DIGITALNA LOGIKA

GLAVINIĆ VLADO

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Brojevni sustavi i kodovi

- pohranjivanje brojeva u registrima
  - ograničen broj mjesta
  - $B^n = m$: modul
  - $W = B^n - 1$: najveći n-znamenkasti broj
- komplement broja
  - koristi pretvaranje oduzimanja u zbrajanje
    -> omogućava korištenje istog hardvera za zbrajanje i oduzimanje

Z1) R_1 = 0A7E3FF8

R_2 = 0004FF2A

$R_3 = R_2 - R_1 = ?$

$\bar{R}_{1_A}$ = F581C007

$\bar{R}_{1_B}$ = F581C008

R_3 = 0004FF2A
+ F581C008
F586BF32

- binarno kodiranje/dekodiranje
  - izražavanje simbola/znakova u binarnom obliku
  - prikaz simbola unutar digitalnog sustava
  - zaštita od djelovanja pogrešaka prilikom prijenosa ili pohrane podataka
- prikaz dekadskih znamenki

~ dekadski kodovi (npr. BCD, 2421, Xs-3, bikvinarni)

Z2) 0111 1000 0010 0101
7 8 2 5

N_{10} = 2174
+ 1
$\bar{N}_{10}$ = 2175

2175 = 0010 0001 0111 0101

Zaštitno kodiranje

- otkrivanje i ispravljanje pogrešaka prilikom prijenosa ili pohrane podataka
- kodne riječi se moraju razlikovati u više od 1 bita : $d_{min} > 1$
- mora postojati zalihost (redundancija) R
  - (izvornim kodnim riječima) dodati zaštitne bitove
- otkrivanje pogrešaka ($d_{min} - 1$)
- ispravljanje pogrešaka ($(d_{min} - 1)/2$ kodnih riječi)

Z3) 0 -> 0 000000
1 -> 1 111111

$X = 2 = \{0, 1\}$ -> kodne riječi

$d_{min} = 7 = ?$

$Y = 7 - 1 = 6$ -> otkriva

$Z = Y/X = 6/2 = 3$ -> ispravlja

- paritet (najjednostavniji način zaštite)
  - dodati paritetni bit (VRC)
    -> otkrivanje neparnih pogrešaka
  - višestruko pariranje
- Hammingov kod (n-duljina kodne riječi, k-broj informacijskih bitova, r-broj zaštitnih bitova)
  - $2^r \geq k + r + 1$, $n = k + r$

k	r	n
1	2	3
4	3	7
11	4	15
120	7	127

Z5) $R_p = \frac{1}{7+1} = \frac{1}{8}$ $\quad \frac{R_H}{R_p} = \frac{32}{11} \approx 2.91$

$R_H = \frac{4}{7+4} = \frac{4}{11}$

Osnove digitalne logike

- sve funkcije digitalnog sustava temeljene na malom skupu "osnovnih logičkih funkcija"
- osnovne logičke funkcije na os. log. sklopovima obrađuju "logičke varijable"
  - konstante: T ~ istina(1) ⊥ ~ neistina(0)
  - kombinatori: ne, i, ili
- Boolova algebra
  - dvije osnovne operacije: +, ·
  - skup aksioma
- "operabilni" postulati:
  - neutralni element (P3) -> $a+0=a$; $a\cdot 1=a$
  - komutativnost (P4) $a+b=b+a$; $a\cdot b=b\cdot a$
  - distributivnost (P5) $(a+(b\cdot c))=(a+b)\cdot(a+c)$; $(a\cdot(b+c))=(a\cdot b)+(a\cdot c)$
  - inverzni element (P6) $a+\bar{a}=1$; $a\cdot\bar{a}=0$
- metateorem o dualnosti
- teoremi boolove algebre

T1) $a+1=1$; $a\cdot 0=0$ (dominacija)

T2) $a+a=a$; $a\cdot a=a$

T3) $a=(\bar{\bar{a}})$ (involucija)

T4) $a+\bar{a}\cdot b=a+b$; $a\cdot(\bar{a}+b)=a\cdot b$

T5) $a+a\cdot b=a$;

T6)

T7)

T8)

T9)

Z1) $\overline{X+Y}\neq\bar{X}+\bar{Y}$

Z2)

A	B	A⊕B	$\bar{A}$	$\bar{B}$	$\bar{A}\oplus\bar{B}$
0	0	0	1	1	0
0	1	1	1	0	1
1	0	1	0	1	1
1	1	0	0	0	0

$\bar{A}\oplus B\oplus\bar{C}=(\bar{A}\oplus\bar{C})\oplus B$

$=A\oplus C\oplus B$

$=A\oplus B\oplus C$

- Boolova funkcija je izraz koji sadrži varijable : kombinatore
  - tablica kombinacija (2^n broj redaka)
- Kanonski oblik

A	B	f
0	0	d_0
0	1	d_1
1	0	d_2
1	1	d_3

$f(A,B)=(M_0+d_0)(M_1+d_1)(M_2+d_2)(M_3+d_3)$

-> preko nula (maxtermi)

-> $M_0=A+B$, $M_1=A+\bar{B}$, $M_2=\bar{A}+B$, $M_3=\bar{A}+\bar{B}$

- $f(A,B)=m_0\cdot d_0+m_1 d_1+m_2 d_2+m_3 d_3$

-> preko jedinica (mintermi)

-> $m_0=\bar{A}\bar{B}$, $m_1=\bar{A}B$, $m_2=A\bar{B}$, $m_3=AB$

- $X\oplus Y=\sum m(1,2)$

$=\prod M(0,3)$

P1) $f(A,B,C)=\bar{A}+B\cdot\bar{C}$

$=\bar{A}(\bar{B}+B)\cdot(\bar{C}+C)+(\bar{A}+A)\cdot B\cdot\bar{C}$

$=(\bar{A}\bar{B}+\bar{A}B)(\bar{C}+C)+\bar{A}\cdot B\cdot\bar{C}+AB\bar{C}$

$=\bar{A}\bar{B}\bar{C}+\bar{A}\bar{B}C+\bar{A}B\bar{C}+\bar{A}BC+AB\bar{C}$

$=m_0+m_1+m_2+m_3+m_6$

$=\sum m(0,1,2,3,6)$

Z3) $M_{24}=\underset{1}{A}+\underset{1}{\bar{B}}+\underset{0}{C}+\underset{0}{D}+\underset{0}{E}$

$=\underset{0}{\bar{A}}+\underset{0}{\bar{B}}+\underset{0}{C}+\underset{0}{D}+\underset{0}{E}$

Z4) $f=A\cdot\bar{B}+C(D+\bar{E})$

$\bar{f}=\overline{A\cdot\bar{B}+C(D+\bar{E})}$ $=(\bar{A}+B)\cdot(\bar{C}+\bar{D}\cdot E)$

$=\overline{A\cdot\bar{B}}\cdot\overline{C(D+\bar{E})}$

$=(\bar{A}+B)\cdot(\bar{C}+\overline{D+\bar{E}})$

25) $f(A,B,C,D) = \sum m(1,2,3,11,15)$

$= \prod M(\ldots)$

$= \bar{A}\bar{B}\bar{C}D + \bar{A}B\bar{C}\bar{D} + A\bar{B}\bar{C}D + A\bar{B}CD + ABCD$

$f_D = (\bar{A}+\bar{B}+\bar{C}+D)(\bar{A}+\bar{B}+C+\bar{D})(A+\bar{B}\bar{C}+D)\cdot$

$(A+\bar{B}+C+D)(A+B+C+D)$

$= M_{14} \cdot M_{13} \cdot M_6 \cdot M_4 \cdot M_0$

$= \prod M(0,4,6,13,14)$

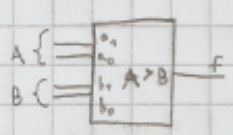
$15+0 = 14+1 = 13+2 = 3+6 = 4+11$

26) f 2 min, 30 max

$\bar{f}$ 30 min, 2 max

27) $f = \sum m(3,5)$

28) $f(a_1, a_0, b_1, b_0)$



A	B	F	$a_1 a_0 b_1 b_0$	
0	0	0	0 0 0 0	
	1	0	0 0 0 1	
	2	0	0 0 1 0	
	3	0	0 0 1 1	
1	0	1	0 1 0 0	m_4
	1	0	0 1 0 1	
	2	0	0 1 1 0	
	3	0	0 1 1 1	
2	0	1	1 0 0 0	m_8
	1	1	1 0 0 1	m_9
	2	0	1 0 1 0	
	3	0	1 0 1 1	
3	0	1	1 1 0 0	m_{12}
	1	1	1 1 0 1	m_{13}
	2	1	1 1 1 0	m_{14}
	3	0	1 1 1 1	

$F = \sum m(4,8,9,12,13,14)$

29) $d_i = \prod M(0,3,5,6)$

30) NI : NILI su dualne funkcije

$\bar{A}B \rightarrow (\overline{A+B})$

- Dualne funkcije su funkcije u kojima se zamijene 0 i 1 te + i ·.
- NI i NILI su univerzalne funkcije

31) $f(A,B,C) = A\cdot(\bar{B}+C)$

$= \overline{\overline{A\cdot(\bar{B}+C)}}$

$= \overline{\bar{A} + \overline{(\bar{B}+C)}}$

$= \overline{\overline{A+A} + \overline{\overline{B+B}+C}}$

$= NILI(NILI(A,A), NILI(NILI(B,B),C))$

32) $f = \bar{A} + B\bar{C}$

$= \overline{\overline{\bar{A} \cdot B\bar{C}}}$

$= \overline{A\overline{B\bar{C}}}$

$= NI(A, NI(B, NI(C,C)))$

Minimizacija booleovih izraza

- Booleova funkcija je opis digitalnog sklopa
  - minimizacijom funkcije pojednostavljuje se sklop
- algebarska minimizacija
  - postupak skraćivanja funkcija primjenom postulata i teorema Booleove algebre
- minimizacija Karnaughovim tablicama

f(A,B)	A=0	A=1
B=0	d_0	d_2
B=1	d_1	d_3

A	B	f
0	0	d_0
0	1	d_1
1	0	d_2
1	1	d_3

$f = d_0 \cdot m_0 + d_1 \cdot m_1 + d_2 \cdot m_2 + d_3 \cdot m_3$

$f = (d_0 + M_0) \cdot (d_1 + M_1) \cdot (d_2 + M_2) \cdot (d_3 + M_3)$

f(A,B,C)

C \ AB	00	01	11	10
0	0	2	6	4
1	1	3	7	5

f(A,B)

B \ A	0	1
0	0	2
1	1	3

- Razlika susjednih polja su potencije broja 2

f(A,B,C,D)

CD \ AB	00	01	11	10
00	0	4	12	8
01	1	5	13	9
11	3	7	15	11
10	2	6	14	10

z1) $z = \overline{(f \oplus 1) \cdot g}$

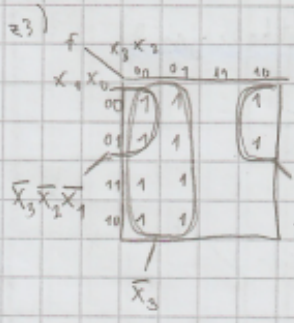
$= \overline{\bar{f} \cdot g}$

$= f + \bar{g}$

$z = \sum m(0,1,3,5,6,8,9,10,12,13,14,15)$

$z = \prod M(2,4,7,11)$

z3) BCD znamenke = {0,...,9}



$\bar{X}_3 \bar{X}_2 \bar{X}_1 \bar{X}_0 + X_3 \bar{X}_2 \bar{X}_1 X_0$

$X_3 \bar{X}_2 \bar{X}_1 (X_0 + \bar{X}_0)$

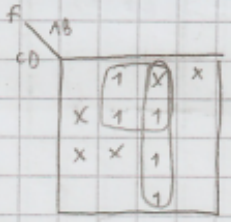
$X_3 \bar{X}_2 \bar{X}_1 + \bar{X}_3 \bar{X}_2 \bar{X}_1$

$\bar{X}_2 \bar{X}_1 (X_3 + \bar{X}_3)$

$\bar{X}_2 \bar{X}_1$

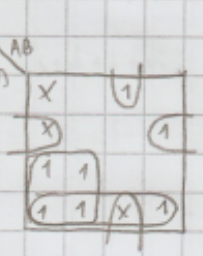
$f = \bar{X}_3 + \bar{X}_2 \cdot \bar{X}_1$

- nepotpuno specificirane tablice
  - polja s X se interpretiraju kao 1 kada to pomaže u formiranju većih zaokruženja, inače se interpretiraju kao 0



$f = \sum m(4,5,13,14,15) + \sum d(1,3,7,8,9)$

z4)



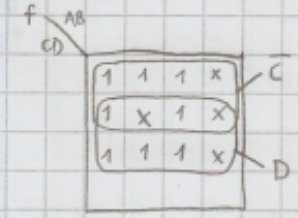
$f(A,B,C,D) = \sum m(2,3,6,7,9,10,12) + \sum d(0,1,14)$

$f = \bar{A}C + C\bar{D} + \bar{B}\bar{C}D + AB\bar{D}$

$= ((\bar{A}C) + (C\bar{D})) + (((\bar{B}\bar{C}) \cdot D) + (AB) \cdot \bar{D}))$

6×I, 3× ILI

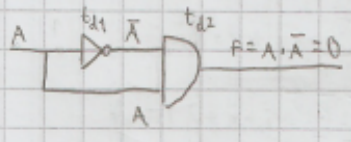
z5) $f(A,B,C,D) = \prod M(2,6,10,14) \cdot \prod d(5,8,9,11)$

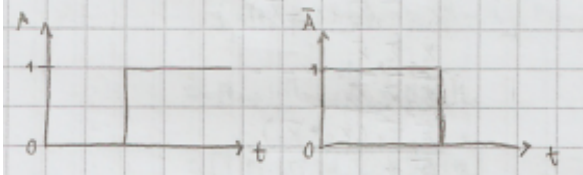


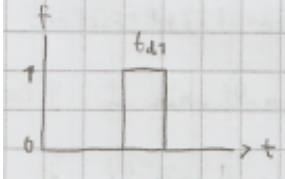
$f = \bar{C} + D$

- vremenski hazard
  - pojava privremenog impulsa prilikom promjene stanja ("prijelazne pojave") izlaza sklopa koji može prouzrokovati njegov pogrešan rad

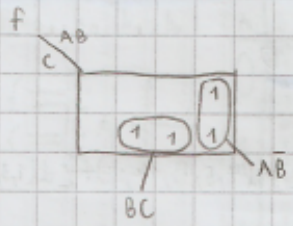
- statički 0-hazard (kratkotrajna 1)
- statički 1-hazard (kratkotrajna 0)



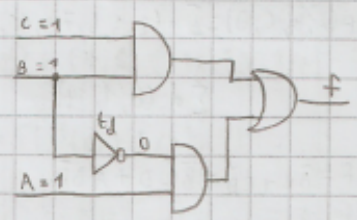




Z6) $f(A,B,C) = \sum m(3,4,5,7)$



$f = A\bar{B} + BC$ $\quad A, C = 1$



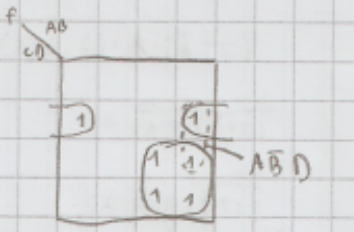
B: 0 -> 1 X

B: 1 -> 0 ✓

$^{AB}_{0}$

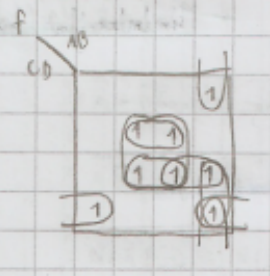
$^{ABC}_{111}$ -> $^{AB\,C}_{10\,7}$

Z7) $f(A,B,C,D) = AC + \bar{B}\bar{C}D$



$f = AC + \bar{B}\bar{C}D \perp A\bar{B}D$

Z8) $f(A,B,C,D) = \sum m(2,5,7,8,10,11,13,15)$



a) $\#_i = \#_m + \#_p + \#_č$

$= 8 + 8 + 1$

$= 17$

b) $\#_{pi} = 1 + 4$

$= 5$

c) $\#_{bpi} = 1 + 2$

$= 3$

Quine - McCluskeyeva metoda

- postupak u 2 faze

1°) Nalaženje potpune sume

2°) Nalaženje minimalne sume

- modifikacije za minimiziranje nepotpune specificiranih funkcija i višeizlaznih funkcija
- manipuliranje indeksima mintermi

P1) $f(A,B,C,D) = \sum m(1,3,4,5,7,8,10,13,14,15)$

①	1✓	①	1,3 (2)✓		①	1,3,5,7 (2,4)✓	$= \bar{A} \cdot b$
	4✓		1,5 (4)✓			1,5,3,7 (4,2)✓	
	8		4,5 (1)		②	5,7,13,15 (1,8)✓	$= \bar{B} D$
②	3✓		8,10 (2)			5,13,7,15 (8,2)✓	
	5✓	②	3,7 (4)				
	10✓		5,7 (2)				
③	7✓		5,13 (8)				
	13✓		10,14 (4)				
	14✓	③	7,15 (8)				
④	15✓		13,15 (2)				
			14,15 (1)				

spajanje susjednih polja

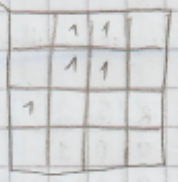
Potpuna suma: $\{4,5(1); 8,10(2); 10,14(4); 14,15(1); 1,3,5,7(2,4); 5,7,13,15(2,8)\} = \{a,b,c,d,e,f\}$

	1	3	4	5	7	8	10	13	14	15
a			✓	✓						
b						✓	✓			
c							✓		✓	
d									✓	✓
e	✓	✓		✓	✓					
f				✓	✓			✓		✓

$f = a + b + e + f + \begin{cases} c \\ d \end{cases}$

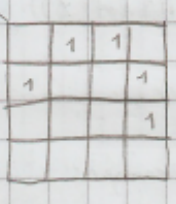
	14
c	✓
d	✓

Zad) f_1



f_2

f_3



- Petrickov postupak
  - u slučaju uvijek dvostrukog prekrivanja minterma
    -> više od 1 kvačice u svakom stupcu
  - minimalna suma = # prekrivanja

Zad) $f = m_{38} + m_{42} + m_{46} + m_{50} + m_{54}$

$f = f(\overset{5}{A}, \overset{4}{B}, \overset{3}{C}, \overset{2}{D}, \overset{1}{E}, \overset{0}{F})$

$38 = 32 + 4 + 2 = \underline{1}0\underline{0}\underline{1}\underline{1}0$ ③

$42 = 32 + 8 + 2 = \underline{1}0\underline{1}0\underline{1}0$ ③

$46 = 32 + 8 + 4 + 2 = \underline{1}0\underline{1}\underline{1}\underline{1}0$ ④

$50 = 32 + 16 + 2 = \underline{1}\underline{1}00\underline{1}0$ ③

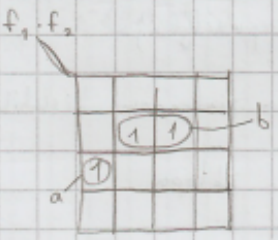
$54 = 32 + 16 + 4 + 2 = \underline{1}\underline{1}0\underline{1}\underline{1}0$ ④

③	38 ✓	38, 46 (8)	a
	42 ✓	38, 54 (16)	b
	50 ✓	42, 46 (4)	c
		50, 54 (4)	d
④	46 ✓		
	54 ✓		

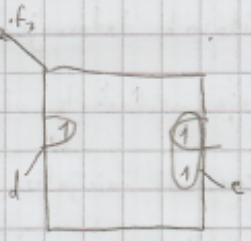
	38	42	46	50	54
a	✓		✓		
b	✓				✓
c		✓	✓		
d				✓	✓

$f = c + d + \begin{cases} a \\ b \end{cases}$

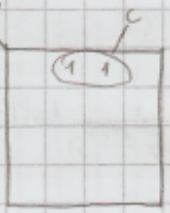
$f_1 \cdot f_2$



$f_2 \cdot f_3$



$f_1 \cdot f_3$



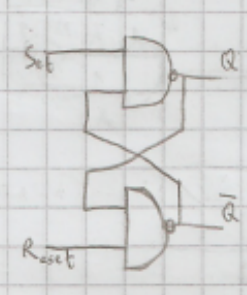
$f_1 = a + b + c$

$f_2 = b + d + e + a$

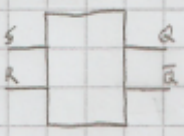
$f_3 = c + e + d$

Bistabili

- memorijski element u jednom od dva stanja



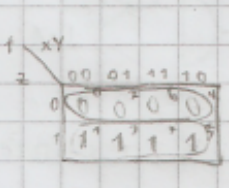
R	S	Q^{n+1}
0	0	Q^n
0	1	1
1	0	0
1	1	X



- prijelazna pojava promjene stanja
  - zaobilazak dodavanjem upravljanja
- dodavanje asinkronih ulaza sinkronom bistabilu
  - tipično radi inicijalizacije sklopa
    -> sve stavi u 0
- tipovi bistabila:
  - SR
  - JK - za 11 mijenja stanje } potpuna tablica
  - T$_{toggle}$ brojila
  - D$_{delay}$ kasni ulazni podatak za 1 impuls CP

1. Domaća zadaća

Z20)



$f(x,y,z) = z$

$= \bar{x}\bar{y}z + \bar{x}yz + x\bar{y}z + xyz$

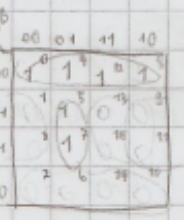
$= \bar{x}z(y+\bar{y}) + xz(y+\bar{y})$

$= \bar{x}z + xz$

$= z(x+\bar{x})$

$= z$

Z19)

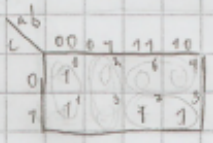


$f(A,B,C,D) = \overline{\bar{C}\bar{D} + \bar{A}BD} = (C+D)\cdot(A+\bar{B}+\bar{D})$ (Z18)

$= \overline{B\bar{D} + A\bar{D} + C\bar{D}} = (\bar{C}+D)(B+\bar{D})(\bar{A}+\bar{D})$

$=$

Z17) $f(a,b,c) = \sum m(0,1,5,7)$



$= \overline{\bar{A}B + A\bar{C}}$

$= (A+\bar{B})(\bar{A}+C)$

Z16) $f(a,b,c) = -11-$

$= \bar{A}\bar{B} + AC$

Z14) AD 31 0D 84$_{(16)}$ = 2 305 673 032$_{(10)}$

− 16 82 6D 33$_{(16)}$ − 377 580 949$_{(10)}$

FE F3 FA 69$_{(16)}$ 2 528 092 143$_{(10)}$

2-komplement

Z13) 1 0000 0000$_{(2)}$

− 1101 0101$_{(2)}$

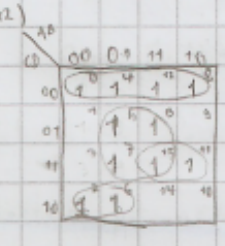
1 0010 1011

1101 0101

0010 1010

0010 1011

Z12)



$f = CD + BD + ACD + \bar{A}C\bar{D}$

$= C(D + AD + \bar{A}\bar{D}) + BD$

$= C(D(A+1) + \bar{A}\bar{D}) + BD$

$= C(D + \bar{A}\bar{D}) + BD$

$= CD + \bar{A}C\bar{D} + BD$

Z11) $f(A,B,C) = (B+\bar{C}) + (((B\cdot C)\cdot C) + (B+\bar{A}))$

$f_D(A,B,C) = (B\bar{C})\cdot(((B+C)+C)\cdot(B\bar{A}))$

Z10) $f =$ (NOT (NOT A OR B) OR B) OR (B OR C)

A OR B = NOR (NOR (A, B))

= (NOT (NOR (NOR (NOT A, B) OR B) OR NOR (NOR (B, C)

= (NOT (NOR (NOR (NOR (NOR (NOT A, B)), B))) OR

NOR (NOR (B, C))

= NOR (NOR (NOT (NOR (NOR (NOR (NOR (NOT A, B)),

, NOR (NOR (B, C)))

f = (NOT (NOR (NOR (NOT A, B))) OR B) OR (NOR (NOR (B, C)))

= (NOR (NOR (NOT (NOR (NOR (NOT A, B))), B))) OR (NOR (NOR (B, C)))

= NOR (NOR (NOR (NOR (NOT (NOR (NOR (NOT A, B))), B))), NOR (NOR (B, C)))

= NOR (NOR (NOR (NOR (NOT (NOR (NOR ((A NOR A), B))), B))), NOR (NOR (B, C)))

= NOR (NOR (NOR (NOR (((NOR (NOR ((A NOR A), B))) NOR (NOR (NOR ((A NOR A), B)))), B))), NOR (NOR (B, C)))

z1) 0010 1101 1110 1111 1111 0001 1101 010

0 1 0 0 1 0 1 1 0 1 1 1 0 1 1 1 1 1 1 0 0 0 1 1 1 0 1 0 1 0

$p_1 = 3$ {0, 0, 0, 1, 0, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 0, 0, 0}

$p_2 = 12$ {0, 1, 0, 10, 10, 11, 11, 11, 1; 1, 00, 1, 1, 10}

$p_4 = 7$ {1 10, 011, 1100, 0101}

$p_8 = 1$ {0111 1111, 01010}

$p_{16} = 2$ {0, 1, 0, 1, 0}

z5) A = 0000 1000 0111 0011 0000 0111

B = 1110 0111 1100 0001 0010 0001

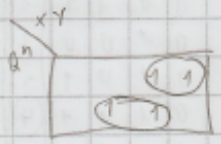
- Bistabili
  - Asinkroni
  - Sinkroni (CP)
    - -> Brid
      - rastući
      - padajući
    - -> Razina
      - visoka
      - niska
- Načini zapisivanja
  - Tablica stanja
  - Jednadžba stanja $Q^{n+1} = f(\text{ulazi}, Q^n)$
  - Uzbudna tablica
  - Dijagram stanja
    - -> čvor = stanje
    - -> strelica = prijelaz

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

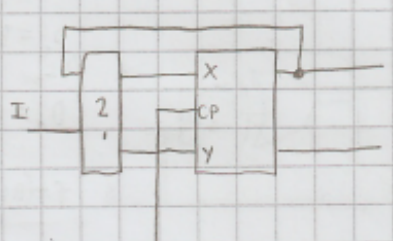
$Q^{n+1} = f(X, Y, Q^n)$

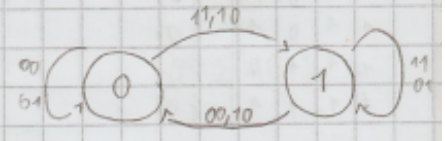
$= \sum m(3, 4, 6, 7)$

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



z4)





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

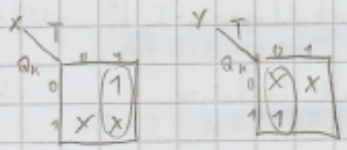
T	Q^n	X	Y
0	0	0	X
0	1	X	1
1	0	1	X
1	1	X	0

$X = \sum m(2) + \sum d(1, 3)$

$= f(T, Q^n)$

$Y = \sum m(1) + \sum d(0, 2)$

$= f(T, Q^n)$

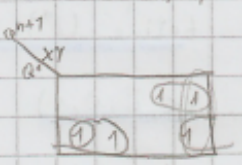


$X = T$ $\quad Y = \overline{T}$

z5) $J = X \cdot \overline{Q^n}$ $\quad K = XY$

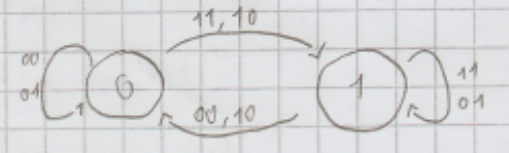
X	Y	Q^n	J	K	Q^{n+1}
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	0	0
0	1	1	0	0	1
1	0	0	1	0	1
1	0	1	0	0	1
1	1	0	1	1	1
1	1	1	0	1	0

$Q^{n+1} = f(X, Y, Q^n) = \sum m(1, 3, 4, 5)$



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

z3)



Standardni kombinacijski moduli

ostvaruju složenije široko korištene funkcije

- dekodiranje i kodiranje

  -> napisanje koda nekoj vrijednosti

  -> n ulaza, 2^n izlaza

  -> potpuno i nepotpuno dekodiranje

  -> dekoderi

  - tipična funkcija: adresiranje

z1)

b_3	b_2	b_1	b_0		$Z = f(b_3, b_2, b_1, b_0)$ $= \sum m(6, 8, 10)$
0	0	0	0		0
0	0	0	1		0
0	0	1	0	0	0
0	0	1	1	1	0
0	1	0	0	2	0
0	1	0	1	3	0
0	1	1	1	4	1
0	1	1	0	5	0
1	0	0	1	6	1
1	0	0	0	7	0
1	0	1	1	8	1
1	0	1	0	9	0
1	1	0	1		0
1	1	0	1		0
1	1	1	0		0
1	1	1	1		0

-> multiplekser

- povezuje različite inpute i outpute

- tipična funkcija: vremenska raspodjela

- ovisno o bočnim ulazima (npr. A_2, B_1, C_0)

  dopušta prolaz inputa (npr. I_0-I_7)

- korištenje trivijalnih funkcija

  -> za pojednostavljenje

  -> koristimo varijable najmanje

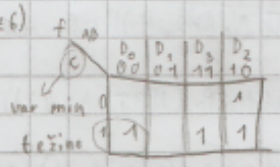
  težine (2^0) koja može biti onda

  ($C, \bar{C}, 0, 1$)

-> prioritetni koder

- pokazuje da se promijenio ulaz

z6)



$D_0 = C$

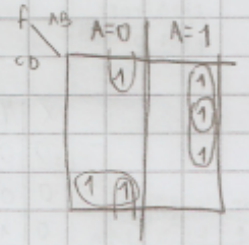
$D_1 = 0$

$D_3 = C$

$D_2 = 1$

b) C, 0, 1, C

z7) $F(A,B,C,D) = \sum m(2,4,6,8,9,11)$



$D_0 = f(B,C,D) = B\bar{D} + C\bar{D} = \bar{D} \cdot (B + C)$

$D_1 = f(B,C,D) = \bar{B}\bar{C} + \bar{B}D = \bar{B}(\bar{C} + D)$

z8) $f(A,B,C)$, 2/1

$D_0 = B + C$

$D_1 = B \oplus C$

$f = \overset{D_0}{(B+C)} \cdot \bar{A} + \overset{D_1}{(B \oplus C)} \cdot A$

$= \bar{A}B + \bar{A}C + A\bar{B}C + AB\bar{C}$

$= \bar{A}B(C + \bar{C}) + \ldots$

$= \sum m(1,2,3,5,6)$

z9) $\bar{A}BE + ABC\bar{D} + D\bar{E}F + \bar{B}\bar{E}$, 4/1

6 varijabli, 4 ulaza za svaka 4 varijable

$a_1 = B$, $a_0 = E$

$d_2 = ?$

$d_1 = 1$

VHDL

1.) Uključivanje biblioteka i paketa

2.) Definicija sučelja sklopa (in & outs)

3.) Definicija arhitekture sklopa

P1) f <= ((A and B) or C) and D;

= (AB + C) · D

- Tip podatka std_logic (9)
  - 0, 1, X (kratki spoj), U (undefined)

- Operatori:
  - not -> A → $\bar{A}$

A	$\bar{A}$
1	0
0	1
U	U

  - and -> A, B → & → A · B

A \ B	0	1	U
0	0	0	0
1	0	1	U
U	0	U	U

  - or -> A, B → ≥1 → A + B

A \ B	0	1	U
0	0	1	U
1	1	1	1
U	1	1	U

N1) $A \cdot \bar{A} \neq 0$

$A \cdot \bar{A} = 0$:(: U

- Komentari (-- bla bla)
- Implicitna lista osjetljivosti:
  - ulazi koji diktiraju vrijeme promjene izlaza
- Ne razlikuje velika i mala slova

Aritmetički sklopovi

- Zbrajala
  - potpuna
  - nepotpuna
- Oduzimala
  - potpuna
  - nepotpuna
- Prijenos (C_{in})
- Operacije se obavljaju bit po bit

24) 0 do 3 -> 1 do 4

4 do 9 -> 6 do 11

$b_3 b_2 b_1 b_0$ ulaz

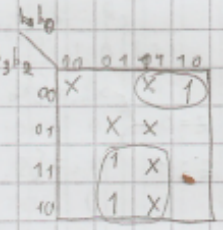
$k_3 k_2 k_1 k_0$ izlaz

$k_2 = ?$

	b_3	b_2	b_1	b_0		k_3	k_2	k_1	k_0
0	0	0	0	1	$\bar{0}$	1	0	1	1
1	0	0	1	0	$\bar{1}$	1	0	1	0
2	0	0	1	1	$\bar{2}$	1	0	0	1
3	0	1	0	0	$\bar{3}$	1	0	0	0
4	0	1	1	0	$\bar{4}$	0	1	1	1
5	0	1	1	1	$\bar{5}$	0	1	1	0
6	1	0	0	0	$\bar{6}$	0	1	0	0
7	1	0	0	1	$\bar{7}$	0	0	1	1
8	1	0	1	0	$\bar{8}$	0	0	1	0
9	1	0	1	1	$\bar{9}$	0	0	0	1

9-komplement

kodirano



$k_2 = \sum_M(6, 7, 8) + \sum d(0, 5, 12, 13, 14, 15)$

$= b_3 \bar{b}_2 \bar{b}_0 + b_2 b_1$

26) $M = 5$

$N = 4$

$M \times N = 20$

27) $01000110010000101_{(2)} >> 5$

$= 0000001000100101$

$= 0219_{(16)}$

28) $Y_3 Y_2 Y_1 Y_0 = ?$

$D_3 D_2 D_1 D_0 = 1 \leftarrow 1 \leftarrow 0 \leftarrow 1$ (2x)

$A_1 A_0 = 1 0 = 2$ pomak kružni

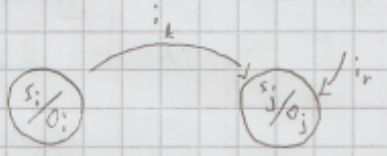
1101 -> 1011 -> 0111

Sekvencijski sklopovi

- unutarnja memorija (registar)
- sinkronizacijom sa CP
- dva klasična kanonska modela
  - Mooreov automat
  - Mealyjev automat

Mooreov automat

- izlaz ovisi samo o unutarnjem stanju



Mealyjev automat

- izlaz ovisi o unutarnjem stanju i ulazu

Z1)

stanje	pobuda	sljedeće stanje	izlaz
S3	0	S2	0
	1	S4	0
S7	0	S2	1
	1	S4	1

- Stanja nisu ekvivalenta jer imaju različite izlaze

Z2) Bistabili: B_0, B_1, B_2

+ Izlazi: $Q_0, Q_1 Q_2$

Izlaz Mooreovog stroja $Z = ?$

Ulaz: X, Y

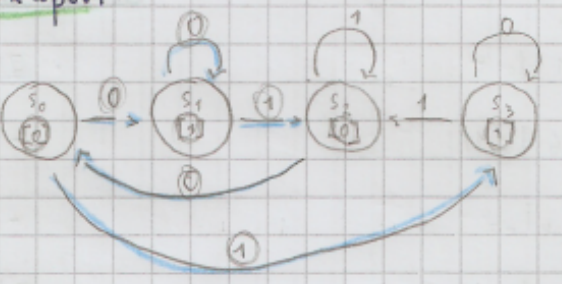
Z može biti: $Q_1 \oplus Q_0 + Q_2$

Z3) Mooreov automat

Početno stanje je S_0

Dovodi se niz na ulaz: 0, 0, 1, 0, 1

Izlaz, stanje = ?



0, 1, 1, 0, 0, 1 S_3

Huffman-Mealyjeva metoda

1. podjela unutarnjih stanja u klase ekvivalentnih stanja
2. podjela na podklase
3. prijelazi se zamjenjuju klasama

Z4) Ekvivalentna stanja = ?

S_1 ; S_3

Q_n	Q_{n+1}		Z_n	
	0	1		
S_0	S_1	S_3	0	→ a = {S_0, S_2} za $Z=0$ → a = {S_0}
S_1	S_1	S_2	1	
S_2	S_0	S_3	0	→ b = {S_1, S_3} za $Z=1$ → c = {S_2}
S_3	S_3	S_2	1	

1. Klasa

Klasa	a				b			
Stanja	S_0		S_2		S_1		S_3	
	0	1	0	1	0	1	0	1
Sljedeća klasa	b	b	a	a	b	a	b	a

2. Klasa

Klasa	a		b				c	
Stanja	S_0		S_1		S_3		S_2	
	0	1	0	1	0	1	0	1
Sljedeća klasa	b	b	b	c	b	c	a	c

Z5) Broj parova ekvivalentnih stanja = ?

$S_1 \equiv S_2$

Broj parova = 1

Ostvarivanje sekv. sklopova

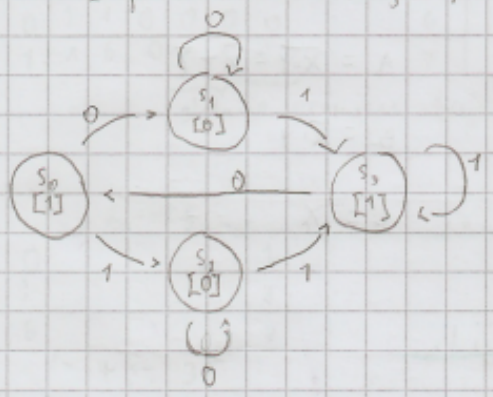
- D, T i JK bistabilima
  - $D_n = B^{n+1}$

Z6) Dva D bistabila

Izlazi bistabila: Q_1 i Q_0

Ulaz stroja: I

Minimalni zapis boolеove funkcije D_1 = ?

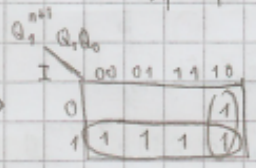


Q^n	Q^{n+1}	
	I=0	I=1
S_0	S_1	S_2
S_1	S_1	S_3
S_2	S_2	S_3
S_3	S_0	S_3

$(Q_1Q_0)^n$	$(Q_1Q_0)^{n+1}$	
	I=0	I=1
00	01	10
01	01	11
10	10	11
11	00	11

$(Q_1Q_0)^n$	Q_1^{n+1}	
	I=0	I=1
00	0	1
01	0	1
10	1	1
11	0	1

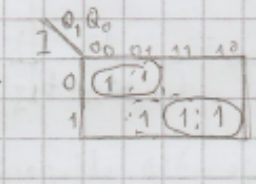
$D_1 = Q_1^{n+1} = Q_1\overline{Q_0} + I$



$(Q_1Q_0)^n$	Q_0^{n+1}	
	I=0	I=1
00	1	0
01	1	1
10	0	1
11	0	1

$D_0 = Q_0^{n+1} = \overline{Q_1}\cdot\overline{I} + Q_1\cdot I + \overline{Q_1}Q_0$

$= \overline{Q_1}\cdot\overline{I} + Q_1\cdot I + Q_0\cdot I$

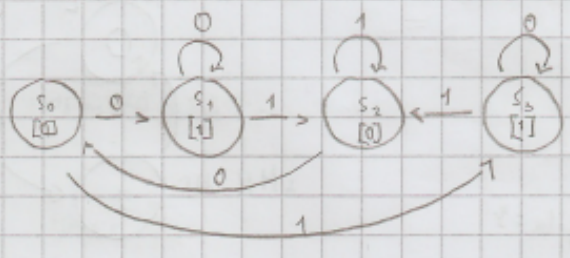


Z7) Dva T bistabila

S: -> :

Ulaz automata: A

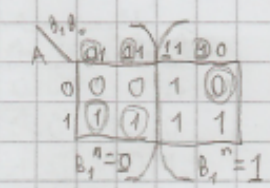
T_1 = ?



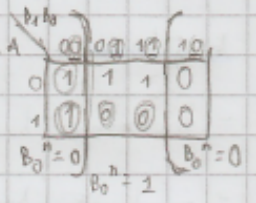
Q_n^n	Q^{n+1}		Z^n
	A=0	A=1	
S_0	S_1	S_3	0
S_1	S_1	S_2	1
S_2	S_0	S_2	0
S_3	S_3	S_2	1

$(B_1B_0)^n$	$(B_1B_0)^{n+1}$		Z^n
	A=0	A=1	
00	01	11	0
01	01	10	1
10	00	10	0
11	11	10	1

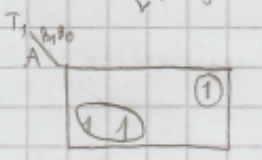
$B_1^{n+1} = f_1(B_1^n, B_0^n, A)$



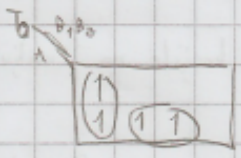
$B_0^{n+1} = f_0(B_1^n, B_0^n, A)$



! promjena stanja



$T_1 = \overline{B_1}\cdot A + B_1\overline{B_0}\cdot\overline{A}$



$T_0 = \overline{B_1}\,\overline{B_0} + B_0A$

Z8) Dva JK bistabila

- postupak isti

Vremenski odnosi:

- max frekvencija rada bistabila (f_{max})
- vrijeme kašnjenja (t_d)
- vrijeme postavljanja (t_{setup})
- vrijeme otpuštanja ($t_{release}$)
- vrijeme pridržavanja (t_{hold})

Z9) $t_{dlo} = 10$ ns

$t_{hold} = 10$ ns

$t_{setup} = 10$ ns

$t_{dh} = 30$ ns

f_{max} = ?

$T_{min} = t_{dh} + t_{dlo} + t_{setup} = 50$ ns

$f_{max} = \frac{1}{T_{min}} = \frac{1}{50_{ns}} = 20$ MHz

- Standardni sekvencijski moduli -

- sadrže kombinacijski sklop i memoriju
- registri
  - registri u užem smislu
  - posmačni regestri
- brojila
  - sinkrona brojila
  - asinkrona brojila
  - brojila na temelju posmačnog registra

Registri

- Registri u užem smislu
  - vreženi skup nepovezanih bistabila
    -> paralelni pristup podatku
- Posmačni registri
  - izlaz prethodnog bistabila spaja se na ulaz slijedećeg
    -> serijski pristup podatku

A	B	S_{in}
0	0	Q_3
0	1	Q_0
1	0	S_{in}
1	1	1

X	Y	posmak	S_{in}
0	0	L	S_{in}
0	1	L	1
1	0	D	S_{in}
1	1	D	Q_3

X	Y	C	S_{in}	A	B
0	0	0	d_2	1	0
0	1	0	d_3	1	1
1	0	1	d_1	1	0
1	1	1	d_0	0	0

$A = \overline{X \cdot Y} = \bar{X} + \bar{Y}$

$B = \bar{X} \cdot Y$

$C = X$

Z1) Multiplekser 4/1

C = 0 -> posmak podatka u lijevo

C = 1 -> posmak podatka u desno

Ulaz uvijek S_{in}/Y

Promjena upravljačkih ulaza u X : Y

XY = 00 -> posmak u lijevo (S_{in})

XY = 01 -> posmak u lijevo (1)

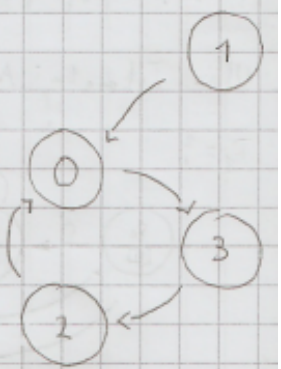
XY = 10 -> posmak u desno (S_{in})

XY = 11 -> posmak u desno (Q_3)

A = ?

Brojila

- Brojila u užem smislu
  - važan je redoslijed izmjene stanju
- Djelitelji frekvencije
  - važno samo odredeno stanje
  - pojednostavljeni dekoder
- Sinkrona brojila (t_{setup})
  - binarna brojila
  - Brojila modula $m \neq 2^n$ (siguran start)
  - Prijenos
    - -> Paralelan $f_{max} = \frac{1}{t_{setup} + t_{dI} + t_{dI}}$
      - Brži, ali više AND sklopova
    - -> Serijski $f_{max} = \frac{1}{t_{setup} + t_{dI} + t_{dI}}$
      - Kaskadiranje AND sklopova
        -> Sporiji, jeftiniji



Z1) Ciklus brojila = 4

$T_2 = Q_1 + Q_0$

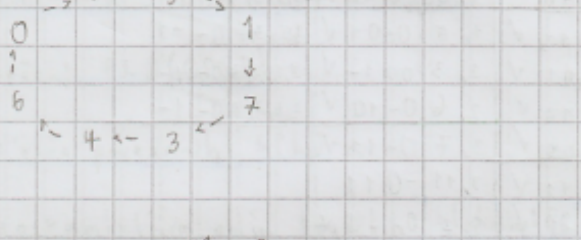
$T_1 = \overline{Q_2} + \overline{Q_0}$

$J_0 = K_0 = T_0 = \overline{Q_2} \cdot Q_1$

Q_2^n	Q_1^n	Q_0^n	T_2	T_1	T_0	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}
0	0	0	0	1	0	0	1	0
0	0	1	1	1	0	1	1	1
0	1	0	1	1	1	1	0	1
0	1	1	1	1	1	1	0	0
1	0	0	0	1	0	1	1	0
1	0	1	1	0	0	0	0	1
1	1	0	1	1	0	0	0	0
1	1	1	1	0	0	0	1	1

gledamo promjene stanja $Q_m \to T_m$

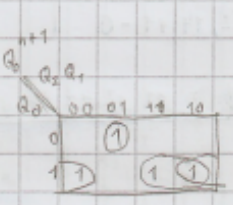
n	n+1
0	2
1	7
2	5
3	4
4	6
5	1
6	0
7	3



23) $B_0 \to D_0$ $\quad Q^{n+1} = D^n$

$D_0 = ?$ $\quad D_0^n = Q_0^{n+1}$

Q_2^n	Q_1^n	Q_0^n	Q_2^{n+1}	Q_1^{n+1}	Q_0^{n+1}
0	0	0	0	1	0
0	0	1	1	1	1
0	1	0	1	0	1
0	1	1	1	0	0
1	0	0	1	1	0
1	0	1	0	0	1
1	1	0	0	0	0
1	1	1	0	1	1



$Q_0^{n+1} = \sum_n(1,2,5,7)$

$= Q_2Q_0 + \overline{Q}_1Q_0 + \overline{Q}_2 \cdot Q_1 \cdot \overline{Q}_0$

24) Serijski prijenos ($n = 5$)

$t_{db} = 20$ ns

$t_{setup} = 15$ ns

$t_{dI} = 5$ ns

$f_{max} = ?$

$$f_{max} = \frac{1}{t_{setup} + t_{db} + (n-2) \cdot t_{dI}}$$

$$= \frac{1}{15\text{ ns} + 20\text{ ns} + 3 \cdot 5\text{ ns}}$$

$$= \frac{1}{50\text{ ns}} = 20\text{ MHz}$$

- brojila na temelju posmačnog registra

-> vrlo brzo, ali vrlo skupo

-> prstenasto brojilo (n stanja)

-> Johnsonovo brojilo (2n stanja)

$$f_{max} = \frac{1}{t_{setup} + t_{db}}$$

-> generator sekvencije

- pseudo random number generators (jako dug niz)

25) Ciklusi: 0, 4, 2, 5, 6, 3, 1 ($17 \neq 2^n$ -> siguran start)

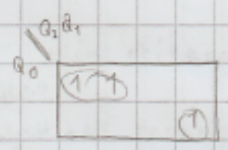
n			n+1		
Q_2	Q_1	Q_0	Q_2	Q_1	Q_0
0	0	0	1	0	0
1	0	0	0	1	0
0	1	0	1	0	1
1	0	1	1	1	0
1	1	0	0	1	1
0	1	1	0	0	1
0	0	1	0	0	0
1	1	1	0	1	1

van

0 :ili: 1,

1 ne može jer $7 \not> 7$

$f(Q_2^n, Q_1^n, Q_0^n) = \sum(0,2,5)$



$f = \overline{Q}_2\overline{Q}_0 + Q_2\overline{Q}_1Q_0$

- Asinkrona brojila (bez t_{setup})

- serijsko okidanje bistabila

- binarna brojila

- brojilo modula m

-> zadnje stanje se prebacuje u $2^n - 1$ (prekoračenje)

-> stanje nakon zadnjeg se prebacuje u 0 (brisanje)

26) 20 stanja

5 bistabila

Prebacivanje $19_{(10)} \to 31_{(10)} \equiv 10011_{(2)} \to 11111_{(2)}$

$S_{in} = Q_4\overline{Q}_3\overline{Q}_2Q_1Q_0 = Q_4Q_1Q_0$

27) 4 bita $\quad t_{100\text{ ns}} = 7_{(10)}$

$t_{db} = 20$ ns

$f_{max} = 10$ MHz

$t = 145$ ns: $? = 0100_{(2)} = 4_{(10)}$

	B_0	B_1	B_2	B_3
	1	1	1	0
20 ns	0			
	-	-	0	-
40 ns			0	
80 ns				0

~ 145 ns

- Programirljivi moduli -

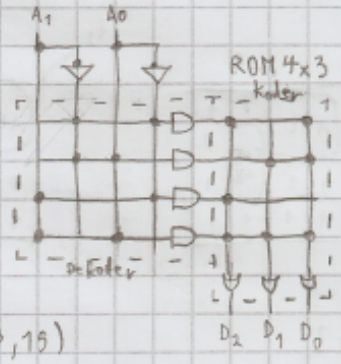
- ostvarivanje složenije funkcije koja nije unaprijed određena (programiranje)
- osnovna struktura je dekoder - koder
- oblici:
  - permanentna memorija: ROM
  - jednostavni PLD (sPLD): PLA, PAL
  - složeni PLD (CPLD)
    -> više povezanih sPLD-a
  - programirljiva polja logičkih blokova: FPGA
    -> vrlo složeni PLD karakteristične strukture

z2) Očitanje {0,1,2,3,3,2,1,0; 0,1,1,3,2,2,1}

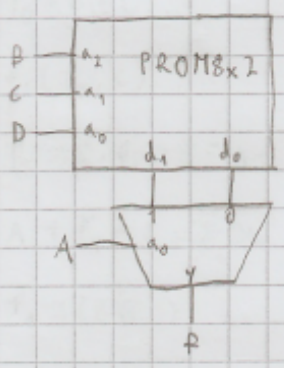
i	i_3	i_2	i_1	i_0	P(i)	n_1	n_0	d_3	d_2	d_1	d_0	Ulaz
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	1	0	1	0	0	1	1	3
2	0	0	1	0	2	1	0	0	1	0	1	5
3	0	0	1	1	3	1	1	1	1	1	1	F
4	0	1	0	0	3	1	1	1	1	1	1	F
5	0	1	0	1	2	1	0	1	1	0	0	C
6	0	1	1	0	1	0	1	1	0	1	0	A
7	0	1	1	1	0	0	0	0	0	0	1	1
8	1	0	0	0	0	0	0					
9	1	0	0	1	1	0	1					
A	1	0	1	0	1	0	1					
B	1	0	1	1	3	1	1					
C	1	1	0	0	3	1	1					
D	1	1	0	1	2	1	0					
E	1	1	1	0	2	1	0					
F	1	1	1	1	1	0	1					

ROM

- dekoder obavlja potpuno binarno dekodiranje
- dekodersko / I polje
- kodersko / ILI polje
- LUT (lookup table)



z1) $f = \Sigma m(0,1,3,5,8,12,13,15)$



8x2 = 16 ✓ (moguće ostvariti funkciju)

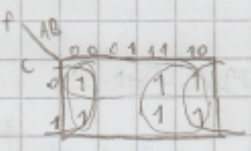
ROM			MUX	
			a0=A	
B	C	D	1	0
a2	a1	a0	d1	d0
0	0	0	1	1
0	0	1	0	1
0	1	0	0	0
0	1	1	0	1
1	0	0	1	0
1	0	1	1	1
1	1	0	0	0
1	1	1	1	0

Očitanje ROM$_a$: 3101 2302

PLA

- veća efikasnost (nepotpuno specificirane funkcije)
- ulazi primarni implikanti (minimizacija)
- proširivanje funkcionalnosti:
  - dodavanje XOR s ulazom za upravljanje

z3) $f = \bar{A}\bar{B}\bar{C} + AC + AB\bar{C} + \bar{A}\bar{B}C + A\bar{B}\bar{C}$



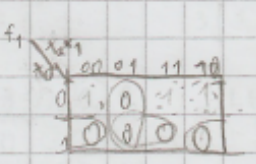
$f = A + \bar{B}$

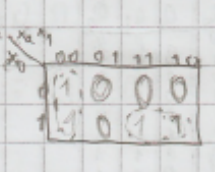
z4) $\bar{f_1} = \overline{x_2 + \bar{x}_1} + \overline{\bar{x}_2 + \bar{x}_0} + \overline{x_1 + \bar{x}_0}$

$\bar{f_2} = \overline{x_2 + \bar{x}_1} + \overline{\bar{x}_2 + x_0}$

$f_1 = (x_2 + \bar{x}_1) \cdot (\bar{x}_2 + \bar{x}_0) * (x_1 + \bar{x}_0)$

$f_2 = (x_2 + \bar{x}_1) \cdot (\bar{x}_2 + x_0)$





$f_1 = x_2 \cdot \bar{x}_0 + \bar{x}_1 \bar{x}_0$ $\quad f_2 = \overline{x_2 x_1} + x_2 x_0$

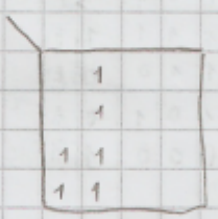
z5) $f = \overline{\overline{A+C} + \overline{\bar{A}+\bar{C}} + \overline{B+C}}$

$f = (\bar{A}+C)(\bar{A}+\bar{C})(B+C)$

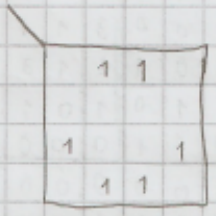
$g = \overline{\overline{\bar{B}+\bar{D}} + \overline{B+C} + \overline{B+D}}$

$g = (\bar{B}+\bar{D})(B+C)(B+D)$

f



g



$f = \bar{A}B + \bar{A}C$ $g = B\bar{D} + \bar{B}CD$

z6) $\bar{f} = \overline{(A+C)} + (\bar{A}+\bar{C})$

$f = (A+C)(\bar{A}+\bar{C})$

$f = A \oplus C$

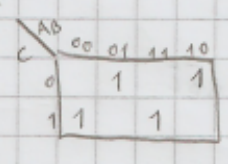
$\bar{f} = \overline{\bar{B}+\bar{f}} + \overline{B+\bar{B}} + \overline{B+f}$

$f = (\bar{B}+\bar{f})(B+f)$

$f = B \oplus f$

$f = A \oplus B \oplus C$ -> šahovska ploča

f



$f(A,B,C) = \sum m(1,2,4,7)$

z7) Ciklus: 0, 4, 2, 5, 6, 7, 3, 1

$Q_2 \rightarrow Q_1 \rightarrow Q_0$ smjer

$S_{in} = ?$

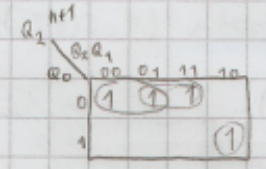
3 varijable ($2^3 = 8$) $3 \times n \times m$

1 izlaz $3 \times n \times 1$

n			n+1		
Q_2	Q_1	Q_0	Q_2	Q_1	Q_0
0	0	0	1	0	0
0	0	1	1	0	0
0	1	0	1	0	1
0	1	1	0	0	1
1	0	0	0	1	0
1	0	1	1	1	0
1	1	0	1	1	1
1	1	1	0	1	1

$Q_2^{n+1} = \sum m(0,2,5,6) = S_{in}$

Q_2^{n+1}



$Q_2^{n+1} = Q_2\bar{Q}_1Q_0 + \bar{Q}_2\bar{Q}_0 + Q_1\bar{Q}_0$

$3 \times 3 \times 1$

• PAL

• poluprogramirljivo logičko polje

- samo dekoder

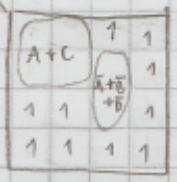
z8) $f_1 = \prod M(0,1,4,5,13,15)$

$f_2 = \prod M(0,1,4,5,7,15)$

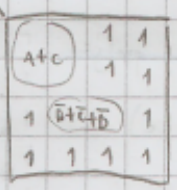
2 funkcije $m \times n \times 2$

4 ulaza $4 \times n \times 2$

f_1



f_2



$4 \times 4 \times 2$

z9) $f = ?$

$f = \overline{\overline{x_2+x_1} + \overline{x_1+x_0}}$

$f = (\bar{x}_2+x_1)(\bar{x}_1+x_0)$

$f = \overline{\overline{x_2+\bar{f}} + \overline{x_1+\bar{x}_1}}$

$f = x_2 + \bar{f}$

$f = x_2 + x_2 \cdot \bar{x}_1 + x_1 \cdot \bar{x}_0$

$f = x_2 \cdot (1+\bar{x}_1) + x_1 \cdot \bar{x}_0$

$f = x_2 + x_1 \cdot \bar{x}_0$

FPGA

- dvodimenzijsko polje logičkih blokova
  - kombinacijsko i sekvencijsko ponašanje

z10) $f = A \cdot (B \oplus C)$

LUT = ?

A	B	C	$B \oplus C$	$A \cdot (B \oplus C)$
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	0	0
1	0	1	1	1
1	1	0	1	1
1	1	1	0	0

LUT = 0, 0, 0, 0, 0, 1, 1, 0

z11) $f_0 = \overline{A \cdot B}$

$f_1 = C \cdot D$

$f = f_0 \oplus f_1$

$f = (\overline{A \cdot B}) \oplus (C \cdot D)$

z12) $f = A + (B \equiv C) = A + (\overline{B \oplus C})$

LUT_1 = ?

$f_0 = B \oplus C$

$f_1(f_0, C)$ = ?

$f_2 = \overline{\bar{A} \cdot f_1} = f = A + \bar{f}_1$

$A + \bar{f}_1 = A + (\overline{B \oplus C})$

$\bar{f}_1 = (\overline{B \oplus C})$

$f_1 = B \oplus C = f_0$

a_1	a_0	Y
0	0	0
0	1	0
1	0	1
1	1	1

$LUT_1 = 0, 0, 1, 1$

z13) $X_2 = A$

$X_1 = B$

$X_0 = f$

$Q^{n+1} = \bar{A} \cdot \bar{Q}_n + B$

LUT = ?

$X_0 = Q$

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

$D = Q^{n+1} = f(A, B, Q^n)$

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

x_2 A	x_1 B	x_0 Q_n	Q^{n+1}	Z
0	0	0	1	I_0
0	0	1	0	I_1
0	1	0	1	I_2
0	1	1	1	I_3
1	0	0	0	I_4
1	0	1	0	I_5
1	1	0	1	I_6
1	1	1	1	I_7

z14) $Q^{n+1} = Q_n \cdot B + A\bar{B}$

LUT_1, S = ?

S = 1 da sklop bude sekvencijski

a_2 A	a_1 B	a_0 Q^n	Q^{n+1}	Z
0	0	0	0	d_0
0	0	1	0	d_1
0	1	0	0	d_2
0	1	1	1	d_3
1	0	0	1	d_4
1	0	1	1	d_5
1	1	0	0	d_6
1	1	1	1	d_7

LUT = 0, 0, 0, 1, 1, 1, 0, 1

z15) Ciklički slijed: 3, 7, 2, 1

S = 0 -> sklop je kombinacijski

S = 1 -> sklop je sekvencijski

LUT_4 = ?

$B_1 = a_1 \quad B_2 = a_0$

$B_1^{n+1} = B_1 \oplus B_2$

$B_2^{n+1} = \bar{B}_2$

	n		n+1		
	B_1	B_2	B_1	B_2	
0	0	0	0	1	1
1	0	1	1	0	2
2	1	0	1	1	3
3	1	1	0	0	0

	B_1	B_2	Q_2	Q_1	Q_0
0	0	0	0	1	1
1	0	1	1	1	1
2	1	0	0	1	0
3	1	1	0	0	1

$LUT_4 = 1, 1, 1, 0$

Sučelje s analognom okolinom

- upravljanje prikupljanjem podataka iz stvarnog svijeta (senzori) - ADC
- vraćanje rezultata u stvarni svijet putem aktuatora - DAC
- ulaz: pretvorba (analognog) napona u broj (ADC)
- izlaz: pretvorba broja u (analogni) napon
- parametri pretvorbe
  - rezolucija: $\frac{U_k}{U_M} = \frac{1}{n_M} = \frac{1}{2^k - 1}$
  - točnost (granica pogreške): $\varepsilon = \frac{\Delta U}{U_M}$, $\varepsilon_d \frac{\Delta U_k}{U_k}$
  - pogreška kvantizacije: $\varepsilon_k = \pm \frac{U_k}{2}$
  - vrijeme pretvorbe

z1) 4-bitni D/A

$R_1 = 8\,k\Omega \rightarrow R_2 = 4\,k\Omega, R_4 = 2\,k\Omega, R_8 = 1\,k\Omega$

$4_{10} = 0100_2$ je $R_{ekv} = R_4$

$\frac{U_{REF}}{R_{ekv}} = -\frac{U_{izl}}{R_f}$

$U_{izl} = -U_{REF} \cdot \frac{R_f}{R_{ekv}}$

$U_{izl} = -5 \cdot \frac{4}{2} = -10\,V$

z2) $\frac{CP}{2} = 500\,\mu s \rightarrow T = 1\,ms$

$t = 2.2\,ms = 2200\,\mu s$

$R = 1\,k\Omega$

$R_f = 2\,k\Omega$

$0 \rightarrow 0V$, $1 \rightarrow +5V$

$U_{izl} = -U_{REF} \cdot \frac{R_f}{R_1} = -5 \cdot \frac{2}{8 \cdot 1} = -1.25\,V$

$V_{t=501\,\mu m} = -1.25\,V$

$V_{t=1501\,\mu m} = -2.5\,V$ ——— $> 2200\,\mu m$

$V_{t=2501\,\mu m} = -3.75\,V$

$U_{izl} = -2.5\,V$

z3) 6-bitni DAC za kod 222111

$U_{REF} = 5V$

$U_{izl_4} = ?$

$U_{izl_7} = -10V$

$I_N = -\frac{U_{REF}}{R_{ekv}} = -\frac{U_{izl}}{R_f}$

$R_f = -R_{ekv} \cdot \frac{U_{izl}}{U_{REF}}$

"7" = 111001 $\rightarrow \frac{1}{R_{ekv_7}} = 3 \cdot \frac{1}{1k\Omega} + \frac{1}{2k\Omega} = \frac{7}{2}\,k\Omega$

$R_{ekv_7} = \frac{2}{7}\,k\Omega$

$R_f = \frac{2}{7} \cdot \frac{10}{5} = \frac{4}{7}\,k\Omega = 571\,\Omega$

"4" = 011000 $\rightarrow R_{ekv_4} = 0.5\,k\Omega$

$U_{izl_4} = -U_{REF} \cdot \frac{R_f}{R_{ekv_4}} = -5 \cdot \frac{4}{7} \cdot 2 = -\frac{40}{7} = -5.71V$

z4) 14 bitova $\rightarrow$ 13 bitova

2 puta manja rezolucija

2 puta veća pogreška (za 100%)

— Implementacija log. sklopova

- CMOS tehnologija - današnji izbor
- problemi elek. prikaza log. vrijednosti:
  - smetnje
  - opterećenje
  - međuovisnost disipacije snage i brzine
- implementacija
  - osnovne funkcije (I ; ILI)
  - komplementiranje (NE)
  - funkcije NI ; NILI
    - -> kombinacija invertora i osnovnih funkcija
    - -> direktno povezivanje tranzistora (MOSFET)
- vrste logike
  - pozitivna (1 ~ V, 0 ~ N)
  - negativna (0 ~ V, 1 ~ N)

z1)

A	B	f
-2V	-2V	-4V
-2V	-4V	-4V
-4V	-2V	-4V
-4V	-4V	-2V

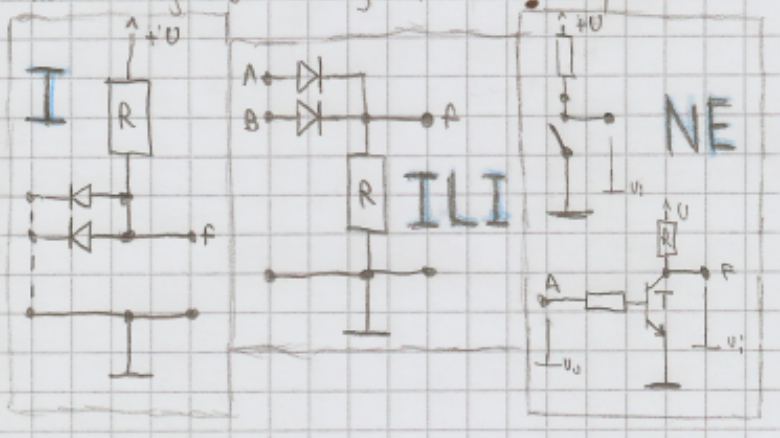
f = ? negativna logika

-2V ~ 0, -4 ~ 1

A	B	f
0	0	1
0	1	1
1	0	1
1	1	0

f = NI

- Osnovne logičke funkcije (i invertor (prikaz)



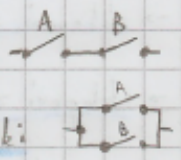
z2) $\overline{A+B} \cdot C = f$

$f = \bar{A} \cdot \bar{B} \cdot C$

$= m_1$

$= \prod (0,2,3,4,5,6,7)$

- funkcije NI ; NILI
  - NI - serijski spoj sklopki:
  - NILI -> paralelan spoj sklopki:



CMOS tehnologija

- kombinacija NMOS ; PMOS tranzistora
  - NMOS vodi na visoku razinu
  - PMOS vodi na nisku razinu
  - invertor -> kombinacija NMOS ; PMOS

Memorijski moduli

- memorija
  - digitalni (pod)sustav za pamćenje većeg broja podataka
  - „građa":
    - -> memorijsko polje (skup ćelija)
    - -> sklopovi za pristup (dekoder)
    - -> sklopovi za čitanje i pisanje
      - pristup: serijski i paralelno

Z1) Nakon 26 impulsa CP, upis $0110\,1001$

$F3\ 47\ 35\ 01_{16} = 1111\,0011\ 0100\,0111\ 0011\,0101\ 0000\,0001_2$ (26)

$A7\ 47\ 35\ 01_{16} = 1010\,0111\ 0100\,0111\ 0011\,0101\ 0000\,0001_2$

Dinamičke memorije (DRAM)

- postoje

Statičke memorije (SRAM)

- volatile (nepostojana)
- tehnologije: bipolarna (cache) : MOSFET (RAM)
- organizacija
  - dekoder
  - memorijsko polje
  - međusklop (čitanje i pisanje)
- organizacija mem. polja
  - 2D (dek-der 2^n)
  - 3D (2 dekodera $2^n/2$)
  - 2.5D
    - -> poboljšano 2D (podjela na podpolja)
    - -> manji broj nizova s većim brojem bitova
    - -> npr. iz 256x1 u 64x4
- projektiranje memorije (povezivanje polja)
  - dodavanje dekodera za pristup polju