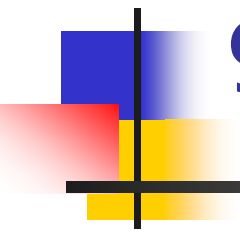


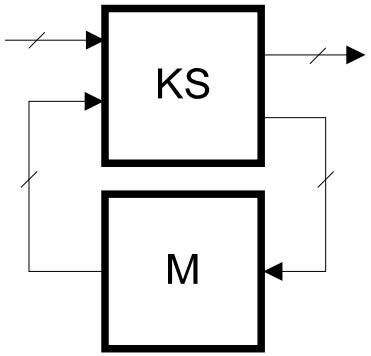
9. Bistabil (1)

Sadržaj predavanja

- **pojam bistabila**
- osnovni bistabil
- sinkroni bistabil
- tipovi bistabila

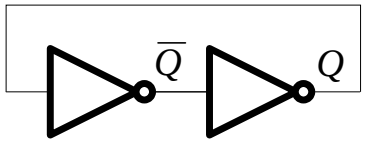
Pojam bistabila

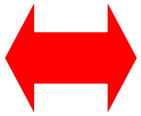
- *sekvencijski sklopovi* (engl. sequential circuits):
  - digitalni sklopovi koji imaju sposobnost pamćenja;
  - izlaz je funkcija:
    - trenutnog stanja ulaza
      ~ trenutno narinute pobude
    - trenutnog unutarnjeg stanja sklopa
      ~ postoji *memorija*
- struktura sekvencijskih sklopova:
  - kombinacijski dio (KS)
  - memorija (M)
    ~ obično memorijski elementi koji pamte *binarne* vrijednosti:
    moraju imati *dva stabilna* stanja

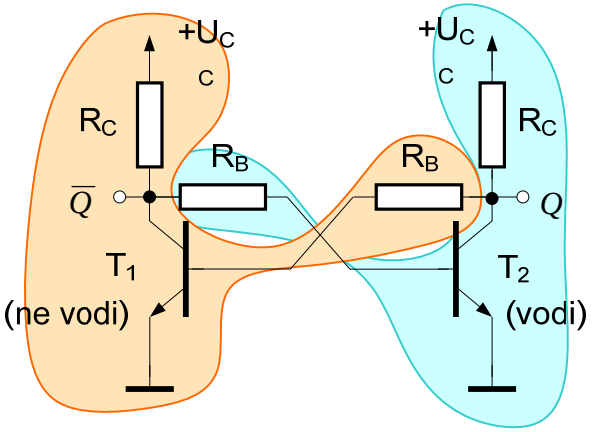


Pojam bistabila

- memorijski element = *bistabil* (engl. flip-flop)
  ~ karakteristični digitalni sklop:
  - *ostaje* u jednom od *dva* moguća *stanja*
    i *bez djelovanja* vanjske pobude
  - stanja su *stabilna*
    ~ posebna struktura sklopa:
    - *unakrsno* povezivanje invertora (sklopki)
      ~ *multivibrator*
    - logički i električki (naponski!) stabilno

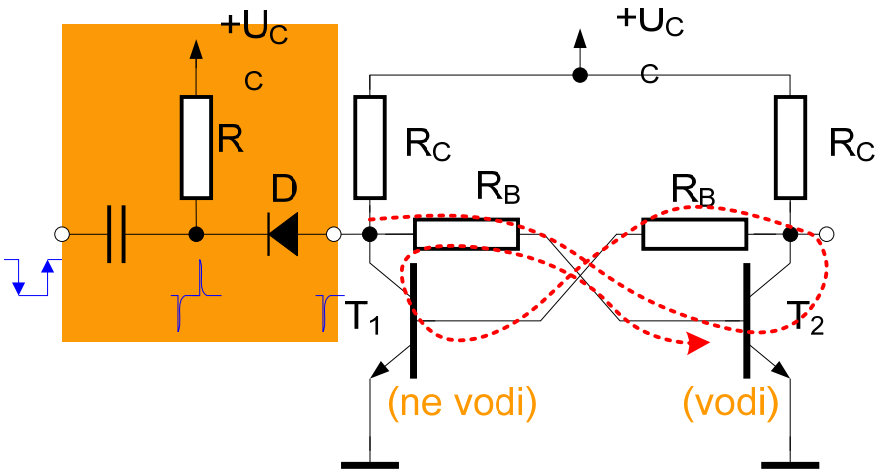






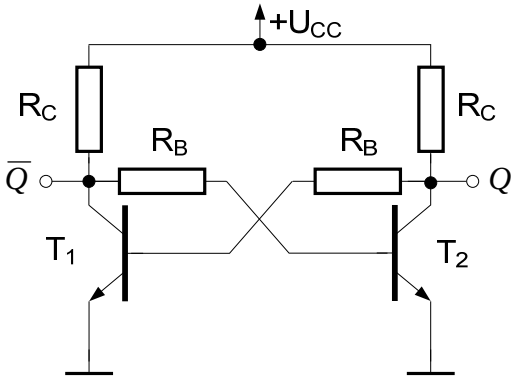
Pojam bistabila

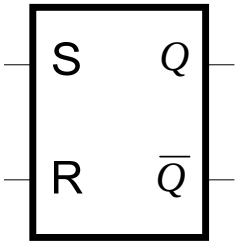
- *promjena stanja* bistabila
  ~ *okidanje* impulsom ("okidni" impuls)
  - samo iniciranje promjene stanja
    ~ T koji vodi (zasićenje!) dovesti u aktivno područje
  - dalje "regenerativna" povratna veza



Pojam bistabila

- *simbol* bistabila:
  - izlazi su komplementarni:
  - ulazi:
    S (engl. set): postavljanje Q = 1
    R (engl. reset): postavljanje Q = 0
    ~ "brisanje"!



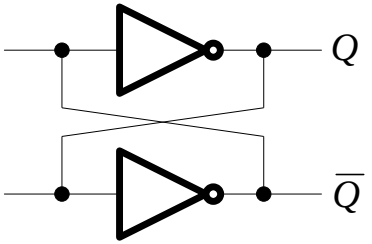


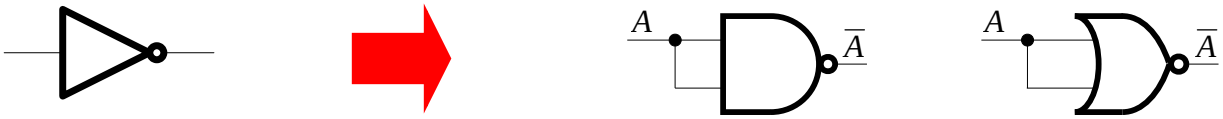
Sadržaj predavanja

- pojam bistabila
- **osnovni bistabil**
  - **bistabil izveden univerzalnim sklopovima**
  - **analiza promjene stanja**
- sinkroni bistabil
- tipovi bistabila

Osnovni bistabil

- "logička" izvedba bistabila
  ~ *izdvojeni* ulazi za okidanje:
  - interpretacija sklopki (invertora) univerzalnim funkcijama
    ~ sklopovi NI i NILI

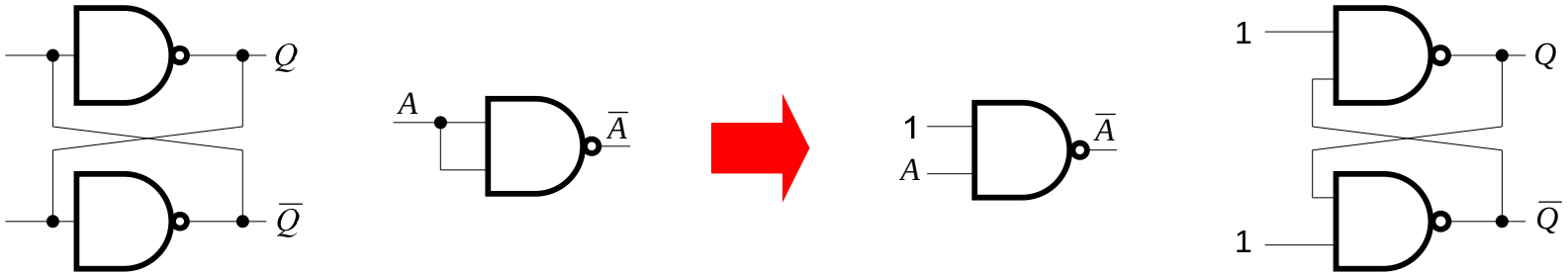




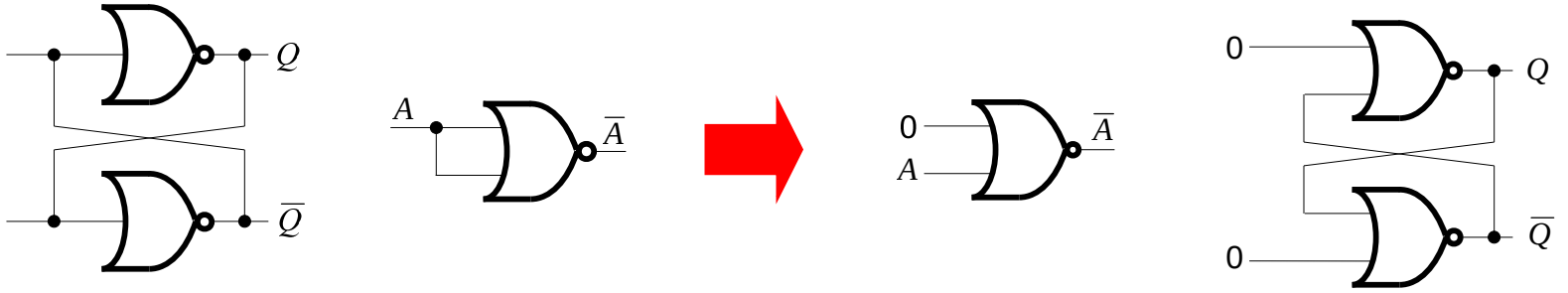
  - bistabil izveden sklopovima NI/NILI
    ~ *osnovni bistabil* (engl. latch):
    primjena u *svim* ostalim složenijim vrstama bistabila te u sekvencijskim sklopovima

Osnovni bistabil

- bistabil ostvaren logičkim sklopovima NI:



- bistabil ostvaren logičkim sklopovima NILI:



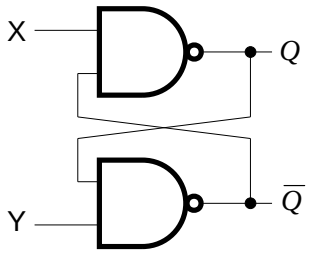
- *okidanje* bistabila (radi promjene stanja)
  ~ druge kombinacije 1 i 0 na ulazima

Osnovni bistabil

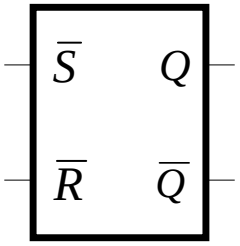
- analiza osnovnog bistabila ostvarenog NI sklopovima:
  - $Q^{n+1} = f(X, Y; Q^n)$: tablica (promjene) stanja
  - identifikacija ulaza:

    $X = \overline{S}$

    $Y = \overline{R}$



  - simbol:



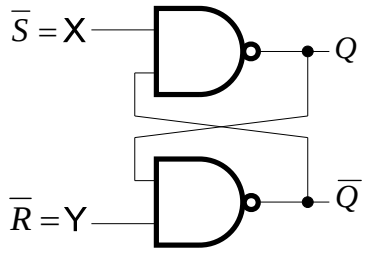
  - terminologija

    ~ osnovni bistabil = "zasun" (engl. latch): podatak ostaje pohranjen u sklopu

X	Y	Q^n	Q^{n+1}	
1	1	0	0	Q^n
1	1	1	1	
0	1	0	1	1
0	1	1	1	
1	0	0	0	0
1	0	1	0	
0	0	0	1	x
0	0	1	1	

Osnovni bistabil

- komentar
  ~ pobuda XY = 00 je *zabranjena*!!!
  - Q= $\overline{Q}$ = 1 za X=Y=0
    ~ proturječi definiciji izlaza bistabila



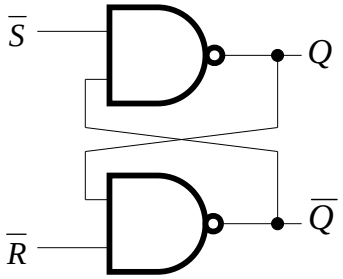
  - nesimetrija sklopa/pobude
    ~ nije jasno u kojem će stanju *ostati* bistabil
    po "otpuštanju" ulaza

X	Y	Q^n	Q^{n+1}	
1	1	0	0	Q^n
1	1	1	1	
0	1	0	1	1
0	1	1	1	
1	0	0	0	0
1	0	1	0	
0	0	0	1	x
0	0	1	1	

Osnovni bistabil

- VHDL model SR bistabila izvedenog sklopovima NI

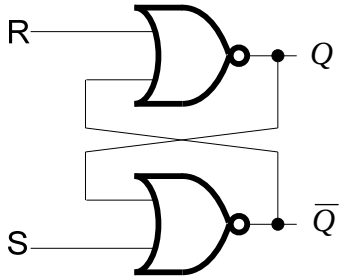
```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

ENTITY SRbistabil IS PORT (
  S, R: IN std_logic;
  Q, Qn: OUT std_logic);
END SRbistabil;

ARCHITECTURE Structural OF SRbistabil IS
  SIGNAL Qint, Qnint: std_logic;
BEGIN
  -- Izračun internih izlaza
  Qint <= NOT S NAND Qnint AFTER 5 ns;
  Qnint <= NOT R NAND Qint AFTER 5 ns;
  -- Preslikavanje na izlaze bistabila
  Q <= Qint;
  Qn <= Qnint;
END Structural;
```



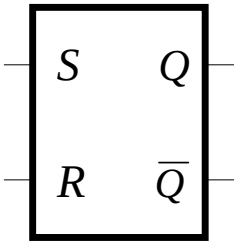
Osnovni bistabil

- osnovni bistabil ostvaren NILI sklopovima:
  - skraćena tablica stanja:

R	S	Q^{n+1}
0	0	Q^n
0	1	1
1	0	0
1	1	X

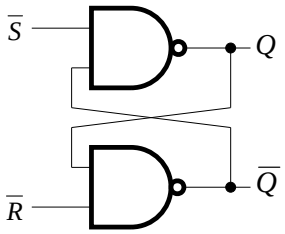


  - simbol:

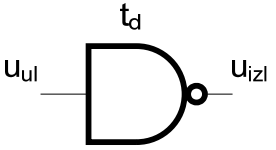


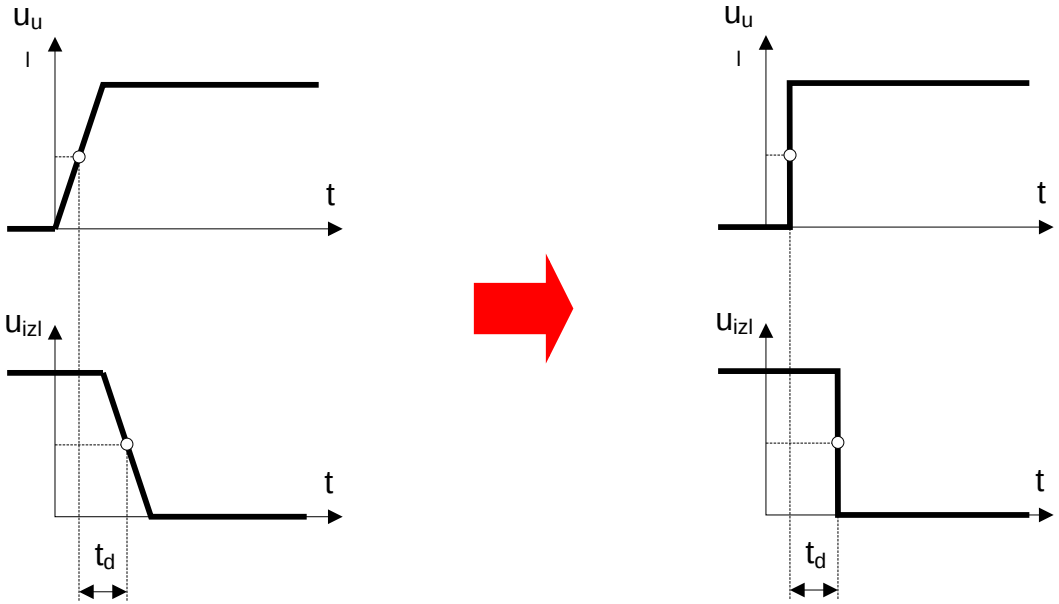
Osnovni bistabil

- analiza *promjene stanja* osnovnog bistabila:
  - bistabil ostvaren sklopovima NI :



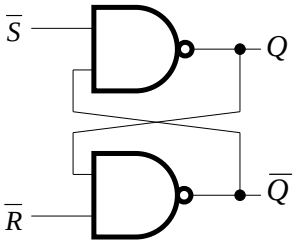
  - uzeti u obzir stvarne sklopove: $\exists\ t_d$



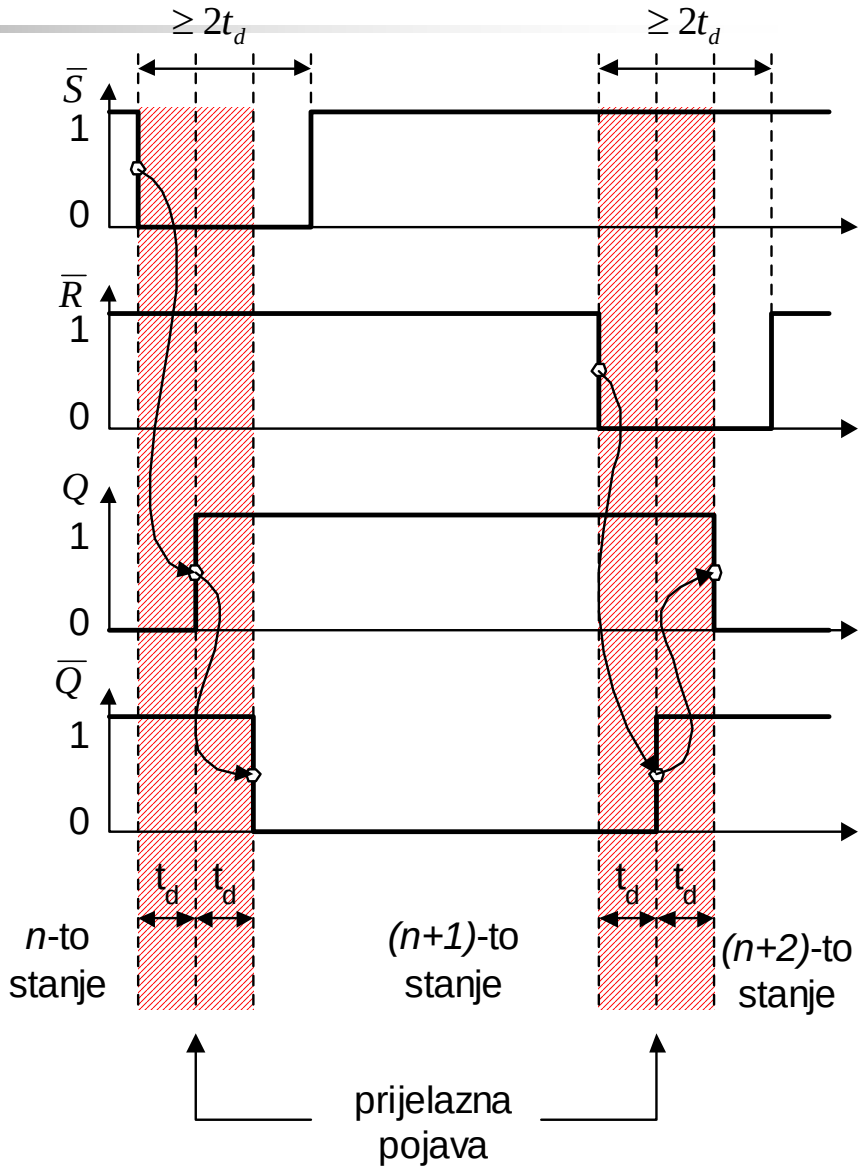


Osnovni bistabil

- analiza promjene stanja osnovnog bistabila:



- sklop je osjetljiv na *trajanje pobude* (okidnog impulsa): $t > 2 \cdot t_d$



Sadržaj predavanja

- pojam bistabila
- osnovni bistabil
- **sinkroni bistabil**
  - **sinkronizacija impuslima takta**
  - **asinkroni ulazi**
- tipovi bistabila

Sinkroni bistabil

- svojstva osnovnog bistabila:
  - mijenja stanje u skladu s pobudom
    ~ "transparentan" za ulaze
  - *trenutno* ($\leq 2 \cdot$td) reagira na pobudu
    ~ promjena stanja *nezavisno* od sustavskog nadzora (tj. zajedničkih sinkronizacijskih impulsa)
  - *hazard* može prouzrokovati neželjenu promjenu stanja
    ~ nezgodno! ☹

Sinkroni bistabil

Primjer: neželjena promjena stanja zbog hazarda

- protufazna pobuda ulaza S

  početno: $A = 1, B = 0 \rightarrow S = 0$

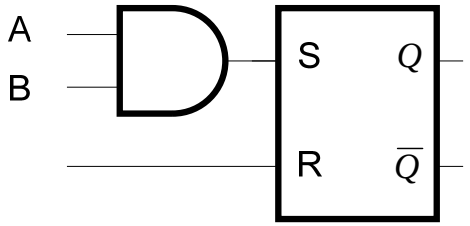
  $R = 0$

  $Q = 0$

  promjena: A: $1 \rightarrow 0$ $\rightarrow$ S = 0 itd.

  B: $0 \rightarrow 1$

  $Q^{n+1} = Q^n = 0$



- promjena A kasni za promjenom B

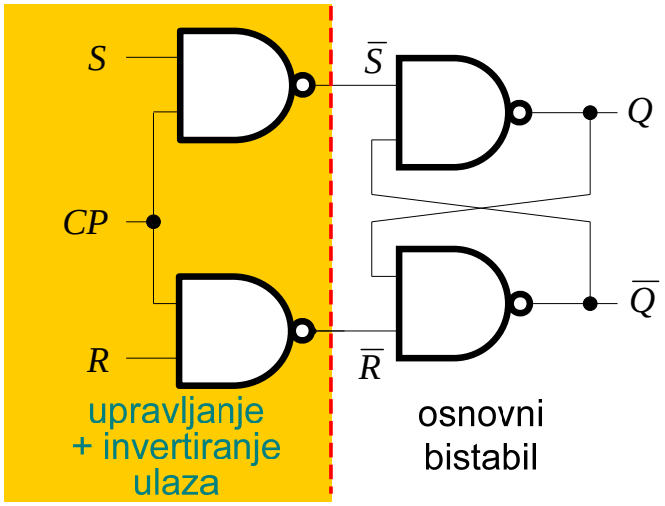
  $\rightarrow$ *hazard*: nakratko $S = A \cdot B = 1 \Rightarrow Q^{n+1} = 1$

Sinkroni bistabil

- rješenje problema moguće pojave hazarda zbog transparentnosti ulaza osnovnog bistabila:
  - dozvoliti upis u bistabil
    samo u određenim trenucima vremena
    ~ izbjegavanje efekata prijelazne pojave
  - upravljanje radom bistabila
    ~ *sinkronizacija*

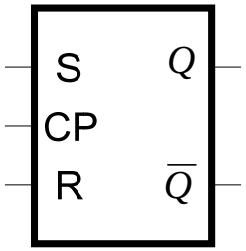
Sinkroni bistabil

- *sinkronizacija* okidanja bistabila
  ~ *sinkronizacijski* impulsi (impulsi *takta*)
  CP (engl. Clock Pulses) na poseban ulaz bistabila:
  sinkroni bistabil
  - promjena stanja bistabila u sinkronizaciji s CP:
    jedino za CP = 1
  - usputno invertiranje ulaza:
    $\overline{S}\,\overline{R} \rightarrow S\,R$

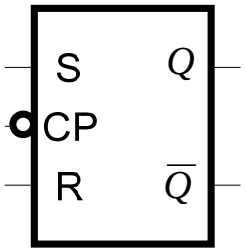


Sinkroni bistabil

- konceptualizacija sinkronizacije okidanja bistabila
  ~ *diskretizacija* vremena
  - (bitno!) olakšava razmatranje sekvencijskih sklopova
    ~ sekvencijski problem sveden na kombinacijski
  - obično se razmatra prijelaz n-to $\rightarrow$ (n+1)-vo stanje
    ~ prije, odnosno poslije, nailaska impulsa CP
- simbol(i) sinkronog bistabila:



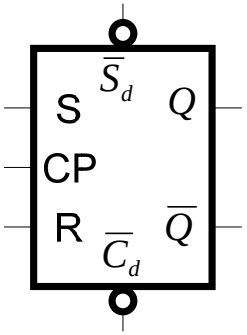
aktivna 1

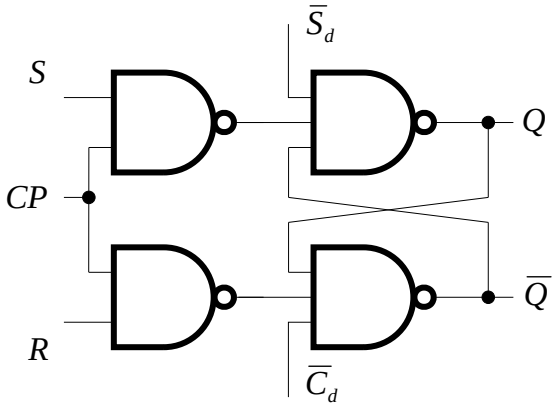


aktivna 0

Sinkroni bistabil

- dodavanje *asinkronih* ulaza:
  ~ na osnovni bistabil,
  zaobiđena mreža za upravljanje:
  direktni ulazi ($\overline{S}_d$, $\overline{C}_d$)



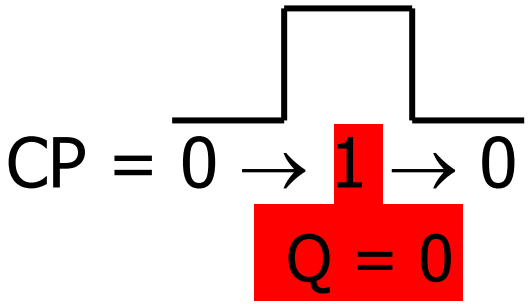


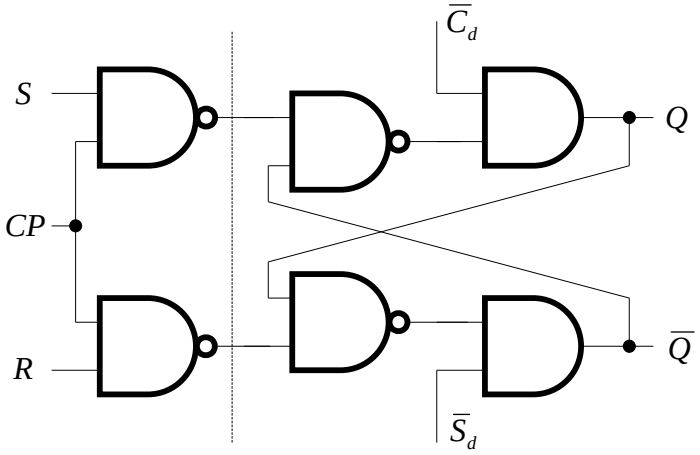
  - aktivni s 0
  - dominiraju nad sinkronim ulazima (S, R)
  - mogući problem
    ~ za vrijeme CP aktivna pobuda
    preko sinkronih i asinkronih ulaza:
    hazard?

Sinkroni bistabil

Primjer: hazard zbog istovremene pobude na sinkronom i asinkronom ulazu

- $\overline{C}_d = 0$, $\overline{S}_d = 1 \rightarrow Q = 0$, $\overline{Q} = 1$
  uz dodatno S = 1, R = 0





- rješenje
  ~ *posebna* izvedba:
  - dodati I sklopove na izlaze
  - zamijeniti značenje asinkronih ulaza

Sadržaj predavanja

- pojam bistabila
- osnovni bistabil
- sinkroni bistabil
- **tipovi bistabila**
  - **SR bistabil**
  - **JK bistabil**
  - **T bistabil**
  - **D bistabil**

Tipovi bistabila

- *tipovi* bistabila:
  - SR bistabil
    ~ osnovna funkcionalnost
  - JK bistabil
    ~ proširena funkcionalnost:
    "univerzalni" bistabil
  - T bistabil
    ~ (samo) promjena stanja
  - D bistabil
    ~ (samo) pamćenje 1 bita informacije

Tipovi bistabila

- *formalizmi* definicije bistabila:
  - tablica (promjene) stanja
  - jednadžba (promjene) stanja, karakteristična jednadžba

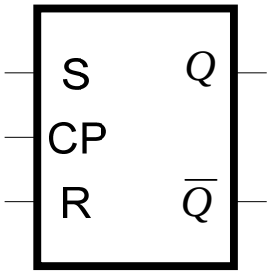
    $$Q^{n+1} = f(ulazi, Q^n)$$

  - uzbudna tablica:

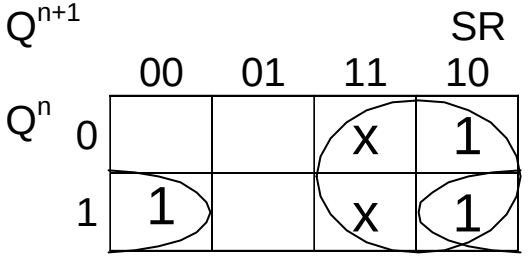
    ulazi = f(promjena_stanja)
  - dijagram stanja
    ~ *grafički* prikaz tablice stanja
    - čvor ≡ stanje
    - strelica ≡ prijelaz

Tipovi bistabila

- *SR bistabil* (rekapitulacija):



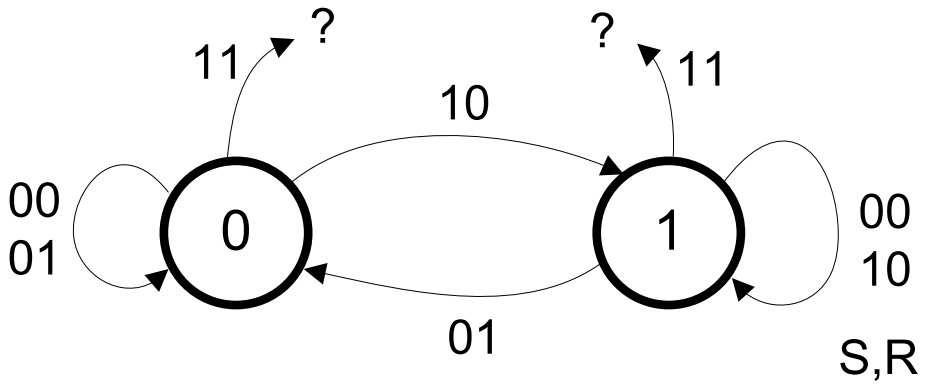
S	R	Q^{n+1}
0	0	Q^n
0	1	0
1	0	1
1	1	X



$$Q^{n+1} = S + \overline{R} \cdot Q^n$$

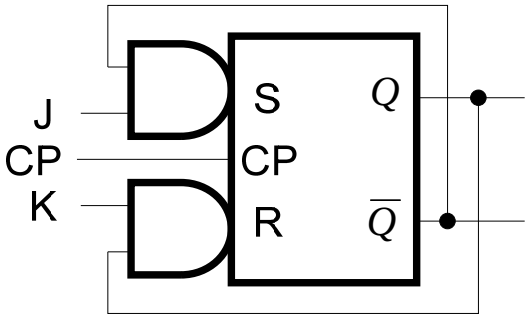
$$S \cdot R = 0$$

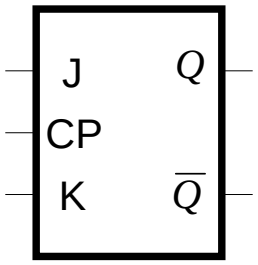
Q^n	Q^{n+1}	S	R
0	0	0	x
0	1	1	0
1	0	0	1
1	1	x	0



Tipovi bistabila

- *JK bistabil*:
  ~ posebna povratna veza na SR bistabil:
  propuštanje "vanjskih" ulaza
  tako da *nema* zabranjene kombinacije ulaza:
  - JK = 11
    ~ bistabil *mijenja stanje* (engl. toggle)
  - JK bistabil
    ~ neka vrsta "univerzalnog" bistabila

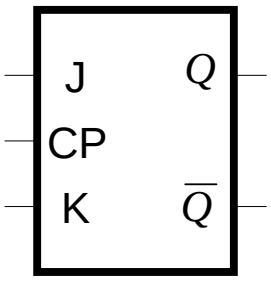




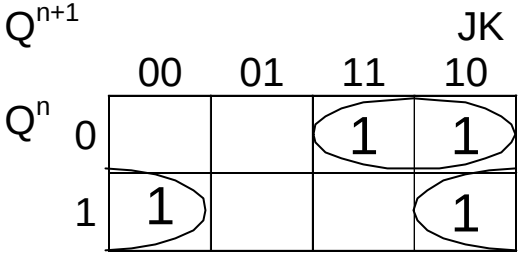
J	K	Q^{n+1}
0	0	Q^n
0	1	0
1	0	1
1	1	$\overline{Q^n}$

Tipovi bistabila

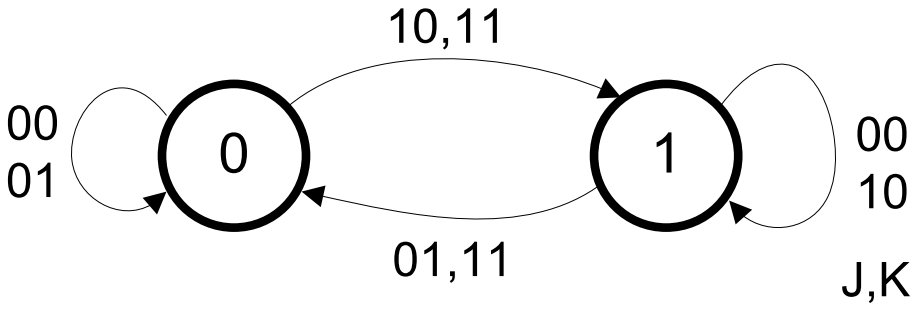
- JK bistabil:
  ~ JK = 11 $\rightarrow$ bistabil *mijenja stanje*



J	K	Q^{n+1}
0	0	Q^n
0	1	0
1	0	1
1	1	$\overline{Q^n}$



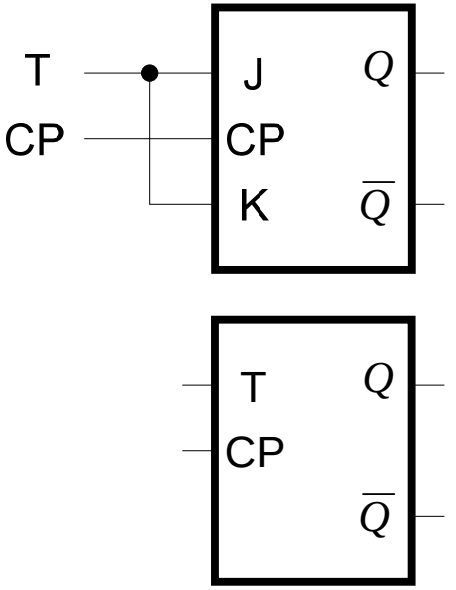
$$Q^{n+1} = J \cdot \overline{Q}^n + \overline{K} \cdot Q^n$$

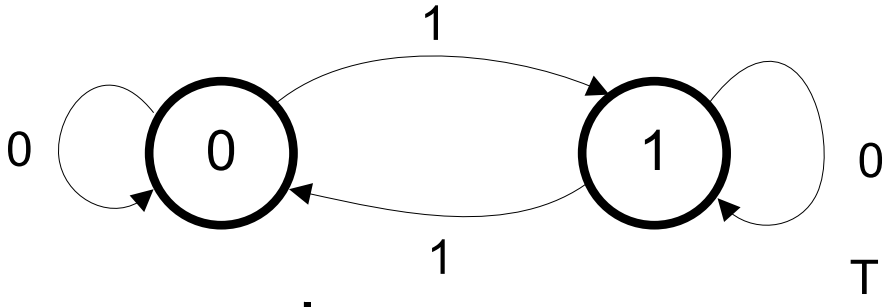


Q^n	Q^{n+1}	J	K
0	0	0	x
0	1	1	x
1	0	x	1
1	1	x	0

Tipovi bistabila

- *T bistabil*
  ~ samo mijenja stanje (engl. toggle)
  - tipična primjena
    ~ brojanje impulsa ($\rightarrow$ *brojila*)
  - jednostavno se dobiva iz JK bistabila





$$Q^{n+1} = T \cdot \overline{Q}^{n} + \overline{T} \cdot Q^{n}$$

J	K	Q^{n+1}
0	0	Q^n
0	1	0
1	0	1
1	1	$\overline{Q}^n$

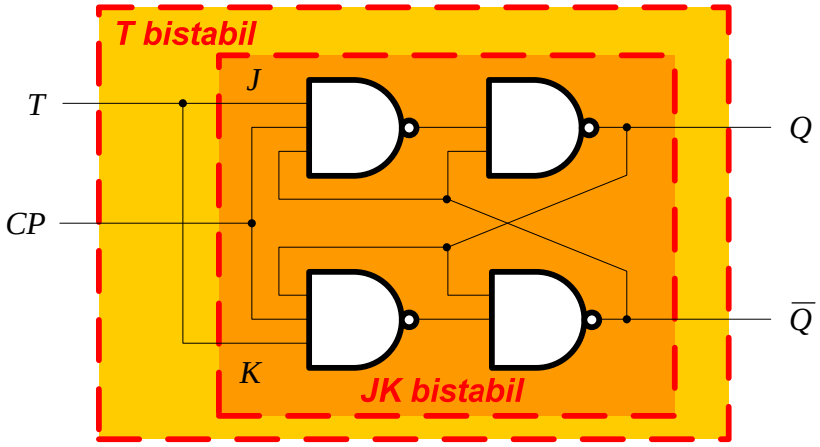
T	Q^{n+1}
0	Q^n
1	$\overline{Q}^n$

Q^n	Q^{n+1}	T
0	0	0
0	1	1
1	0	1
1	1	0

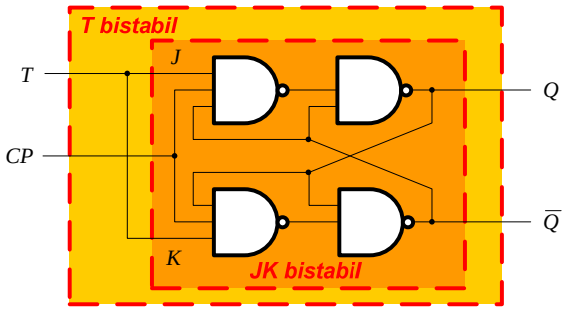
Tipovi bistabila

- VHDL model T bistabila
  - izlazni signali se koriste kao ulazni
    ~ povratna veza: dvosmjerni signali (tip `INOUT`)

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
ENTITY Tbistabil IS PORT (
  T, CP: IN std_logic;
  Q, Qn: INOUT std_logic);
END Tbistabil;
```



Tipovi bistabila

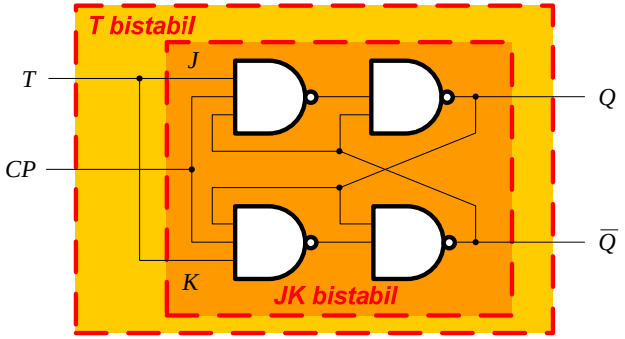



```
ARCHITECTURE Structural OF Tbistabil IS
  COMPONENT NI3
       PORT (i1, i2, i3: IN std_logic; y: OUT std_logic);
  END COMPONENT;
  SIGNAL JCPQn, KCPQ: std_logic; -- izlazi prvog reda NI sklopova
  SIGNAL J, K: std_logic;
BEGIN
       J <= T; K <= T;
  c1:  NI3 PORT MAP(J, CP, Qn, JCPQn);
  c2:  NI3 PORT MAP(K, CP, Q, KCPQ);
  c3:  NI3 PORT MAP(JCPQn, JCPQn, Qn, Q);
  c4:  NI3 PORT MAP(KCPQ, KCPQ, Q, Qn);
END Structural;
```

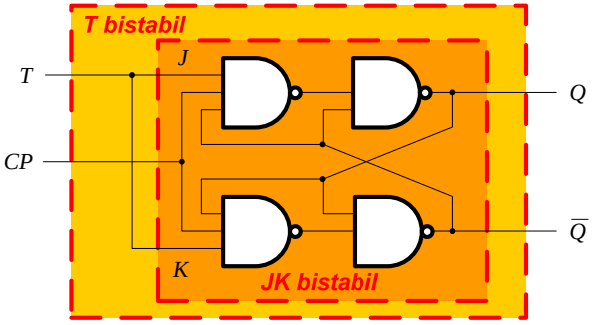
Tipovi bistabila

- izlazni signali su tipa `OUT`
  ~ povratna veza ostvarena unutarnjim signalima
  `Qint, Qnint: std_logic`

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
ENTITY Tbistabil IS PORT (
  T, CP: IN std_logic;
  Q, Qn: OUT std_logic);
END Tbistabil;
```



Tipovi bistabila




```
ARCHITECTURE Structural OF Tbistabil IS
  COMPONENT NI3
       PORT (i1, i2, i3: IN std_logic; y: OUT std_logic);
  END COMPONENT;
  SIGNAL JCPQn, KCPQ: std_logic; -- izlazi prvog reda NI sklopova
  SIGNAL J, K: std_logic;
  SIGNAL Qint, Qnint: std_logic; -- interni izlazi bistabila
BEGIN
  -- modeliranje samog bistabila
       J <= T; K <= T;
  c1:  NI3 PORT MAP(J, CP, Qnint, JCPQn);
  c2:  NI3 PORT MAP(K, CP, Qint, KCPQ);
  c3:  NI3 PORT MAP(JCPQn, JCPQn, Qnint, Qint);
  c4:  NI3 PORT MAP(KCPQ, KCPQ, Qint, Qnint);
  -- preslikavanje internih izlaza na izlaze sklopa
  Q  <= Qint;
  Qn <= Qnint;
END Structural;
```

Tipovi bistabila

- modeliranje *jednadžbama promjene stanja*
  (izlazi tipa `INOUT` ostvaruju povratnu vezu ~ *stanje!*)

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

ENTITY Tbistabil IS PORT (
  T, CP: IN std_logic;
  Q, Qn: INOUT std_logic);
END Tbistabil;

ARCHITECTURE Behavioral OF Tbistabil IS
BEGIN
  PROCESS (T,CP)
  BEGIN
    IF CP='1' THEN
      Q  <= (NOT T AND Q) OR (T AND NOT Q) AFTER 15 ns;
      Qn <= (NOT T AND NOT Q) OR (T AND Q) AFTER 15 ns;
    END IF;
  END PROCESS;
END Behavioral;
```

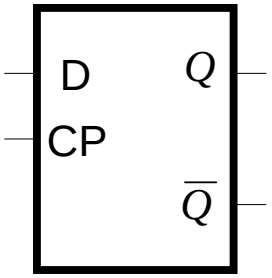
Tipovi bistabila

- modeliranje stanja korištenjem *varijable*

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

ENTITY Tbistabil IS PORT (
  T, CP: IN std_logic;
  Q, Qn: OUT std_logic);
END Tbistabil;

ARCHITECTURE Behavioral OF Tbistabil IS
BEGIN
  PROCESS (T,CP)
    VARIABLE stanje: std_logic;
  BEGIN
    IF CP='1' THEN
      stanje  := (NOT T AND stanje) OR (T AND NOT stanje);
    END IF;
    Q  <= stanje AFTER 15 ns;
    Qn <= NOT stanje AFTER 15 ns;
  END PROCESS;
END Behavioral;
```

Tipovi bistabila

- *D bistabil*
  ~ kasni (engl. delay) za 1 x CP
  - "pamti" podatak narinut na ulazu
  - primjena: *pohranjivanje* podataka ($\rightarrow$ *registri*)

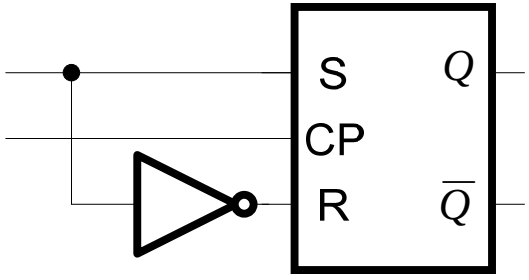


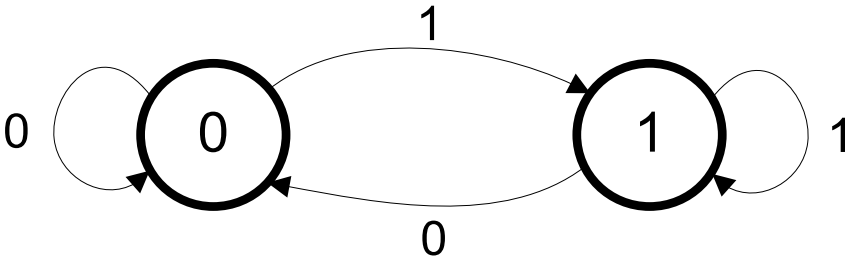
J	K	Q^{n+1}
0	0	Q^n
0	1	0
1	0	1
1	1	$\overline{Q^n}$

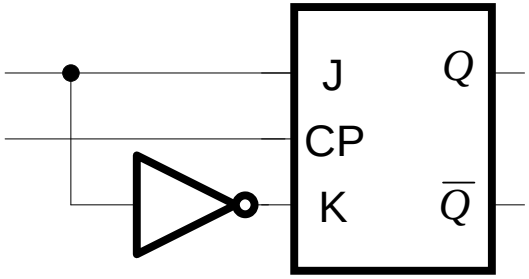
D	Q^{n+1}
0	0
1	1

$$Q^{n+1} = D^n$$

Q^n	Q^{n+1}	D
0	0	0
0	1	1
1	0	0
1	1	1





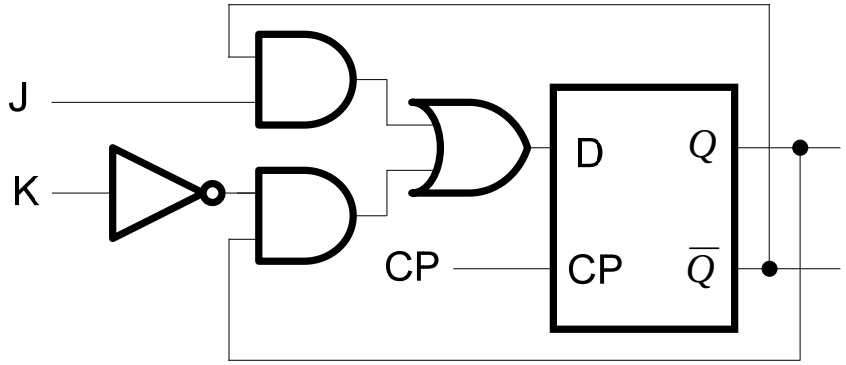


Tipovi bistabila

Primjer: JK bistabil ostvaren D bistabilom

- "logika" u dodatni kombinacijski sklop na ulazu D
- povratna veza s Q i $\overline{Q}$
- D bistabil: $Q^{n+1} = D^n \quad \Rightarrow \quad D^n = Q^{n+1}$

$$Q^{n+1} = J \cdot \overline{Q}^n + \overline{K} \cdot Q^n = D^n$$

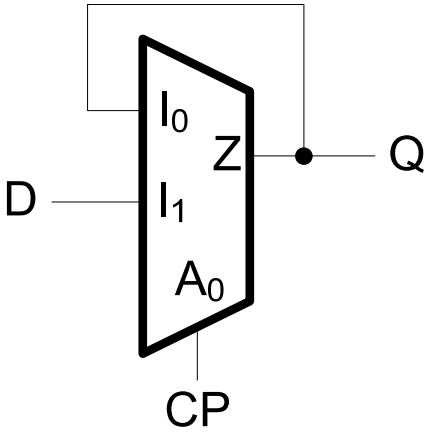


Tipovi bistabila

Primjer: izvedba bistabila multipleksorom

- "zabravljivanje" podatka u multipleksoru
  ~ povratna veza s izlaza *na jedan* od ulaza
- drugi ulaz za vanjski podatak
- adresni ulaz za impuls takta
  ~ upravljanje razinom CP
  CP = 1 upis podatka

$A_0 = CP$	$Z = Q^{n+1}$
0	$I_0 = Q^n$
1	$I_1 = D$



Literatura

U. Peruško, V. Glavinić: *Digitalni sustavi*, Poglavlje 5: Bistabil.

- pojam bistabila: str. 165-169
- osnovni bistabil: str. 169-176
- sinkroni bistabil: str. 176-179
- tipovi bistabila: str. 179-189

Zadaci za vježbu (1)

U. Peruško, V. Glavinić: *Digitalni sustavi*, Poglavlje 7: Standardni kombinacijski moduli.

- tipovi bistabila: 5.1-5.4, 5.7

Zadaci za vježbu (2)

M. Čupić: *Digitalna elektronika i digitalna logika. Zbirka riješenih zadataka*, Cjelina 6: Standardni programirljivi moduli.

- tipovi bistabila:
  - riješeni zadaci: 7.1-7.6
  - zadaci za vježbu: 1-3