UNIT-2

Standard Form of Boolean Expression

All the boolean Exp. can be converted into either of two standard form

→ Sum of Product (SOP – Minterm)
→ Product of Sum (POS – Maxterm)

SOP (Minterm) :- Each individual term is SSOP is called Minterm. Small m Represent Minterm.

POS (Maxterm) :- Each individual term in SPOS is called Maxterm.

For 2 variable function →

A	B	Minterm SOP	Maxterm POS
0	0	$\bar{A}\cdot\bar{B} = m_0$	$A+B = M_0$
0	1	$\bar{A}B = m_1$	$A+\bar{B} = M_1$
1	0	$A\bar{B} = m_2$	$\bar{A}+B = M_2$
1	1	$AB = m_3$	$\bar{A}+\bar{B} = M_3$

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

$$\Sigma m\,(m_3 + m_1)$$

$$\Sigma m\,(1,3)$$

SOP → Sum of Product

$Y = AB + BC + AC$

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

SSOP :- Standard SOP

$F(A,B,C) = \bar{A}B + \bar{B}C$ ✗

$AB\bar{C} + \bar{A}\bar{B}C$ ✓

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

$\bar{A}B \times 1 + \bar{B}C \times 1$ $C + \bar{C} = 1$

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

$F(A,B,C) = \bar{A}BC + \bar{A}B\bar{C} + \bar{A}\bar{B}C + A\bar{B}C$ ✓

↓
Minterm (m)

$F(A,B,C) = (m_3, m_2, m_1, m_5)$

$F(A,B,C) = \Sigma (m_1, m_2, m_3, m_5)$

POS - Product of Sum

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

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

$(\bar{A}+\bar{B}+0) \cdot (B+C+0)$ $A \cdot \bar{A} = 0$

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

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

$(M_6 \quad M_7 \quad M_0 \quad M_1) = \Sigma\pi(0,1,6,7)$

A n variable function will contain 2^n Minterm / 2^n Maxterm.

Minterm $F(A,B) = 2^2 = 4$

$m_0 = \bar{A}\cdot\bar{B}$

$m_1 = \bar{A}\cdot B$

$m_2 = A\cdot\bar{B}$

$m_3 = A B$

A	B	m
0	0	$\bar{A}\bar{B}$
0	1	$\bar{A}B$
1	0	$A\bar{B}$
1	1	AB

Maxterm

$M_0 = A+B$

$M_1 = A+\bar{B}$

$M_2 = \bar{A}+B$

$M_3 = \bar{A}+\bar{B}$

A	B	M
0	0	$A+B$
0	1	$A+\bar{B}$
1	0	$\bar{A}+B$
1	1	$\bar{A}+\bar{B}$

We use this thing in K-map.

For 3 variable. (Minterm & Maxterm)

A	B	C	m	M
0	0	0	$\bar{A}\bar{B}\bar{C} = m_0$	$A+B+C = M_0$
0	0	1	$\bar{A}\bar{B}C = m_1$	$A+B+\bar{C} = M_1$
0	1	0	$\bar{A}B\bar{C} = m_2$	$A+\bar{B}+C = M_2$
0	1	1	$\bar{A}BC = m_3$	$A+\bar{B}+\bar{C} = M_3$
1	0	0	$A\bar{B}\bar{C} = m_4$	$\bar{A}+B+C = M_4$
1	0	1	$A\bar{B}C = m_5$	$\bar{A}+B+\bar{C} = M_5$
1	1	0	$AB\bar{C} = m_6$	$\bar{A}+\bar{B}+C = M_6$
1	1	1	$ABC = m_7$	$\bar{A}+\bar{B}+\bar{C} = M_7$

KARNAUGH MAP [K-Map]

→ Developed by Karnaugh in 1953

→ Used to simplify algebraic expression.

→ This is practical solution of Boolean algebra.

Different K-map are there :-

1) 2-variable
2) 3-variable
3) 4-variable

2-variable K-map :-

There are 2-variable i.e A, B value is 0, 1.

$2^2 = 4$

A \ B	0	1
0		
1		

OR

B \ A	0	1
0		
1		

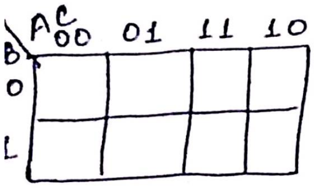
No. of cell $= 2^n = 2^2 = 4$

n = no. of variable

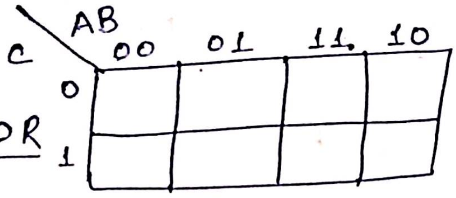
3-Variable K-map :- Three variables are there. A, B, C

no. of Cell = 3

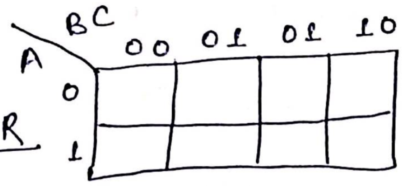
$2^n = 2^3 = 8$



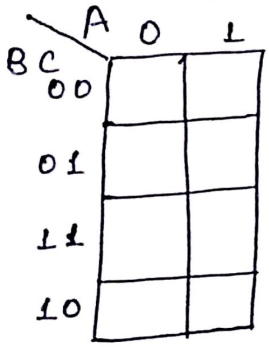
OR



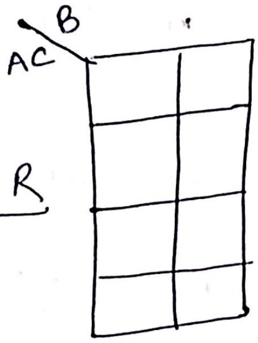
OR



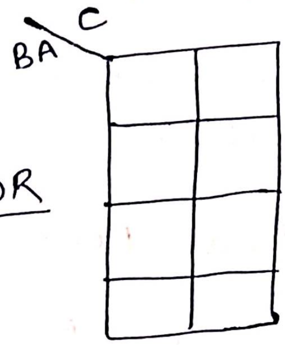
OR we can Represent this in Vertical manner.



OR



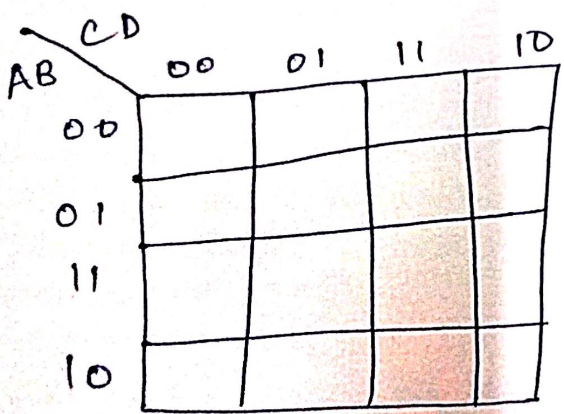
OR



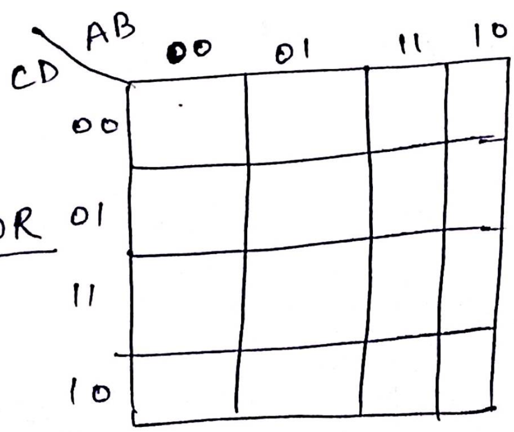
4-Variable K-map :- Four variable are there. ABCD.

no. of cell = 4

$2^n = 2^4 = 16$



OR



Rules For K-Map Simplification :-

1. Groups may not contain zero.
2. We can group 1, 2, 4, 8 or 2^n cell.
3. Each group should be as large as possible.
4. Cells containing 1 must be grouped.
5. Group may overlap.
6. Opposite grouping & corner grouping is allowed.
7. There should be as few groups as possible.

The minimal form of the logical expression is

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

000   010   011   110

A \ BC	00	01	11	10
0	1		1	1
1				1

$\bar{A}\bar{C} + \bar{A}B + B\bar{C}$ Ans

The Boolean Expression :- [GATE-2007]

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

$$\quad 0001 \qquad 0110 \qquad 1001 \qquad 1100$$

AB \ CD	00	01	11	10
00		1		
01				1
11	1			
10		1		

$$\Rightarrow \bar{B}\bar{C}D + AB\bar{C}\bar{D} + \bar{A}BC\bar{D}$$

Simplify the following expression :-

$$F(A,B,C,D) = \Sigma(0,3,5,7,9,11,13,15)$$

AB \ CD	00	01	11	10
00	1		1	
01		1	1	
11		1	1	
10		1	1	

$$CD + AD + \cancel{A}BD + \bar{A}\bar{B}\bar{C}\bar{D}$$

4- Variable :-

$$F = \overset{0000}{\bar{A}\bar{B}\bar{C}\bar{D}} + \overset{\substack{8 \\ 1000}}{A\bar{B}\bar{C}\bar{D}} + \overset{\substack{12 \\ 1100}}{AB\bar{C}\bar{D}} + \overset{\substack{15 \\ 1111}}{ABCD} + \overset{\substack{7 \\ 0111}}{\bar{A}BCD}$$

AB \ CD	00	01	11	10
00	1			
01			1	
11	1		1	
10	1			

$\bar{B}\bar{C}\bar{D} + A\bar{C}\bar{D} + BCD$

SOP Form :-

$Z = \sum A,B,C\,(1,3,6,7)$

A \ BC	00	01	11	10
0		1	1	
1			1	1

$\bar{A}C + AB$

$\sum A,B,C\,(0,3,6,7)$

A \ BC	00	01	11	10
0	1		1	
1			1	1

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

$F(a,b,c,d) = \sum m\,(3,7,11,12,13,14,15)$

ab \ cd	00	01	11	10
00			1	
01			1	
11	1	1	1	1
10			1	

$ab + cd$

Q. 1 $Y = m_1 + m_3 + m_5 + m_7 + m_8 + m_9 + m_{12} + m_{13}$

Q. 2 $ABCD + A\bar{B}\bar{C}\bar{D} + A\bar{B}C + AB$

Q. 3 $Y = \Sigma_m (7, 9, 10, 11, 12, 13, 14, 15)$

Q. 4 $Y = \Sigma_m (1, 5, 10, 11, 12, 13, 15)$

Q. 5 $Y = \Sigma_m (3, 4, 5, 7, 9, 13, 14, 15)$

Q. 6 $F = ABC + \bar{A}BC + \bar{B}\bar{C}$

Q. 7 $F = A + B + \bar{C}$

Q. 8 $F = AB + \bar{B}CD$

Q. 9 $X = \bar{A}BC + A\bar{B}C + AB\bar{C} + ABC$

Q. 10 $F(x, y) = \Sigma(0, 2, 3)$

Q. 11 $F(x, y, z) = \Sigma(0, 1, 6, 7)$

Q. 12 $F = \bar{x}y + xy$

Don't Care :-

The no. of Product term in the minimized sum of Product Expression obtained through the following K-map. [where d denotes don't care]

1	0	0	1
0	d	0	0
0	0	d	1
1	0	0	1

2 don't care is there.

Simplify the Boolean Funⁿ.

$$F(w, x, y, z) = \Sigma(1, 3, 7, 11, 15)$$

which has don't care condition

$$d(w, x, y, z) = \Sigma(0, 2, 5)$$

wx \ yz	00	01	11	10
00	d	1	1	d
01		d	1	
11			1	
10			1	

$\bar{w}\bar{x} + yz$

Q. $f = m(1, 5, 6, 12, 13, 14) + d(4)$

Q. $m(1, 2, 6, 7, 8, 13, 14, 15) + d(3, 5, 12)$

Q. $\Sigma m(1, 5, 6, 12, 13, 14) + d(2, 4)$

Q. $f = \Sigma m(1, 3, 7) + \Sigma d(0, 5)$

Q. $f = \Sigma_m(1,3,7,11,15) + \Sigma d(0,2,5)$

Q. $f = \Sigma_m(1,3,5,7,9) + \Sigma d(6,12,13)$

Q. $F = \Sigma_m(1,6,10,11,12,13,15) + d(4,5,7,8,14)$

$f(A,B,C) = \Sigma_m(2,3,4,5) + \Sigma d(6,7)$

A \ BC	00	01	11	10
0			1	1
1	1	1	d	d

$B + A$

K-Map's using Max Term :-

→ In this we group 0's.

Ex.

A \ BC	00	01	11	10
0	0	0	0	1
1	1	1	1	1

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

$(\bar{A}\bar{B})' \cdot (\bar{A}C)'$

$(\hat{A} + B) \cdot (A + C')$

POS

$F(A,B,C,D) = \Sigma_m(1,3,4,5,9,11,14,15)$ ← Min term

↳ Max term

$\pi_M(0,2,6,7,8,10,12,13)$

AB \ CD	00	01	11	10
00	0			0
01			0	0
11	0	0		
10	0			0

~~$BD + A\bar{B}\bar{C} + \bar{A}\bar{B}C$~~

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

Ans.

Ex. $Y = \pi_M(0,2,3,5,7)$

A \ BC	00	01	11	10
0	0		0	0
1		0	0	

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

Ex.

Maxterm
$Y = \pi_M(0,2,3,7)$
$Y = \pi_M(0,4,5,7,10,11,14,15)$
$Y = \pi_M(0,2,7) + d(4,6)$
$Y = \Sigma_m(0,1,2,4) + d(3,5)$

Minterms $Y = \Sigma_m(1,3,7,11,15) + d(0,2,5)$

Drawback of K-Map :-

→ It does not for higher dimensions like - 7-variable etc.

→ Minimization is complicated as the no. of variable is exceed 5 or 6.

Quine - mc - clusky

→ This method is overcome the problem of K-Map.

→ with the help of this method we can solve large no. of variable.

→ It is also use to minimized the Boolean expression.

→ This is also called as Tabulation method.

Important Aspects :-

Prime Implicants :- It is a group of minterm which can-not be combined in any other minterm or group.

$F(A, B, C, D) = \Sigma(0, 1, 2, 8, 10, 11, 14, 15)$

0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
8	1	0	0	0
10	1	0	1	0
11	1	0	1	1
14	1	1	1	0
15	1	1	1	1

Step - a

	A	B	C	D		
G_0	0	0	0	0	(0)	✓
G_1	0	0	0	1	(1)	✓
	0	0	1	0	(2)	✓
	1	0	0	0	(8)	✓
G_2	1	0	1	0	(10)	
G_3	1	0	1	1	(11)	
	1	1	1	0	(14)	
G_4	1	1	1	1	(15)	

Step (b)

(G_0, G_1)	A	B	C	D	
(0,1)	0	0	0	–	
(0,2)	0	0	–	0	✓
(0,8)	–	0	0	0	✓

(G_1, G_2)					
(2,10)	–	0	1	0	✓
(8,10)	1	0	–	0	✓

(G_2, G_3)					
(10,11)	1	0	1	–	✓
(10,14)	1	–	1	0	✓

(G_3, G_4)					
(11,15)	1	–	1	1	✓
(14,15)	1	1	1	–	✓

Step (c)

$(G_0 - G_1)(G_1 G_2)$				
(0, 2, 8, 10)	–	0	–	0
(0, 2, 8, 10)	–	0	–	0

$(G_1 G_2 - G_2 G_3)$ – No Match

$(G_2 G_3 - G_3 G_4)$				
(10, 11, 14, 15)	1	–	1	–
(10, 11, 14, 15)	1	–	1	–

Again Compare But no match, So we stop here.

Now Final Prime Implicants :-

		A	B	C	D
(0,1)	→	0	0	0	-
(0,2,8,10)	→	-	0	-	0
(10,11,14,15)	→	1	-	1	-

$\bar{A}\bar{B}\bar{C} + \bar{B}\bar{D} + AC$ ← Ans.

No check on No Match

	0	1 ✓	2 ✓	8 ✓	10 ✓	11 ✓	14 ✓	15 ✓
(0,1)	×	⊗						
(0,2,8,10)	×		⊗	⊗	×			
(10,11,14,15)					×	⊗	⊗	⊗

Q. $F(w,x,y,z) = \Sigma_m(0,3,5,6,7,10,12,13) + d(2,9,15)$

	w	x	y	z
0	0	0	0	0
2	0	0	1	0
3	0	0	1	1
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
9	1	0	0	1
10	1	0	1	0
12	1	1	0	0
13	1	1	0	1
15	1	1	1	1

Step (a)

	w	x	y	z		
G_0	0	0	0	0	0	✓
	0	0	1	0	2	✓
G_1	0	0	1	1	3	✓
	0	1	0	1	5	✓
G_2	0	1	1	0	6	✓
	1	0	0	1	9	
	1	0	1	0	10	✓
	1	1	0	0	12	
G_3	0	1	1	1	7	✓
	1	1	0	1	13	✓
G_4	1	1	1	1	15	✓

Step (b)

(G_0, G_1)	w	x	y	z	
(0,2)	0	0	-	0	
(G_1, G_2)					
(2,3)	0	0	1	-	✓
(2,6)	0	-	1	0	✓
(2,10)	-	0	1	0	
(G_2, G_3)					
(3,7)	0	-	1	1	✓
(5,7)	0	1	-	1	✓
(6,7)	0	1	1	-	✓
(5,13)	-	1	0	1	✓
(9,13)	1	-	0	1	
(12,13)	1	1	0	-	
(G_3, G_4)					
(7,15)	-	1	1	1	✓
(13,15)	1	1	-	1	✓

Step (c)

$(G_0 G_1 - G_1 G_2)$ — No Match

$(G_1 G_2 - G_2 G_3)$				
(2,3,6,7)	0	-	1	-
(2,3,6,7)	0	-	1	-
$(G_2 G_3 - G_3 G_4)$	-	1	-	1
(5,13,7,15)				
(5,7,13,15)	-	1	-	1

Further No Match, So continue

		0 ✓	3 ✓	5 ✓	6 ✓	7 ✓	10	12	13 ✓
$\bar{w}\bar{x}\bar{z}$	0, 2	×							
$\bar{x}y\bar{z}$	2, 10						×		
$w\bar{y}z$	9, 13								×
$wx\bar{y}$	12, 13							×	×
$\bar{w}y$	2, 3, 6, 7		×		×	×			
xz	5, 7, 13, 15			×		×			×
		✓	✓	✓	✓	✓	✓	✓	✓

Only one × then circle it

$\bar{w}\bar{x}\bar{z} + \bar{w}y + xz + \bar{x}y\bar{z} + wx\bar{y}$ Ans:-

Q. $F(v,w,x,y,z) = \Sigma(0,2,5,7,9,11,13,15,16,18,21,23,25,27,29,31)$

Q. $F(w,x,y,z) = \Sigma_m(2,6,8,9,10,11,14,15)$

	w	x	y	z
2	0	0	1	0
6	0	1	1	0
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
14	1	1	1	0
15	1	1	1	1

Group - G_0
No value

G_1
0 0 1 0 → 2 ✓
1 0 0 0 → 8 ✓

G_2
0 1 1 0 → 6 ✓
1 0 0 1 → 9 ✓
1 0 1 0 → 10 ✓

G_3
1 0 1 1 → 11 ✓
1 1 1 0 → 14 ✓

G_4
1 1 1 1 → 15 ✓

Group (G_1-G_2)	w	x	y	z	
(2, 6)	0	-	1	0	✓
(2, 10)	-	0	1	0	✓
(8, 9)	1	0	0	-	✓
(8, 10)	1	0	-	0	✓

Group (G_2-G_3)					
(6, 14)	-	1	1	0	✓
(9, 11)	1	0	-	1	✓
(10, 11)	1	0	1	-	✓
(10, 14)	1	-	1	0	✓

Group (G_3-G_4)					
(11, 15)	1	-	1	1	✓
(14, 15)	1	1	1	-	✓

Group (G_1G_2 - G_2G_3)	w	x	y	z	
(2, 6, 10, 14)	-	-	1	0	✓
(2, 6, 10, 14)	-	-	1	0	
(8, 9, 10, 11)	1	0	-	-	✓
(8, 9, 10, 11)	1	0	-	-	

(G_2G_3 - G_3G_4)					
(10, 11, 14, 15)	1	-	1	-	✓
(10, 11, 14, 15)	1	-	1	-	

PI		✓ 2	✓ 6	✓ 8	✓ 9	✓ 10	✓ 11	✓ 14	15
yz'	2, 6, 10, 14	⊗	⊗			x		x	
wx'	8, 9, 10, 11			⊗	⊗	x	x		
wy	10, 11, 14, 15					x	x	x	⊗
		✓	✓	✓	✓				✓

Essential Prime Implicants. $\Rightarrow yz' + wx' + wy$

<u>By using K-map</u> :-

wx \ yz	00	01	11	10
00				1
01				1
11			1	1
10	1	1	1	1

$w\bar{x} + wy + y\bar{z}$ Ans.

$F(A,B,C,D) = \Sigma_m(4,8,10,11,12,15) + d(9,14)$

	A	B	C	D
4	0	1	0	0
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
14	1	1	1	0
15	1	1	1	1

G_0 → No value

G_1

0	1	0	0	→ 4 ✓
1	0	0	0	→ 8 ✓

G_2

1	0	0	1	→ 9 ✓
1	0	1	0	→ 10 ✓
1	1	0	0	→ 12 ✓

G_3

1	0	1	1	→ 11 ✓
1	1	1	0	→ 14 ✓

G_4

1	1	1	1	→ 15 ✓

Group

$(G_1 - G_2)$

(4,12)	-	1	0	0
(8,9)	1	0	0	-
(8,10)	1	0	-	0 ✓
(8,12)	1	-	0	0 ✓

$G_2 - G_3$

(9,11)	1	0	-	1 ✓
(10,14)	1	-	1	0 ✓
(12,14)	1	1	-	0 ✓

$(G_3 - G_4)$

(11,15)	1	-	1	1 ✓
(14,15)	1	1	1	-

$(G_1 G_2 - G_2 G_3)$

	A	B	C	D
(8, 9, 10, 11)	1	0	–	–
(8, 10, 12, 14)	1	–	–	0
(8, 10, 12, 14)	1	–	–	0

$G_2 G_3 - G_3 G_4$

	A	B	C	D
(10, 11, 14, 15)	1	–	1	–

		4	8	10	11	12	15
$B\bar{C}\bar{D}$	(4, 12)	x				x	
$A\bar{B}\bar{C}$	(8, 9)		x				
ABC	(14, 15)						x
$A\bar{B}$	(8, 9, 10, 11)		x	x	x		
$A\bar{D}$	(8, 10, 12, 14)		x	x		x	
AC	(10, 11, 14, 15)			x	x		x

~~$A\bar{B}\bar{C} + ABC$~~ ~~$B\bar{C}\bar{D} + A\bar{B}\bar{D} + ACD$~~

(8, 10, 11, 15) → unticked

$B\bar{C}\bar{D} + A\bar{B} + AC$ Ans.

AB \ CD	00	01	11	10
00				
01	1			
11	1		1	d
10	1	d	1	1

AC

$A\bar{B}$

$A\bar{B} + AC + B\bar{C}\bar{D} = A\bar{B} + AC + B\bar{C}\bar{D}$ Ans.

$$Y(A,B,C,D) = \Sigma_m(4,6,9,10,11,13) + \Sigma_d(2,12,15)$$

	A	B	C	D
2	0	0	1	0
4	0	1	0	0
6	0	1	1	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
15	1	1	1	1

$G_0 \rightarrow$ No - value

$G_1 \rightarrow$	0	0	1	0	(2) ✓
	0	1	0	0	(4) ✓
$G_2 \rightarrow$	0	1	1	0	(6) ✓
	1	0	0	1	(9) ✓
	1	0	1	0	(10) ✓
	1	1	0	0	(12) ✓
$G_3 \rightarrow$	1	0	1	1	(11) ✓
	1	1	0	1	(13) ✓
$G_4 \rightarrow$	1	1	1	1	(15) ✓

Group $(G_1 - G_2)$

	A	B	C	D
(2,6)	0	-	1	0
(2,10)	-	0	1	0
(4,6)	0	1	-	0
(4,12)	-	1	0	0

Group $(G_2 - G_3)$

(9,11)	1	0	-	1 ✓
(9,13)	1	-	0	1 ✓
(10,11)	1	0	1	-
(12,13)	1	1	0	-

Group $(G_3 - G_4)$

(11-15)	1	-	1	1 ✓
(13-15)	1	1	-	1 ✓

Group $(G_1G_2 - G_2G_3)$

No Match

Group $(G_2 - G_3) - (G_3 - G_4)$

(9,11,13,15)	1	-	-	1
(9,11,13,15)	1	-	-	1

		4	6	9 ✓	10	11 ✓	13 ✓
(2,6)	$\bar{A} C \bar{D}$		x				
(2,10)	$\bar{B} C \bar{D}$				x		
(4,6)	$\bar{A} B \bar{D}$	x	x				
(4,12)	$B \bar{C} \bar{D}$	x					
(10,11)	$A \bar{B} C$				x	x	
(12,13)	$A B \bar{C}$						x
(9,11,13,15)	AD			x		x	x

Single cross

9,11,13,15 → cover
4,6,10, → Remaining

$\underline{AD} + \bar{A} B \bar{D} + A \bar{B} C$ Ans.

By using K-map.

AB \ CD	00	01	11	10
00				d
01	1			1
11	d	1	d	
10		1	1	1

$AD + \bar{A} B \bar{D} + A \bar{B} C$

3-Variable K-map :- Three variables are there. A, B, C

no. of cell = 3

$2^n = 2^3 = 8$

B \ AC	00	01	11	10
0				
1				

OR

C \ AB	00	01	11	10
0				
1				

OR

A \ BC	00	01	01	10
0				
1				

OR we can Represent this in vertical manner.

BC \ A	0	1
00		
01		
11		
10		

OR

AC \ B		

OR

BA \ C		

4-Variable K-map :- Four variable are there. ABCD.

no. of cell = 4

$2^n = 2^4 = 16$

AB \ CD	00	01	11	10
00				
01				
11				
10				

OR

CD \ AB	00	01	11	10
00				
01				
11				
10				