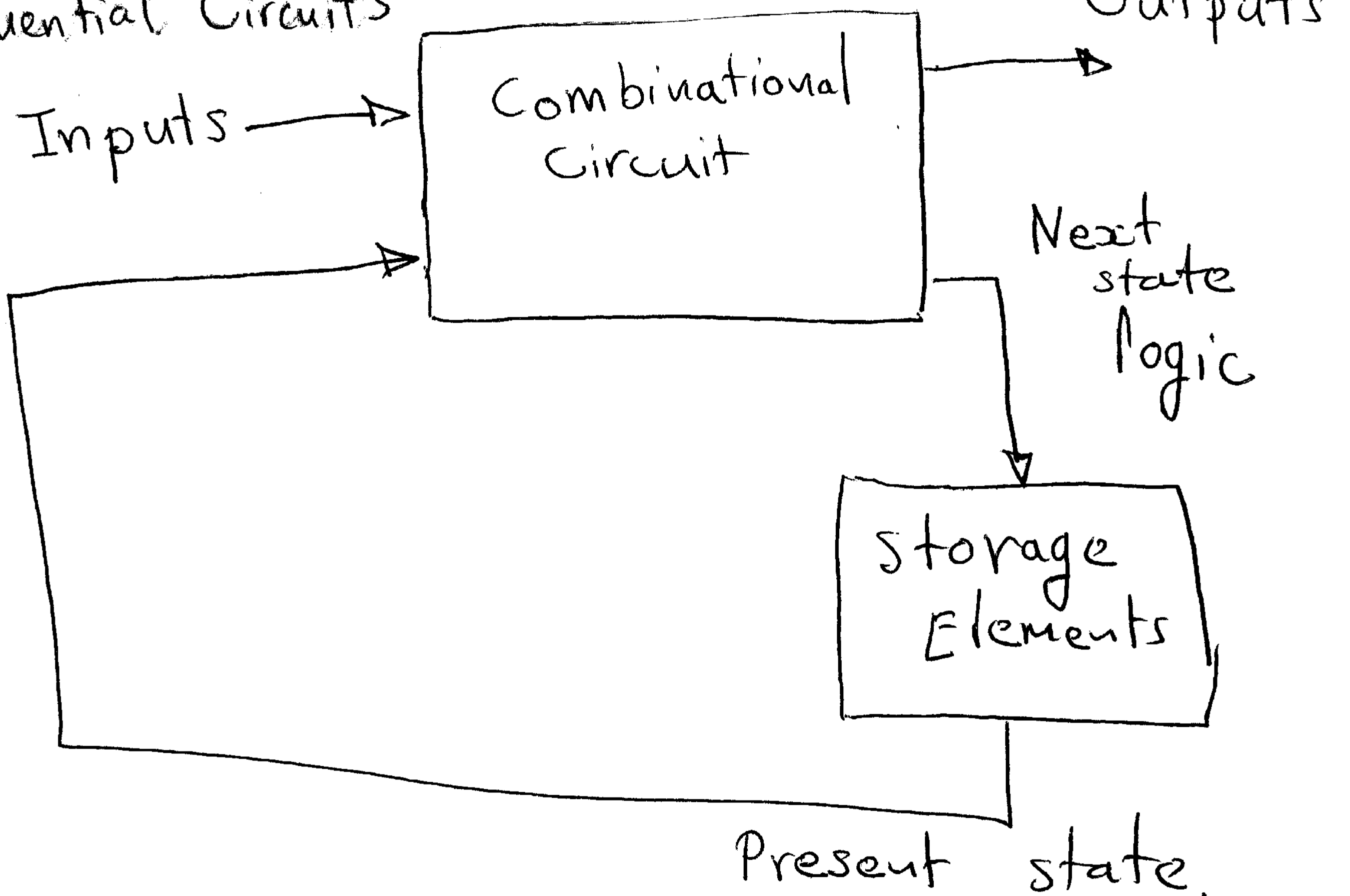
Chapter 4 Sec (4.1-4.3)

Sequential Circuits



eg: drink dispenser machine.
It remembers the money we put in.

synchronous sequential circuits:

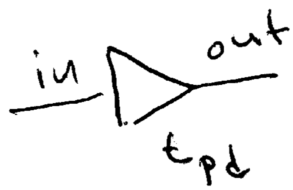
We have a clock: ,
and we only allow changes when we have: (i) a rising edge or a falling edge of the clock. (edge-trigger)
or (ii) when clock is at $C=0$ or $C=1$. (pulse-trigger)

Asynchronous sequential circuits

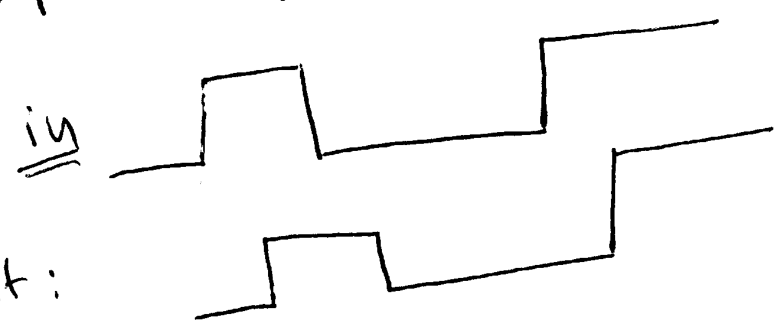
- Like combinational circuits, changes occur when the inputs change.

For asynchronous circuits, to avoid oscillations, inputs cannot change indefinitely.

Eg:

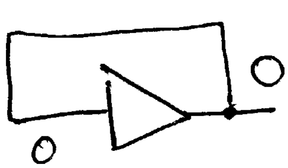


- A buffer: , reproduces its input after t_{pd}:

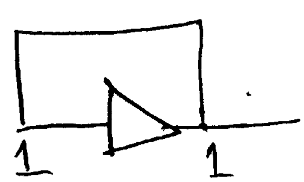


delayed input by t_{pd}

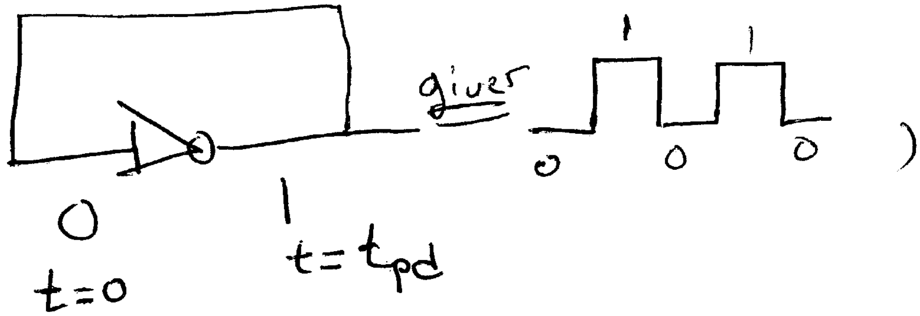
will converge with feedback:

- 

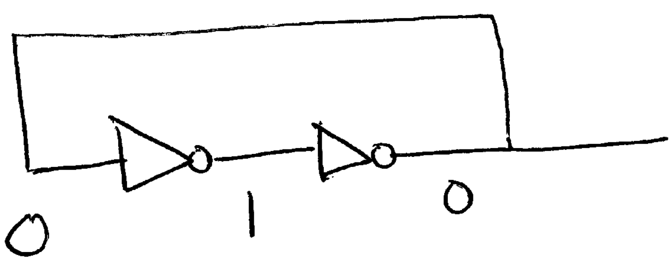
or



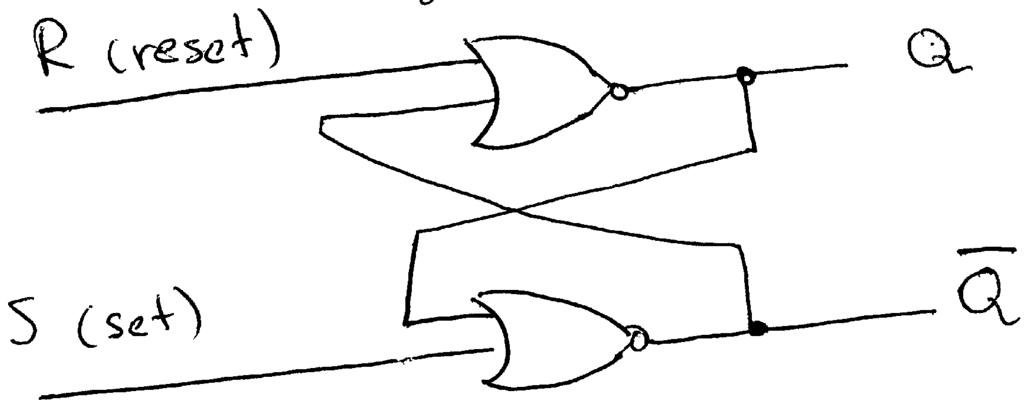
A single inverter will oscillate: 3/16



but 2 inverters will work:



SR Latch: p187 Latches are the most basic storage elements, from which flip-flops are usually constructed.

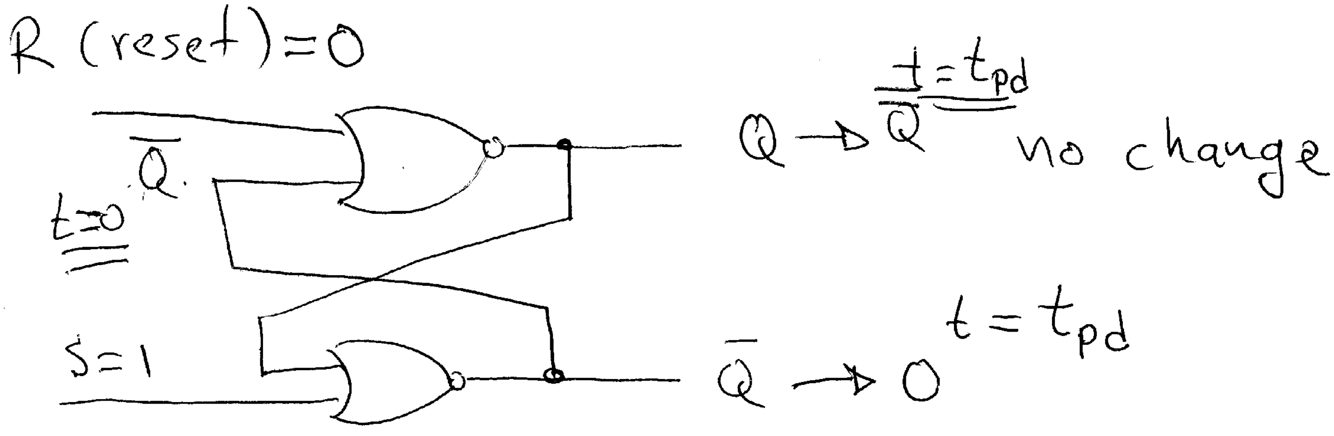


SR Latch with NOR gates.

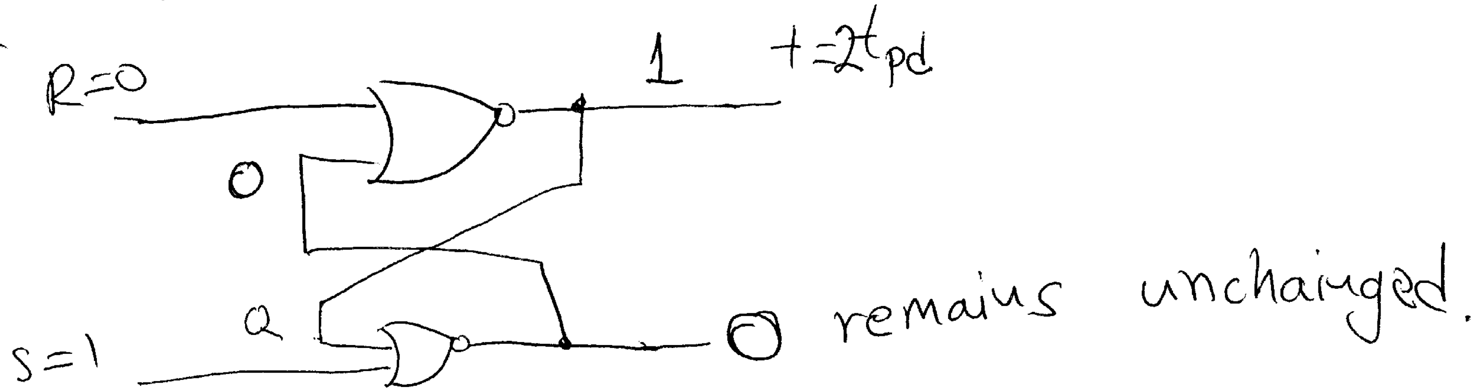
Function table

S	R	Q	$\overline{Q}$	
1	0	1	0	Set State
0	0	1	0	
0	1	0	1	Reset state
0	0	0	1	
1	1	0	0	Undefin

Let $S=1$, $R=0$, $\underline{t=t_{pd}}$.

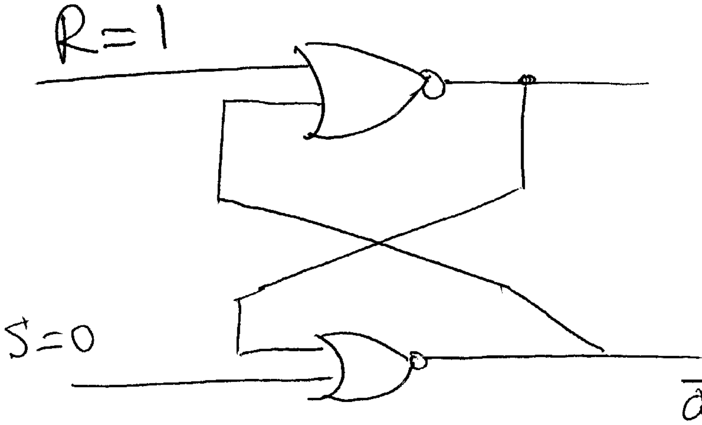


$\underline{t=2t_{pd}}$



$t=3\,t_{pd}$ ... nothing changes.

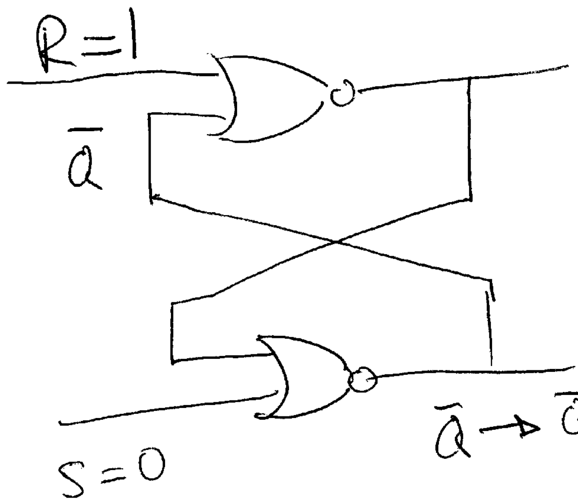
Let $S=0$, $R=1$. $\underline{t = t_{pd}}$



$Q \to 0$ from $\overline{(1+\bar{Q})} = 0$

$\bar{Q}$ remains.

$\underline{t = 2t_{pd}}$



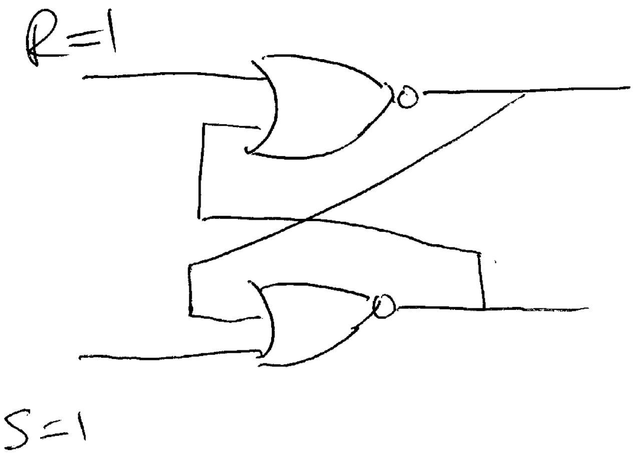
$Q = 0$ remains

$\bar{Q} \to \bar{Q} = 1$ becomes

from $\overline{(0+0)} = 1$

After this, nothing changes.

- $S=1$, $R=1$, $t=t_{pd}$



$Q \rightarrow \overline{(Q+1)} = 0$

$\bar{Q} \rightarrow \overline{(\bar{Q}+1)} = 0$

$t = 2t_{pd}$, ... outputs remain.

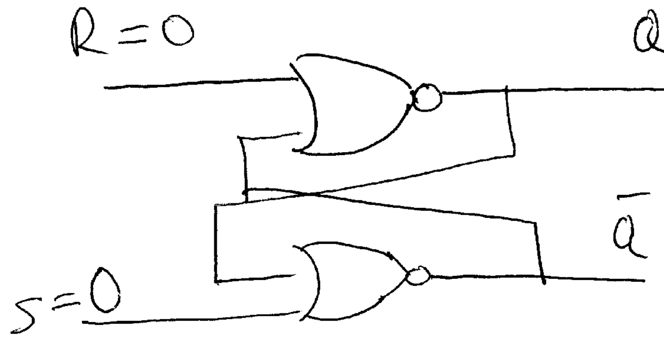
- But this state is invalid since:

$Q=0$, $\bar{Q}=0$, ($\bar{Q}$ should be the complement of Q).

If this state is followed by $S=R=0$ at $t=5t_{pd}$, then...

-

$t = 6\, t_{pd}$



$Q \quad 0 \to \overline{(0+0)} = 1$

$\bar{Q} \quad 0 \to \overline{(0+0)} = 1$

$t = 7\, t_{pd}$

$Q \to \overline{(1+0)} = 0$

$\bar{Q} \to \overline{(1+0)} = 0$

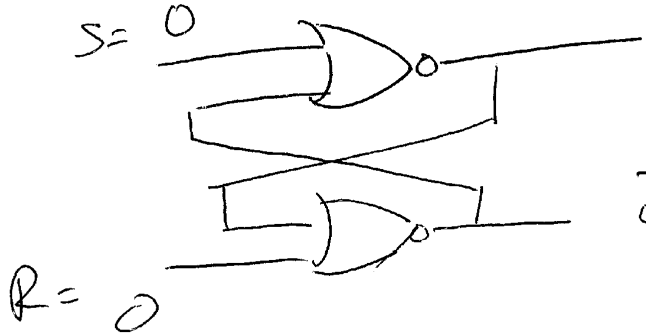
$t = 8\, t_{pd}$

$Q \to \overline{(0+0)} = 1$

$\bar{Q} \to \overline{(0+0)} = 1$

and it keeps oscillating from $(Q=0, \bar{Q}=0)$ to $(Q=1, \bar{Q}=1)$ to $(Q=0, \bar{Q}=0)$ to $(Q=1, \bar{Q}=1)$, ... (see Fig. 4-5)

Normally, $S=R=0$ has no effect:

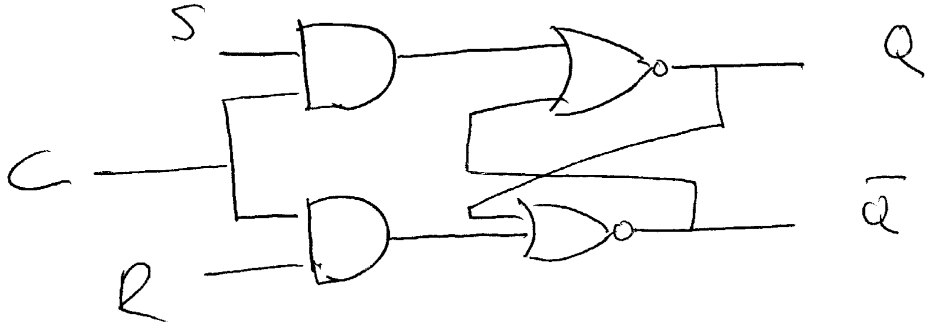


$$Q = \overline{(\bar{Q}+0)}$$

$$\bar{Q} = \overline{(Q+0)}$$

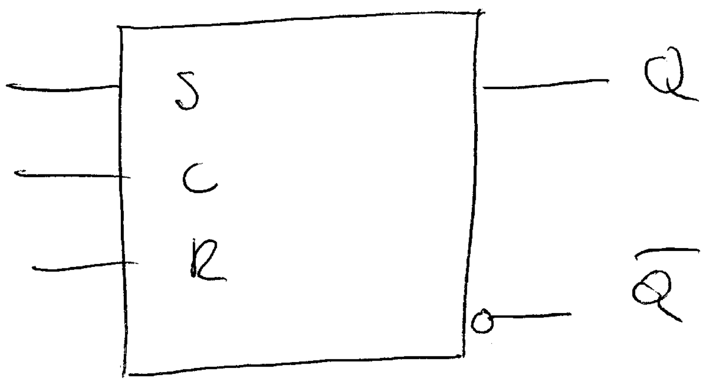
Hence, we can introduce a control input C, for controlling changes:

SR Latch with Control input



when $C=0$, no change.
when $C=1$, we have regular operation.

- In summary, we use:

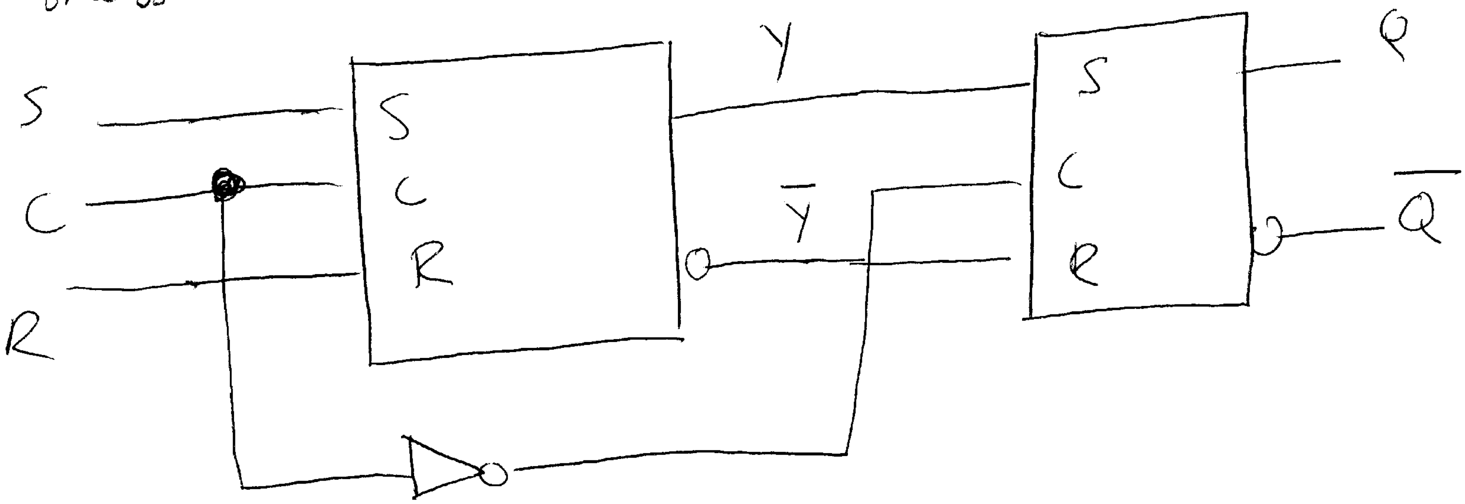


C	S	R	Next state of Q
0	x	x	No change
1	0	0	No change
1	0	1	Q=0; Reset state
1	1	0	Q=1; Set state
1	1	1	Undefined

Master-Slave Flip-Flop p 192

- The state of a latch in a flip-flop is allowed to switch by a momentary change in value on the control input. This change is called a *trigger*, and it enables or triggers the flip-flop.

Master Slave



- Note that only one of the 2 FFs is active at any time. (they have complemented controls)
- This allows the master FF to settle to an output Y, $\bar{Y}$ (C= while the slave is inactive
- ($\bar{C}=0$), maintaining its previous outputs.

- Then, when $C=0$, the master is not affected by anything, and it holds $Y, \bar{Y}$ steady for the slave to copy into $Q, \bar{Q}$.

Problem:

Suppose that: (i) we allow S & R to change during $C=1$.

(ii) We want to change to $S=0=R$, but we allow S & R to go from: either:

$(S, R, Q\ \bar{Q})$

A. $S=1$, $R=0$ to $S=0, R=0$, OR

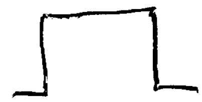
B. $S=0$, $R=1$ to $S=0, R=0$ when $C=1$.

A I. B/C we first have: $S=1, R=0$ we will set the master FF to $Y=1$, despite our intention to leave it as is.

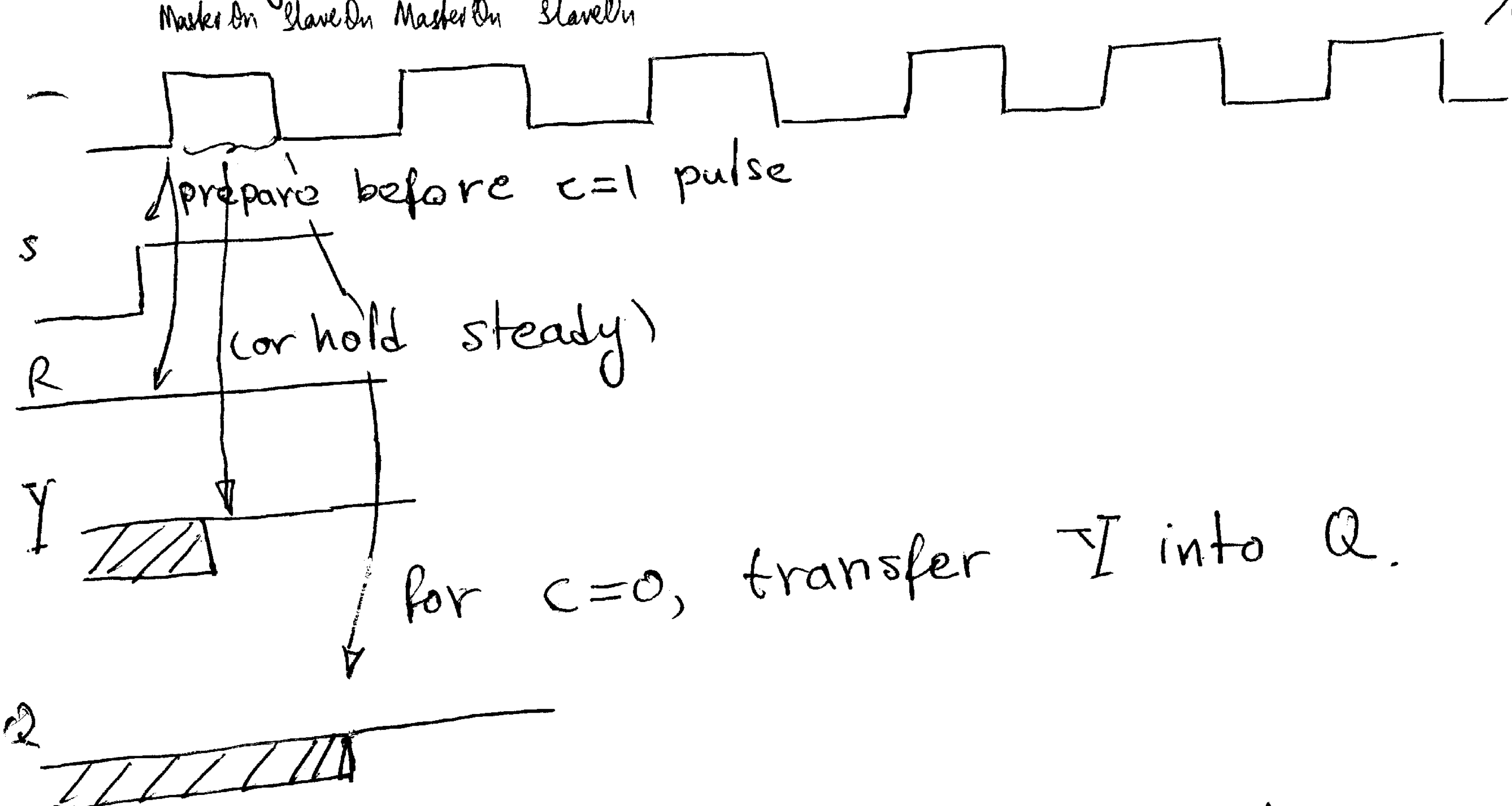
B II. B/C we first have: $S=0, R=1$, we will set $Y=0$, instead of unchanged.

$\therefore$ We cannot change S & R for $C=1$.

12/1

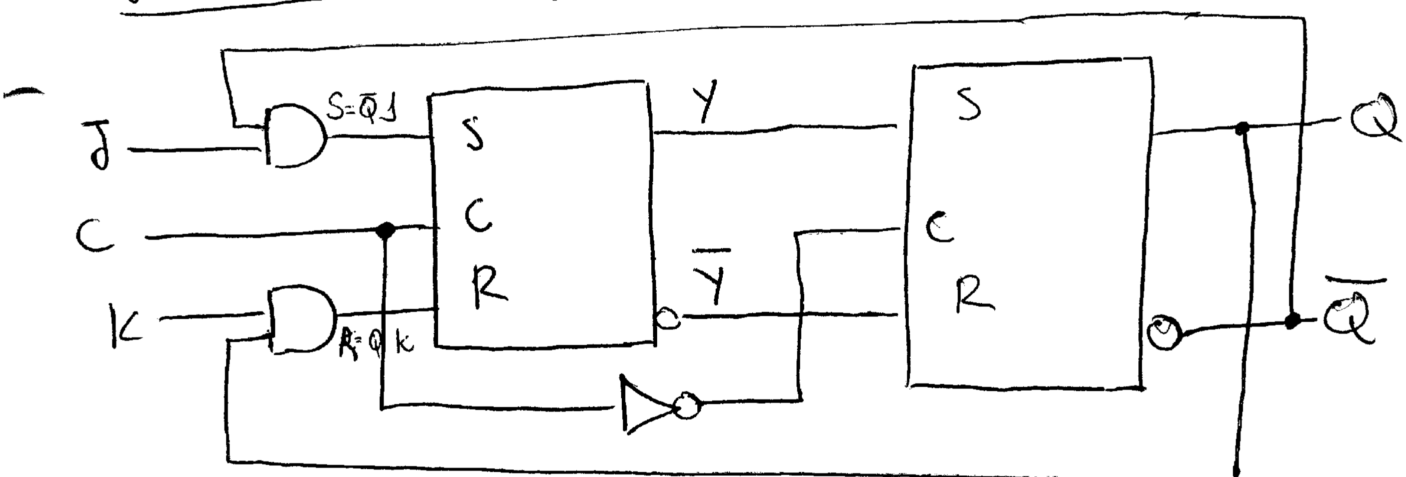
B/c the FF can change incorrectly (ie +ve edge, ~~or -ve edge~~) for C=1, we call it pulse-triggered, and we should make sure that ~~you~~ we prepare & hold its inputs before the pulse .

p193, fig. 4-11



similarly, during c=0, we can change S & R to new inputs, and then:
(i) wait for the pulse c=1 to change Y, and (ii) change Q to Y when c goes to zero again.

JK FF. (fig 4-12, p194)



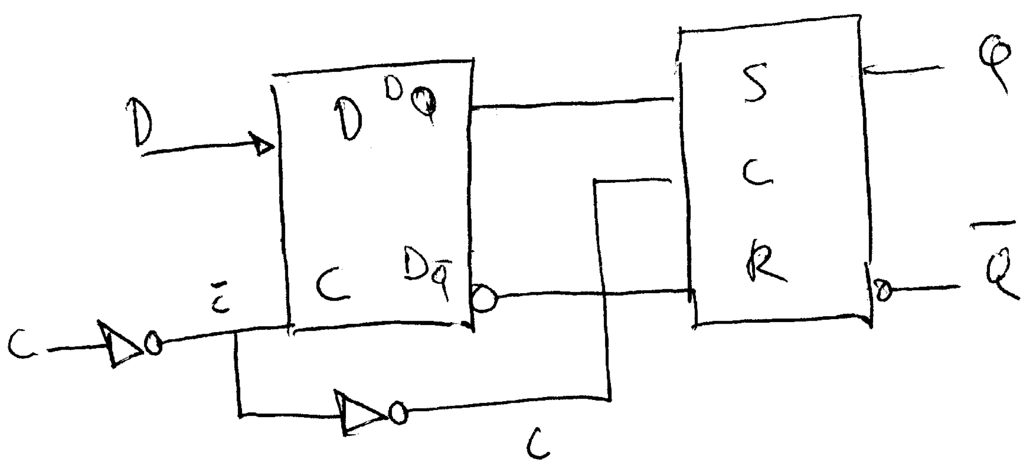
Master-Slave JK Flip-Flop.

J	K	Next-State $Q(t+1)$
0	0	$S=R=0$, Q (unchanged)
0	1	$S=0, R=KQ \; (=Q)$, taking/keeping Q. to 0
1	0	$S=\bar{Q}J \; (=\bar{Q}), R=0$, taking/keeping Q to 1
1	1	$S=\bar{Q}, R=Q$, taking Q to $\bar{Q}$

Edge-triggered FF.

A D-latch (p 190) simply follows its input:

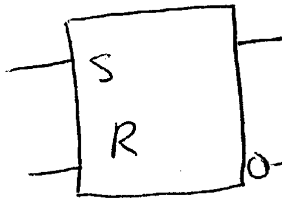
C	D	Next state
0	X	No change
1	0	0
1	1	1



As before, but now Q samples (copies) D at the rising edge of C.

(i) For the clock input equal to 0, the master latch is enabled and transparent and follows the D input value.
(ii) The slave latch is disabled and holds the state of the flip-flop fixed.

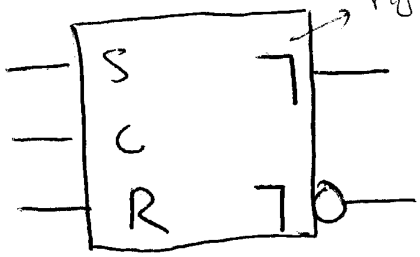
p198 symbols.



SR Latch

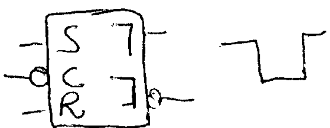
right-angle symbol

Pulse



Trigger SR FF.

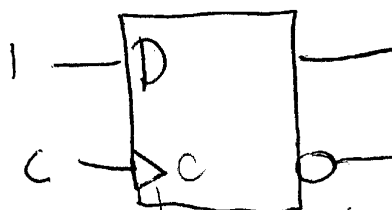
or



Triggered SR

edge

edge-triggered

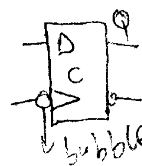


positive

Triggered D FF.

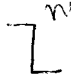
arrowhead-like symbol

or

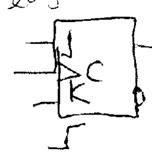


bubble

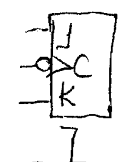
negative edge-triggered



or



or



...

characteristic table for T FF:

T	Q(t+1)	
0	Q(t)	No change
1	$\overline{Q}(t)$	Complement.

In this class, it is assumed that all flip-flops are of the positive-edge-triggered type, unless otherwise indicated.

Characteristic Tables

They define the next state as a function of the inputs and present state. Q(t) refers to the present state prior to the application of a clock pulse. Q(t+1) is the state one clock period later, which is referred

Memorize me! p219, table 4-10.

Flip-Flop Excitation Tables

JK FF.

$Q(t) \to Q(t+1)$	J	K
$0 \to 0$	0	X
$0 \to 1$	1	X
$1 \to 0$	X	1
$1 \to 1$	X	0

[illegible]

Flip-flop characteristic tables

J	K	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	$\overline{Q(t)}$

SR FF

$Q(t) \to Q(t+1)$	S	R
$0 \to 0$	0	X
$0 \to 1$	1	0
$1 \to 0$	0	1
$1 \to 1$	X	0

S	R	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	~~No~~ Undefined

D FF

$Q(t) \to Q(t+1)$	D
$0 \to 0$	0
$0 \to 1$	1
$1 \to 0$	0
$1 \to 1$	1

Q	D	Q(t+1)
~~Q~~	~~X~~	~~No change~~
	0	0
	1	1

T FF

$Q(t) \to Q(t+1)$	T
$0 \to 0$	0
$0 \to 1$	1
$1 \to 0$	1
$1 \to 1$	0

T	Q(t+1)
0	Q(t) No change
1	$\overline{Q(t)}$ complement