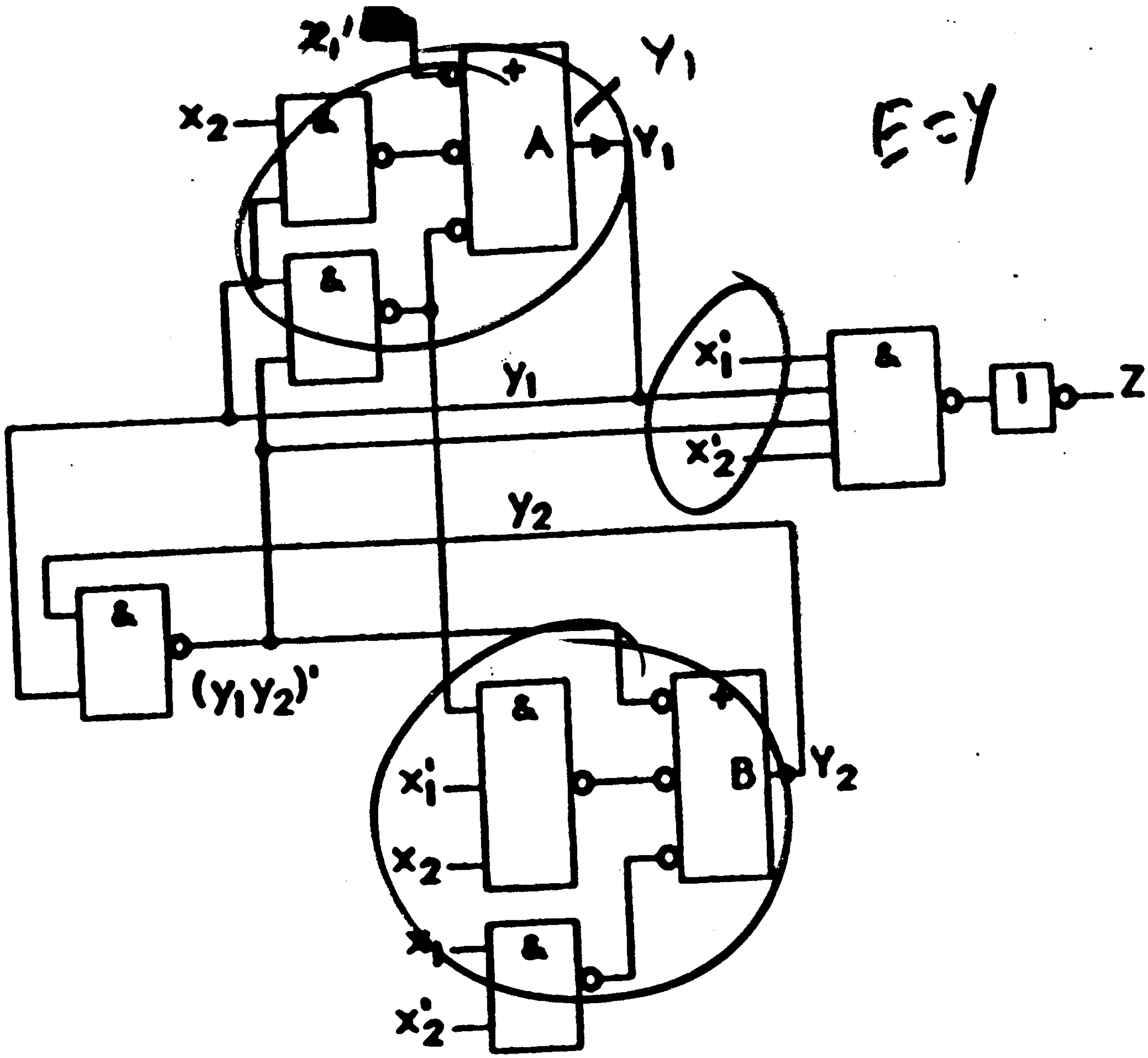



$$Y_1 = x_1 + x_2 y_1 + y_1 (y_1 y_2)' = x_1 + x_2 y_1 + y_1 y_2'$$

$$Y_2 = y_1 y_2 + (y_1' + y_1 y_2) x_1' x_2 + x_1 x_2' = y_1 y_2 + x_1' x_2 y_1' + x_1 x_2'$$

$$Z = x_1' x_2' y_1 (y_1' + y_2') = x_1' x_2' y_1 y_2'$$

**Figure 7.6-1** Sequential circuit illustrating races.

Excitation table and transition table identical because $Y = E$.

| $y_1 y_2$ \ $x_1 x_2$ | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 00 | (00) | 01 | 10 | 11 |
| 01 | 00 | (01) | 10** | 11 |
| 11 | 01 | (11) | (11) | (11) |
| 10 | (10) | (10) | (10) | 11 |

1 0 1
00 → 01 → (11)
00 → 10 → (11)
1 1 1

* denotes a race

** critical race

01 → 00
01 → 11

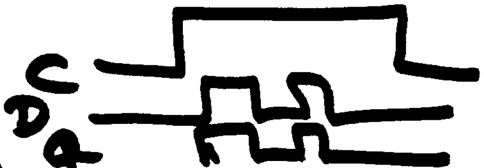
to

* Critical race above may be "fixed" by gate A slower than gate B

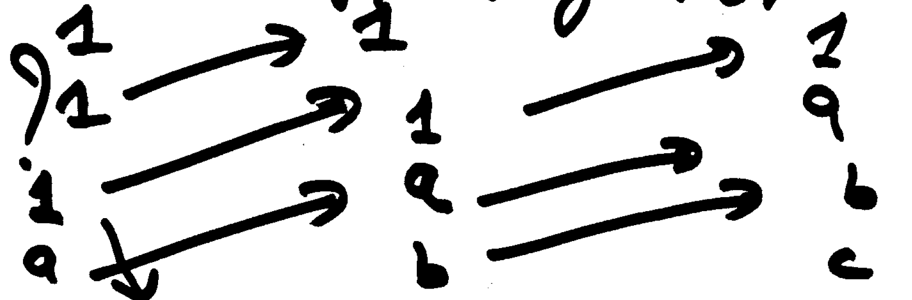
* Or by replacing the next state for $x_1 x_2, y_1 y_2 = 11, 01$ by 00

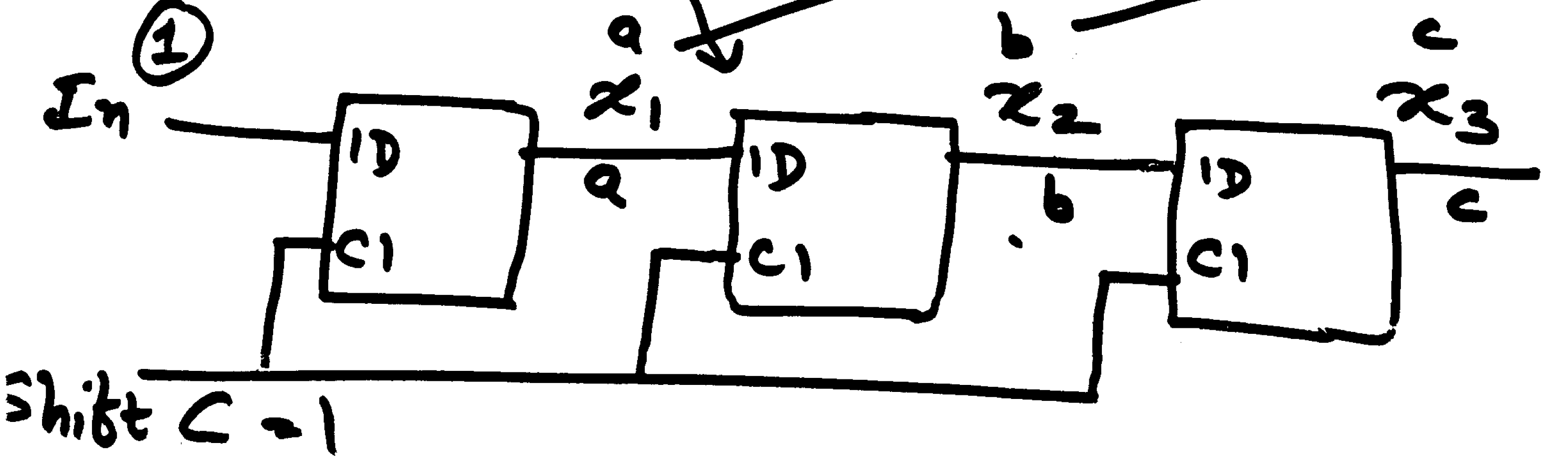
# Fundamental mode flip-flops

§ 7.7




How to build a shift register with latches?




Ideally:

| | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|
| initial State : | → a → | b → | c → |
| new State after shifting in 1 : | 1 | a | b |
| insert 0 : | 0 | 1 | a |

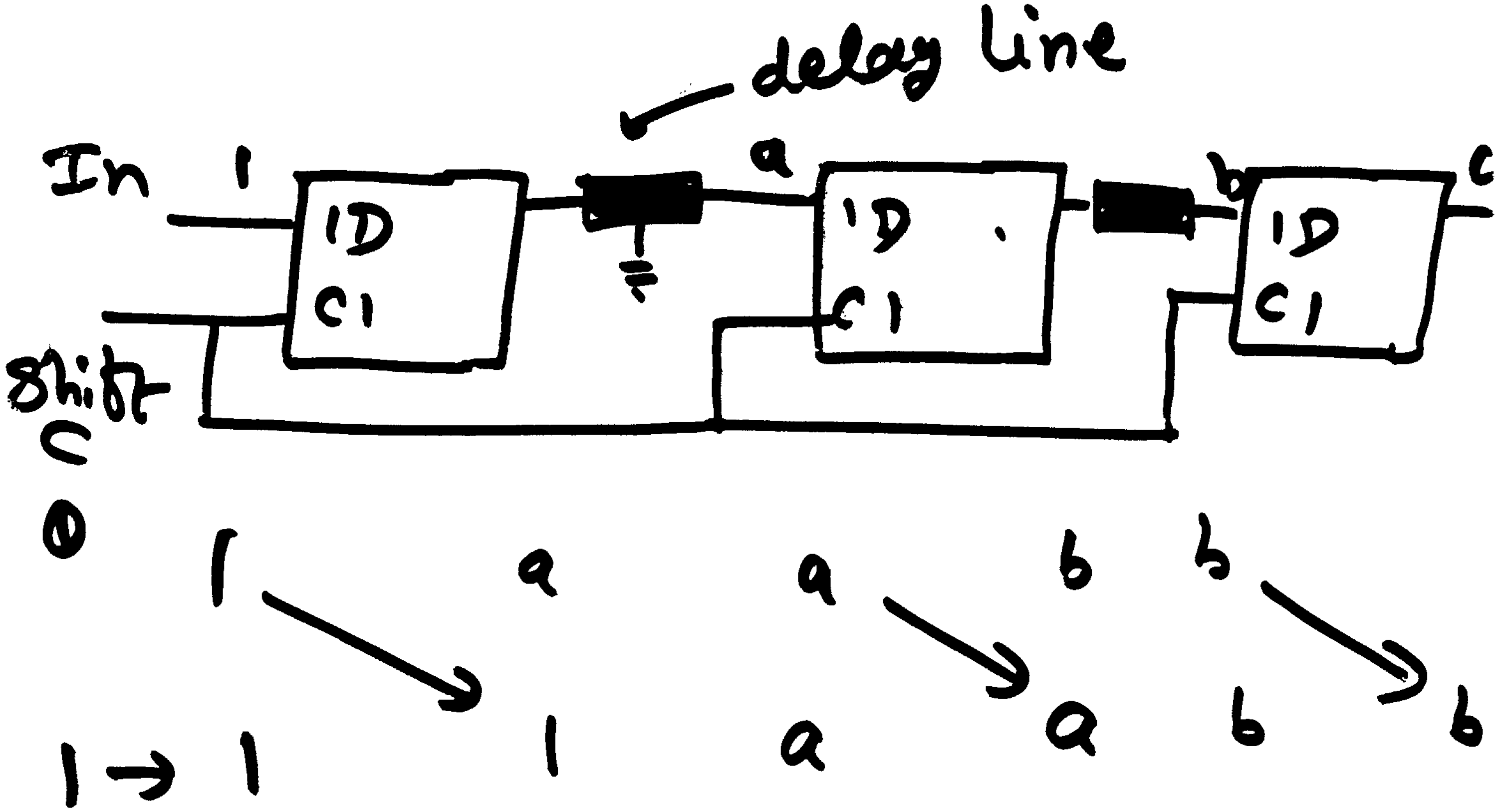
Actually?

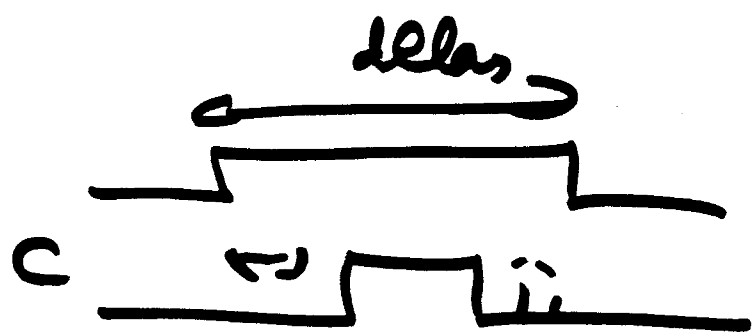
| | | | |
|---|---|---|---|
| initial State | 0 | 0 | 1 |

Shift in 1 with C = 1, In = 1

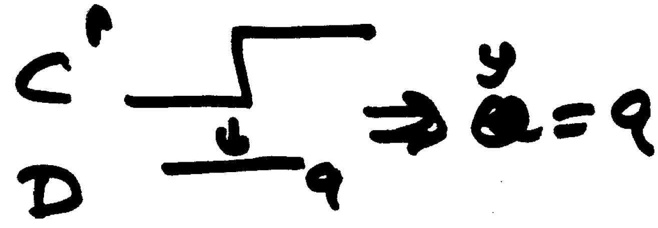
# How to solve the problem?

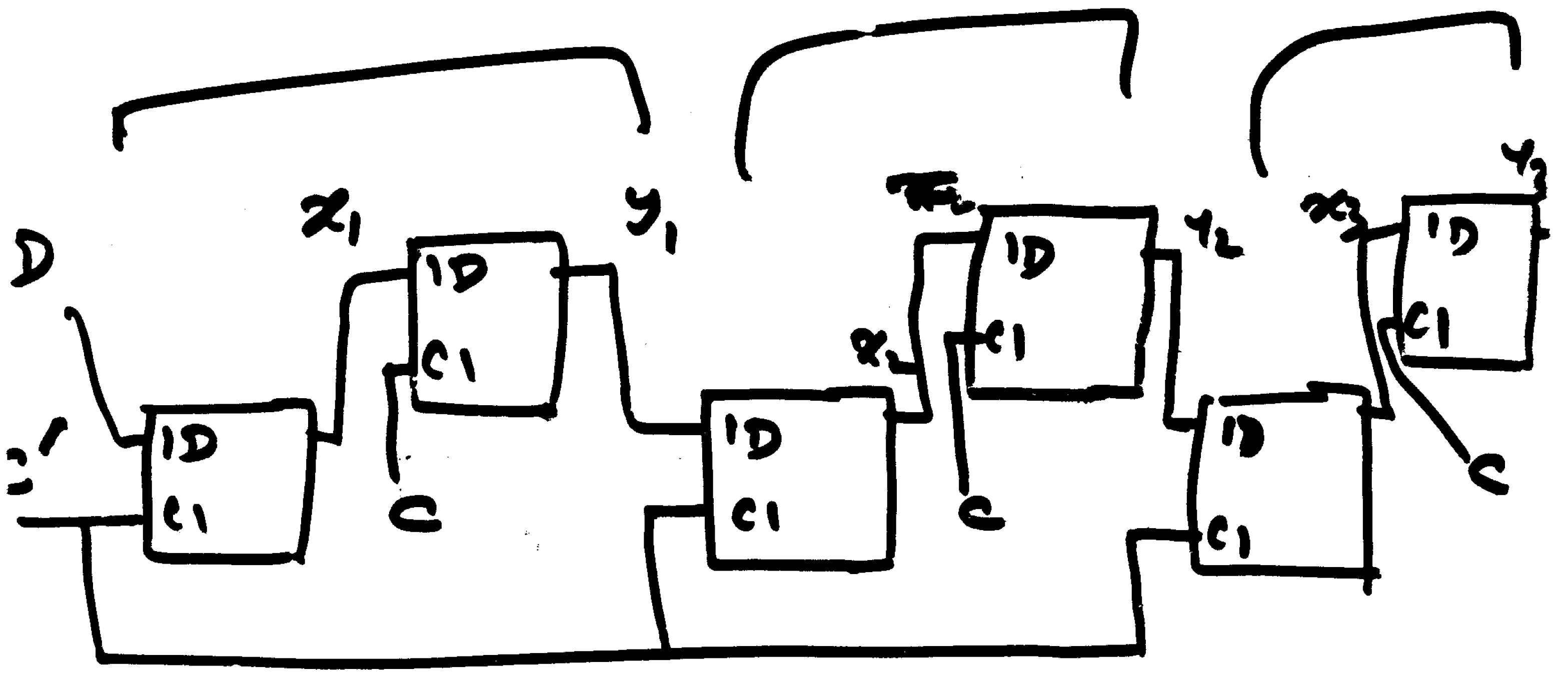
Slow down the bits.

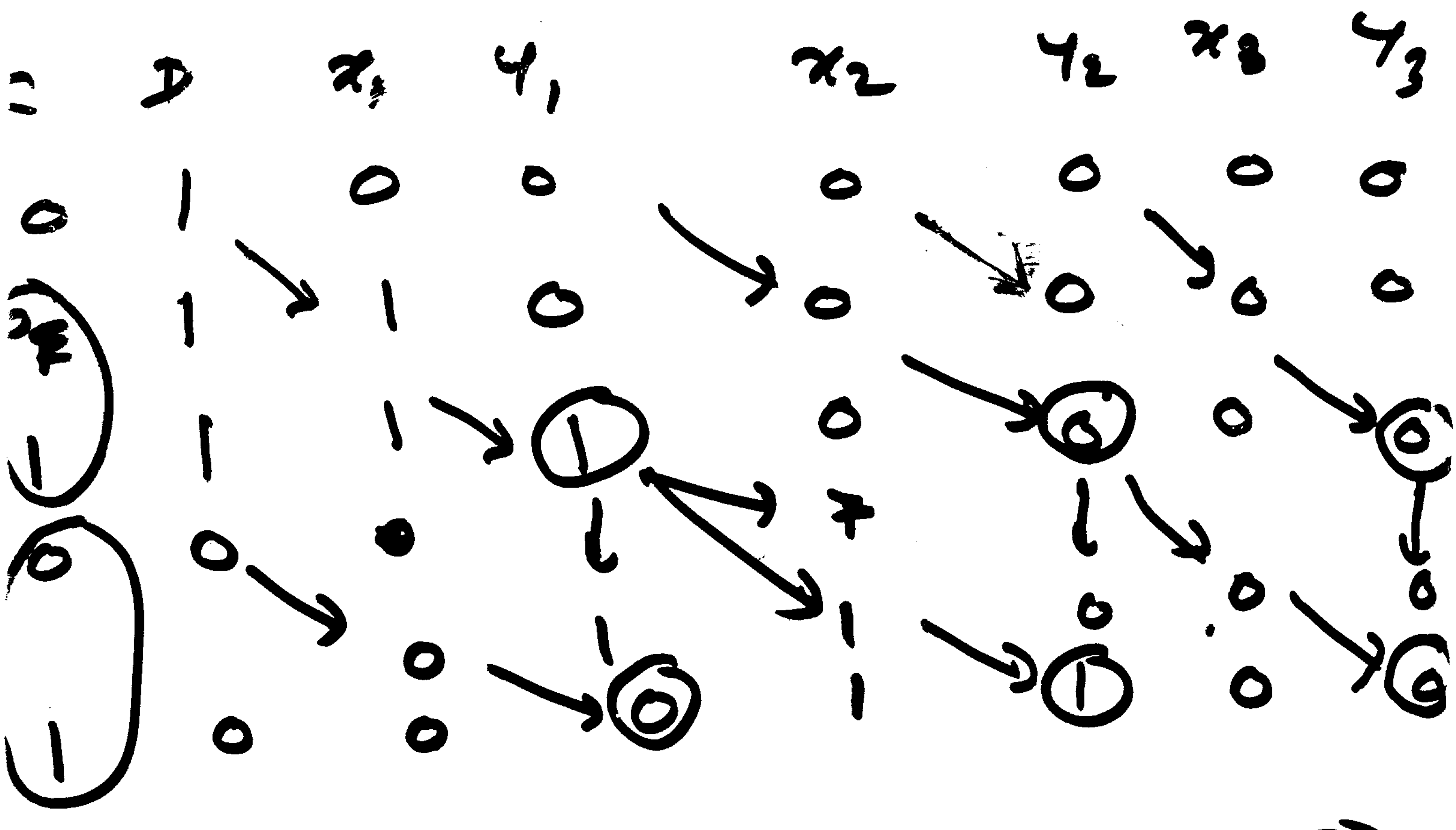


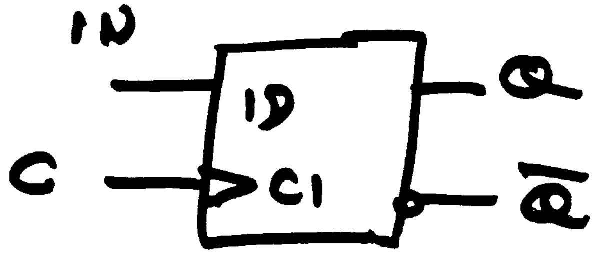



Another alternative:



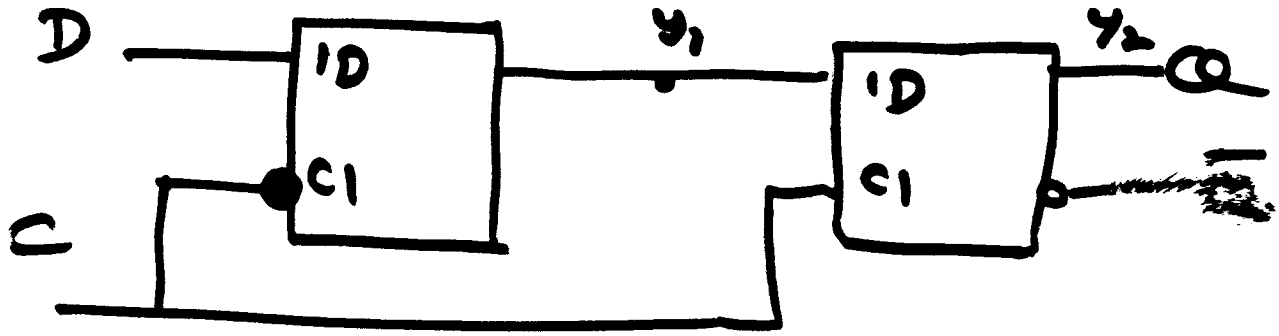



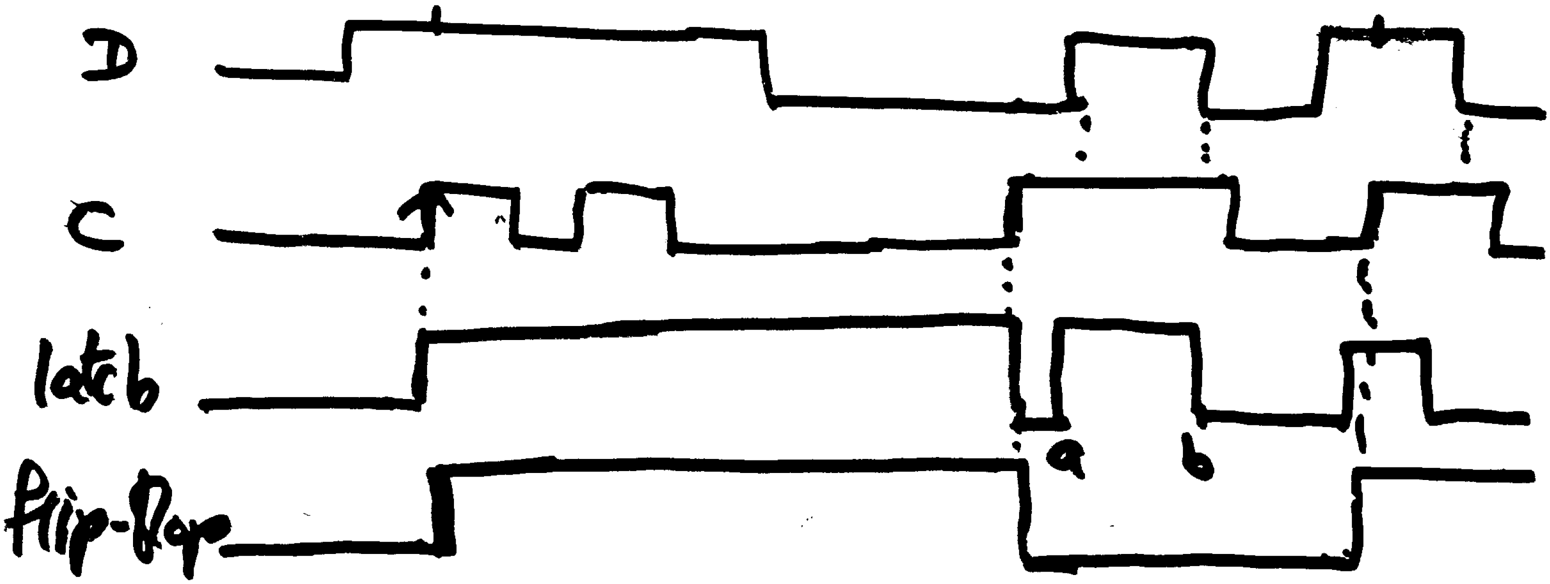



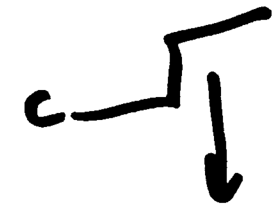



Edge-triggered D flip-flop.

Master-slave arrangement of D latches:

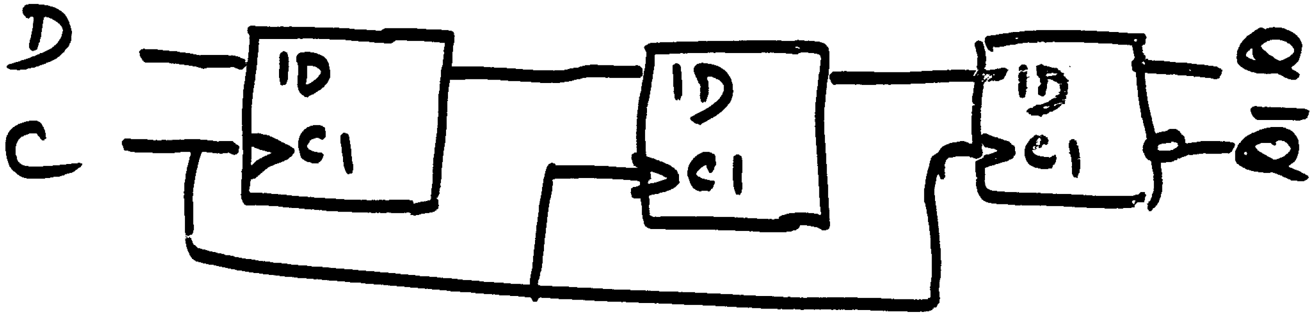


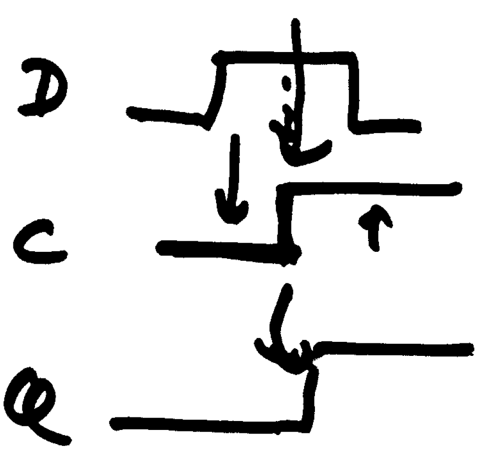



D. flip-flop state after C input changes from 0 to 1: 

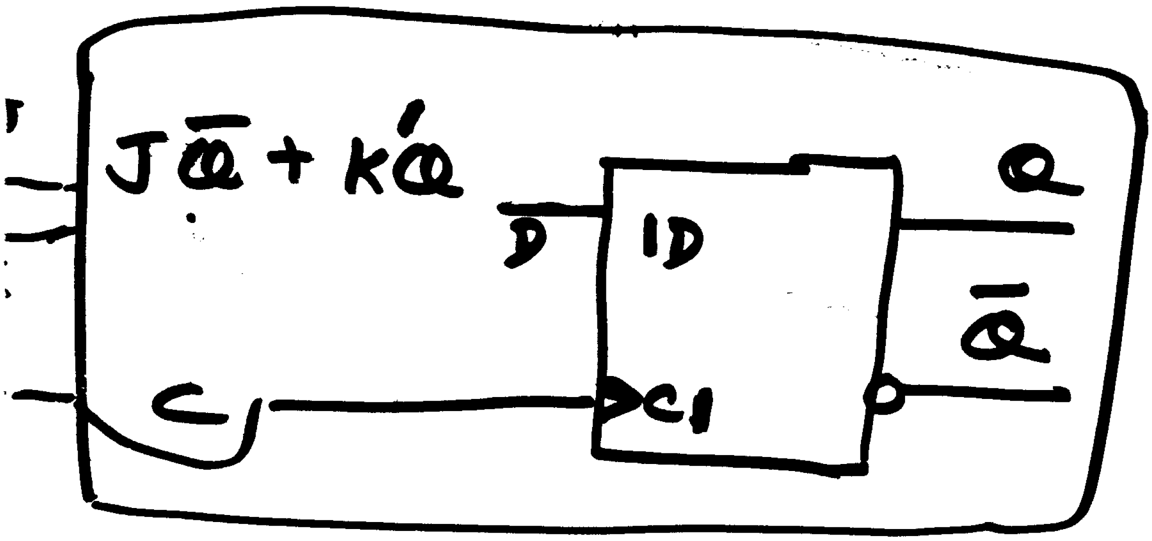

| D | before | after |
|---|---|---|
| 0 | Q | 0 |
| 1 | Q | 1 |

Shift register:



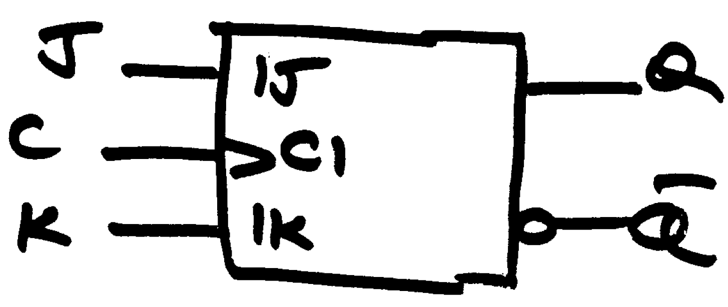
# J-K flip flop



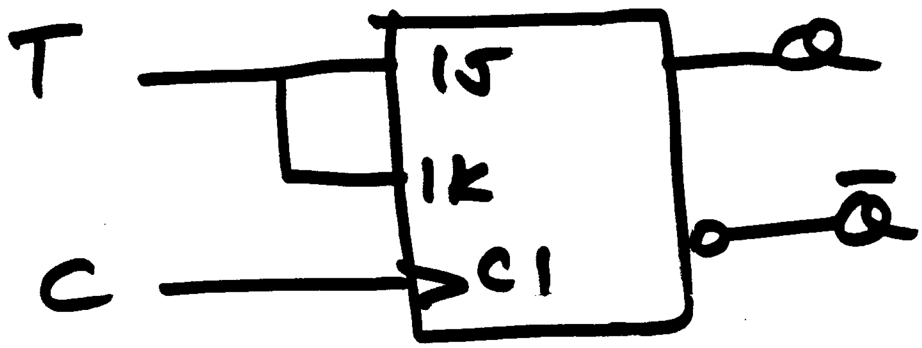

C changing from 0 to 1

| J K | D | Q before | after |
|---|---|---|---|
| 0 0 | Q | Q | Q |
| 0 1 | 0 | Q | 0 |
| 1 0 | $\bar{Q}+Q$ = 1 | Q | 1 |
| 1 1 | $\bar{Q}$ | Q | $Q'$ |

Symbol:



# T flip-flop




| T | J K | before | after |
|---|---|---|---|
| 0 | 0 0 | Q | Q |
| 1 | 1 1 | Q | Q' |