Digitalna vezja, BVS-RI

Mira TREBAR

P8 Sekvenčna vezja - pomnilne celice

Vsebina

- Sekvenčna vezja
- Pomnilne celice
- Digitalni impulzi
- Urin signal
- Sinhronske pomnilne celice
- Primeri

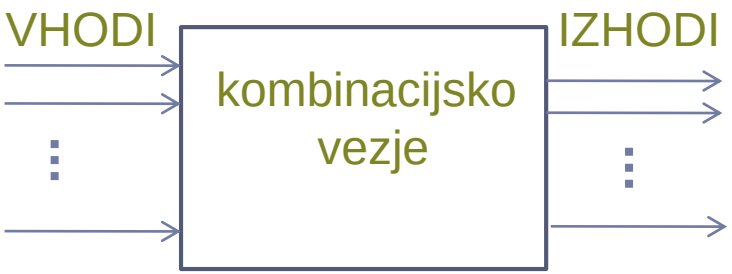
- Vir
  - Widmer N.S., Moss G.L., Tocci R.J, Digital Systems Principles in Applications, Pearson Education, 2018 (P5)
  - Trebar, Osnove logičnih vezij (P10)
  - Video:

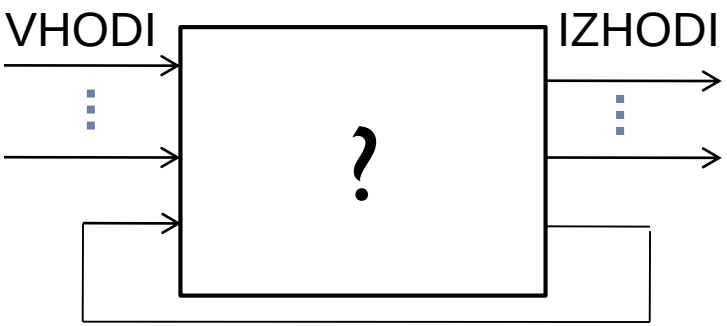
https://www.youtube.com/watch?v=-aQH0ybMd3U&ab_channel=ComputerScience
https://www.youtube.com/watch?v=Hi7rK0hZnfc

1 Sekvenčna vezja

KOMBINACIJSKO VEZJE
- izhod je funkcija vhodov

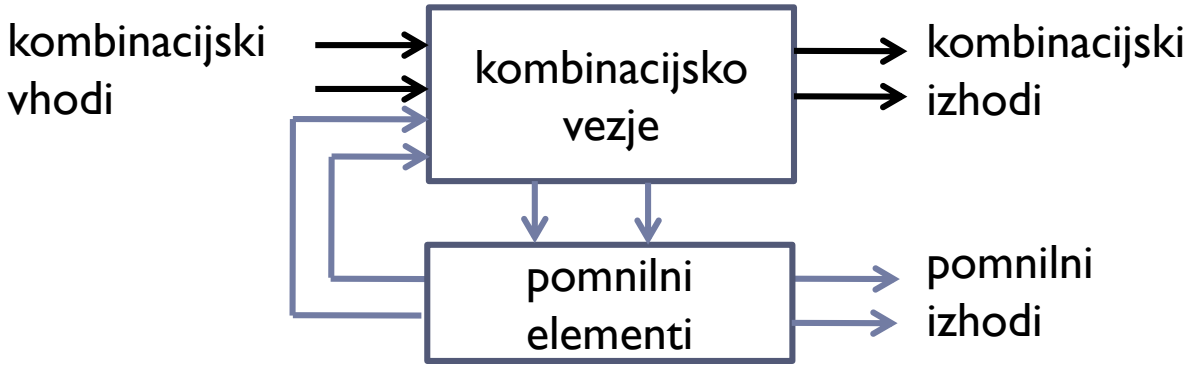
SEKVENČNO VEZJE
- trenutni vhodi
- zgodovina prejšnjih vhodov



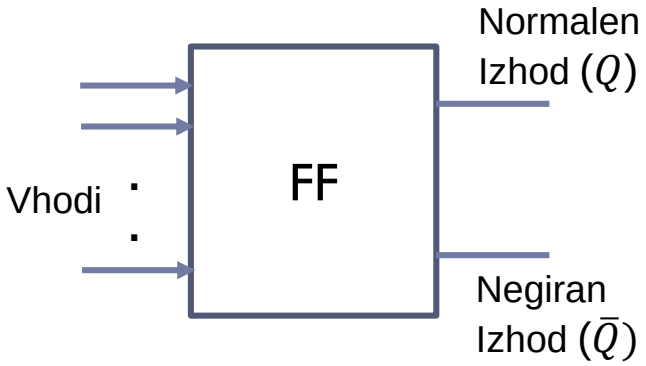


- Kombinacijsko ali odločitveno vezje – določa naslednja stanja in izhode
- Pomnilni elementi – stanja, ki hranijo zgodovino prejšnjih vhodov
- Delovanje:
  - Sinhronska vezja
  - Asinhronska vezja
- Primeri sekvenčnih vezij: števci, registri, krmilniki, semaforji, …

- Splošno sekvenčno vezje

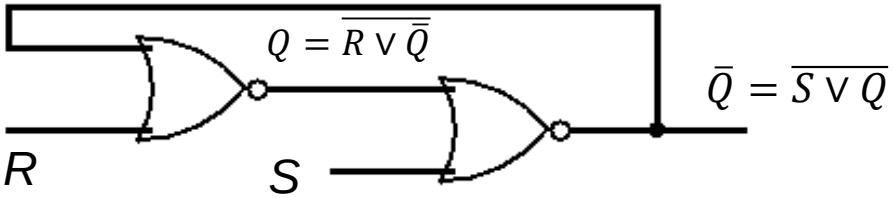


- Pomnilni elementi (flip-flop, krajše FF) – stabilni stanji 0 in 1
- Splošen simbol z definicijo vhodov in izhodov
- Izhodni stanji:
  - $Q = 1, \bar{Q} = 0$ – stanje SET, HIGH ali 1
  - $Q = 0, \bar{Q} = 1$ – stanje RESET, LOW ali 0

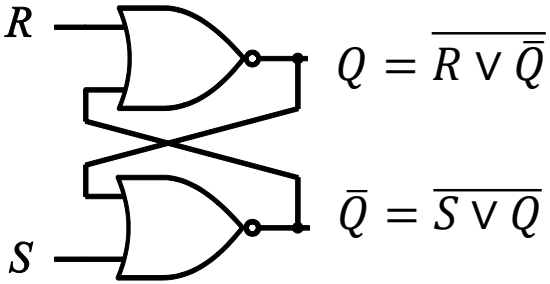


1.1 Pomnilna celica RS (vrata NOR)

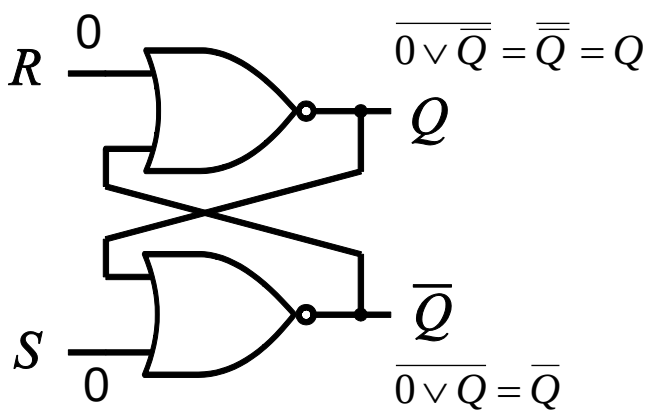
- Pomnilna celica RS je vezje, ki shrani 1 bit informacije.
- Povratna vezava dveh NOR vrat.
- Krmilna vhoda:
  - R (RESET) - izhod Q se postavi na 0 ($Q = 0, \bar{Q} = 1$)
  - S (SET) – izhod Q se postavi na 1 ($Q = 1, \bar{Q} = 0$)
- Izhoda Q in negirani Q (oznaka $\bar{Q}$) se odzivata na trenutne spremembe na krmilnih vhodih R in S.
- Oznake: $Q = Q(t)$ - trenutno stanje in $Q(t+1)$ - naslednje stanje



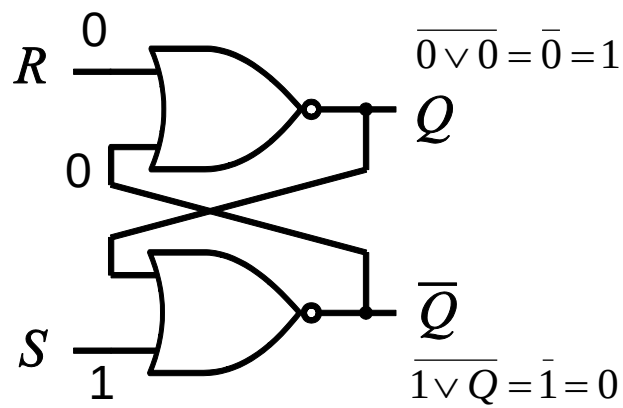
$$Q = \overline{R \vee \bar{Q}} = \overline{R \vee (\overline{Q \vee S})} = \bar{R}.\left(\overline{\overline{Q \vee S}}\right) =$$
$$= \bar{R}.(Q \vee S) = \bar{R}.Q \vee \bar{R}.S$$



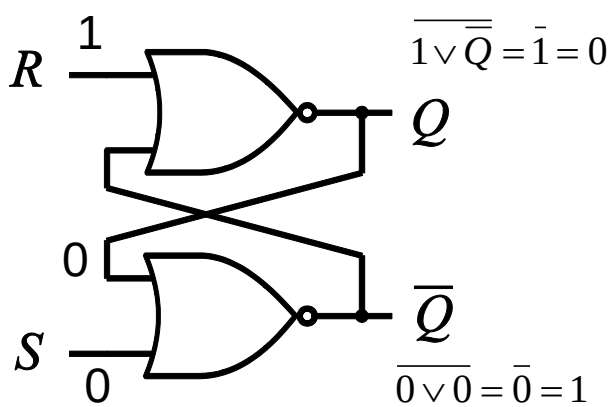
R=0, S=0 → *Q* se ohrani



R=0, S=1 → *Q*=1



R=1, S=0 → Q=0



R	S	*Q*(*t*+1)
0	0	*Q*(*t*) – ni spremembe stanja
0	1	1 (Set)
1	0	0 (Reset)
1	1	x - prepovedano stanje $Q(t+1) = \overline{Q(t+1)} = 0$

Pravilnostna tabela

R	*S*	*Q(t)*	Q (t+1)
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	**0,1 - x**
1	1	1	**0,1 - x**

	$\bar{Q}$	Q
$\bar{R}\,\bar{S}$		1
$\bar{R}\,S$	1	1
$R\,S$	x	x
$R\,\bar{S}$		

$$Q(t+1) = \bar{R}.Q(t) \vee \bar{R}.S$$

prepovedano stanje x = 0

Pomnilna ali karakteristična enačba

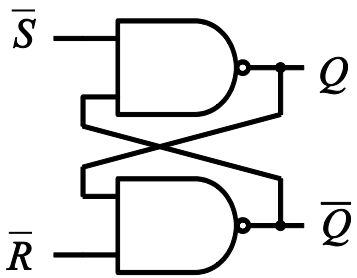
	$\bar{Q}$	Q
$\bar{R}\,\bar{S}$		1
$\bar{R}\,S$	1	1
$R\,S$	x	x
$R\,\bar{S}$		

$$Q(t+1) = S \vee \bar{R}.Q(t)$$

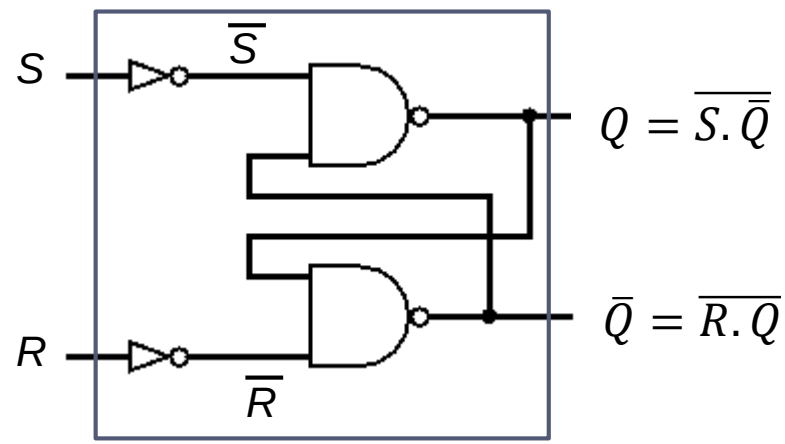
prepovedano stanje x = 1

1.2 Pomnilna celica RS (vrata NAND)

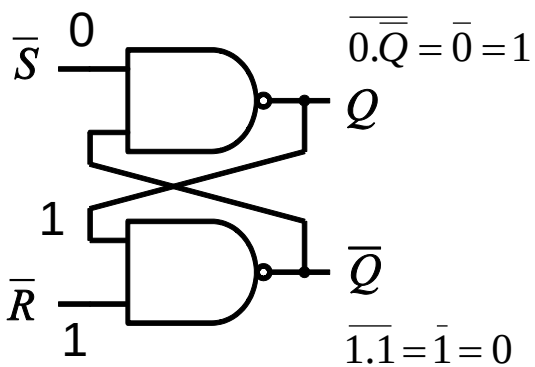
- Pomnilna celica RS je vezje, ki shrani 1 bit informacije.
- Povratna vezava dveh NAND vrat
- Krmilna vhoda SET in RESET sta negirana:
  - $\bar{R}$ - izhod Q se postavi na 0 ($Q = 0, \bar{Q} = 1$)
  - $\bar{S}$ - izhod Q se postavi na 1 ($Q = 1, \bar{Q} = 0$)
- Izhoda Q in negirani Q (oznaka $\bar{Q}$) se odzivata na trenutne spremembe na krmilnih vhodih $\bar{R}$ in $\bar{S}$.
- Oznake: $Q = Q(t)$ - trenutno stanje in $Q(t+1)$ - naslednje stanje
- Na vhodih je dodan negator in dobimo rešitev za vhoda R in S.



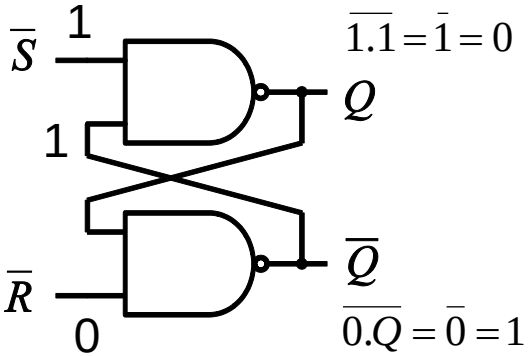
$$Q = \overline{\bar{S}.\bar{Q}} = \overline{\bar{S}.(\overline{Q.\bar{R}})} =$$
$$= \bar{\bar{S}} \vee \left(\overline{Q.\bar{R}}\right)$$
$$= S \vee \bar{R}.Q$$



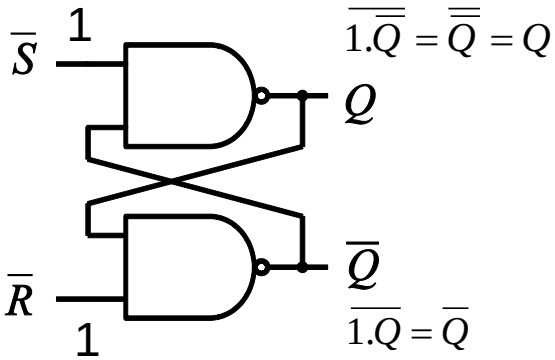
$\bar{S} = 0, \bar{R} = 1 \rightarrow Q = 1$



$\bar{S} = 1, \bar{R} = 0 \rightarrow Q = 0$



$\bar{S} = 1, \bar{R} = 1 \rightarrow Q$ se ohrani



$\bar{R}$	$\bar{S}$	Q(t+1) = Q
0	0	x - prepovedano stanje ($Q = \bar{Q} = 1$)
0	1	0 (Reset)
1	0	1 (Set)
1	1	Q(t) – ni spremembe stanja

Pravilnostna tabela

$\bar{R}$	$\bar{S}$	$Q(t)$	Q (t+1)
0	0	0	0,1-x
0	0	1	0,1-x
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	1

	Q	$\bar{Q}$
$R\,S$	x	x
$R\,\bar{S}$		
$\bar{R}\,\bar{S}$		1
$\bar{R}\,S$	1	1

$$Q(t+1) = \bar{R}.Q(t) \vee \bar{R}.S$$

prepovedano stanje x = 0

Pomnilna ali karakteristična enačba

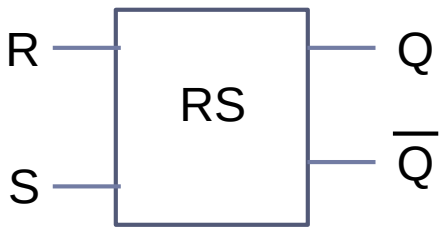
	Q	$\bar{Q}$
$R\,S$	x	x
$R\,\bar{S}$		
$\bar{R}\,\bar{S}$		1
$\bar{R}\,S$	1	1

$$Q(t+1) = S \vee \bar{R}.Q(t)$$

prepovedano stanje x = 1

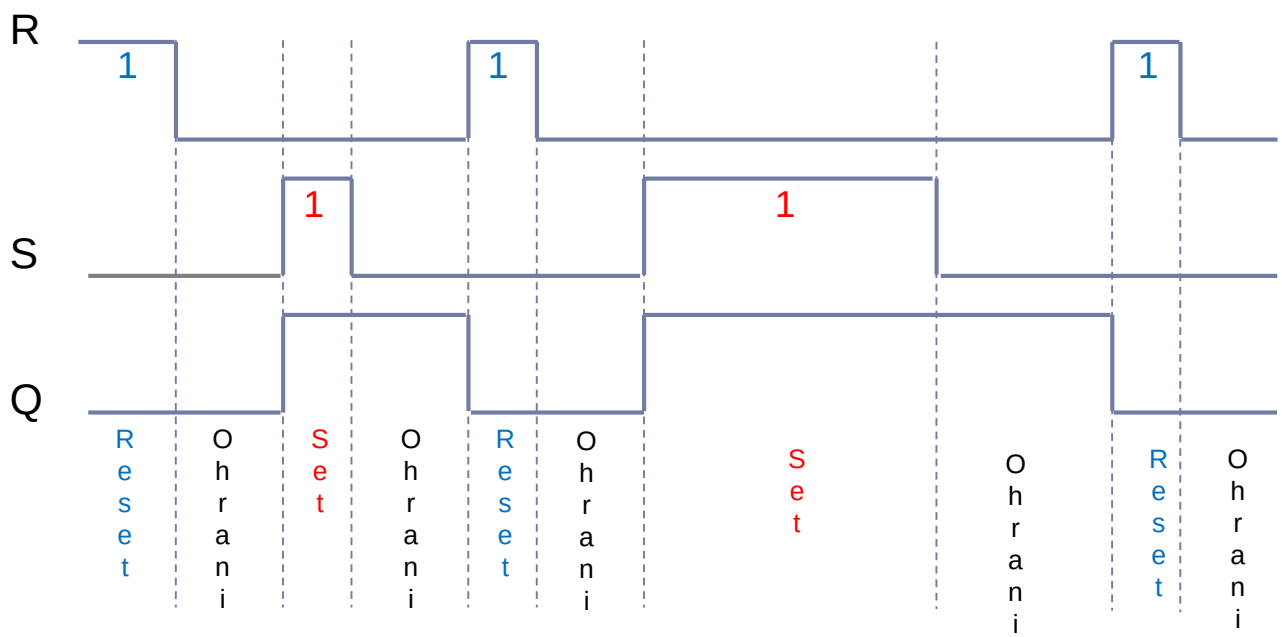
1.3 Pomnilna celica RS – časovni diagram

- Vhoda: R – Reset, S - Set



R	S	Q(t+1)
0	0	Q(t)
0	1	1
1	0	0
1	1	x

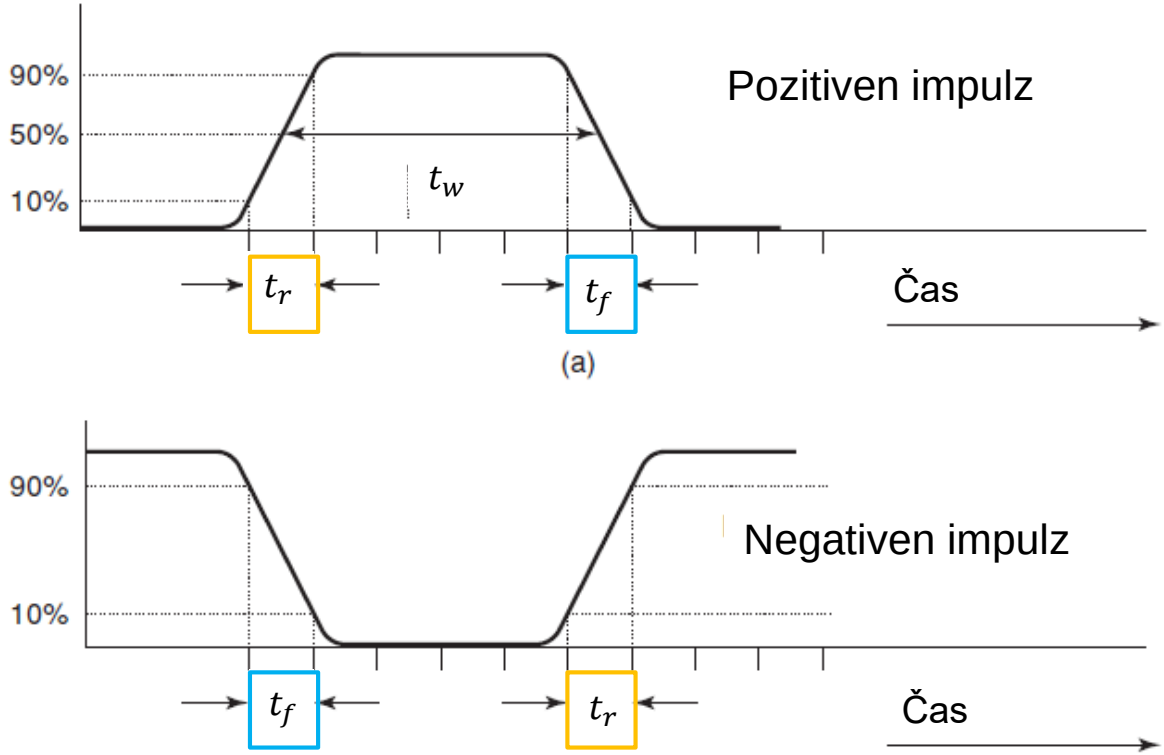
$\bar{R}$	$\bar{S}$	Q(t+1)
0	0	x
0	1	0
1	0	1
1	1	Q(t)



1.4 Digitalni impulzi

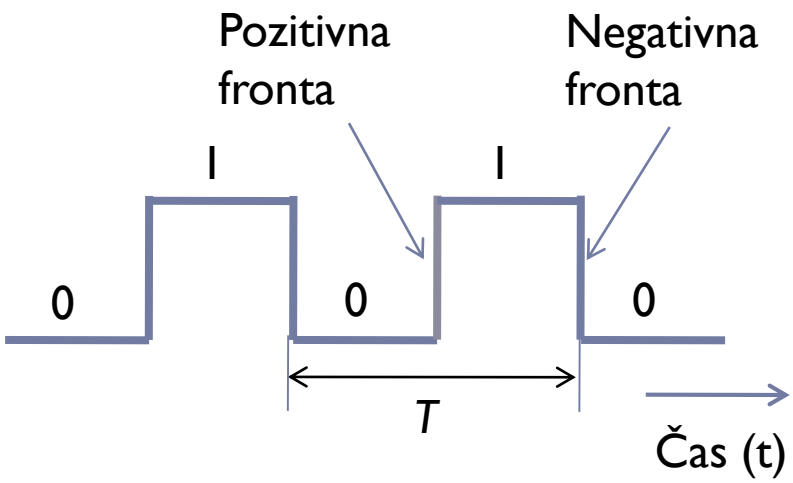
- Preklop signala iz normalnega, neaktivnega v nasprotno, aktivno stanje.
- Signali se imenujejo impulzi (ang. pulses).
- Potrebni časi za spremembo napetosti iz 10% na 90% in iz 90% na 10%.

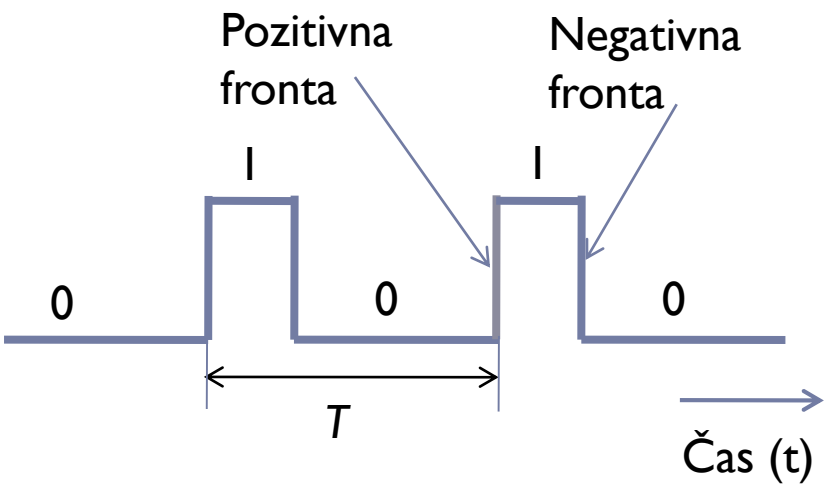
- t_r - čas vzpona (ang. rise time)
- t_f - čas padca (ang. fall time)
- t_w - čas trajanja (ang. width)



1.5 Urin signal

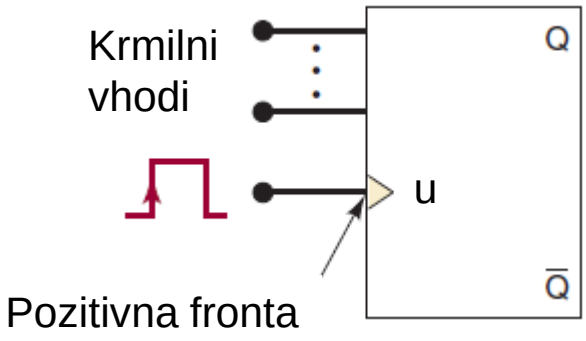
- **Ura** (ang. clock) – signal, ki določa čase v katerih lahko izhod spremeni stanje (ponavljajoče zaporedje ničel in enic v podanem časovnem intervalu, kjer je vsak naslednji impulz enak prejšnjemu).
- Pravokoten impulz ali kvadraten val, kjer je *T* perioda (časovna dolžina med dvema prehodoma iz 0 v 1 ali iz 1 v 0).
  - Pozitivna fronta - prehod iz 0 v 1
  - Negativna fronta - prehod iz 1 v 0

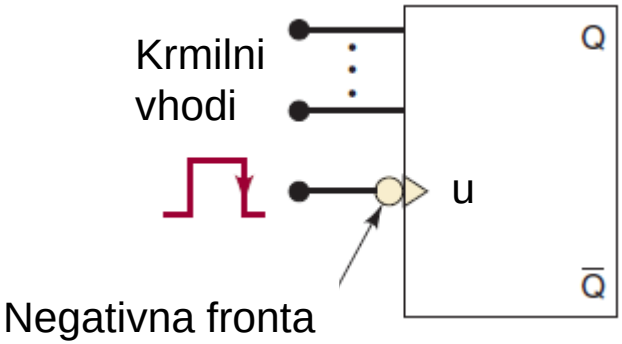




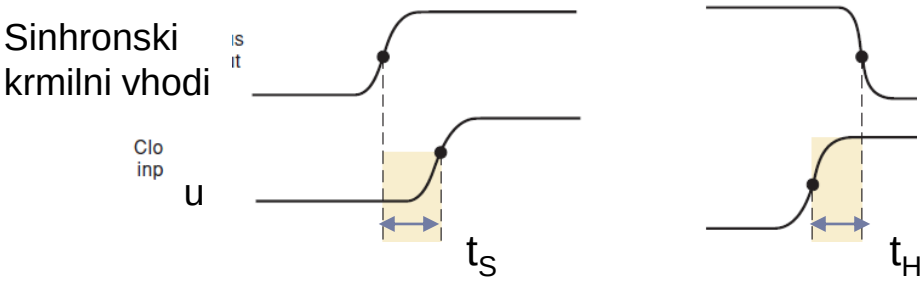
1.6 Sinhronske pomnilne celice

- **Sinhronske pomnilne celice** - na vhodu imajo urin signal (u ali Clk), ki je določen s pozitivno ali negativno fronto.
- Krmilni vhodi nimajo vpliva na izhod Q, dokler se ne pojavi aktivni prehod ure s podano fronto.



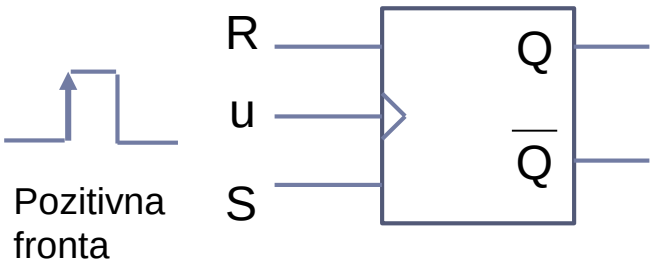


- Zahteve za pravilno delovanje pomnilne celice:
  - t_S - 'Setup time'
  - t_H- 'Hold time'



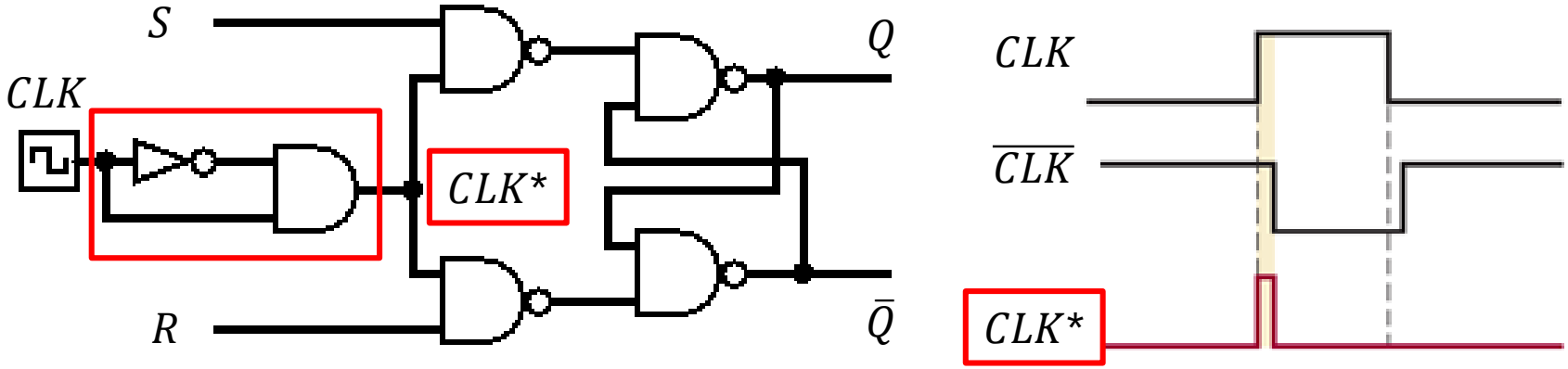
1.6.1 Sinhronska pomnilna celica RS (RS FF)

- Sprememba stanja 0 ali 1 se izvede ob pozitivni fronti ure (u).



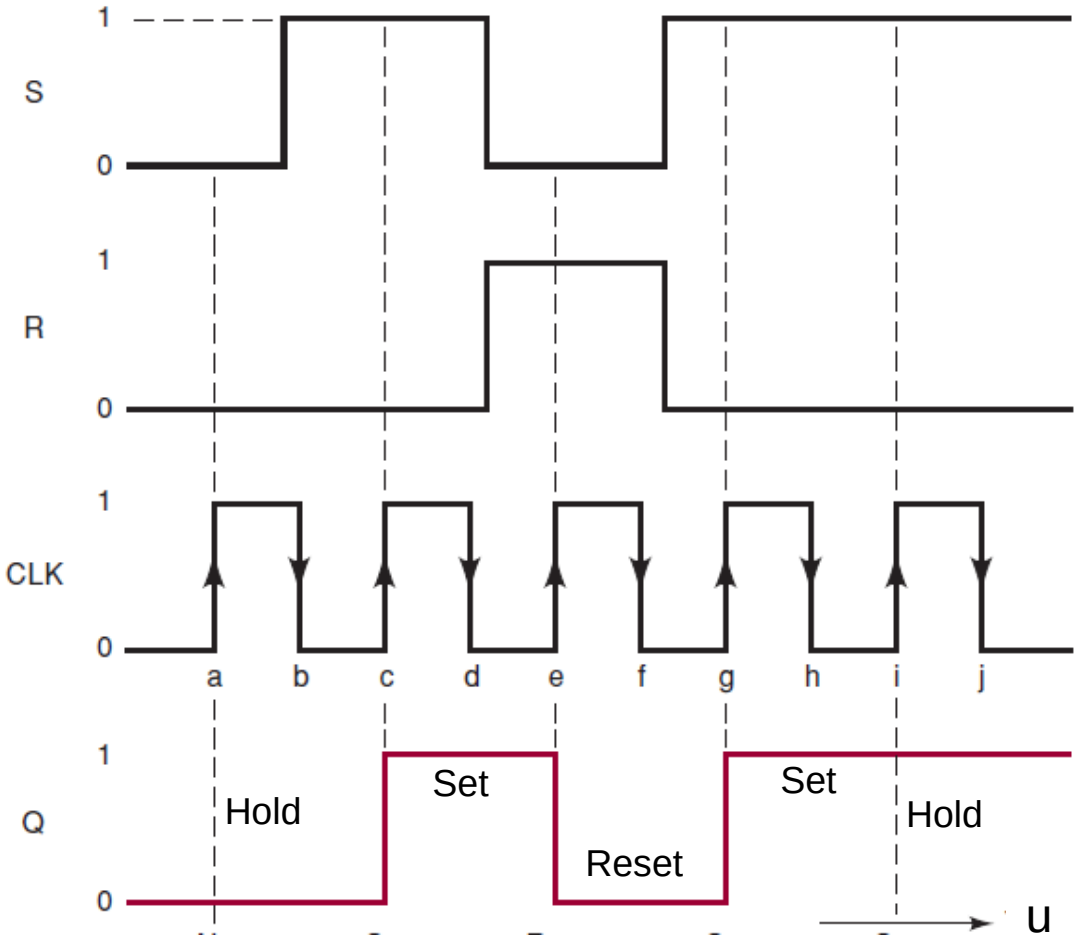
R	S	u	Q(t+1)
0	0	↑	Q(t)
0	1	↑	1
1	0	↑	0
1	1	↑	x

- Delovanje RS FF (Clk = u) in zaznavanje fronte (ang. Edge detector)



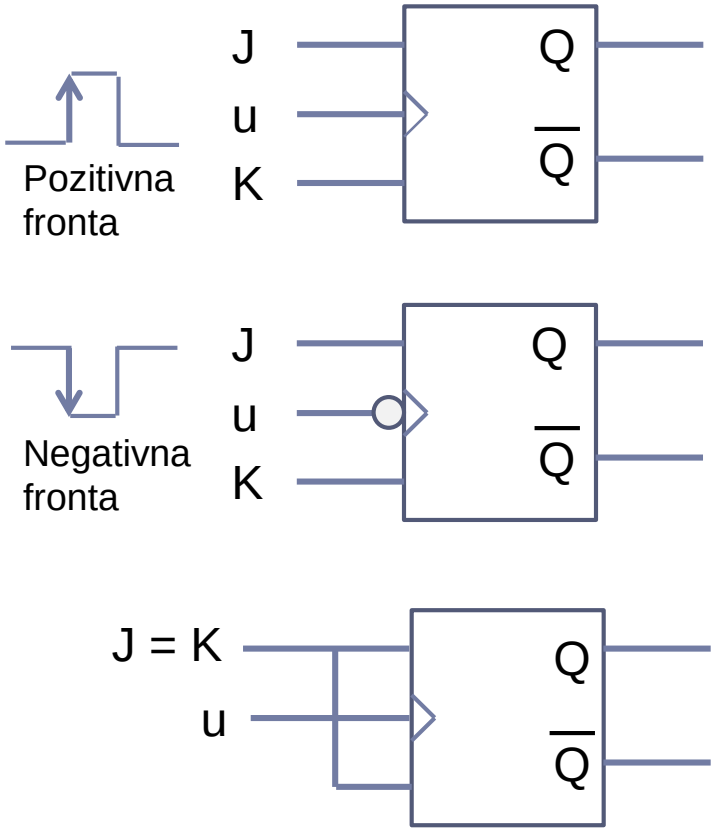
Časovni diagram delovanja sinhronske pomnilne celice RS
(↑ - pozitivna fronta)

- Hold – ohrani stanje
- Set – izhod Q = 1
- Reset – izhod= 0



1.6.2 Sinhronska pomnilna celica JK (JK FF)

- Vhoda J in K imata naslednjo povezavo s pomnilno celico RS:
  - vhod J = 1, K = 0 - SET
  - vhod K = 1, J = 0 - RESET

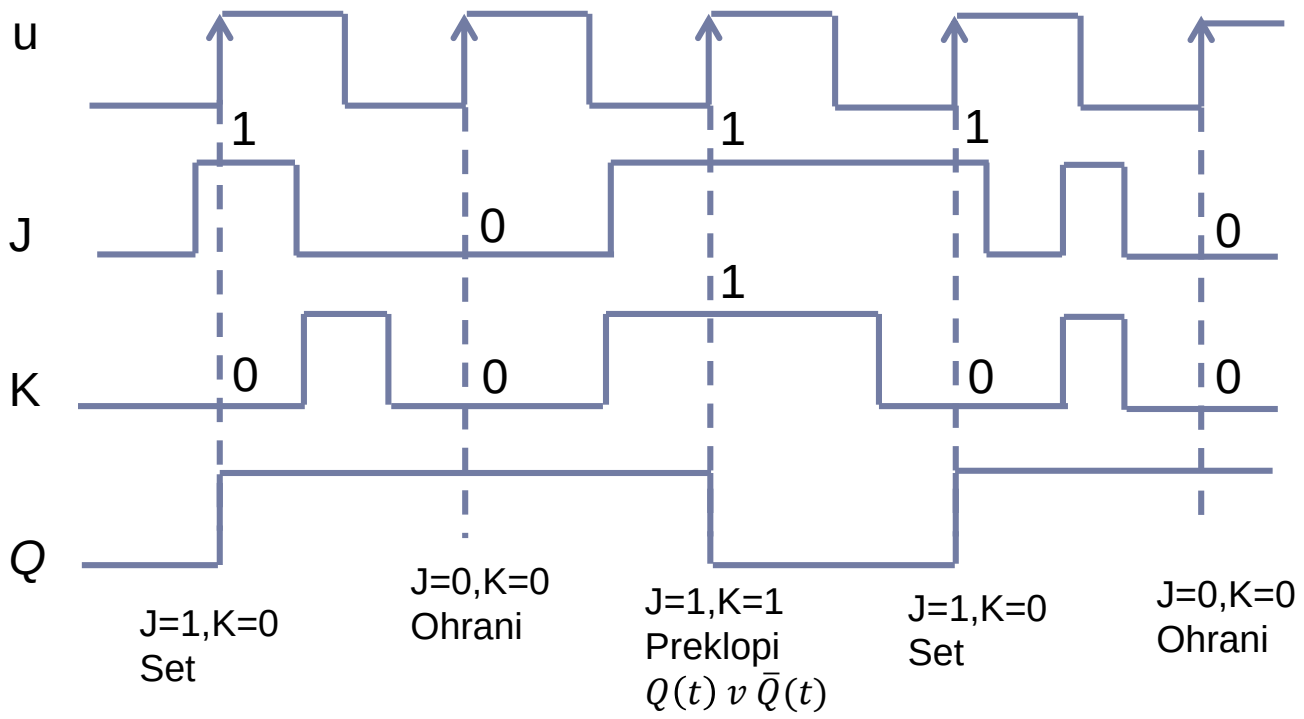


J	K	$Q(t+1)$	$\bar{Q}\ (t+1)$
0	0	$Q(t)$	$\bar{Q}\ (t)$
0	1	0	1
1	0	1	0
1	1	$\bar{Q}\ (t)$	$Q(t)$

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

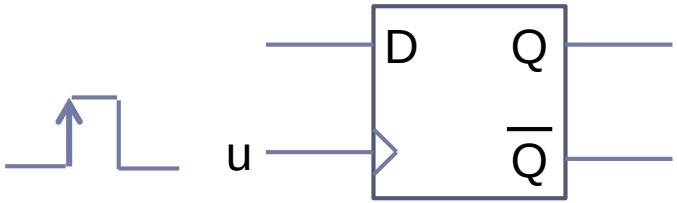
Časovni diagram JK pomnilne celice

- Časovni diagram izhoda Q v odvisnosti od sprememb vhodov J in K in pozitivne fronte urinega signala u (↑).



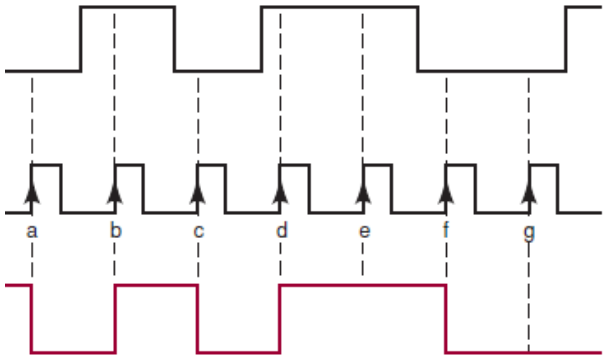
1.6.3 Sinhronska pomnilna celica D (D FF)

- Sinhronska pomnilna celica D s pozitivno fronto urinega signala (u).
- Signal na vhodu D se preslika na izhod (D - delay)



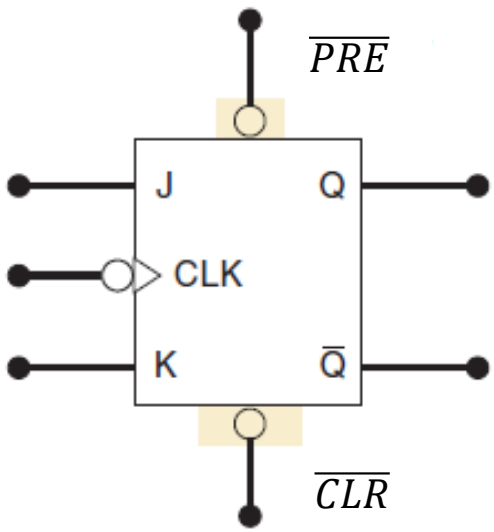
u	D	$Q(t+1)$	$\bar{Q}(t+1)$	Opis
↑	0	0	1	Izhod je enak vhodu (Q(t+1)=D=0)
↑	1	1	0	Izhod je enak vhodu (Q(t+1)=D=1)

- Časovni diagram



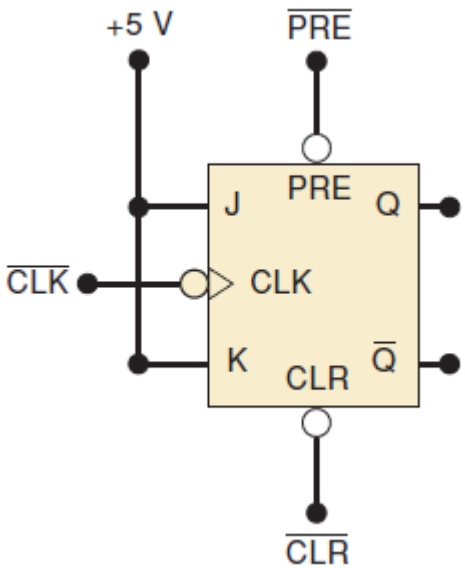
1.7 Asinhronski vhodi pomnilnih celic

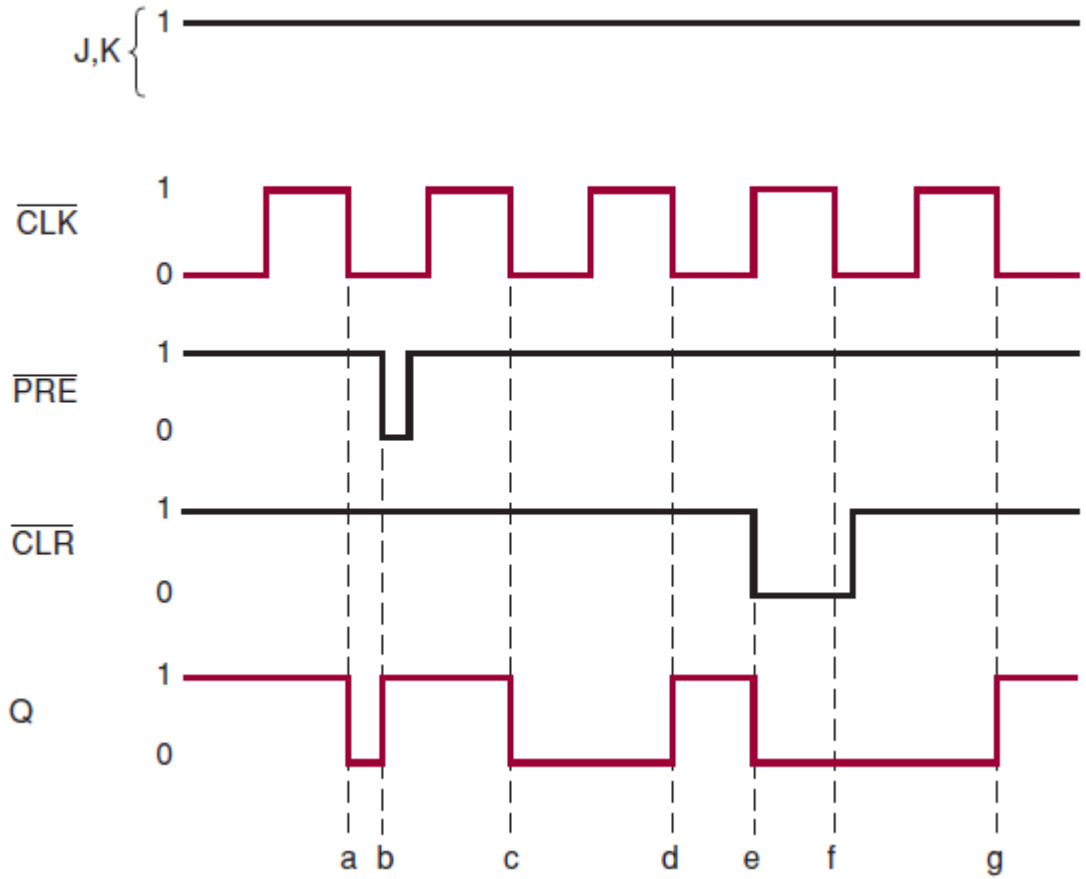
- Vhodni signali, ki delujejo neodvisno od sinhronskih in urinega signala.
- Pomnilna celica JK:
  - Asinhronski SET: Vhod $\overline{\mathrm{PRE}}$ = 0 – izhod je takoj postavljen na 1
  - Asinhronski RESET: Vhod $\overline{\mathrm{CLR}}$ = 0 – izhod je takoj postavljen na 0



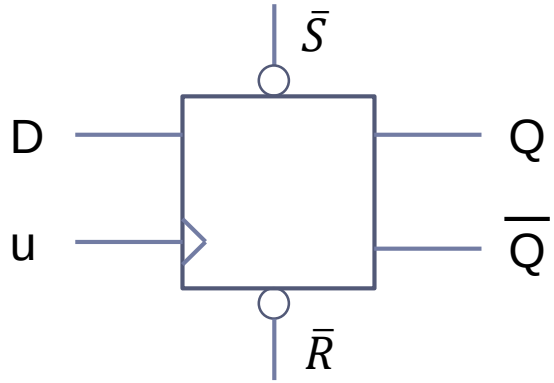
J	K	CLK	$\overline{PRE}$	$\overline{CLR}$	Q(t+1)	
0	0	↓	1	1	$Q(t)$	Sinhronsko delovanje
0	1	↓	1	1	0	
1	0	↓	1	1	1	
1	1	↓	1	1	$\overline{Q(t)}$	
x	x	x	1	1	$Q(t)$	Asinhronsko delovanje
x	x	x	1	0	0	
x	x	x	0	1	1	
x	x	x	0	0	x	

- Časovni diagram za JK in asinhronska vhoda
  - Krmilna vhoda: J = K = 1
  - Negativna fronta ure (↓)
  - $\overline{\mathrm{PRE}}$ = 0 - Q = 1
  - $\overline{\mathrm{CLR}}$ = 0 - Q = 0





- Pomnilna celica D
  - Asinhronski SET: Vhod $\bar{S}$ = 0 – izhod je takoj postavljen na 1
  - Asinhronski RESET: Vhod $\bar{R}$. = 0 – izhod je takoj postavljen na 0



$\bar{S}$	$\bar{R}$	u	D	Q(t+1)	$\bar{Q}$(t+1)	Opis
0	1	x	x	1	0	Set – asinhronsko (S=1)
1	0	x	x	0	1	Reset – asinhronsko (R=1)
0	0	x	x	-	-	Ni uporabljeno
1	1	↑	0	0	1	Izhod je enak vhodu (Q(t+1)=D=0)
1	1	↑	1	1	0	Izhod je enak vhodu (Q(t+1)=D=1)

1.8 Prehajanje stanj pomnilne celice RS

- Sprememba stanj 0 in 1 v odvisnosti od krmilnih vhodov

Karakteristična tabela

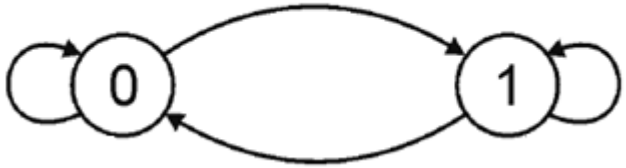
S	R	$Q(t+1)$
0	0	$Q(t)$
0	1	0
1	0	1
1	1	x

? Q(t+1) = 0,
če je Q(t) = 0

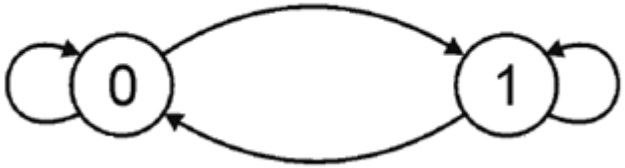
Vzbujevalna tabela

Q(t)	Q(t+1)	S	R
0	0	0,0 0	0,1 x
0	1	1	0
1	0	0	1
1	1	0,1 x	0,0 0

Diagram prehajanja stanj



SR
00
01



- Sprememba stanj 0 in 1 v odvisnosti od krmilnih vhodov

Karakteristična tabela

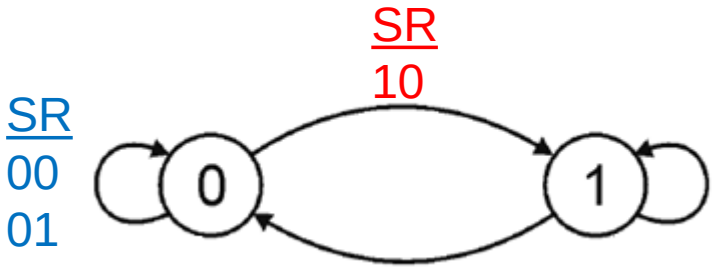
S	R	$Q(t+1)$
0	0	$Q(t)$
0	1	0
1	0	1
1	1	x

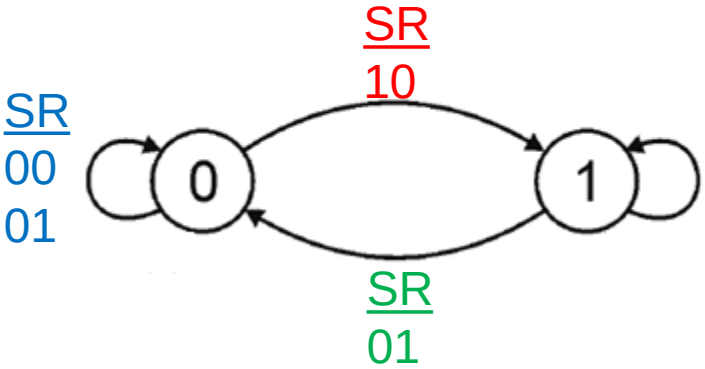
? Q(t+1) = 0,
če je Q(t) = 1

? Q(t+1) = 1,
če je Q(t) = 0

Vzbujevalna tabela

Q(t)	Q(t+1)	S	R
0	0	0,0 0	0,1 x
0	1	1	0
1	0	0	1
1	1	0,1 x	0,0 0





- Sprememba stanj 0 in 1 v odvisnosti od krmilnih vhodov

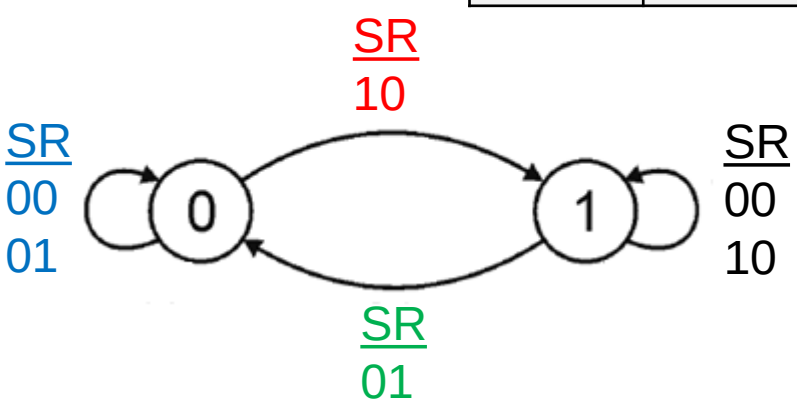
Karakteristična tabela

S	R	$Q(t+1)$
0	0	$Q(t)$
0	1	0
1	0	1
1	1	x

? Q(t+1) = 1,
če je Q(t) = 1

Vzbujevalna tabela

Q(t)	Q(t+1)	S	R
0	0	0,0 0	0,1 x
0	1	1	0
1	0	0	1
1	1	0,1 x	0,0 0



1.9 Prehajanje stanj pomnilne celice JK

- Sprememba stanj 0 in 1 v odvisnosti od krmilnih vhodov J, K

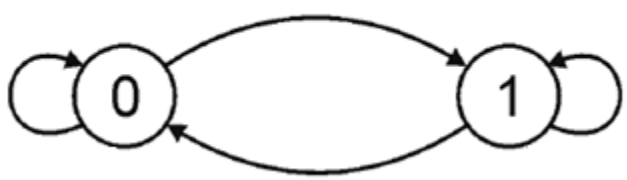
Karakteristična tabela

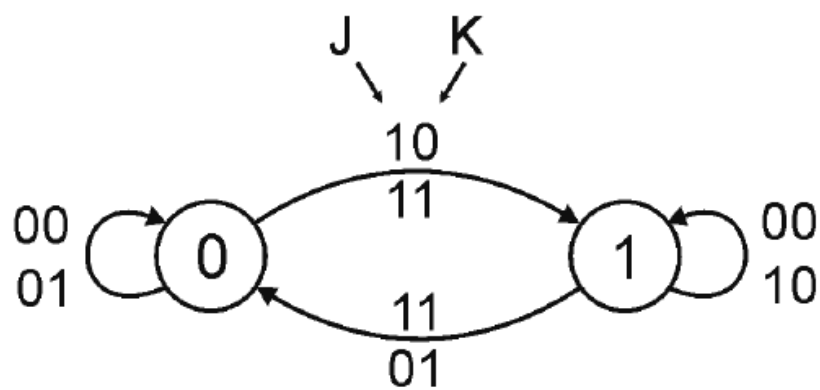
J	K	$Q(t+1)$
0	0	$Q(t)$
0	1	0
1	0	1
1	1	$\bar{Q}(t)$

Vzbujevalna tabela

Q(t)	Q(t+1)	J	K
0	0	0,0 0	0,1 x
0	1	1,1 1	0,1 x
1	0	0,1 x	1,1 1
1	1	0,1 x	0,0 0

Diagram prehajanja stanj





1.10 Pomnilna enačba: RS, JK, D, J=K

RS – Reset, Set

R	S	$Q(t+1)$
0	0	$Q(t)$
0	1	1
1	0	0
1	1	x

$$Q(t+1) = \bar{R}.Q(t) \vee \bar{R}.S$$

JK

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

$$Q(t+1) = \bar{K}.Q(t) \vee J.\overline{Q(t)}$$

D - delay

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

$$Q(t+1) = D$$

J=K (v logisimu je to T pomnilna celica)

J=K (T)	$Q(t+1)$
0	$Q(t)$
1	$\bar{Q}(t)$

$$Q(t+1) = \bar{T}.Q(t) \vee T.\overline{Q(t)}$$

1.11. Vzbujevalna tabela: RS, JK, D, J=K

- Poznamo trenutno stanje (Q(t)) in naslednje stanje (Q(t+1)).
- Določimo vhodne funkcije, ki zagotavljajo prehode stanj iz 0 v 1 ali iz 1 v 0.

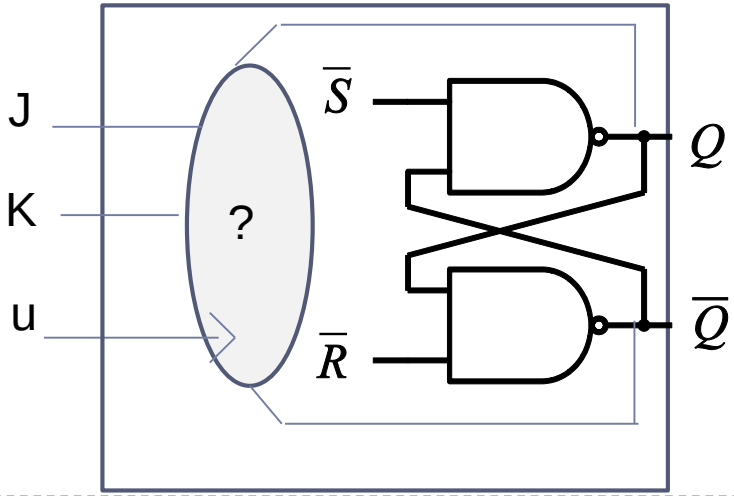
- Za izračun smo uporabili karakteristične tabele pomnilnih celic RS, JK, J=K, D (prejšnja prosojnica) oziroma določanje prehajanja stanj.
- Vzbujevalna tabela za RS, JK, J=K in D

Q(t)	Q(t+1)	R	S		J	K		J=K		D
0	0	X (0,1)	0		0	X (0,1)		0		0
0	1	0	1		1	X (0,1)		1		1
1	0	1	0		X (0,1)	1		1		0
1	1	0	X (0,1)		X (0,1)	0		0		1

Naloga 1: JK pomnilna celica

- Realizirajte sinhronsko JK pomnilno celico, če uporabite povratno vezavo logičnih vrat NAND.
  1. Narišite blok shemo pomnilne celice JK
  2. Zapišite karakteristično tabelo za povratno vezavo z logičnimi vrati NAND $(\bar{R}, \bar{S})$.
  3. Zapišite pravilnostno tabelo za pomnilno celico JK in krmilne funkcije za $\bar{R}$ in $\bar{S}$.
  4. Definirajte MDNO krmilnih vhodov iz vzbujevalne tabele.
  5. Zapišite krmilni funkciji za $\bar{R}$ in $\bar{S}$ z NAND operatorji.
  6. Narišite logično shemo vezja.

1.



2.

$\bar{R}$	$\bar{S}$	Q(t+1)
0	0	x
0	1	0
1	0	1
1	1	Q(t)

Varianta a) z redundancami za ohranjanje stanja (0→0 ($\bar{R} = x, \bar{S} = 1$)

0→0 : $\bar{R} = x, \bar{S} = 1$, 1→1 : $\bar{R} = 1, \bar{S} = x$)

3.

J	K	Q(t)	Q (t+1)	$\bar{R}$	$\bar{S}$
0	0	0	0	x	1
0	0	1	1	1	x
0	1	0	0	x	1
0	1	1	0	0	1
1	0	0	1	1	0
1	0	1	1	1	x
1	1	0	1	1	0
1	1	1	0	0	1

4.,5.

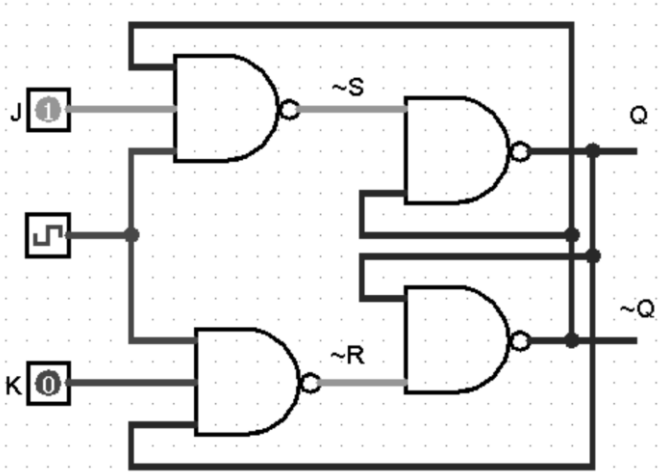
	$\bar{Q}$	Q
$\bar{J}\,\bar{K}$	x	1
$\bar{J}\,K$	x	
$J\,K$	1	
$J\,\bar{K}$	1	1

$$\bar{R} = \bar{K} \vee \overline{Q(t)} = \overline{K.Q(t)} = K \uparrow Q(t)$$

	$\bar{Q}$	Q
$\bar{J}\,\bar{K}$	1	x
$\bar{J}\,K$	1	1
$J\,K$		1
$J\,\bar{K}$		x

$$\bar{S} = \bar{J} \vee Q(t) = \overline{J.\overline{Q(t)}} = J \uparrow \overline{Q(t)}$$

6.



Varianta b) s fiksnimi prehodi za ohranjanje stanja ($\bar{R} = \bar{S} = 1$)

3.

J	K	Q(t)	Q (t+1)	$\bar{R}$	$\bar{S}$
0	0	0	0	1	1
0	0	1	1	1	1
0	1	0	0	1	1
0	1	1	0	0	1
1	0	0	1	1	0
1	0	1	1	1	1
1	1	0	1	1	0
1	1	1	0	0	1

4.,5.

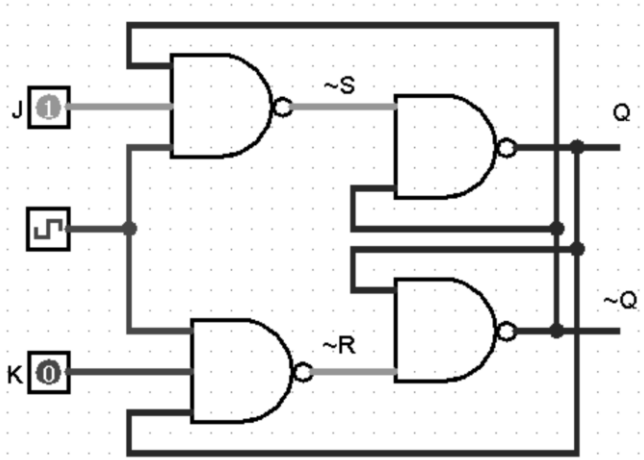
	$\bar{Q}$	Q
$\bar{J}\,\bar{K}$	1	1
$\bar{J}\,K$	1	
$J\,K$	1	
$J\,\bar{K}$	1	1

$$\bar{R} = \bar{K} \vee \overline{Q(t)} = \overline{K.Q(t)} = K \uparrow Q(t)$$

	$\bar{Q}$	Q
$\bar{J}\,\bar{K}$	1	1
$\bar{J}\,K$	1	1
$J\,K$		1
$J\,\bar{K}$		1

$$\bar{S} = \bar{J} \vee Q(t) = \overline{J.\overline{Q(t)}} = J \uparrow \overline{Q(t)}$$

6.

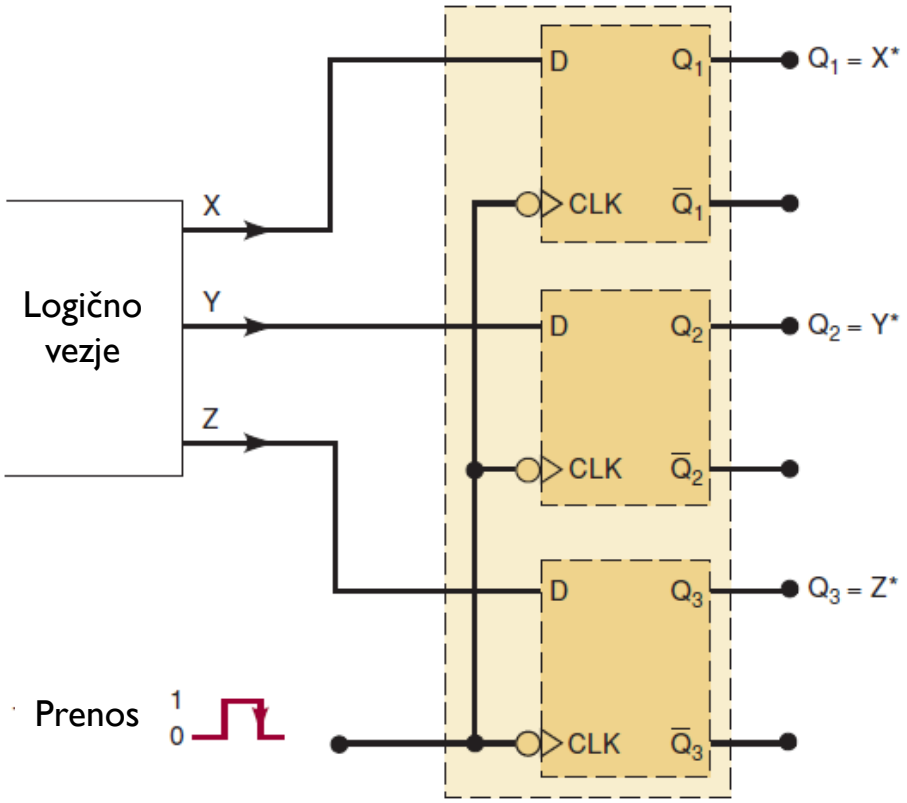


Naloga 2: Uporaba D pomnilnih celic

- Za vzporedni prenos podatkov v binarni obliki uporabimo D pomnilne celice. Vsi trije biti X, Y in Z, ki so izhodi kombinacijskega vezja, se hkrati prenesejo na vodilo.

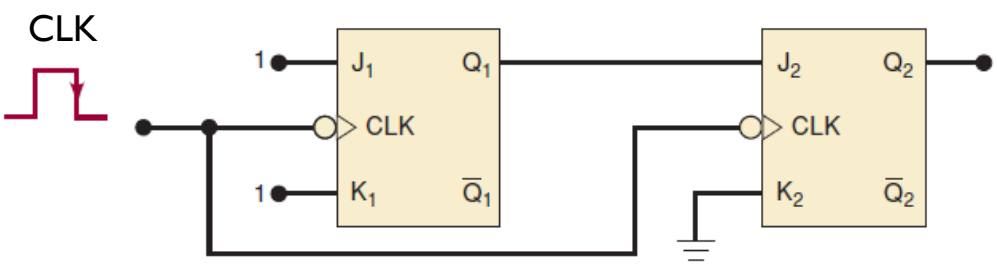
- Urin signal: negativna fronta
- Izhodi pomnilnih celic:

  Q(t+1)= D

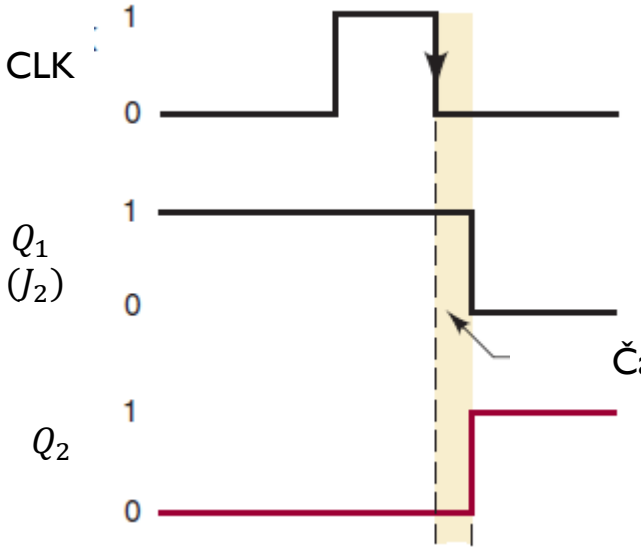


Naloga 3: Uporaba JK pomnilnih celic

- Izhod Q_2 se spremeni v odvisnosti od izhoda Q_1 ob negativni fronti.
- Logično vezje



- Časovni diagram



Čas zakasnitve razširjanja

$J_1 = K_1 = 1$, ob negativni fronti preklopi izhod Q_1 v 1,

$J_2 = 1$, ob negativni fronti preklopi izhod Q_2 v 1,