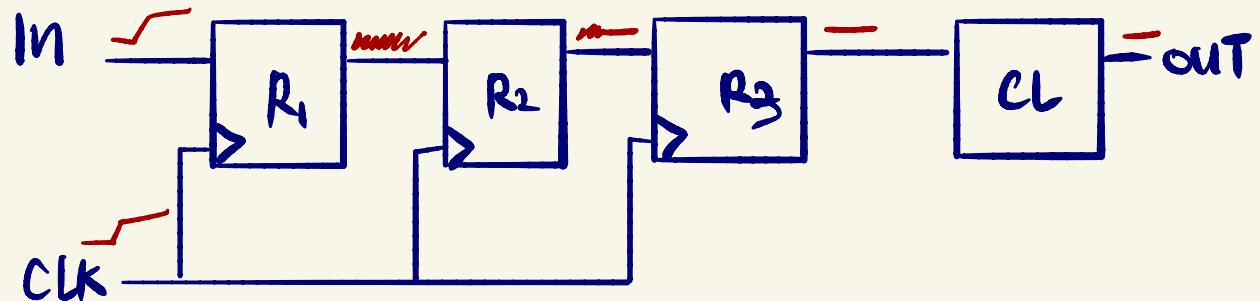
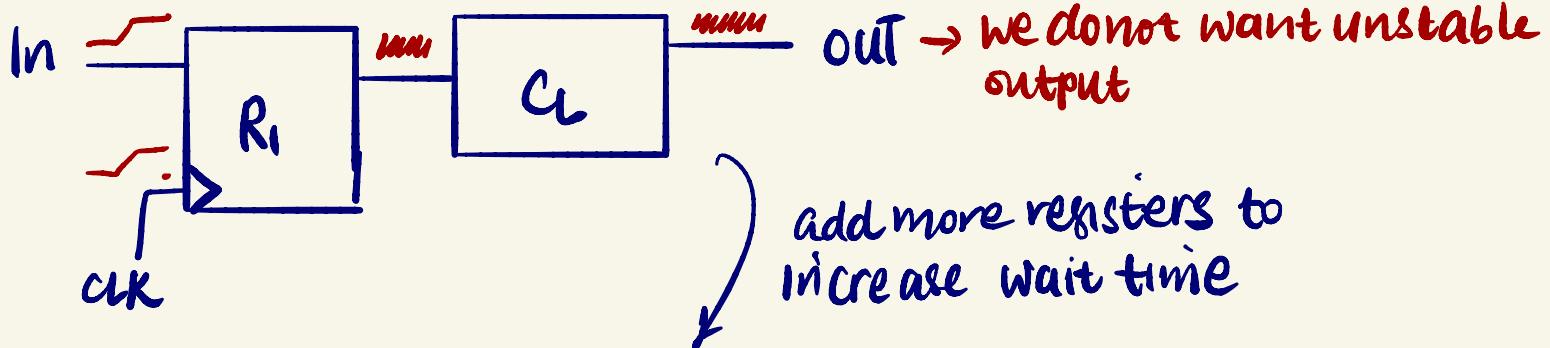
$$\text{at } t=t_2 \rightarrow V_{in} = V_{out}(t=1) \stackrel{\text{+ noise}}{=} V_m - 0.01$$

{ 3rd loop }

$$V_{out} = V_m + 0.02$$

oscillating

METASTABLE STATE

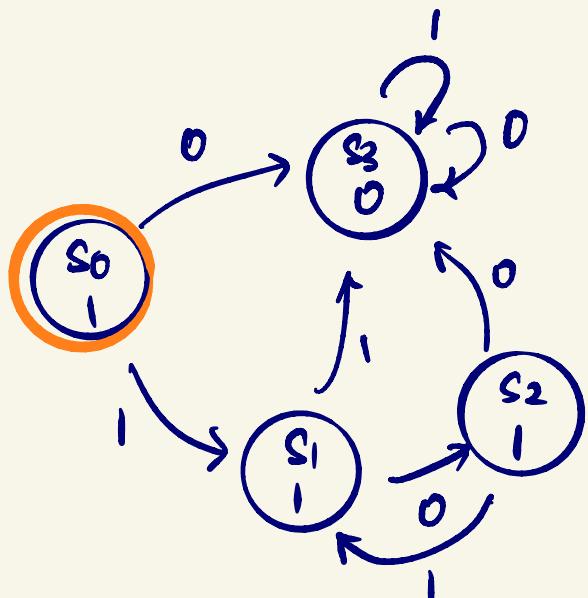


Task: Binary parser

101010 ✓
1110 X
0001 X

input	state	next state	output
0	S0	S3	0
1	S0	S1	1
0	S1	S2	1
1	S1	S3	0
0	S2	S3	0
1	S2	S1	1
0	S3	S3	0
1	S3	S3	0

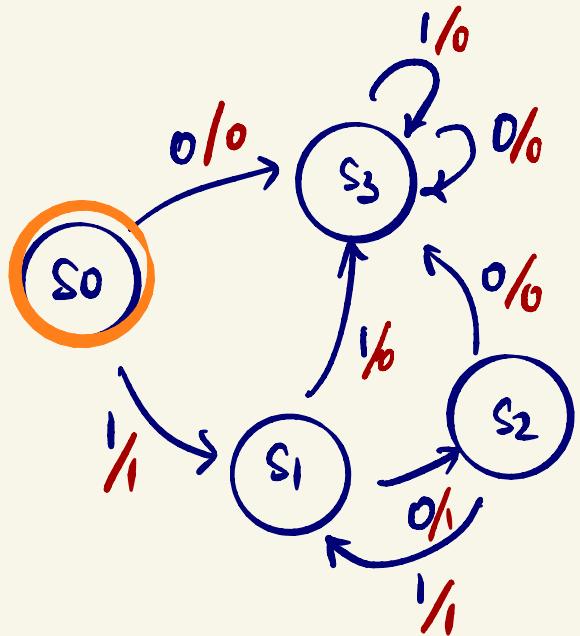
Moore machine



input	state	next state	output
0	S0	S3	0
1	S0	S1	1
0	S1	S2	1
1	S1	S3	0
0	S2	S3	0
1	S2	S1	1
0	S3	S3	0
1	S3	S3	0

} one state-output pair
if we have $\boxed{S_2 \ 0}$, then
this is another state-output pair

meally machine

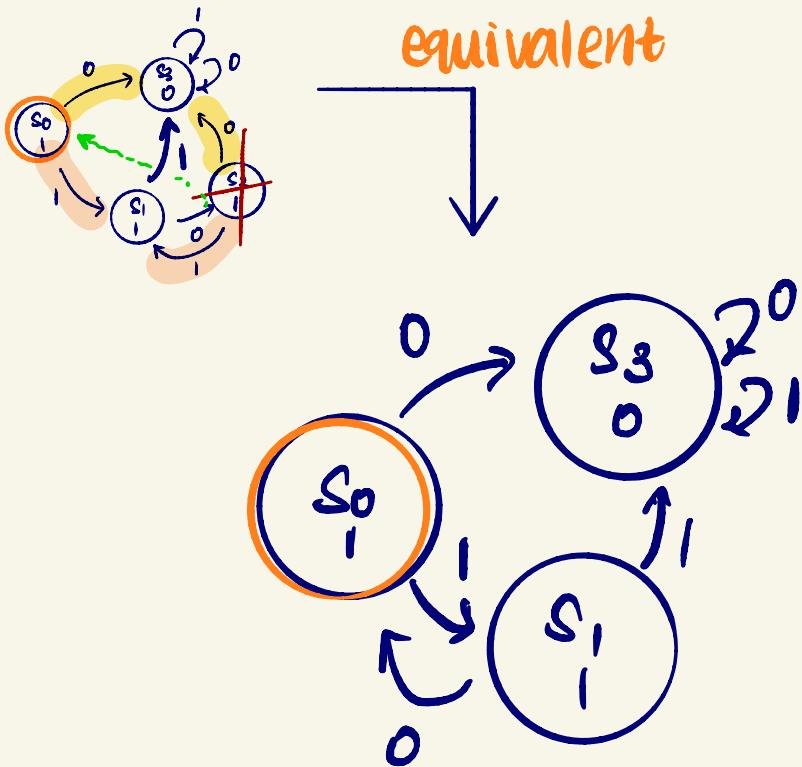


input	state	next state	output
0	S0	S3	0
1	S0	S1	1
0	S1	S2	1
1	S1	S3	0
0	S2	S3	0
1	S2	S1	1
0	S3	S3	0
1	S3	S3	0

} one per state.
if we have entrance
to S_2 that produces '0',
that's another "arrow" to S_2 :

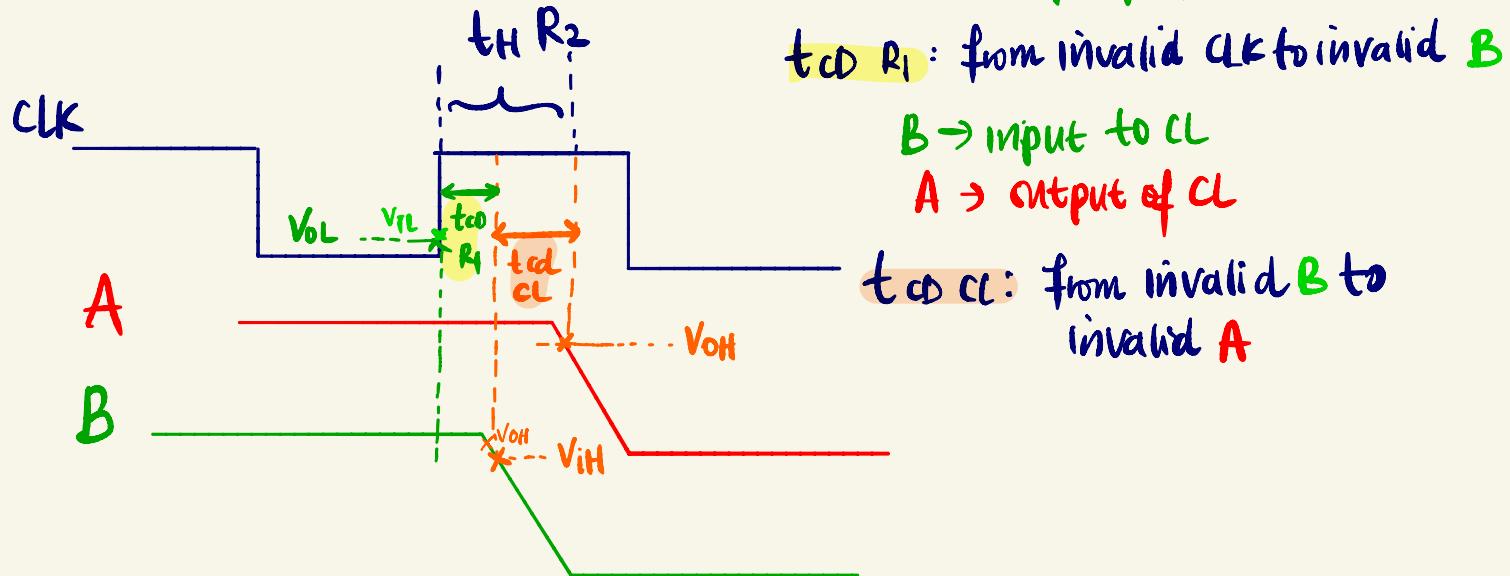
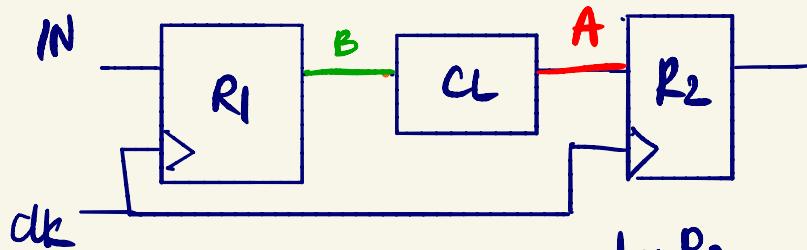
e.g.: $I/O \rightarrow S_2$

Equivalence

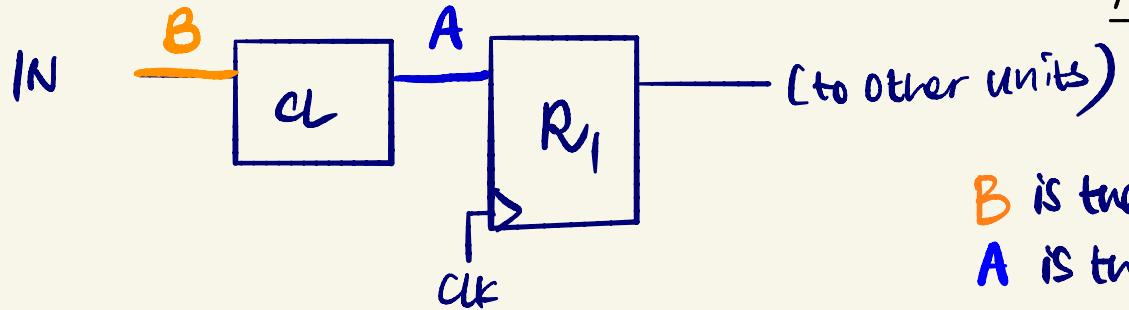


input state	next state output
0 S_0	S_3 0
1 S_0	S_1 1
0 S_1	S_2 1
1 S_1	S_3 0
0 S_2	S_3 0
1 S_2	S_1 1
0 S_3	S_3 0
1 S_3	S_3 0

About min tcd CL



from graph: t_HR₂ ≤ t_{cd} R₁ + t_{cd} CL \Rightarrow t_{cd} CL = t_HR₂ - t_{cd} R₁ *



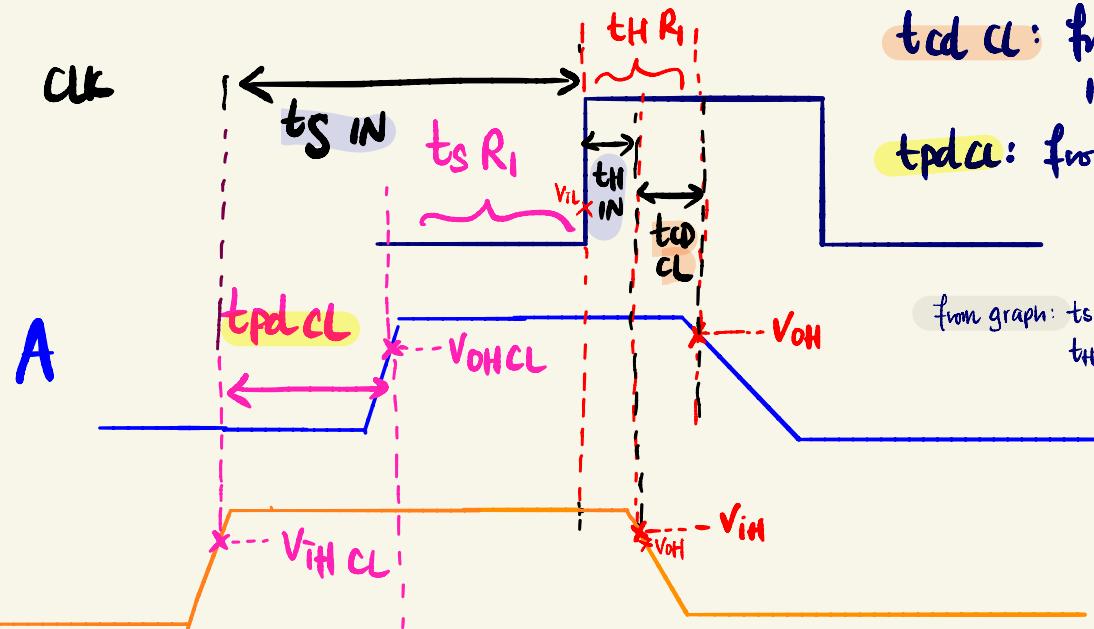
About $t_{S\ IN}$ & $t_{H\ IN}$

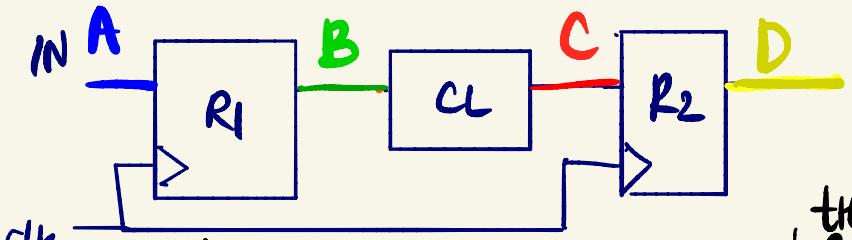
B is the input to CL

A is the output of CL

tcd CL: from invalid A to invalid B

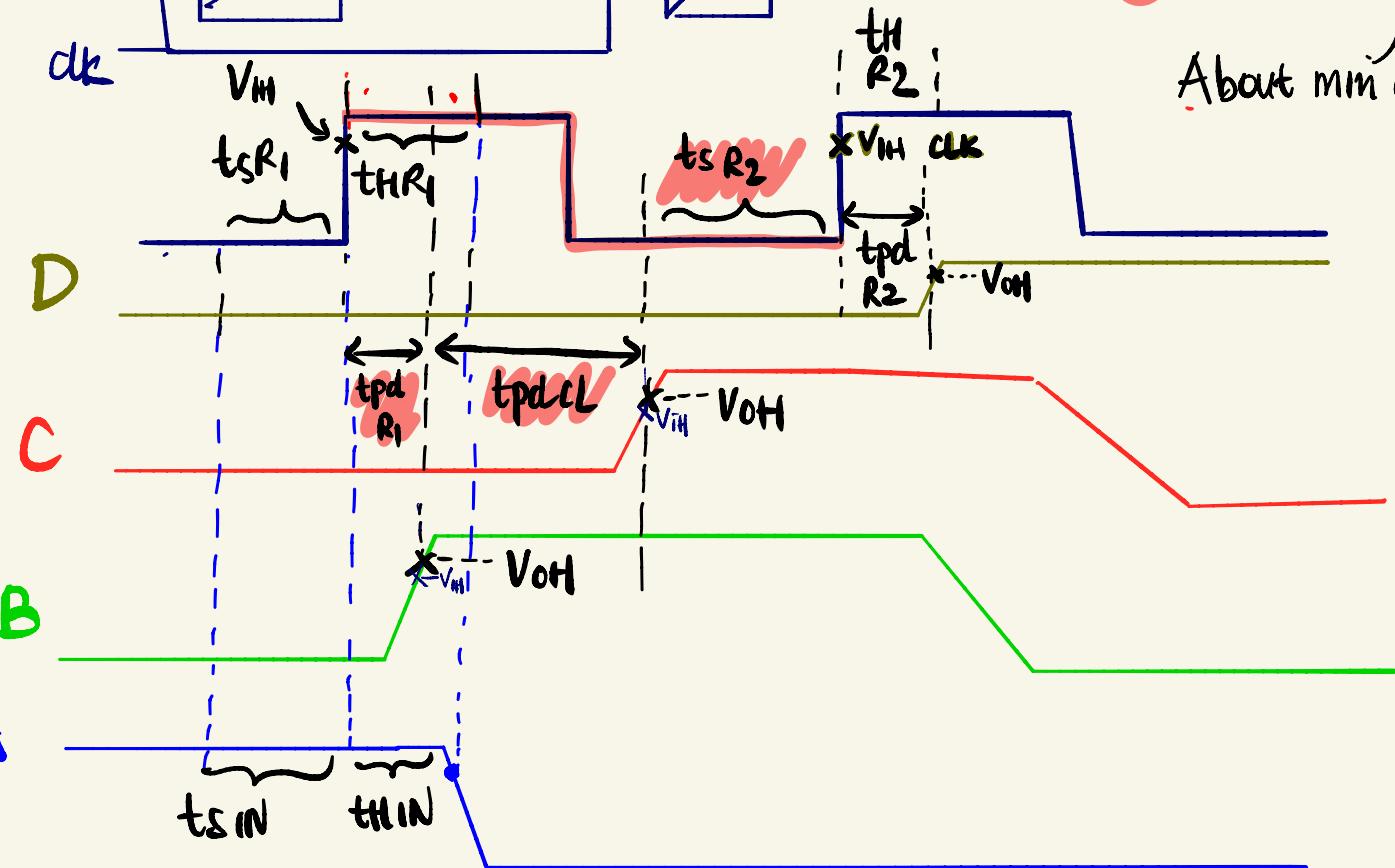
tpdCL: from valid A to valid B

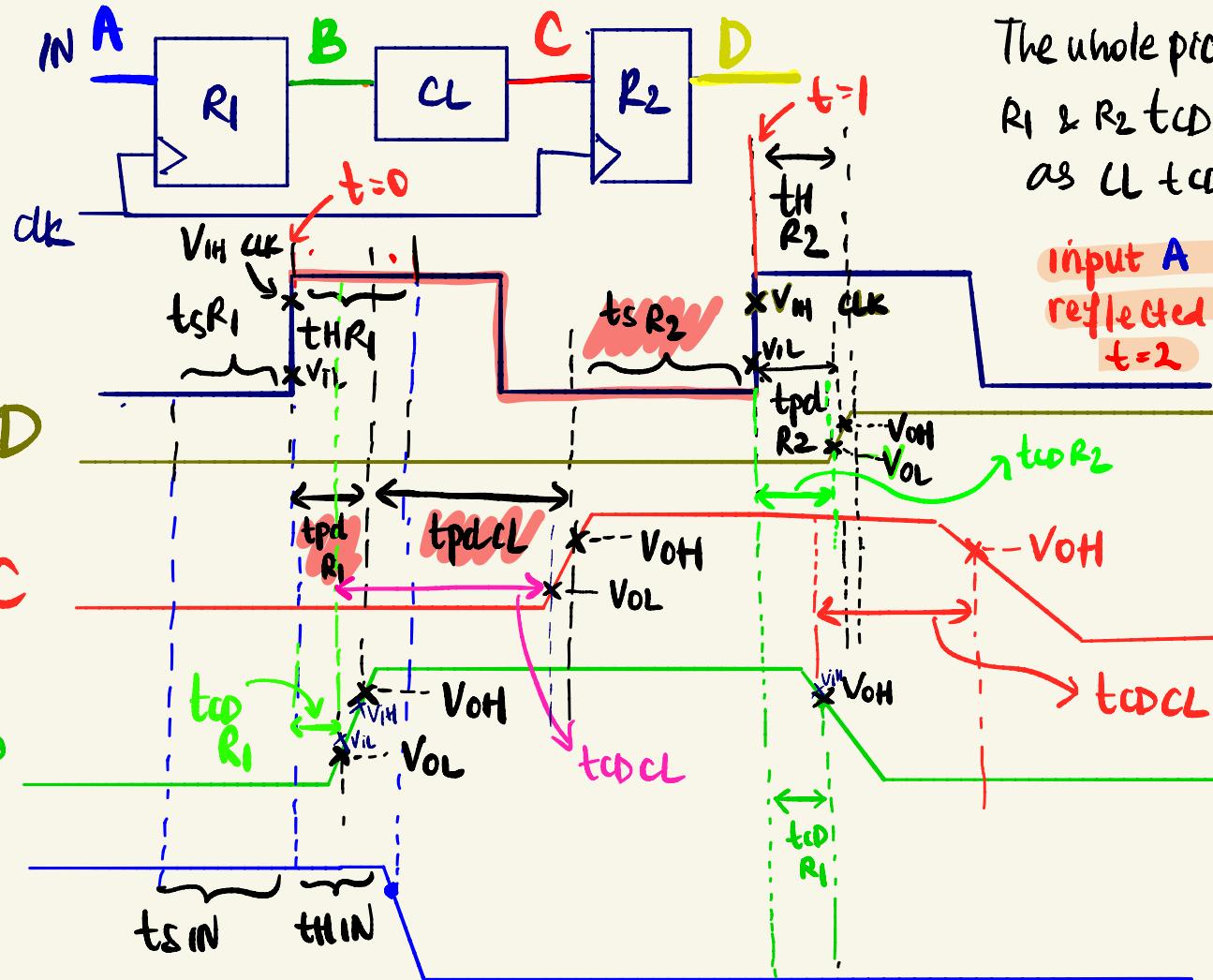




In ONE period we must fit:
 $t_{pd} R_1 + t_{pd} CL + t_{SR_2}$

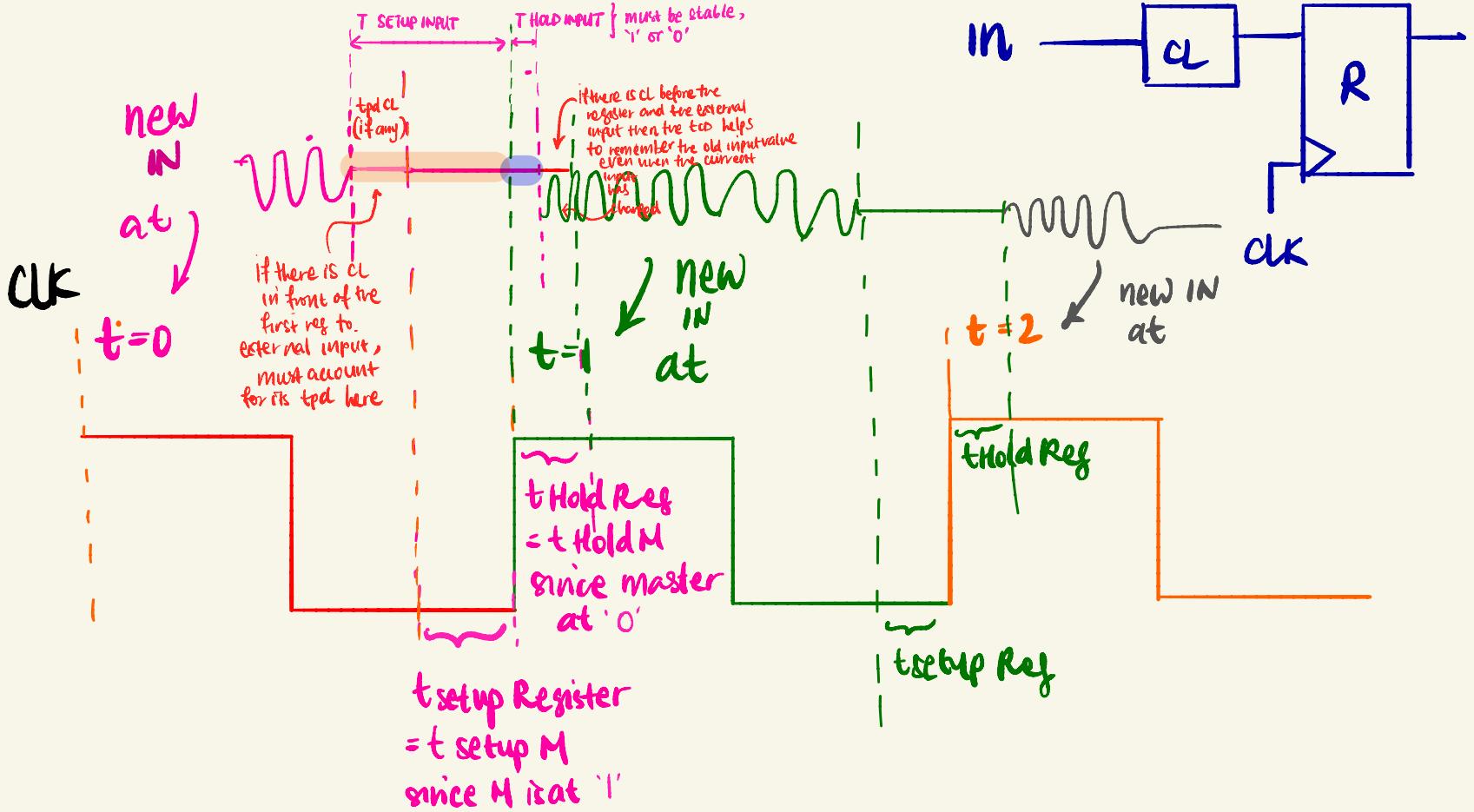
↑
About min clk period





The whole picture with
 R_1 & R_2 t_{CD} , as well
as CL t_{CD}

input A at $t=1$ is
reflected at D at
 $t=2$



CLK

