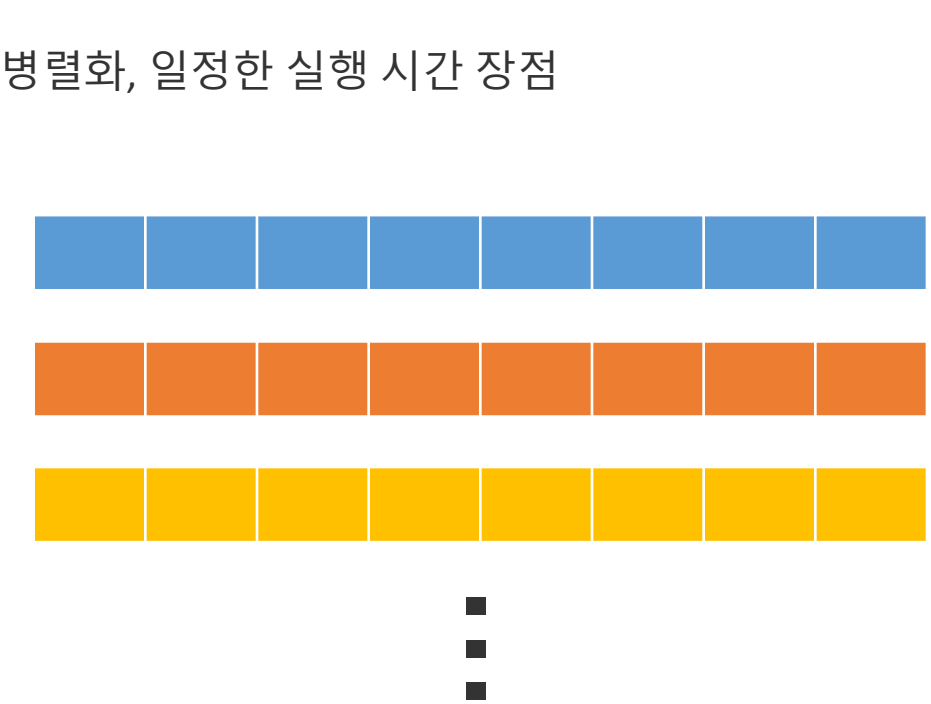
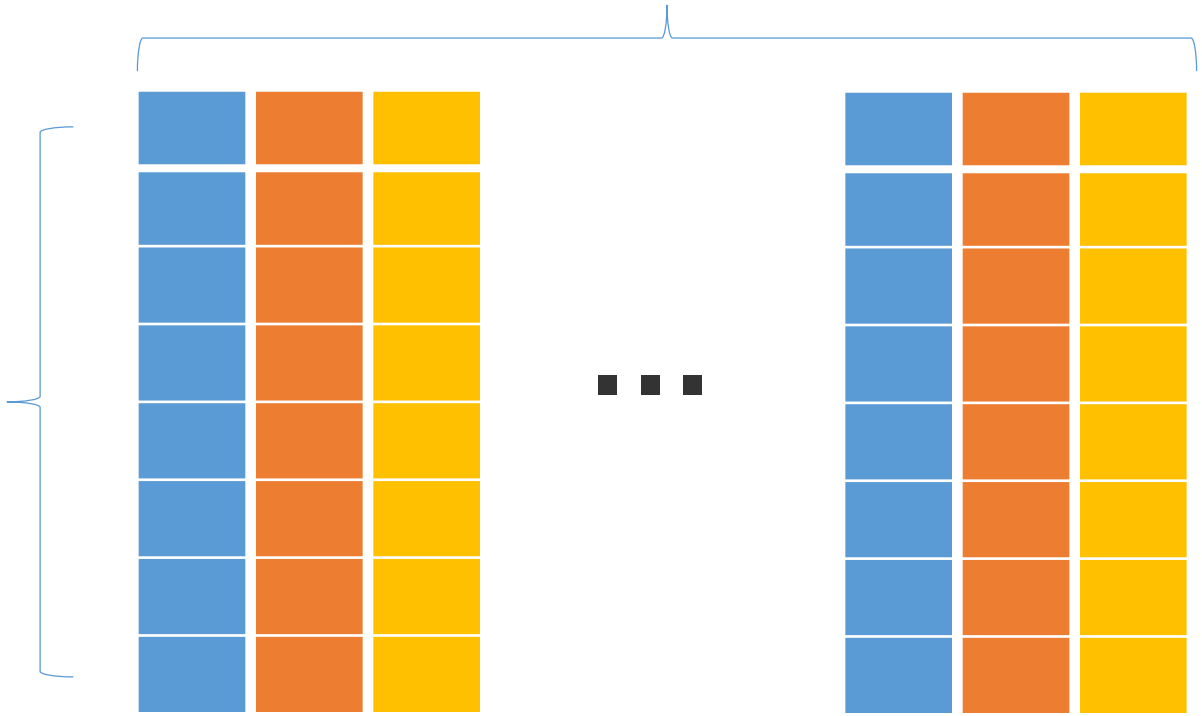
KARNAUGH MAPS를 사용한 S-box 비트슬라이스 변환 방법

https://youtu.be/N9h4eaMKogM

비트 슬라이싱

- Eli Biham이 A Fast New DES Implementation in Software 라는 논문에서 처음 사용
- 하드웨어에서 논리 회로를 구현하는 것처럼 단일 비트 논리 연산(*AND* , *XOR* , *OR* , *NOT* 등) 으로 기능을 표현
- 그런 다음 CPU에서 비트 연산을 사용하여 병렬로 함수의 여러 인스턴스를 수행
- 속도, 병렬화, 일정한 실행 시간 장점





KARNAUGH MAPS

- 3-to-2-bit S-box

```
uint8_t  SBOX [] = { 1 , 0 , 3 , 1 , 2 , 2 , 3 , 0 };
```

f(0,0,0) = 0b01, f(0,0,1) = 0b00, f(0,1,0) = 0b11, ⋯

SBOX(a,b,c)

abc	out
000	01
001	00
010	11
011	01
100	10
101	10
110	11
111	00

$f_L(a,b,c)$

abc	out
000	0
001	0
010	1
011	0
100	1
101	1
110	1
111	0

$f_R(a,b,c)$

abc	out
000	1
001	0
010	1
011	1
100	0
101	0
110	1
111	0

KARNAUGH MAPS

- K-맵을 사용한 S-박스 비트슬라이스

uint8_t SBOX [] = { 1 , 0 , 3 , 1 , 2 , 2 , 3 , 0 };

f(0,0,0) = 0b01, f(0,0,1) = 0b00, f(0,1,0) = 0b11, ⋯

SBOX(a,b,c)

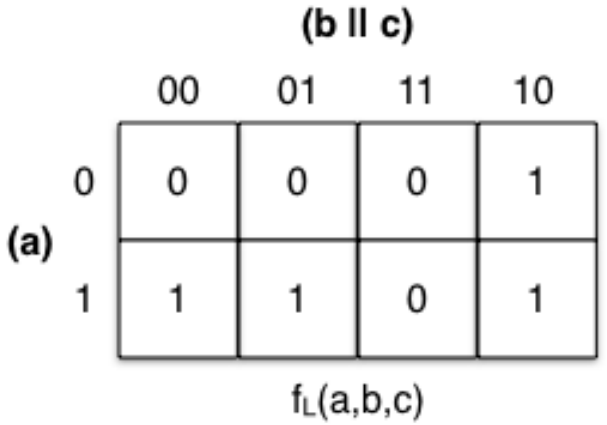
abc	out
000	01
001	00
010	11
011	01
100	10
101	10
110	11
111	00

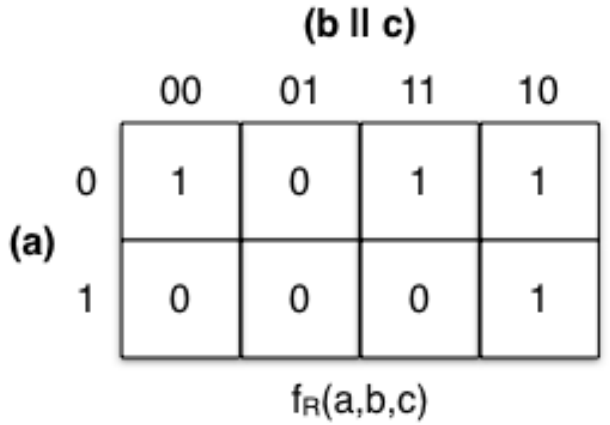
$f_L(a,b,c)$

abc	out
000	0
001	0
010	1
011	0
100	1
101	1
110	1
111	0

$f_R(a,b,c)$

abc	out
000	1
001	0
010	1
011	1
100	0
101	0
110	1
111	0

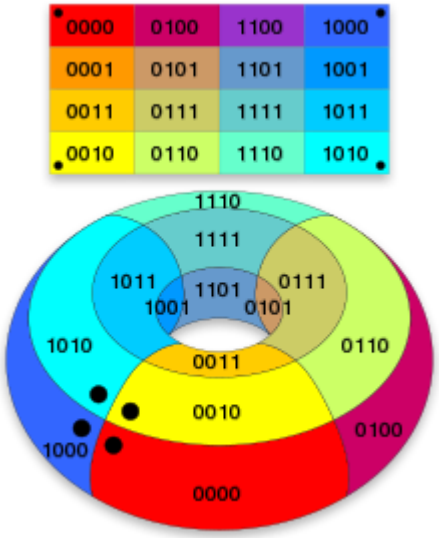




그룹화

인접 셀 그룹이 1인 값을 찾기 - K-map을 통해 부울 표현식을 단순화

- 2^n개의 1의 값을 가진 사각형 그룹 (0이 포함될 수 없음)
- 가능한 크고 적은 수의 그룹이 있어야함
- 그룹은 겹칠 수 있음



(b ll c)

(a)	00	01	11	10
0	0	0	0	1
1	1	1	0	1

$f_L(a,b,c)$

(b ll c)

(a)	00	01	11	10
0	1	0	1	1
1	0	0	0	1

$f_R(a,b,c)$

(b ll c)

(a)	00	01	11	10
0	0	0	0	**1**
1	**1**	**1**	0	**1**

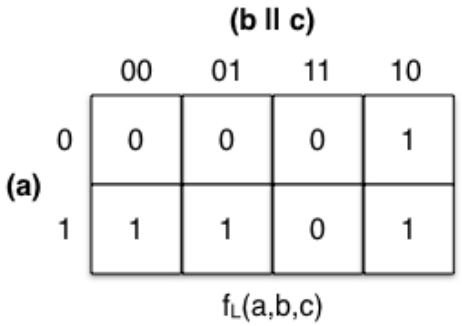
$f_L(a,b,c)$

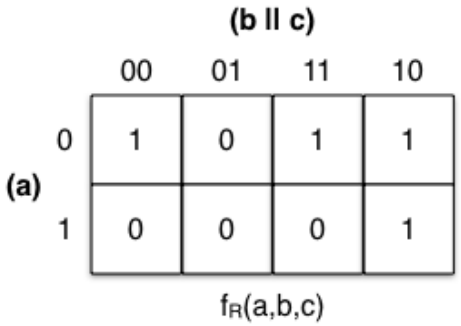
(b ll c)

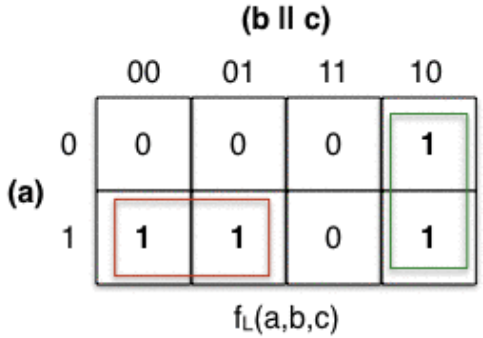
(a)	00	01	11	10
0	**1**	0	**1**	**1**
1	0	0	0	**1**

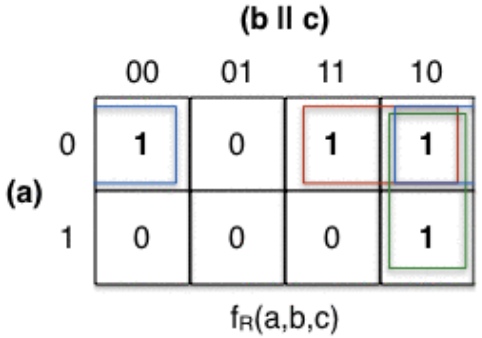
$f_R(a,b,c)$

BITSLICED SBOX()









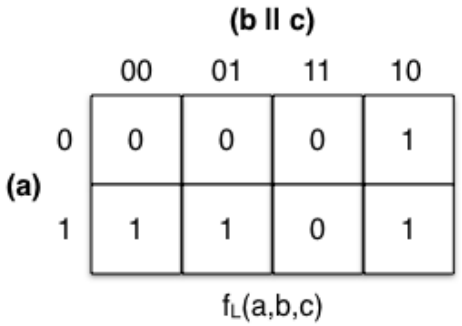
- $f_{L(a,b,c)}$

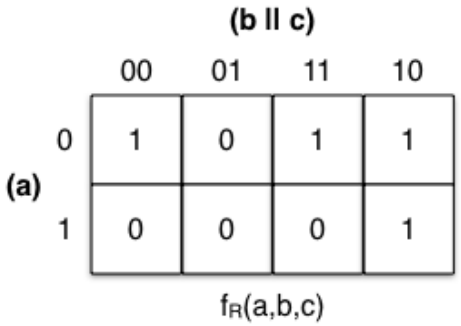
빨간색 그룹 100, 101.
a=1및 b=0는 그룹에 포함. c는 값의 변화와 무관 (a & ~b)

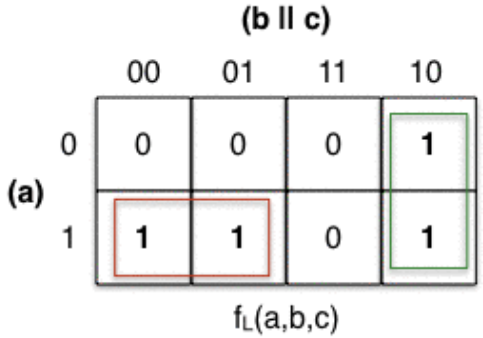
녹색 그룹 010, 110.
a 무시, b=1, c=0. (b & ~c)

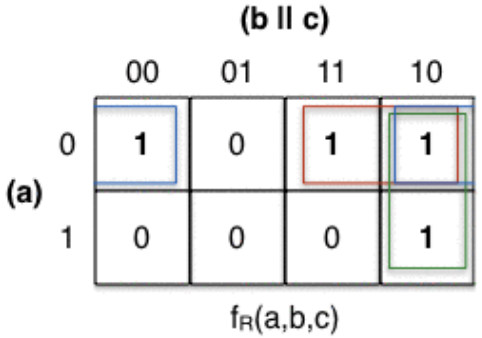
```
uint8_t SBOXL(uint8_t a, uint8_t b, uint8_t c) {
  return (a & ~b) | (b & ~c);
}
```

BITSLICED SBOX()









- $f_{R(a,b,c)}$

011, 010 (~a & b)
010, 110 (b & ~c)
000, 010 (~a & ~c)

```
uint8_t SBOXR(uint8_t a, uint8_t b, uint8_t c) {
  return (~a & b) | (b & ~c) | (~a & ~c);
}
```

BITSLICED SBOX()

```
uint8_t SBOXL(uint8_t a, uint8_t b, uint8_t c) {
  return (a & ~b) | (b & ~c);
}
```

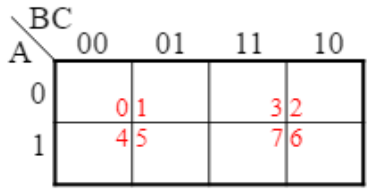
```
uint8_t SBOXR(uint8_t a, uint8_t b, uint8_t c) {
  return (~a & b) | (b & ~c) | (~a & ~c);
}
```

```
void SBOX(uint8_t a, uint8_t b, uint8_t c, uint8_t* l, uint8_t* r) {
  uint8_t na = ~a;
  uint8_t nb = ~b;
  uint8_t nc = ~c;

  uint8_t t0 = b & nc;

  *l = (a & nb) | t0;
  *r = (na & b) | (na & nc) | t0;
}
```

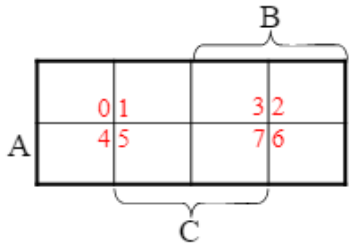
```
void SBOX(uint8_t a, uint8_t b, uint8_t c, uint8_t* l, uint8_t* r) {
  uint8_t na = ~a;
  uint8_t nb = ~b;
  uint8_t nc = ~c;

  uint8_t t0 = b & nc;
  uint8_t t1 = b | nc;

  *l = (a & nb) | t0;
  *r = (na & t1) | t0;
}
```

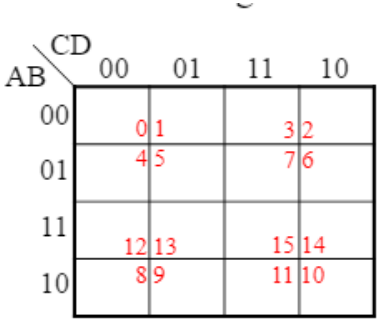
n-variable K-map

form 1

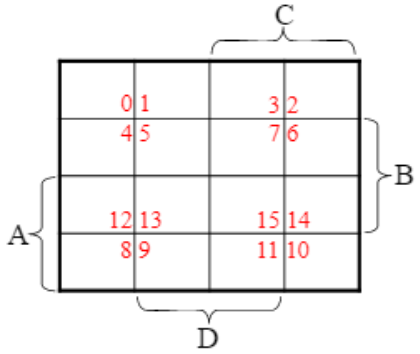


form 2

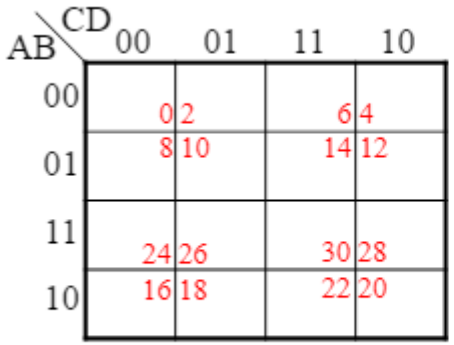




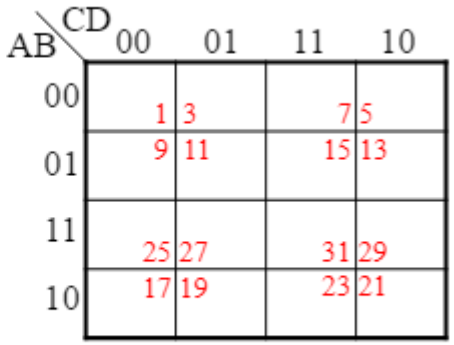
form 1



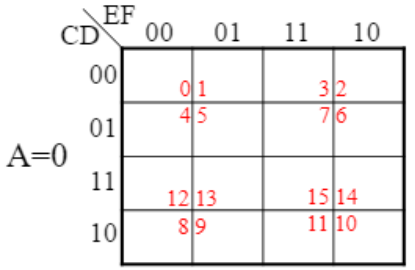
form 2

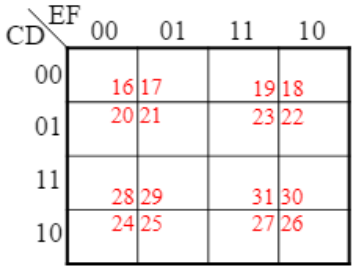


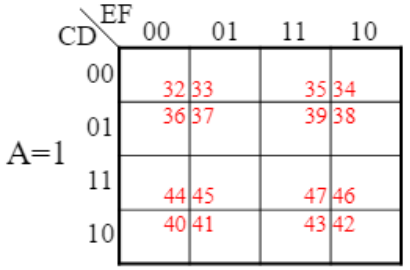
E=0



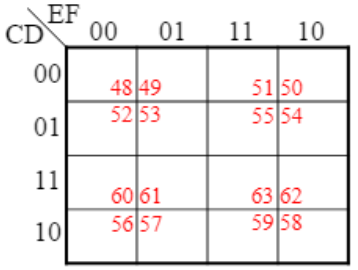
E=1







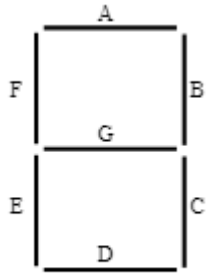
B=0

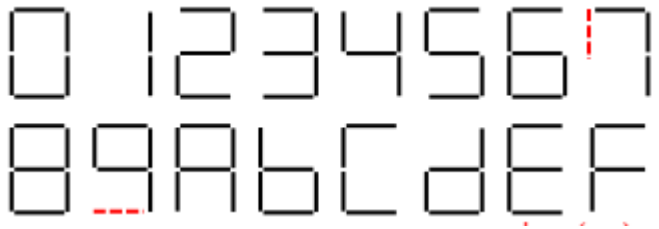


B=1

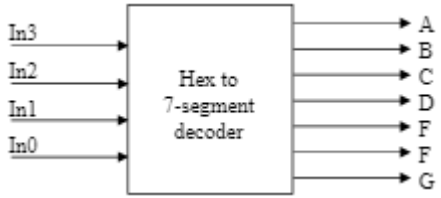
Example

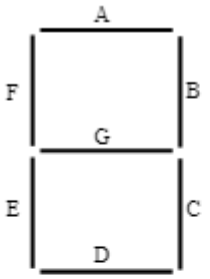
- 7-segment display decoder





7 segments



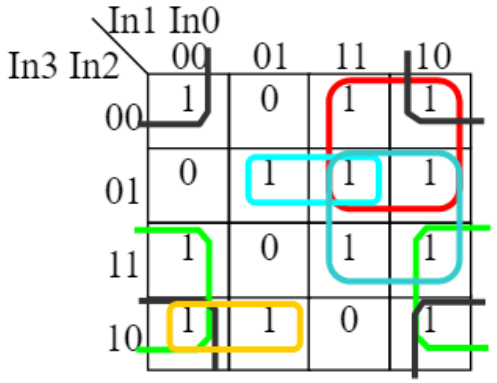


--- = don't care

In3	In2	In1	In0	A	B	C	D	E	F	G
0	0	0	0	1	1	1	1	1	1	0
0	0	0	1	0	1	1	0	0	0	0
0	0	1	0	1	1	0	1	1	0	1
0	0	1	1	1	1	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1	1
0	1	0	1	1	0	1	1	0	1	1
0	1	1	0	1	0	1	1	1	1	1
0	1	1	1	1	1	1	0	0	X	0
1	0	0	0	1	1	1	1	1	1	1
1	0	0	1	1	1	1	X	0	1	1
1	0	1	0	1	1	1	0	1	1	1
1	0	1	1	0	0	1	1	1	1	1
1	1	0	0	1	0	0	1	1	1	0
1	1	0	1	0	1	1	1	1	0	1
1	1	1	0	1	0	0	1	1	1	1
1	1	1	1	1	0	0	0	1	1	1

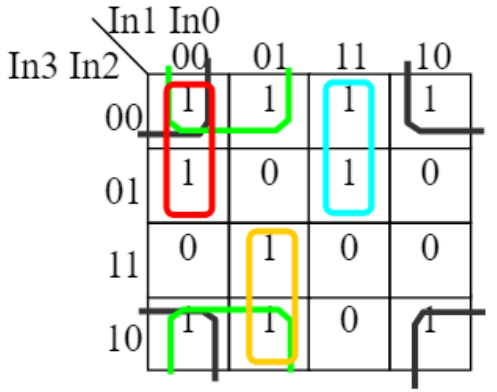
Example

In3	In2	In1	In0	A	B	C	D	E	F	G
0	0	0	0	1	1	1	1	1	1	0
0	0	0	1	0	1	1	0	0	0	0
0	0	1	0	1	1	0	1	1	0	1
0	0	1	1	1	1	1	1	0	0	1
0	1	0	0	0	1	1	0	0	1	1
0	1	0	1	1	0	1	1	0	1	1
0	1	1	0	1	0	1	1	1	1	1
0	1	1	1	1	1	1	0	0	0	0
1	0	0	0	1	1	1	1	1	1	1
1	0	0	1	1	1	1	0	0	1	1
1	0	1	0	1	1	1	0	1	1	1
1	0	1	1	0	0	1	1	1	1	1
1	1	0	0	1	0	0	1	1	1	0
1	1	0	1	0	1	1	1	1	0	1
1	1	1	0	1	0	0	1	1	1	1
1	1	1	1	1	0	0	0	1	1	1



K-map for A output

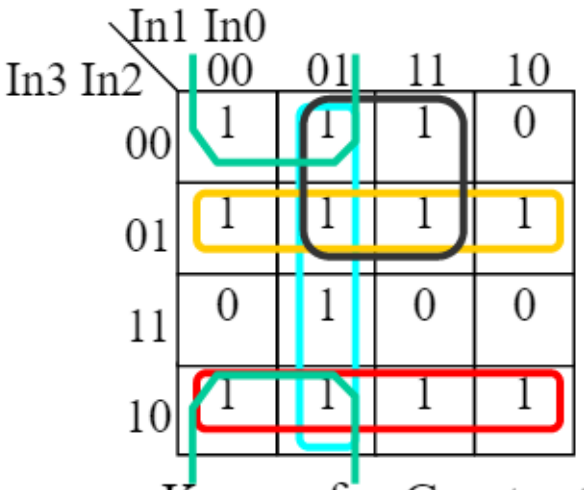
A = In2'In0' + In3'In1 + In2 In1
+ In3 In0' + In3'In2 In0 + In3 In2'In1'



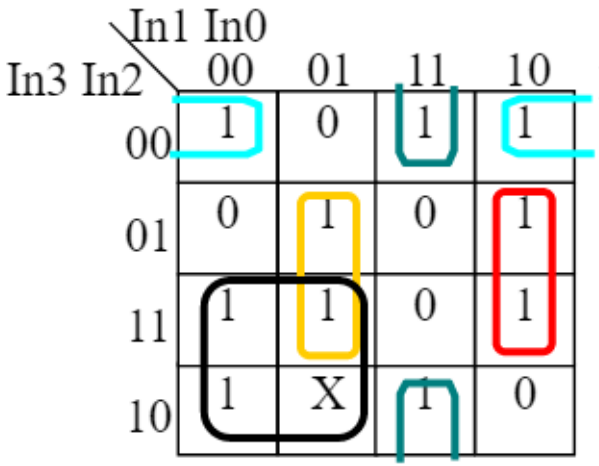
K-map for B output

B = In2'In0' + In2'In1' + In3'In1'In0'
+ In3 In1'In0 + In3'In1 In0

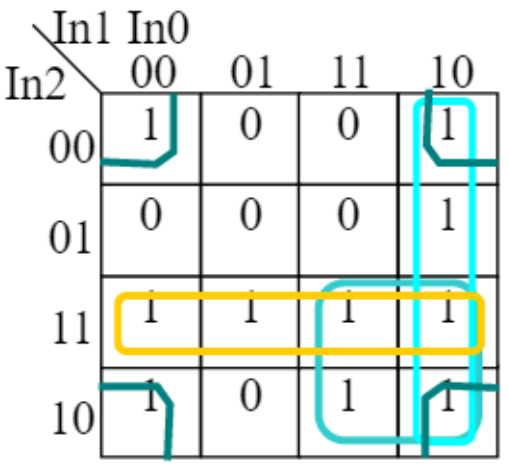
Example



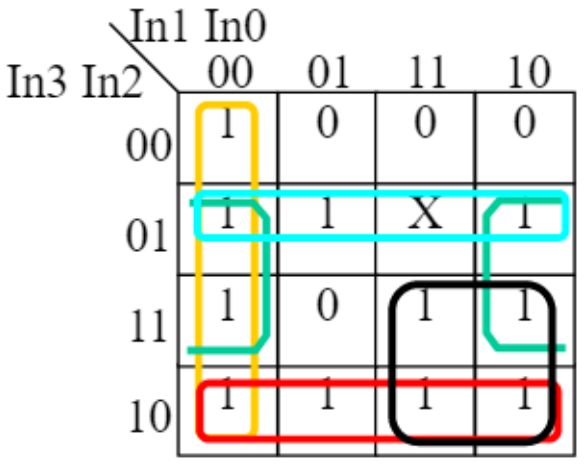
K-map for C output



K-map for D output



K-map for E output



K-map for F output

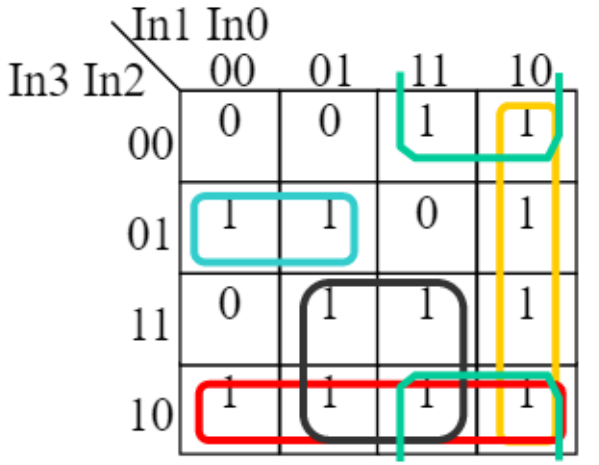
C = In3 In2’ + In1’In0 + In2’In1’ + In3’In0 + In3’In2

D = In3’In2’In0’ + In2’In1 In0 + In2 In1’In0
+ In3 In1’ + In2 In1 In0’

E = In2’In0’ + In3 In2 + In1 In0’ + In3 In1

F = In1’In0’ + In3 In2’ + In2 In0’ + In3 In1 + In3’In2

G = In3 In2’ + In1 In0’ + In3 In0 + In3’In2 In1’ + In2’In1



K-map for G output

Q & A