EE309: IITB-RISC

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1 DATAPATH

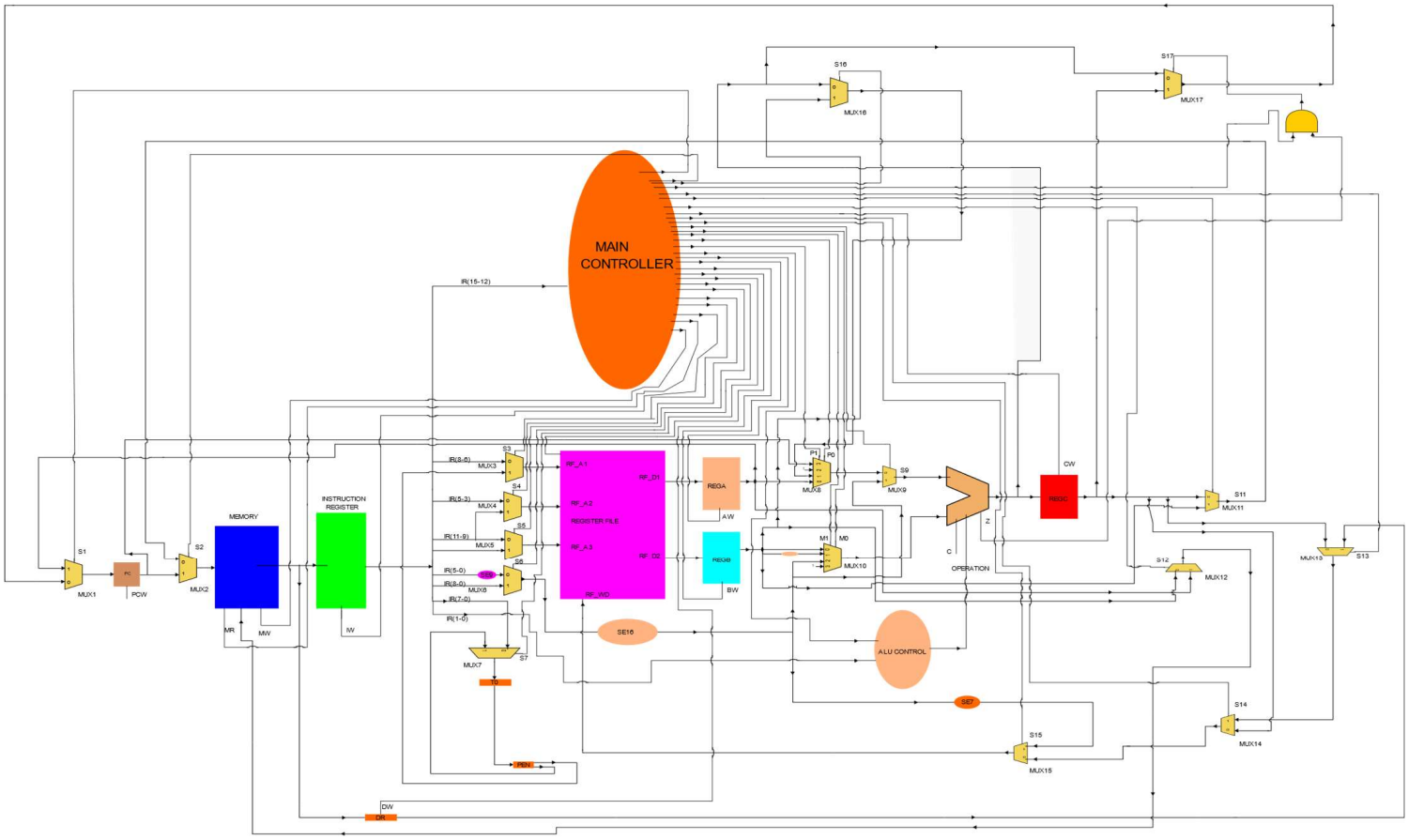
The method of designing the final datapath is as follows:

1. First we divided the instructions into their respective category of R,I and J

2. Started with R type instructions to make the datapath for each instruction seperately and then combining it to get the final datapath for R type instruction.

3. We designed datapath of one instruction at a time and then added the design of next instructions by improvising the existing design.

Below is the descriptive datapath with controller (both ALU and MAIN controller) designed using **Inkspace** software showing all the labels appropriately.


MAIN CONTROLLER
IR(15-12)
S16
MUX16
S17
MUX17
S1
MUX1
PC
PCW
S2
MUX2
MEMORY
MR
MW
INSTRUCTION REGISTER
IW
S3
MUX3
IR(8-6)
S4
MUX4
IR(5-3)
S5
MUX5
IR(11-9)
S6
MUX6
IR(5-0)
SE6
IR(8-0)
IR(7-0)
IR(1-0)
S7
MUX7
T0
PRN
DW
DR
RF_A1
RF_A2
REGISTER FILE
RF_A3
RF_WD
RF_D1
RF_D2
REGA
AW
REGB
BW
SE16
P1
P0
MUX8
S9
MUX9
M1
M0
MUX10
A
B
Z
C
OPERATION
CW
REGC
S11
MUX11
S12
MUX12
MUX13
S13
ALU CONTROL
SE7
S14
MUX14
S15
MUX15

FLOWCHART

RAUSHAN KUMAR

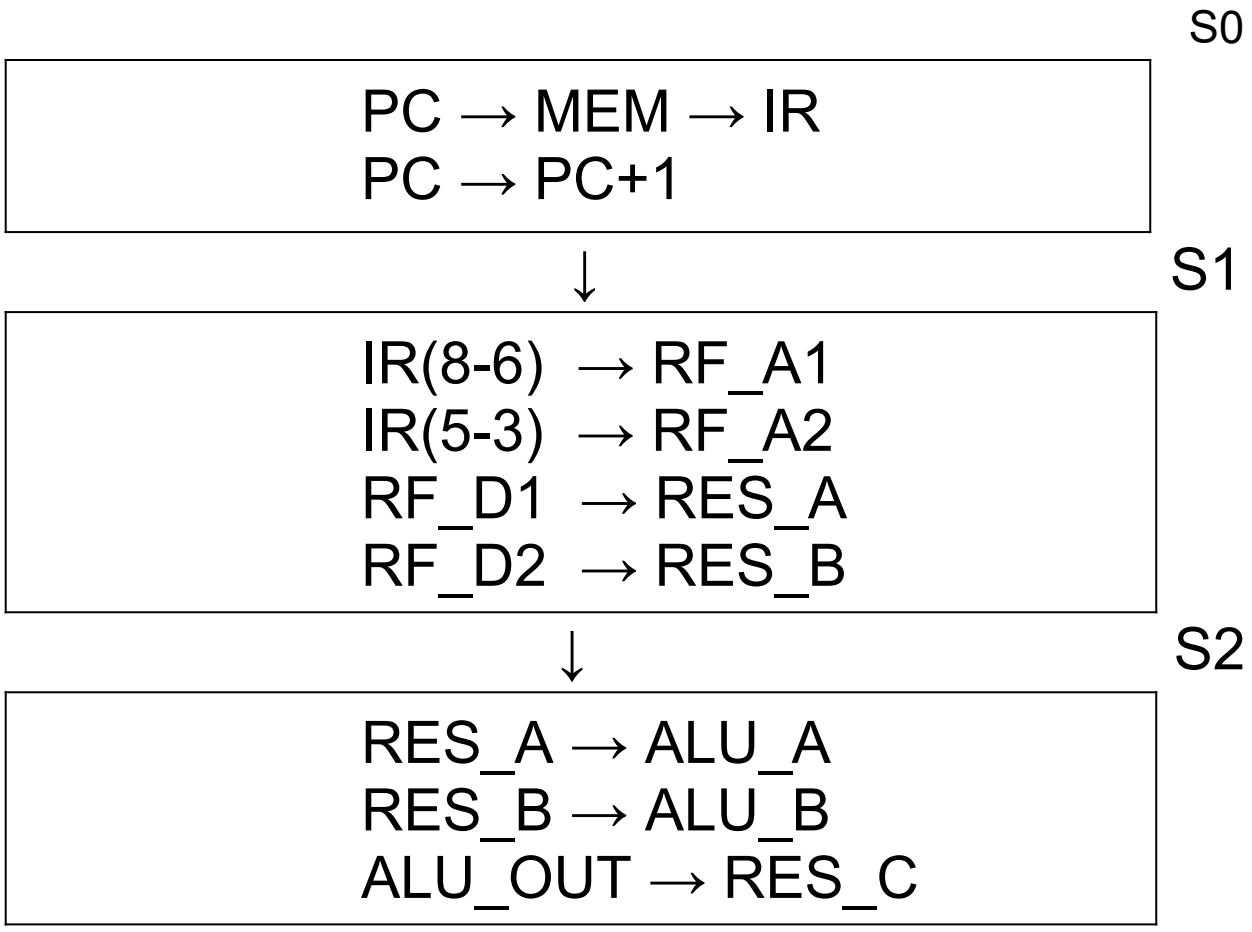
‘

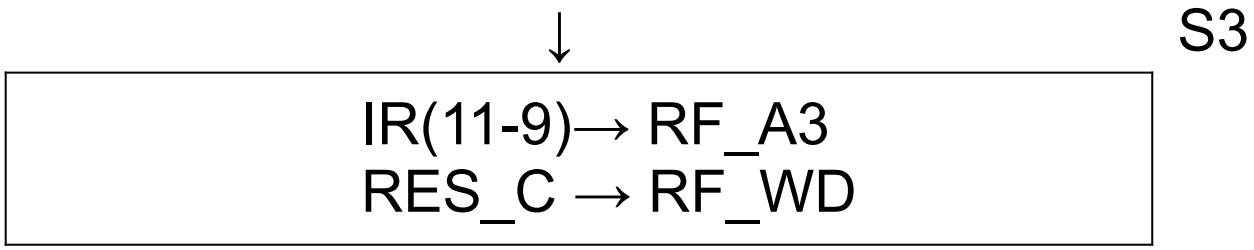
MONU KUMAR YADAV

Akshay Kaushal

R-Type instruction

Op_code	Rc	Rb	a	c	fn
15 – 12	11–9	8–6	5–3	2	1–0

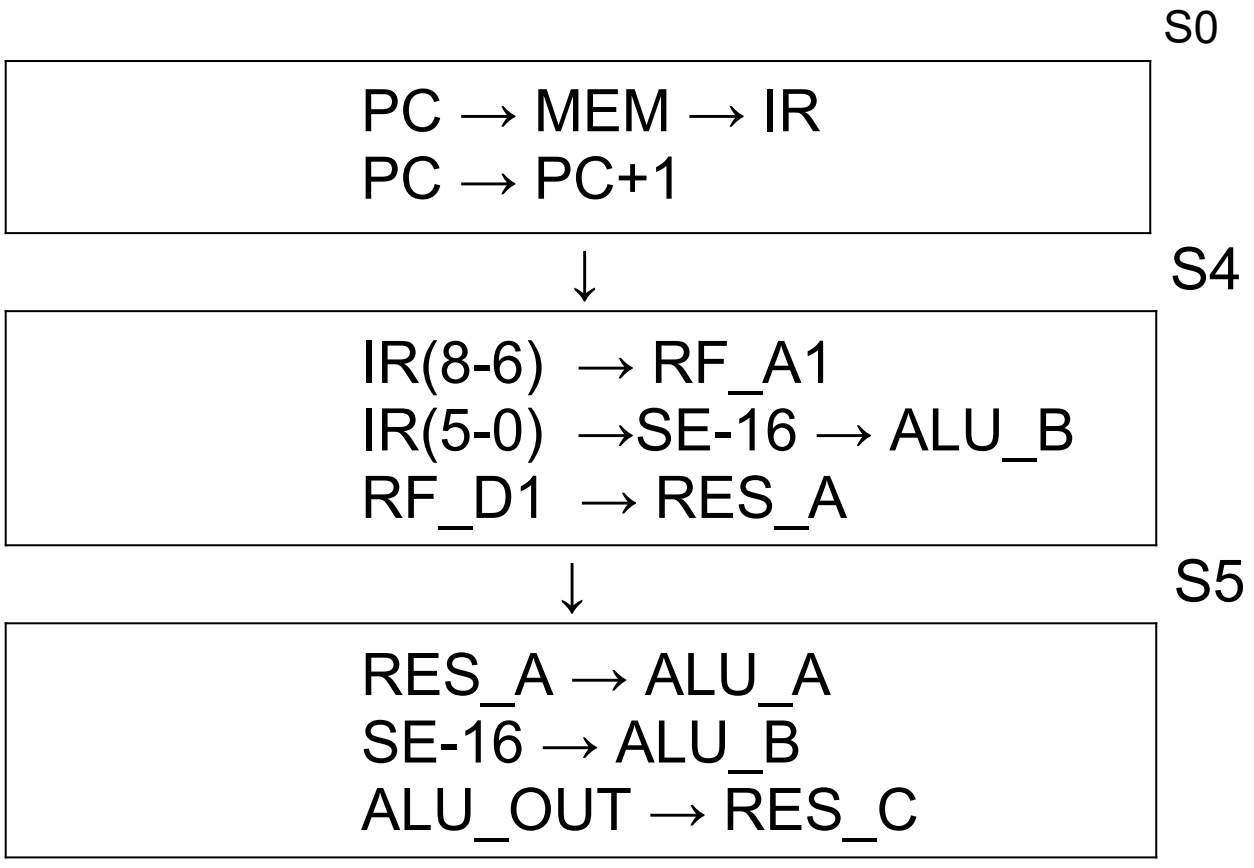


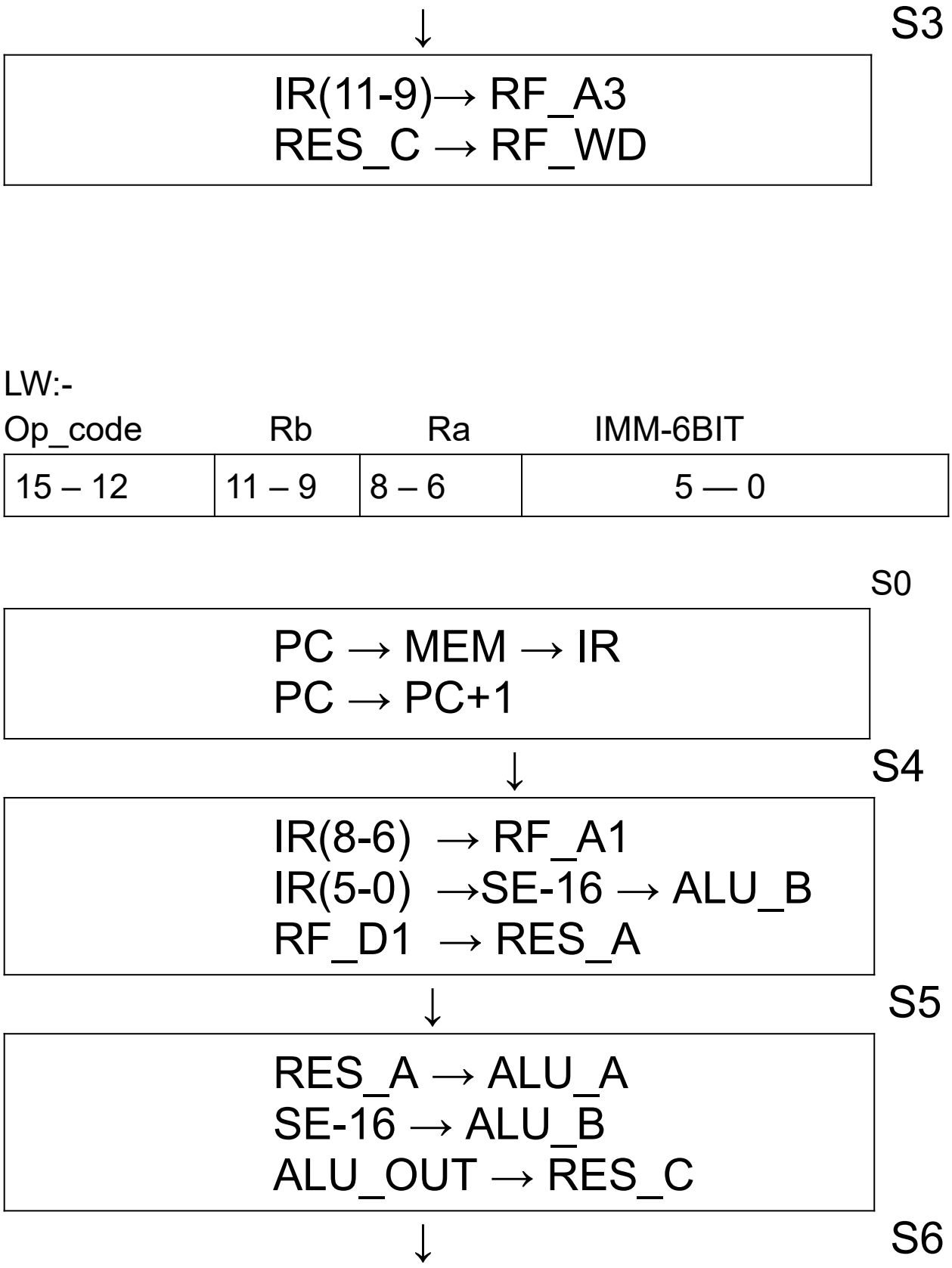


I-Type instruction

ADI:-

Op_code	Rb	Ra	IMM-6BIT
15 – 12	11 – 9	8 – 6	5 — 0





LW:-

Op_code	Rb	Ra	IMM-6BIT
15 – 12	11 – 9	8 – 6	5 — 0

RES_C → ADDRM
RD → DR → RF_WD
IR(11-9) → RF_A3

SW:-

Op_code	Rb	Ra	IMM-6BIT
15 – 12	11 – 9	8 – 6	5 — 0

S0

PC → MEM → IR
PC → PC+1

↓ S4

IR(8-6) → RF_A1
IR(5-0) →SE-16 → ALU_B
RF_D1 → RES_A

↓ S5

RES_A → ALU_A
SE-16 → ALU_B
ALU_OUT → RES_C

↓ S7

RES_C → ADDRM
IR(11-9) → RF_A2
RF_D2 → RES_B
RES_B → WD

BEQ:-

Op_code	Rb	Ra	IMM-6BIT
15 – 12	11 – 9	8 – 6	5 — 0

S0

PC → MEM → IR
PC → PC+1

↓

S8

IR(11-9) → RF_A2
IR(8-6) →RF_A1
RF_D1 → RES_A → ALU_A
RF_D2 → RES_B → ALU_B

↓

S9

IR(5-0) →SE-16 → ALU_B
PC → ALU_A
ALU_OUT → RES_C

↓ S10

IF(A==B){
RES_C → PC}

JLR:-

Op_code	Ra	Rb	IMM-6BIT
15 – 12	11 – 9	8 – 6	000000

S0

PC → MEM → IR
PC → PC+1

↓ S11

PC → ALU_A
+1 → ALU_B
IR(11-9) → RF_A3
ALU_OUT → RF_WD

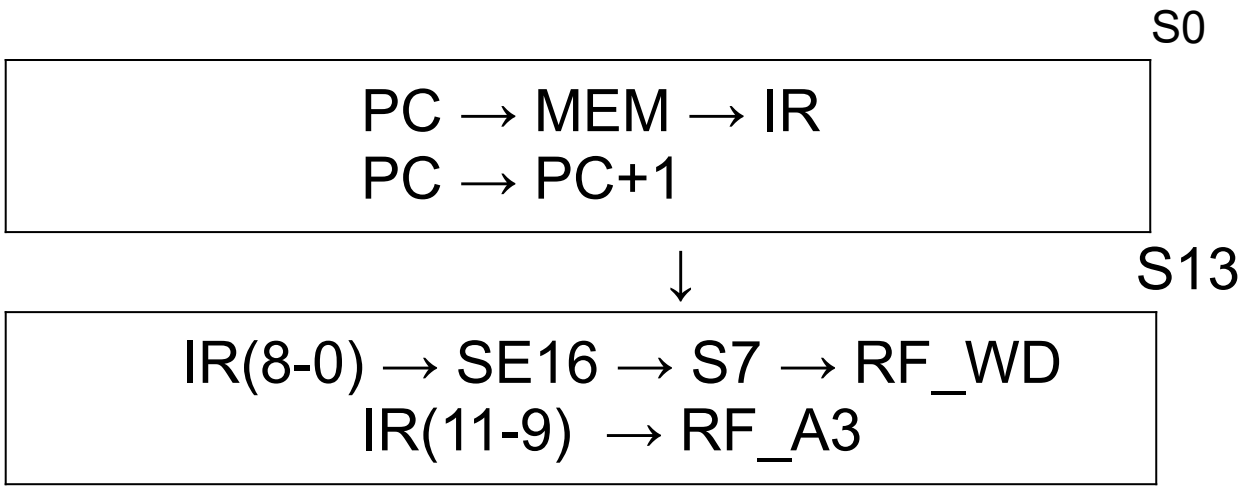
↓ S12

IR(8-6) → RF_A1
RF_D1 →RES_A → PC

J-Type instruction:-

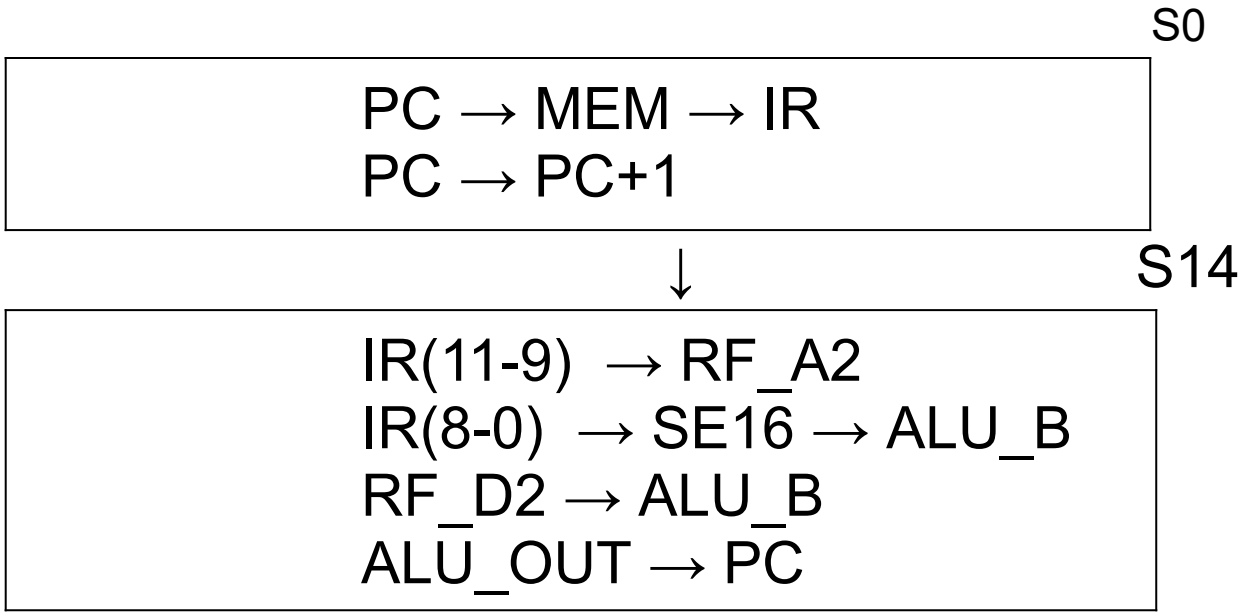
LHI:-

Op_code	Ra	IMM-9BIT
15 – 12	11 – 9	8 – 0



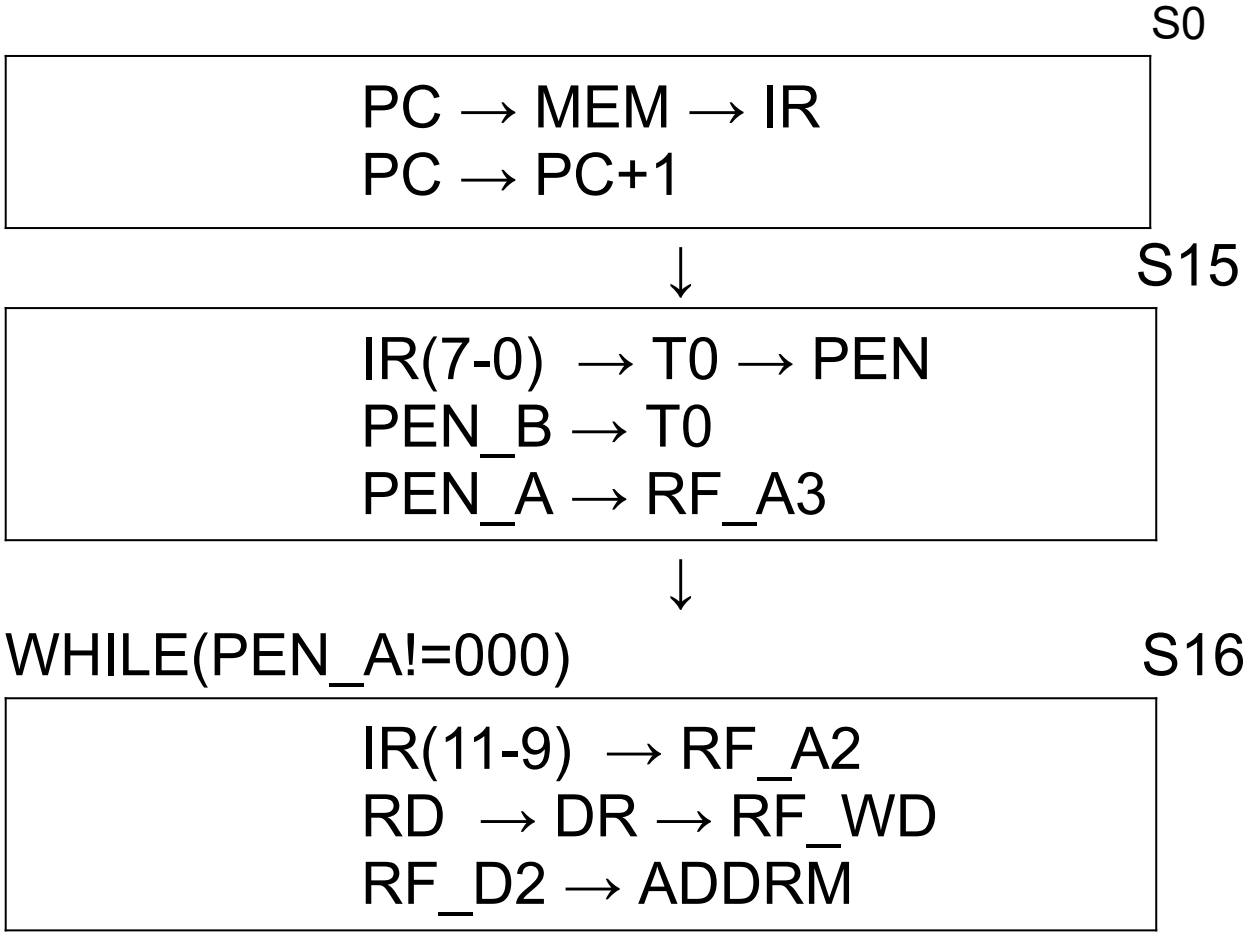
JRI:-

Op_code	Ra	IMM-9BIT
15 – 12	11 – 9	8 – 0



LM:-

Op_code	Ra	IMM-9BIT
15 – 12	11 – 9	8 – 0



SM:-

Op_code	Ra	IMM-9BIT
15 – 12	11 – 9	8 – 0

S0

PC → MEM → IR
PC → PC+1

↓

S17

IR(7-0) → T0 → PEN
PEN_B → T0
PEN_A → RF_A1

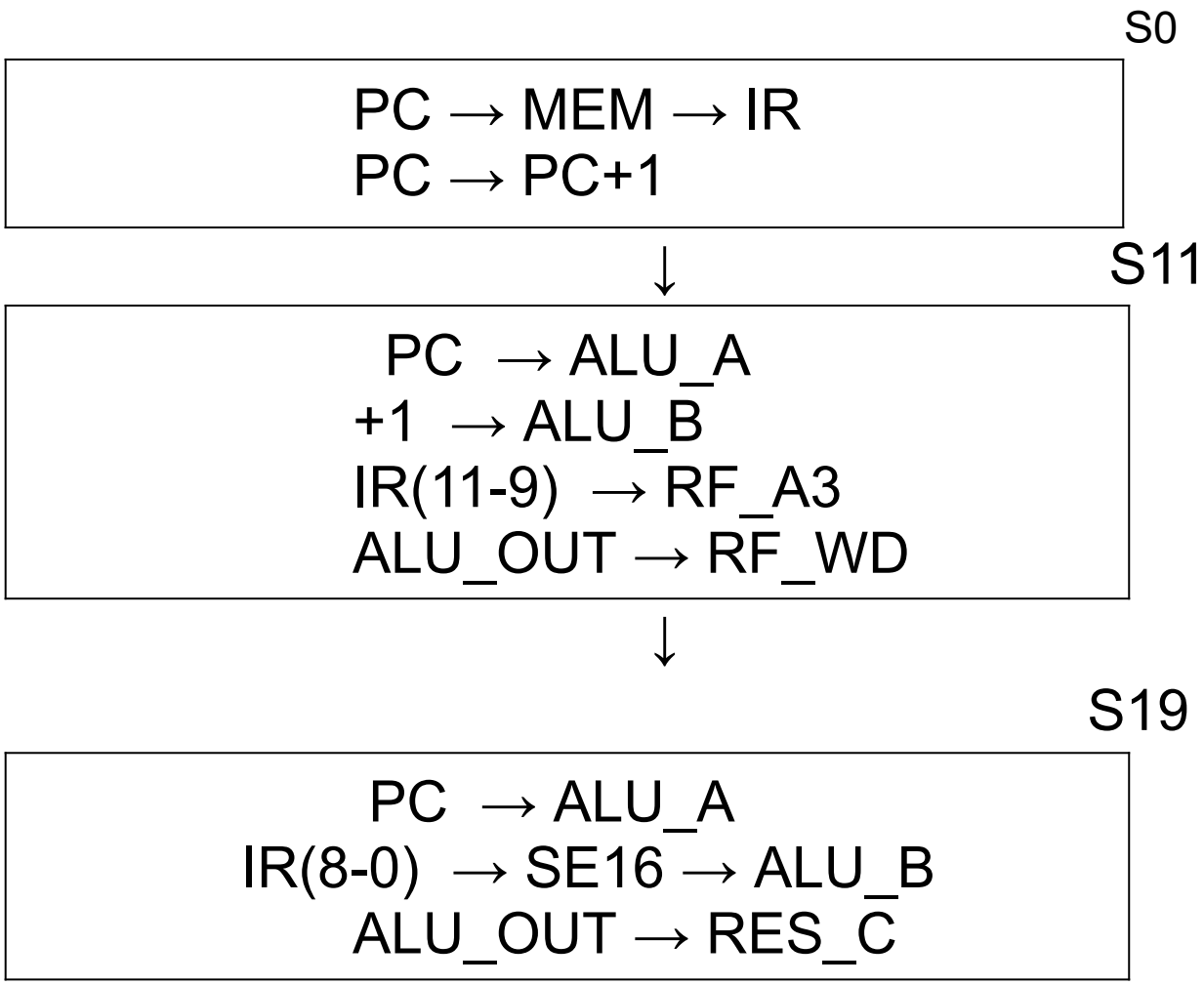
↓

WHILE(PEN_A!=000) S18

IR(11-9) → RF_A2
RF_D1 → WD
RF_D2 → ADDRM

JAL:-

Op_code	Ra	IMM-9BIT
15 – 12	11 – 9	8 – 0



RES_C → PC

2 ALL CONTROL

Our controller takes opcode of 4 bits as an input and gives 28 outputs(27 of 1 bit each and 1 of 2 bits) accordingly make corresponding device ON and OFF for a particular instruction.It decides the following:

1. Whether MUX should be ON or OFF

2. Memory is written or read

3. It sends an output that takes ALU controller as an input to decide which type of instruction it is like R,I or J type of instruction.

4. Whether ALU operation will take place or not

Basically it is the component of hardware design that decides what to do according to opcode.

We made a table to see which device is ON or OFF for an instruction and then got an minimised expression by solving the respective K-map.All the truth table and corresponding minimized boolean expressions are given at the end of the report all in one.

INSTRUCTION		OPCODE	MUX_1	MUX_2	MUX_3	MUX_4	MUX_5	MUX_6	MUX_7	MUX_8		MUX_9	MUX_10		MUX_11	MUX_12	MUX_13	MUX_14	MUX_15	MUX_16	MUX_17	MEM		IR	DR	RF	ResA	ResB	ResC
		INPUT	S1	S2	S3	S4	S5	S6	S7	P1	P0	S9	M1	M0	S11	S12	S13	S14	S15	S16	S17	MR	MW	IW	DW	RW	AW	BW	CW
ADD	R-TYPE	0001	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
ADC	R-TYPE	0001	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
ADZ	R-TYPE	0001	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
ADL	R-TYPE	0001	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
NDU	R-TYPE	0010	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
NDC	R-TYPE	0010	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
NDZ	R-TYPE	0010	0	0	0	0	0	X	X	0	0	0	0	0	X	X	X	0	0	X	0	1	0	1	0	1	1	1	1
ADI	I-TYPE	0000	0	0	0	X	0	0	X	0	0	0	1	0	X	X	X	0	0	X	0	1	0	1	X	1	1	X	1
LW	I-TYPE	0111	0	X	0	X	0	0	X	0	0	0	1	0	0	X	0	1	0	X	X	X	X	X	1	1	1	X	1
SW	I-TYPE	0101	0	X	0	1	0	0	X	0	0	0	1	0	0	0	0	1	0	X	X	1	1	X	1	1	1	1	1
BEQ	I-TYPE	1000	0	0	0	1	X	0	X	X	X	0	X	0	X	X	X	X	X	X	1	1	0	1	1	0	1	1	1
JLR	I-TYPE	1010	X	0	0	X	0	X	X	1	1	X	1	1	X	X	X	0	0	X	X	1	X	1	X	1	1	0	1
LHI	J-TYPE	0000	0	0	X	X	0	1	X	X	X	X	X	X	X	X	X	X	1	X	X	1	X	1	X	1	X	X	X
LM	J-TYPE	1100	0	X	X	1	1	X	X	X	X	X	X	X	1	X	1	1	0	X	X	1	X	1	1	1	X	1	X
SM	J-TYPE	1101	0	X	1	1	X	X	X	X	X	X	X	X	1	1	X	X	X	X	X	1	1	1	1	X	1	1	X
JAL	J-TYPE	1001	0	0	X	X	0	1	X	1	1	X	1	X	X	X	X	0	0	X	1	1	0	1	X	1	1	1	1
JRI	J-TYPE	1011	0	0	X	1	X	1	X	0	0	0	1	0	X	X	X	X	X	X	1	1	0	1	X	X	1	X	1

3 ALU CONTROLLER

ALU controller takes 2 input : Function field of 2 bits; and an output of main controller of 2 bits.

Now by taking these 2 as an input, ALU gives an output of 2 bit called operation(addition, subtraction and NAND)

While solving K-map we were facing difficulties with addition and subtraction in the same circuit , that's why we designed ALU keeping addition and subtraction seperately in VHDL.

Truth table and minimized boolean expressions for operations are at the end of the report.

INSTRUCTION			TYPE_BIT	FUNCTION	alu_ctrl
					op
ADD	R-TYPE	ADDITION	00	00	01
ADC	R-TYPE	ADDITION	00	10	01
ADZ	R-TYPE	ADDITION	00	01	01
ADL	R-TYPE	ADDITION	00	11	01
NDU	R-TYPE	NAND	00	00	00
NDC	R-TYPE	NAND	00	10	00
NDZ	R-TYPE	NAND	00	01	00
ADI	I-TYPE	ADDITION	01	XX	01
LW	I-TYPE	ADDITION	01	XX	01
SW	I-TYPE	ADDITION	01	XX	01
BEQ	I-TYPE	SUBTRACTION	01	XX	10
JLR	I-TYPE	XXX	01	XX	xx
LHI	J-TYPE	XXX	11	XX	xx
LM	J-TYPE	ADDITION	11	XX	01
SM	J-TYPE	ADDITION	11	XX	01
JAL	J-TYPE	ADDITION	11	XX	01
JRI	J-TYPE	ADDITION	11	XX	01

4 STATE CONTROLLER

We have used flowchart, opcodes, some additional conditions like C and Z flags to make states and FSM. We also created a table that shows the status of each device based on flowchart.

Truth table and minimized boolean expressions for operations are at the end of the report.

STATES		MUX_1	MUX_2	MUX_3	MUX_4	MUX_5	MUX_6	MUX_7	MUX_8		MUX_9	MUX_10		MUX_11	MUX_12	MUX_13	MUX_14	MUX_15	MUX_16	MUX_17	MEM		IR	DR	REGISTER FILE				ResA	ResB	ResC	ALU		PC
		S1	S2	S3	S4	S5	S6	S7	P1	P0	S9	M1	M0	S11	S12	S13	S14	S15	S16	S17	MR	MW	IW	DW	RF_A1	RF_A2	RF_A3	RW	AW	BW	CW	C	Z	PCW
S0	00000	0	0	x	x	x	x	x	1	1	0	1	1	x	x	x	x	x	x	0	1	0	1	x	x	x	x	x	x	x	x	x	x	1
S1	00001	x	x	0	0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	x	x	x	x	x	1	1	x	x	x	x
S2	00010								0	0	0	0	0										1						1	1	1			
S3	00011					0											0	0					1					1			1			
S4	00100			0			0					1	0										1						1					
S5	00101								0	0	0																		1		1			
S6	00110		1			0								0		1	1	0			1	0	1	1				1			1			
S7	00111		1		1										0						0	1	1							1	1			
S8	01000			0	1				0	0	0	0	0																1	1				
S9	01001						0		1	1	0	1	0																					
S10	01010	0																		1											1			
S11	01011					0			1	1	0	1	1				0	0					1					1			1			
S12	01100	1		0																			1						1					
S13	01101					0	1											1					1					1						
S14	01110	0			1		1				1	0	0							1			1							1	1			
S15	01111					1		0															1											
S16	10000		1		1			x						1		1	1	0			1	0	1	1				1		1				
S17	10001			1				x															1											
S18	10010		1		1									1	1						0	1	1						1	1				
S19	10011						1		1	1	0	1	0							1			1								1			

NOTE: BLANK BLOCK REPRESENTS DON"T CARE CONDITION

State Machine Viewer - C:/Users/Monu kumar yadav/Desktop/download/project/MultiCycle - RF

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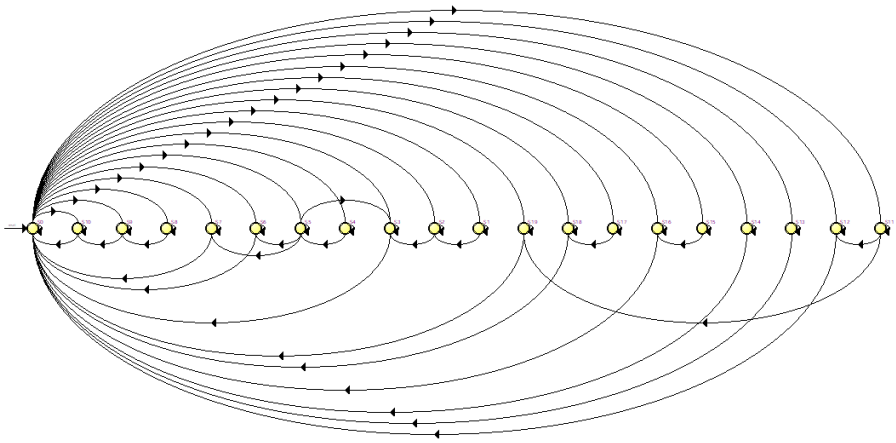
State Machine: |processor|control:controlport|Q



State Table

	Source State	Destination State	
1	S0	S19	(\state_machine:NQ).(!op_code[0]).(!op_code[1]).(op_code[2]).(!op_code[3]).(!controls).(!state_machine).(!rst) + (\state_machine:NQ).(!op_code[0]).(op_code[1]).(!op_code[2]).(!op_code[3]).(c
2	S0	S18	(\state_machine:NQ).(!op_code[0]).(!op_code[1]).(op_code[2]).(!op_code[3]).(!controls).(!state_machine).(!rst) + (\state_machine:NQ).(!op_code[0]).(op_code[1]).(!op_code[2]).(!op_code[3]).(c

Transitions Encoding

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}$.B	0	1	1	0
A.B	0	x	0	0
A.$\overline{B}$	1	x	x	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(8,9,10,11)	A.$\overline{B}$
(5,7)	$\overline{A}$.B.D

y = AB' + A'BD

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	1
8	1	0	0	0	1
9	1	0	0	1	x
10	1	0	1	0	x
11	1	0	1	1	x
12	1	1	0	0	0
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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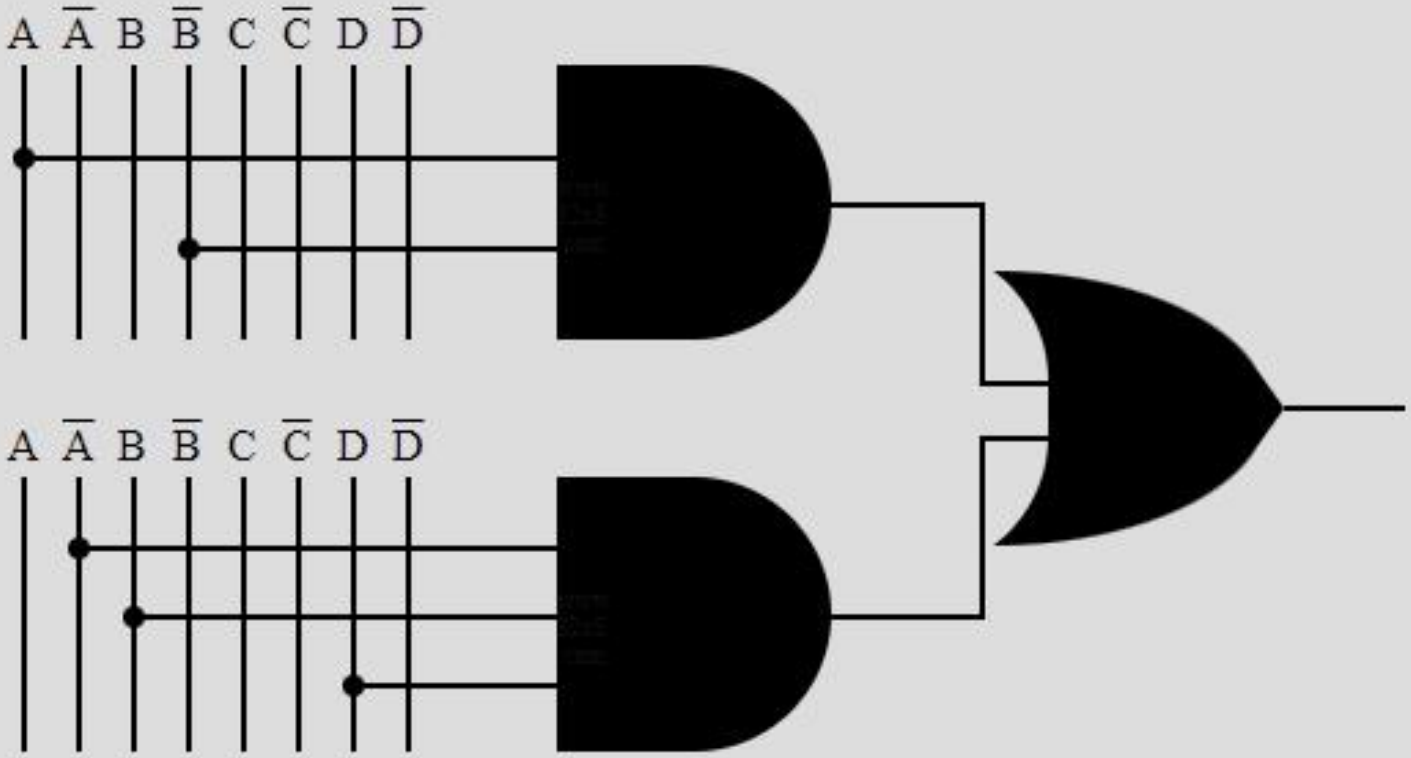
$y = AB' + A'BD$


A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$
A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	1	1	0	1
$\overline{A}$.B	0	x	x	0
A.B	1	1	1	0
A.$\overline{B}$	1	1	1	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(0,1,8,9)	$\overline{B}.\overline{C}$
(0,2,8,10)	$\overline{B}.\overline{D}$
(8,9,12,13)	A.$\overline{C}$
(9,11,13,15)	A.D

y = B'C' + B'D' + AC' + AD

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	1
1	0	0	0	1	1
2	0	0	1	0	1
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	x
6	0	1	1	0	0
7	0	1	1	1	x
8	1	0	0	0	1
9	1	0	0	1	1
10	1	0	1	0	1
11	1	0	1	1	1
12	1	1	0	0	1
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	1

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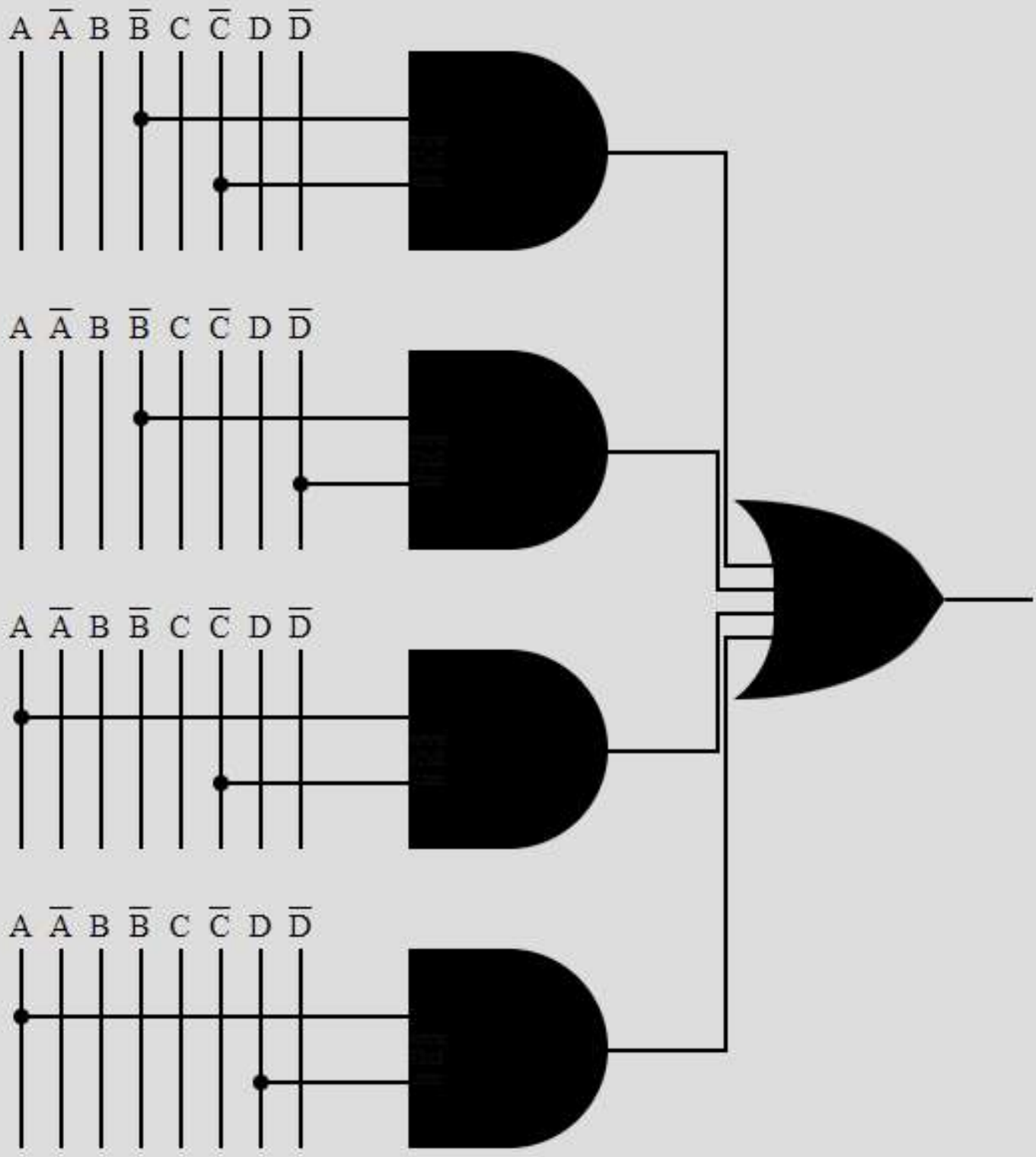
$y = B'C' + B'D' + AC' + AD$



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	1	0	0	0
$\overline{A}.B$	0	1	1	0
$A.B$	1	1	0	0
$A.\overline{B}$	1	1	1	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
$A.B$	12	13	15	14
$A.\overline{B}$	8	9	11	10

Groups

(8,9,10,11)	$A.\overline{B}$
(8,9,12,13)	$A.\overline{C}$
(0,8)	$\overline{B}.\overline{C}.\overline{D}$
(5,7)	$\overline{A}.B.D$

y = AB' + AC' + B'C'D' + A'BD

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	1
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	1
8	1	0	0	0	1
9	1	0	0	1	1
10	1	0	1	0	1
11	1	0	1	1	1
12	1	1	0	0	1
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	0

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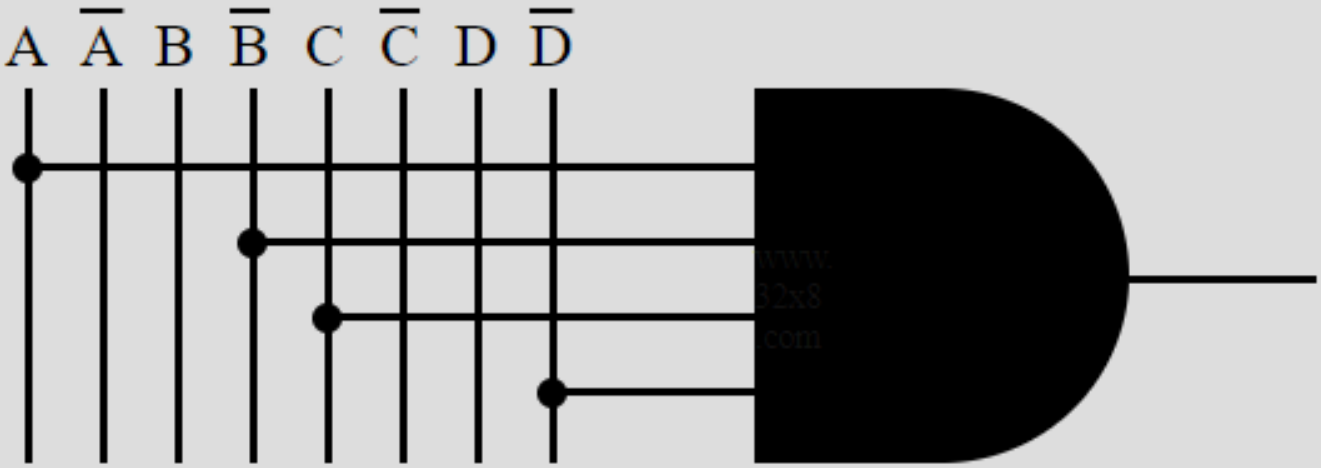
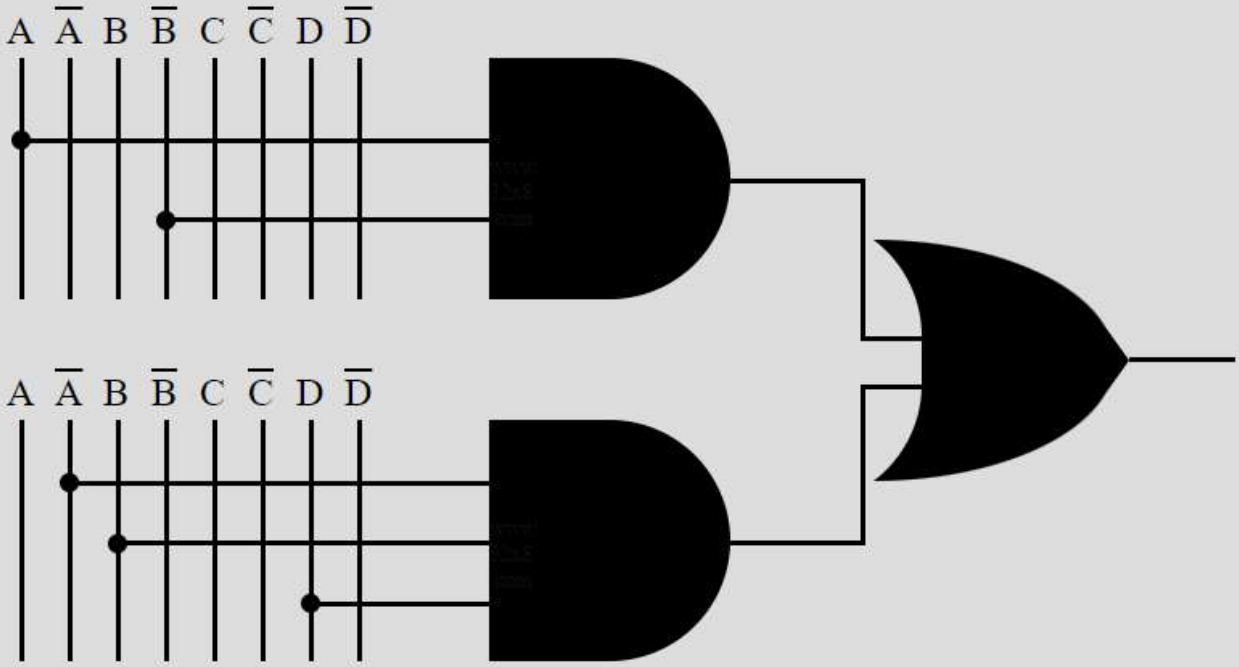
y = AB'CD'



y = AB' + A'BD


A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$
A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	1	1	0	1
$\overline{A}$.B	0	1	x	0
A.B	1	1	1	0
A.$\overline{B}$	1	1	1	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(0,2,8,10)	$\overline{B}.\overline{D}$
(1,5,9,13)	$\overline{C}.D$
(8,9,12,13)	A.$\overline{C}$
(9,11,13,15)	A.D

y = B'D' + C'D + AC' + AD

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	1
1	0	0	0	1	1
2	0	0	1	0	1
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	x
8	1	0	0	0	1
9	1	0	0	1	1
10	1	0	1	0	1
11	1	0	1	1	1
12	1	1	0	0	1
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	1

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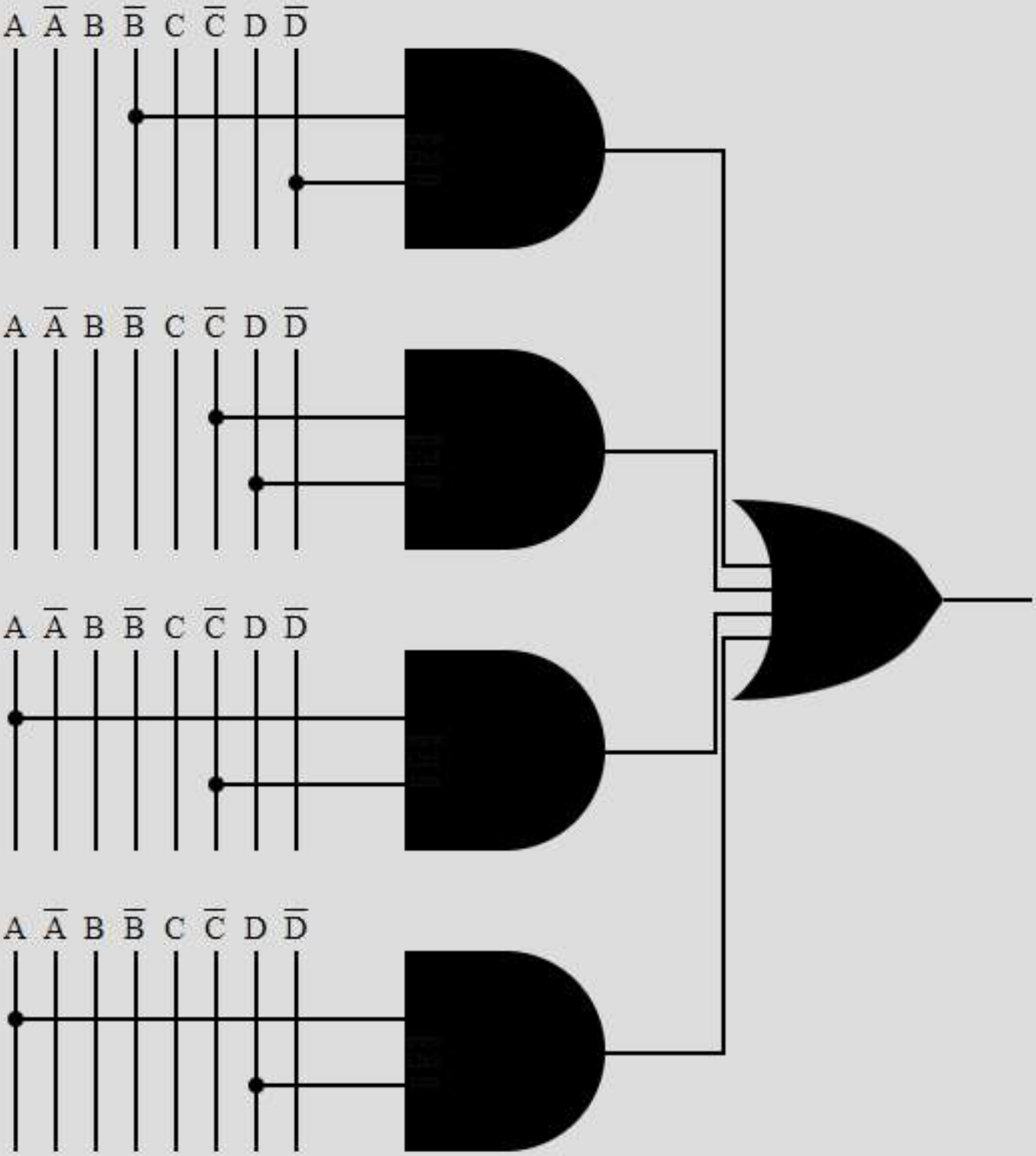
$y = B'D' + C'D + AC' + AD$



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}$.B	0	1	x	0
A.B	x	1	0	0
A.$\overline{B}$	0	0	0	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(5,13)	B.$\overline{C}$.D

y = BC'D

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x

1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	x
8	1	0	0	0	0
9	1	0	0	1	0
10	1	0	1	0	x
11	1	0	1	1	0
12	1	1	0	0	x
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	0

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}.B$	0	0	0	0
A.B	x	x	0	0
A.$\overline{B}$	0	x	0	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(10)	A.$\overline{B}$.C.$\overline{D}$

y = AB'CD'

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x

1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0
8	1	0	0	0	0
9	1	0	0	1	x
10	1	0	1	0	1
11	1	0	1	1	0
12	1	1	0	0	x
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	1	0	0	0
$\overline{A}.B$	0	0	0	0
$A.B$	1	1	0	0
$A.\overline{B}$	0	1	1	0

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
$A.B$	12	13	15	14
$A.\overline{B}$	8	9	11	10

Groups

(9,11)	$A.\overline{B}.D$
(12,13)	$A.B.\overline{C}$
(0)	$\overline{A}.\overline{B}.\overline{C}.\overline{D}$

y = AB'D + ABC' + A'B'C'D'

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	1
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0
8	1	0	0	0	0
9	1	0	0	1	1
10	1	0	1	0	0
11	1	0	1	1	1
12	1	1	0	0	1
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	0

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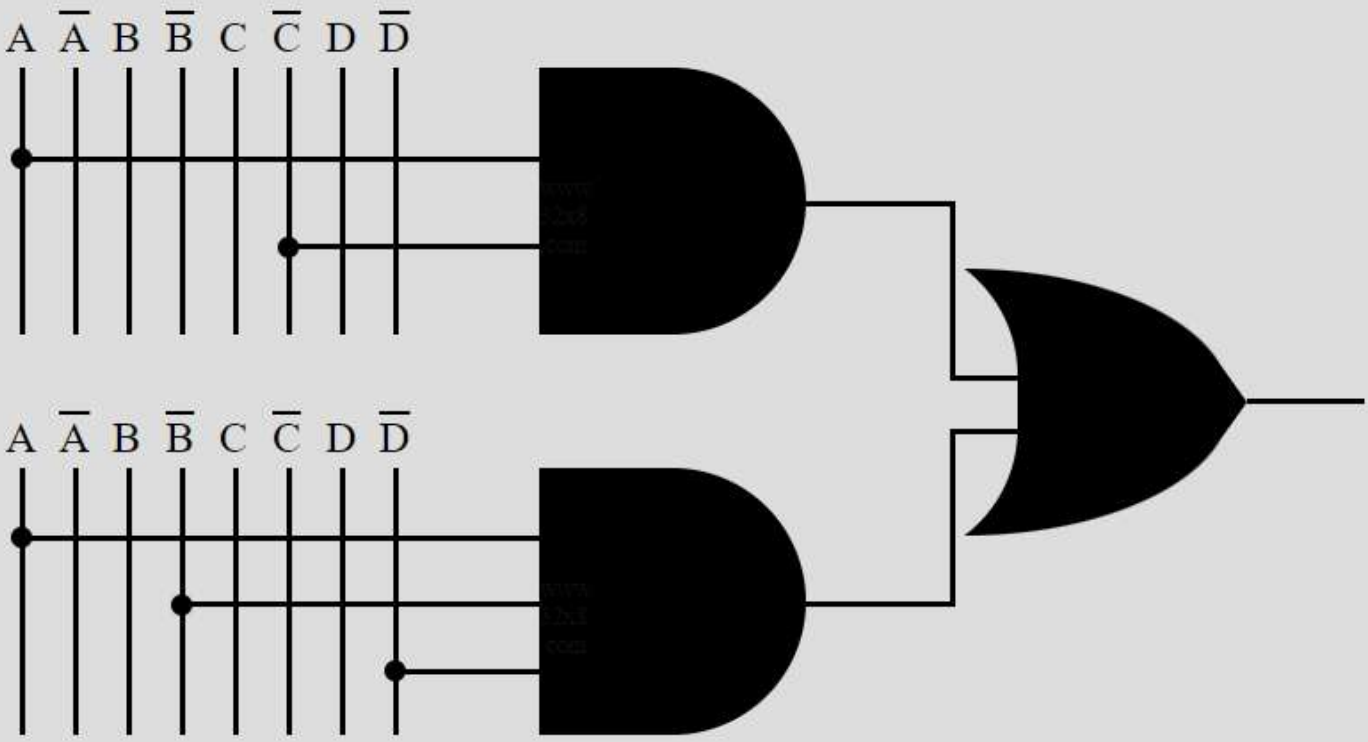
y = AC' + AB'D'



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}$.B	0	0	0	0
A.B	x	x	0	0
A.$\overline{B}$	x	1	0	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(8,9,12,13)	A.$\overline{C}$
(8,10)	A.$\overline{B}$.$\overline{D}$

y = AC' + AB'D'

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0
8	1	0	0	0	x
9	1	0	0	1	1
10	1	0	1	0	1
11	1	0	1	1	0
12	1	1	0	0	x
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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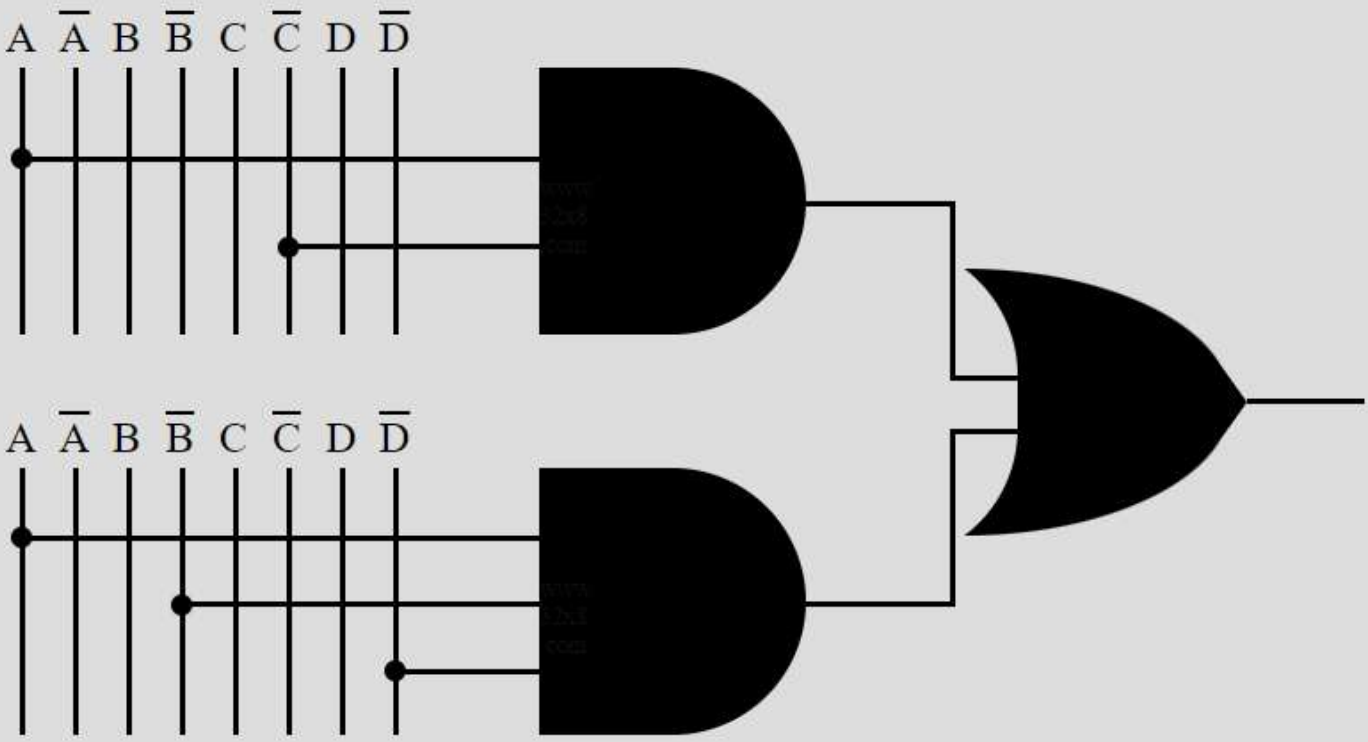
y = AC' + AB'D'



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}.B$	0	1	1	0
$A.B$	x	x	0	0
$A.\overline{B}$	x	1	1	1

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	$C.D$	$C.\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
$A.B$	12	13	15	14
$A.\overline{B}$	8	9	11	10

Groups

(8,9,10,11)	$A.\overline{B}$
(5,7)	$\overline{A}.B.D$

y = AB' + A'BD

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A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	1
8	1	0	0	0	x
9	1	0	0	1	1
10	1	0	1	0	1
11	1	0	1	1	1
12	1	1	0	0	x
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	x	0	x
$\overline{A}$.B	0	0	0	0
A.B	1	1	x	0
A.$\overline{B}$	x	x	x	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}$.B	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(8,9,12,13)	A.$\overline{C}$

y = AC'

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x

1	0	0	0	1	x
2	0	0	1	0	x
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0
8	1	0	0	0	x
9	1	0	0	1	x
10	1	0	1	0	x
11	1	0	1	1	x
12	1	1	0	0	1
13	1	1	0	1	1
14	1	1	1	0	0
15	1	1	1	1	x

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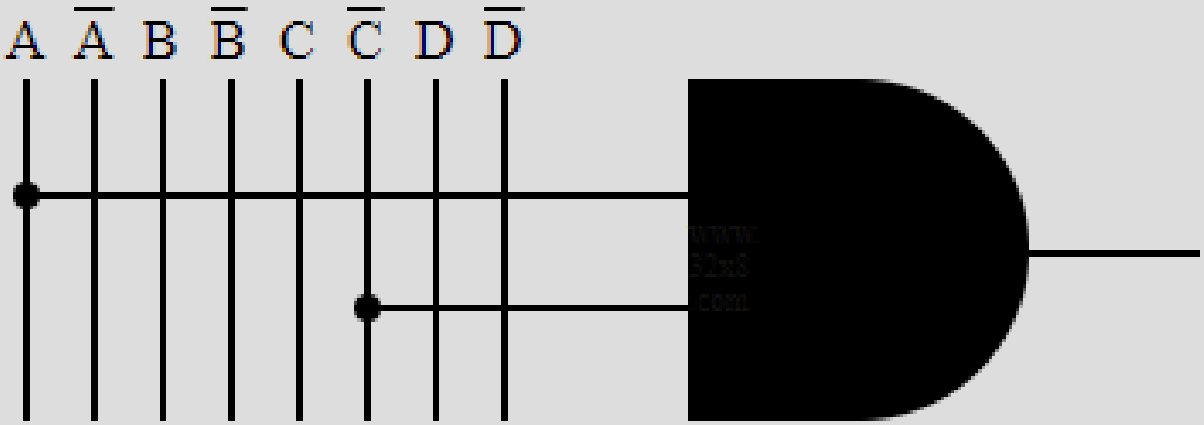
$y = AC'$



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	x	0	x
$\overline{A}.B$	0	0	x	0
A.B	x	0	x	0
A.$\overline{B}$	x	x	x	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

y = 0

Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	x
2	0	0	1	0	x
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	x

8	1	0	0	0	x
9	1	0	0	1	x
10	1	0	1	0	x
11	1	0	1	1	x
12	1	1	0	0	x
13	1	1	0	1	0
14	1	1	1	0	0
15	1	1	1	1	x

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	x	0	x
$\overline{A}.B$	0	0	0	0
A.B	1	x	x	0
A.$\overline{B}$	x	x	x	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(8,9,12,13)	A.$\overline{C}$

y = AC'

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x

1	0	0	0	1	x
2	0	0	1	0	x
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0
8	1	0	0	0	x
9	1	0	0	1	x
10	1	0	1	0	x
11	1	0	1	1	x
12	1	1	0	0	1
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	x

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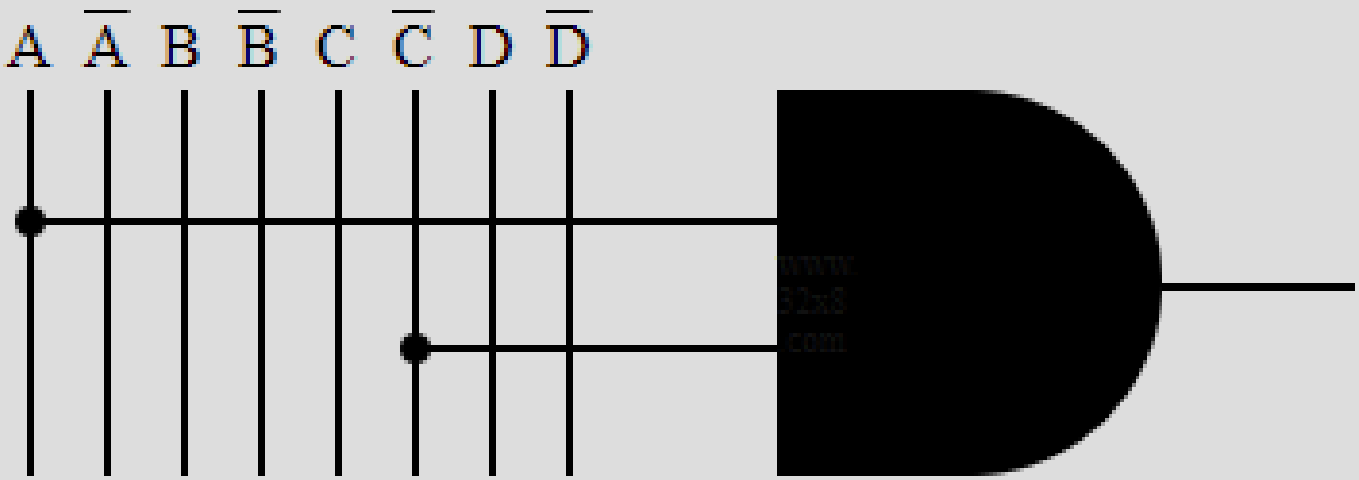
$y = AC'$



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}.B$	0	1	1	0
A.B	x	x	0	0
A.$\overline{B}$	x	0	x	0

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

(5,7)	$\overline{A}$.B.D

y = A'BD

A $\overline{A}$ B $\overline{B}$ C $\overline{C}$ D $\overline{D}$

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Truth Table

	A	B	C	D	Y
0	0	0	0	0	x

1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	1
6	0	1	1	0	0
7	0	1	1	1	1
8	1	0	0	0	x
9	1	0	0	1	0
10	1	0	1	0	0
11	1	0	1	1	x
12	1	1	0	0	x
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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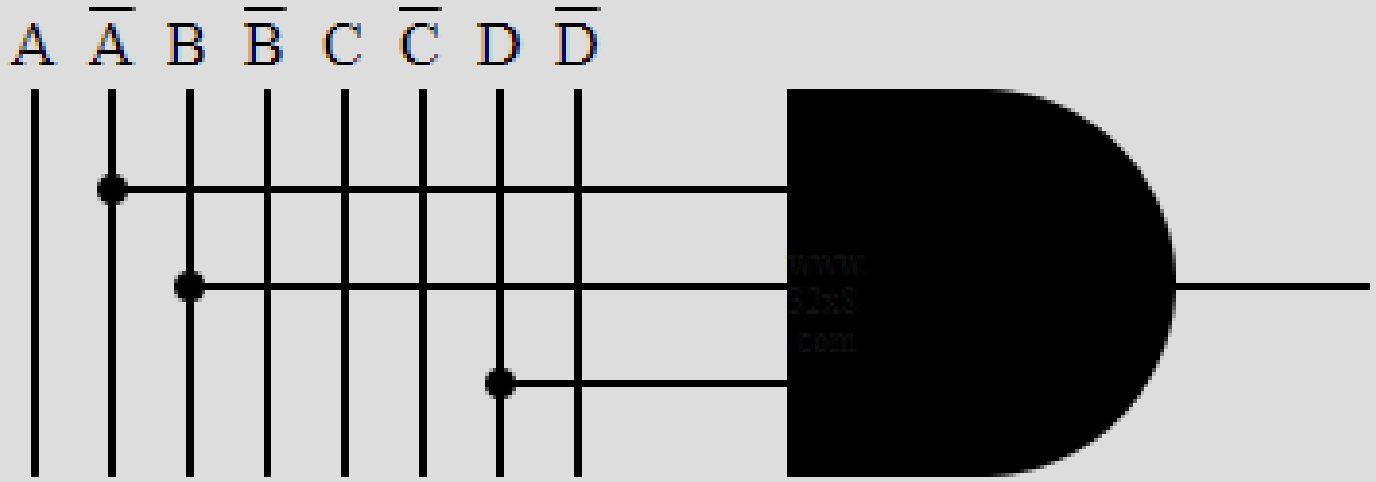
$y = A'BD$



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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	0	0	0
$\overline{A}.B$	0	0	0	0
A.B	0	x	0	0
A.$\overline{B}$	x	0	x	0

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

y = 0

Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	0
4	0	1	0	0	0
5	0	1	0	1	0
6	0	1	1	0	0
7	0	1	1	1	0

8	1	0	0	0	x
9	1	0	0	1	0
10	1	0	1	0	0
11	1	0	1	1	x
12	1	1	0	0	0
13	1	1	0	1	x
14	1	1	1	0	0
15	1	1	1	1	0

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SUM of PRODUCTS

Map

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	x	x	x	x
$\overline{A}.B$	x	x	x	x
A.B	x	x	x	x
A.$\overline{B}$	x	x	x	x

Map Layout

	$\overline{C}.\overline{D}$	$\overline{C}.D$	C.D	C.$\overline{D}$
$\overline{A}.\overline{B}$	0	1	3	2
$\overline{A}.B$	4	5	7	6
A.B	12	13	15	14
A.$\overline{B}$	8	9	11	10

Groups

y = 0y = 1

Truth Table

	A	B	C	D	Y
0	0	0	0	0	x
1	0	0	0	1	x
2	0	0	1	0	x
3	0	0	1	1	x
4	0	1	0	0	x
5	0	1	0	1	x
6	0	1	1	0	x
7	0	1	1	1	x

8	1	0	0	0	x
9	1	0	0	1	x
10	1	0	1	0	x
11	1	0	1	1	x
12	1	1	0	0	x
13	1	1	0	1	x
14	1	1	1	0	x
15	1	1	1	1	x

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Digital circuit and truth table of all control signals are seperately given in a folder $\text{all}_{c}ontroller_{c}ombined.pdf.Herewehaveshownalltogether$.