※ Synchronous finite state machine specification:

Repetitive state order: 2, 7, 13, 6, 12, 14, 4, 3, 8, 1, 10, 5

Z active on state: 7.

※ Asynchronous finite state machine specification:

Lock sequence: 5, 2, 4, 1, 9.

(1) state diagram (2) state table (3) code assignment (4) transition table (5) K-map

(6) minimised transition table (7) force it into not-allowed state

(8) inclusion of transition equations assuming D-type flip-flops

~~Moore model finite state machine~~

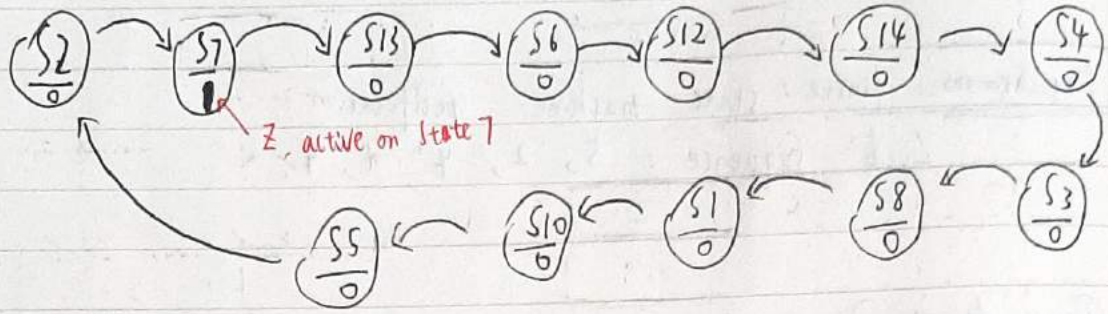
2)

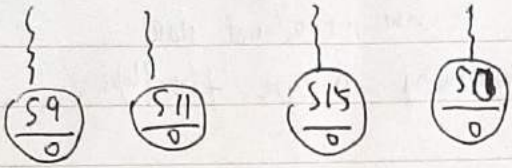
Synchronous

Output active on state 7.
Order of allowed states: 2, 7, 13, 6, 12, 14, 4, 3, 8, 1, 10, 5

Assume there are 16 states in total. Then unallocated states are 0, 9, 11, 15.

State diagram:





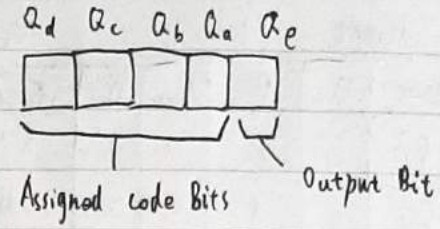
Unallocated states

State table:

Present state	Next State	Present Output
S2	S7	0
S7	S13	1
S13	S6	0
S6	S12	0
S12	S14	0
S14	S4	0
S4	S3	0
S3	S8	0
S8	S1	0
S1	S10	0
S10	S5	0
S5	S2	0
S9	?	0
S11	?	0
S15	?	0
S0	?	0

Assign binary Gray code to each of these states.

State	Assigned code Q_d Q_c Q_b Q_a
S0	0 0 0 0
S1	0 0 0 1
S2	0 0 1 1
S3	0 0 1 0
S4	0 1 1 0
S5	0 1 1 1
S6	0 1 0 1
S7	0 1 0 0
S8	1 1 0 0
S9	1 1 0 1
S10	1 1 1 1
S11	1 1 1 0
S12	1 0 1 0
S13	1 0 1 1
S14	1 0 0 1
S15	1 0 0 0



We can reduce the code to four bits.

Present Time		Future time
D_n	Q_n	Q_{n+1}
0	0	0
0	1	0
1	0	1
1	1	1

Full-Form Transition Table of D-type

D-type flip-flops will be used in this assignment.

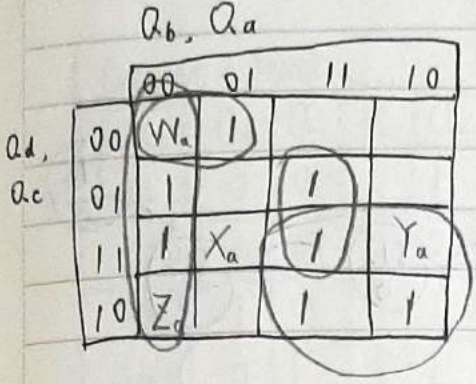
4)

The transition table can be derived: (ordered by specification)

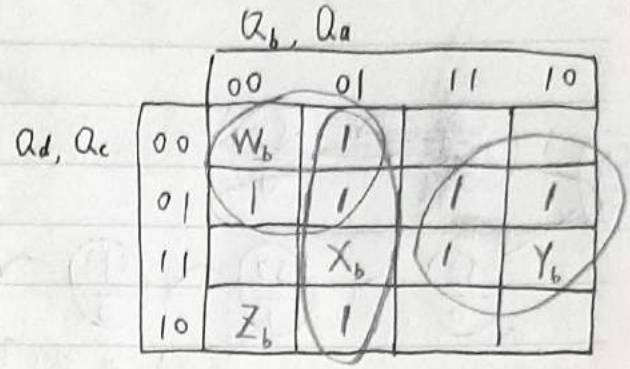
Current State					Next State					Next D-Inputs				Z
State	Q_d	Q_c	Q_b	Q_a	State	Q_d	Q_c	Q_b	Q_a	D_d	D_c	D_b	D_a	
S2	0	0	1	1	S7	0	1	0	0	0	1	0	0	
S7	0	1	0	0	S13	1	0	1	1	1	0	1	1	1
S13	1	0	1	1	S6	0	1	0	1	0	1	0	1	
S6	0	1	0	1	S12	1	0	1	0	1	0	1	0	
S12	1	0	1	0	S14	1	0	0	1	1	0	0	1	
S14	1	0	0	1	S4	0	1	1	0	0	1	1	0	
S4	0	1	1	0	S3	0	0	1	0	0	0	1	0	
S3	0	0	1	0	S8	1	1	0	0	1	1	0	0	
S8	1	1	0	0	S1	0	0	0	1	0	0	0	1	
S1	0	0	0	1	S10	1	1	1	1	1	1	1	1	
S10	1	1	1	1	S5	0	1	1	1	0	1	1	1	
S5	0	1	1	1	S2	0	0	1	1	0	0	1	1	
S0	0	0	0	0	?	W_d	W_c	W_b	W_a	W_d	W_c	W_b	W_a	
S9	1	1	0	1	?	X_d	X_c	X_b	X_a	X_d	X_c	X_b	X_a	
S11	1	1	1	0	?	Y_d	Y_c	Y_b	Y_a	Y_d	Y_c	Y_b	Y_a	
S15	1	0	0	0	?	Z_d	Z_c	Z_b	Z_a	Z_d	Z_c	Z_b	Z_a	

Z active on S7, $Z = \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a$

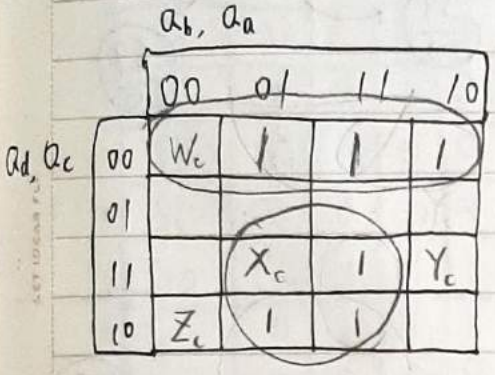
K-maps:



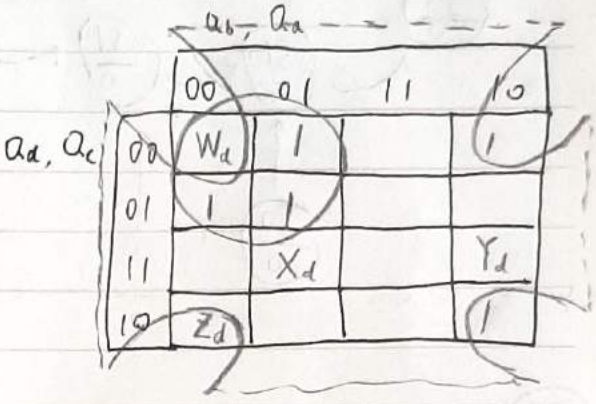
Transition Logic for D_a



Transition Logic for D_b



Transition Logic for D_c



Transition Logic for D_d

According to above, we can get

S0 → $W_d W_c W_b W_a = 1111$, corresponding to S10 which is an allowed state.

S9 → $X_d X_c X_b X_a = 0110$, corresponding to S4 which is allowed.

S11 → $Y_d Y_c Y_b Y_a = 0011$, corresponding to S2 which is allowed.

S15 → $Z_d Z_c Z_b Z_a = 1001$, corresponding to S14 which is allowed.

Then we can confirm the design can satisfy the specification.

$$D_a = \bar{Q}_b \bar{Q}_a + \bar{Q}_d \bar{Q}_c \bar{Q}_b + Q_c Q_b Q_a + Q_d Q_b$$

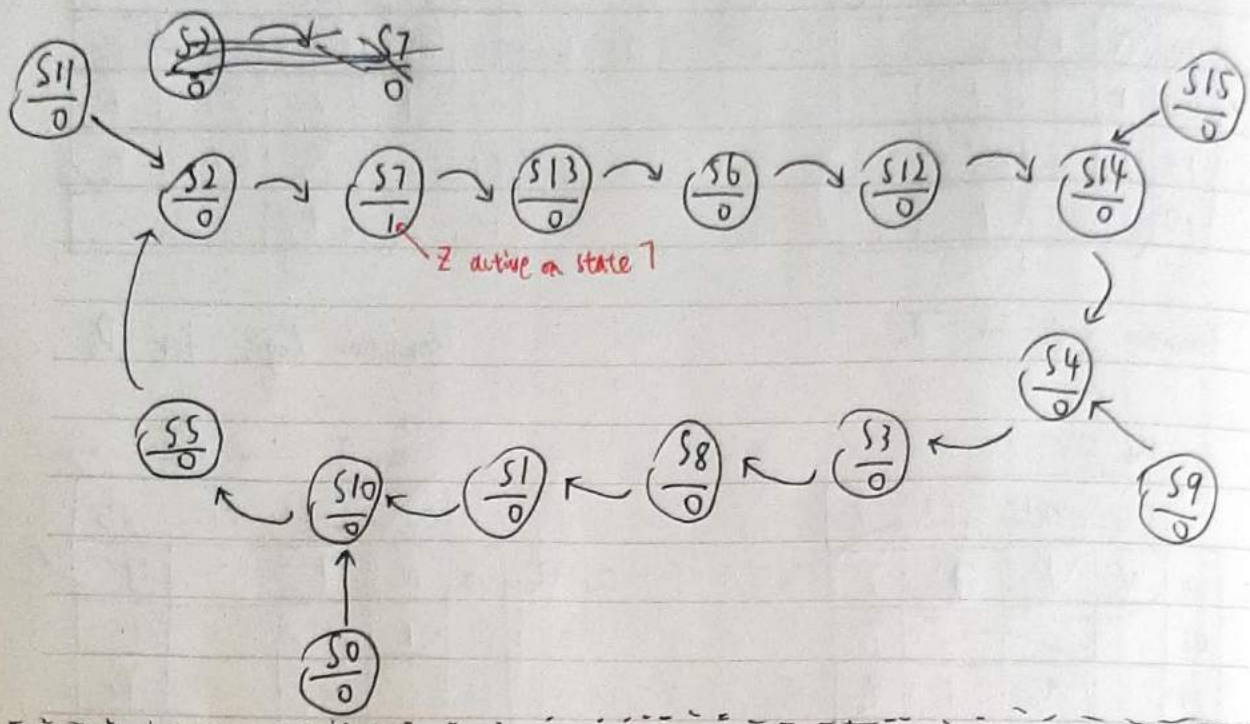
$$D_b = \bar{Q}_d \bar{Q}_b + \bar{Q}_b Q_a + Q_c Q_b$$

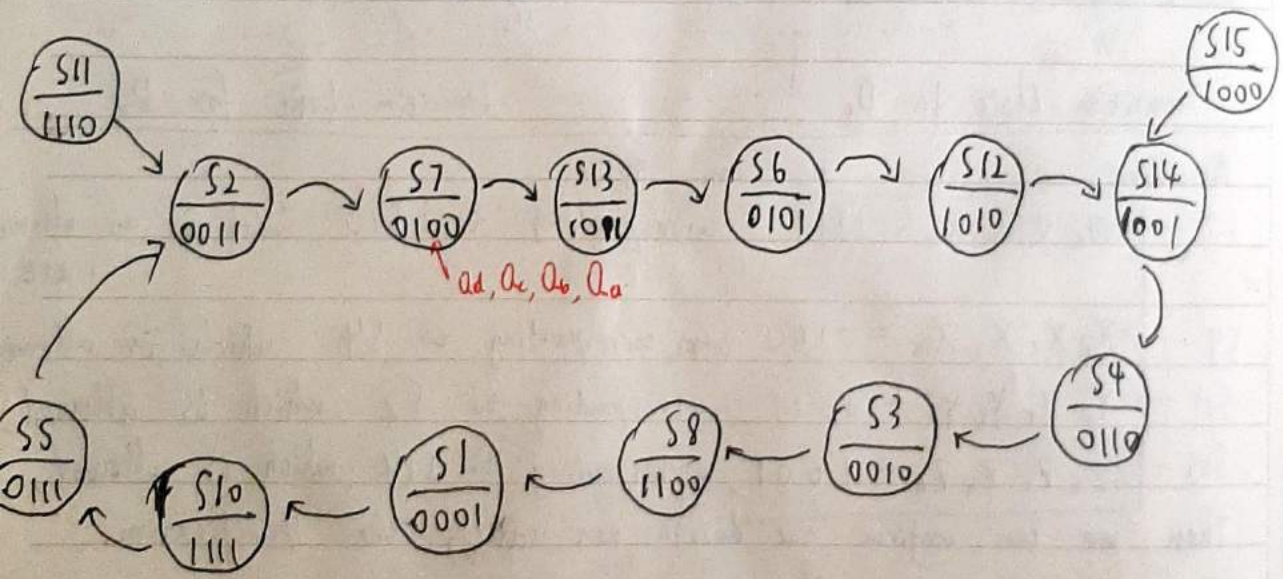
$$D_c = \bar{Q}_d \bar{Q}_c + Q_d Q_a$$

$$D_d = \bar{Q}_d \bar{Q}_b + \bar{Q}_c \bar{Q}_a$$

6)

Re-draw the final state Diagram:





Final transition Table :

Current State					Next State					Next D-Inputs				Z
State	Q_d	Q_c	Q_b	Q_a	State	Q_d	Q_c	Q_b	Q_a	D_d	D_c	D_b	D_a	
S2	0	0	1	1	S7	0	1	0	0	0	1	0	0	0
S7	0	1	0	0	S13	1	0	1	1	1	0	1	1	1
S13	1	0	1	1	S6	0	1	0	1	0	1	0	1	0
S6	0	1	0	1	S12	1	0	1	0	1	0	1	0	0
S12	1	0	1	0	S14	1	0	0	1	1	0	0	1	0
S14	1	0	0	1	S4	0	1	1	0	0	1	1	0	0
S4	0	1	1	0	S3	0	0	1	0	0	0	1	0	0
S3	0	0	1	0	S8	1	1	0	0	1	1	0	0	0
S8	1	1	0	0	S1	0	0	0	1	0	0	0	1	0
S1	0	0	0	1	S10	1	1	1	1	1	1	1	1	0
S10	1	1	1	1	S5	0	1	1	1	0	1	1	1	0
S5	0	1	1	1	S2	0	0	1	1	0	0	1	1	0
S0	0	0	0	0	S10	1	1	1	1	1	1	1	1	0
S9	1	1	0	1	S4	0	1	1	0	0	1	1	0	0
S11	1	1	1	0	S2	0	0	1	1	0	0	1	1	0
S15	1	0	0	0	S14	1	0	0	1	1	0	0	1	0

Asynchronous

Key 1	Key 2	Key 3	Key 4	Key 5
5	2	4	1	9

State Diagram:

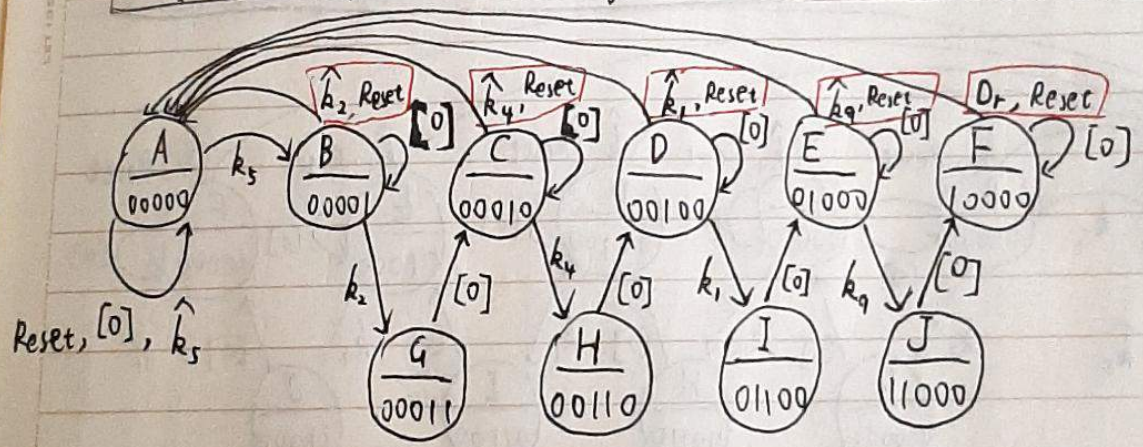
First, we should define some pre-processed functions. As the five-digit code sequence is 5,2,4,1,9 in specification, ~~Let~~ Pre-prossed functions are as following:

~~k_x: represent key number 5 pressed and no other key~~

k_x: represent key number X (0~9) pressed and no other key.

$\hat{k}_x$: represent any key other than key X, or a combination of keys pressed.

[0]: represent no keys pressed

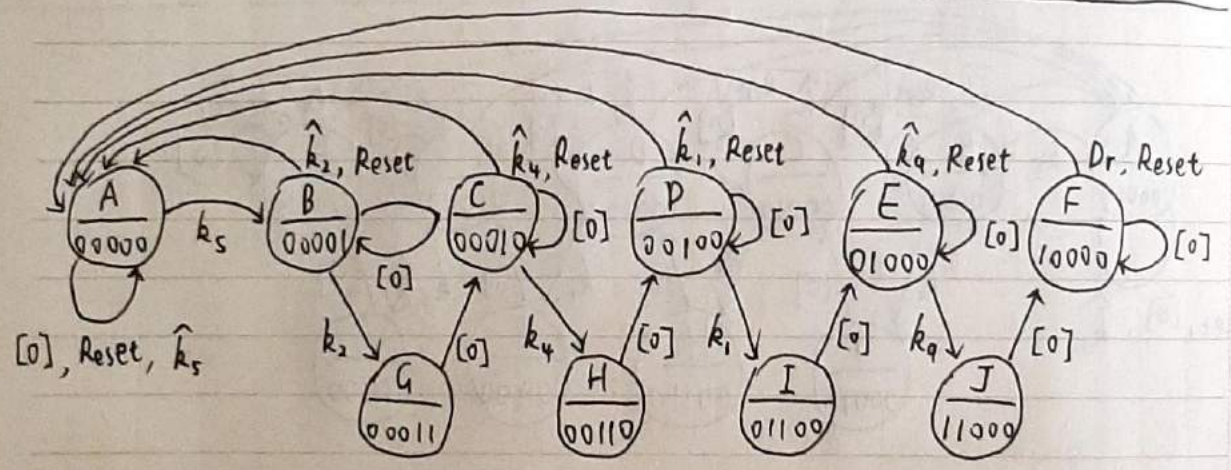


In order to add fraud-protection transitions and avoid race hazards, we use one-hot ~~code str~~ and ~~two-h~~ two-hot code strategy to assign states.

Code Assignment :

State	Q_e	Q_d	Q_c	Q_b	Q_a	Z
A	0	0	0	0	0	0
B	0	0	0	0	1	0
C	0	0	0	1	0	0
P	0	0	1	0	0	0
E	0	1	0	0	0	0
F	1	0	0	0	0	1
G	0	0	0	1	1	0
H	0	0	1	1	0	0
I	0	1	1	0	0	0
J	1	1	0	0	0	0

Lock sequence: 52419



Flow Table :

Current State	Next State												
	Reset	[0]	k_5	$\hat{k}_5$	k_2	$\hat{k}_2$	k_4	$\hat{k}_4$	k_1	$\hat{k}_1$	k_9	$\hat{k}_9$	D_r
A	A	A	B	A									
B	A	B			G	A							
C	A	C					H	A					
D	A	D							I	A			
E	A	E									J	A	
F	A	F											A
G		C											
H		D											
I		E											
J		F											

Transition Table

Present State																	Next State					
State	Q_e	Q_d	Q_c	Q_b	Q_a	Reset	[0]	k_5	$\hat{k}_5$	k_2	$\hat{k}_2$	k_4	$\hat{k}_4$	k_1	$\hat{k}_1$	k_3	$\hat{k}_3$	D_r	State	Q_e	Q_d	Q_c	Q_b	Q_a
A	0	0	0	0	0	1													A	0	0	0	0	0
A	0	0	0	0	0		1												A	0	0	0	0	0
A	0	0	0	0	0			1											B	0	0	0	0	1
A	0	0	0	0	0				1										A	0	0	0	0	0
B	0	0	0	0	1	1													A	0	0	0	0	0
B	0	0	0	0	1		1												B	0	0	0	0	1
B	0	0	0	0	1					1									G	0	0	0	1	1
B	0	0	0	0	1						1								A	0	0	0	0	0
C	0	0	0	1	0	1													A	0	0	0	0	0
C	0	0	0	1	0		1												C	0	0	0	1	0
C	0	0	0	1	0							1							H	0	0	1	1	0
C	0	0	0	1	0								1						A	0	0	0	0	0
D	0	0	1	0	0	1													A	0	0	0	0	0
D	0	0	1	0	0		1												D	0	0	1	0	0
D	0	0	1	0	0									1					I	0	1	1	0	0
D	0	0	1	0	0										1				A	0	0	0	0	0
E	0	1	0	0	0	1													A	0	0	0	0	0
E	0	1	0	0	0		1												E	0	1	0	0	0
E	0	1	0	0	0											1			J	1	1	0	0	0
E	0	1	0	0	0												1		A	0	0	0	0	0
F	1	0	0	0	0	1													A	0	0	0	0	0
F	1	0	0	0	0		1												F					
F	1	0	0	0	0													1	A	0	0	0	0	0
G	0	0	0	1	1		1												C	0	0	0	1	0
H	0	0	1	1	0		1												D	0	0	1	0	0
I	0	1	1	0	0		1												E	0	1	0	0	0
J	1	1	0	0	0		1												F	1	0	0	0	0

14

Expand the pre-processed functions:

~~$[0] = \bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$~~

$k_5 = \bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ k_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$

$\hat{k}_5 = \overline{\bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ k_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9}$

$k_2 = \bar{k}_0\ \bar{k}_1\ k_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$

$\hat{k}_2 = \overline{\bar{k}_0\ \bar{k}_1\ k_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9}$

$k_4 = \bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ k_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$

$\hat{k}_4 = \overline{\bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ k_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9}$

$k_1 = \bar{k}_0\ k_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$

$\hat{k}_1 = \overline{\bar{k}_0\ k_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9}$

$k_9 = \bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ k_9$

$\hat{k}_9 = \overline{\bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ k_9}$

$[0] = \bar{k}_0\ \bar{k}_1\ \bar{k}_2\ \bar{k}_3\ \bar{k}_4\ \bar{k}_5\ \bar{k}_6\ \bar{k}_7\ \bar{k}_8\ \bar{k}_9$

Note: Ten keys on key board

Extraction of implicants:

$$Q_a = \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{Q}_a k_5 + \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a [0] + \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a k_6$$
$$= \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ k5\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a \bar{k0}\ \bar{k1}\ k2\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$

$$Q_b = \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a k_2 + \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a k_4 + \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a [0]$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b Q_a [0]$$
$$= \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a \bar{k0}\ \bar{k1}\ k2\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ k4\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b Q_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$

$$Q_c = \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a k_4 + \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a [0] + \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a k_1$$
$$+ \bar{Q}_e \bar{Q}_d Q_c Q_b \bar{Q}_a [0]$$
$$= \bar{Q}_e \bar{Q}_d \bar{Q}_c Q_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ k4\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a \bar{k0}\ k1\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e \bar{Q}_d Q_c Q_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$

$$Q_d = \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a k_1 + \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a [0] + \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a k_9$$
$$+ \bar{Q}_e Q_d Q_c \bar{Q}_b \bar{Q}_a [0]$$
$$= \bar{Q}_e \bar{Q}_d Q_c \bar{Q}_b \bar{Q}_a \bar{k0}\ k1\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ k9$$
$$+ \bar{Q}_e Q_d Q_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$

$$Q_e = \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a k_9 + Q_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{Q}_a [0] + Q_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a [0]$$
$$= \bar{Q}_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ k9$$
$$+ Q_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$
$$+ Q_e Q_d \bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9}$$

Extraction of Prime Implicants:

Q_a = (Common Variables) . (Remaining Variables)

~~$Q_a = \bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b Q_a$~~

$$Q_a = (\bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{k0}\ \bar{k1}\ \bar{k3}\ \bar{k4}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9})(\cancel{\bar{Q}_a k5 + Q_a \bar{k5}})$$
$$\cdot (\bar{Q}_a \bar{k2}\, k5 + Q_a \bar{k2}\, \bar{k5} + Q_a k2\, \bar{k5})$$

$$Q_b = (\bar{Q}_e \bar{Q}_d \bar{Q}_c\ \bar{k0}\ \bar{k1}\ \bar{k3}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9})$$
$$\cdot (\bar{Q}_b Q_a k2 \bar{k4} + Q_b \bar{Q}_a k2\, k4 + Q_b \bar{Q}_a \bar{k2}\, \bar{k4} + Q_b Q_a \bar{k2}\, \bar{k4})$$

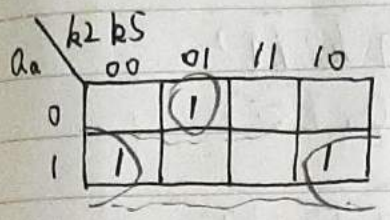
$$Q_c = (\bar{Q}_e \bar{Q}_d \bar{Q}_a\ \bar{k0}\ \bar{k2}\ \bar{k3}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8}\ \bar{k9})$$
$$\cdot (\bar{Q}_c Q_b \bar{k1}\, k4 + Q_c \bar{Q}_b \bar{k1}\, \bar{k4} + Q_c \bar{Q}_b k1\, \bar{k4} + Q_c Q_b \bar{k1}\, \bar{k4})$$

$$Q_d = (\bar{Q}_e \bar{Q}_b \bar{Q}_a\ \bar{k0}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8})$$
$$\cdot (\bar{Q}_d Q_c k1\, \bar{k9} + Q_d \bar{Q}_c \bar{k1}\, \bar{k9} + Q_d \bar{Q}_c \bar{k1}\, k9 + Q_d Q_c \bar{k1}\, \bar{k9})$$

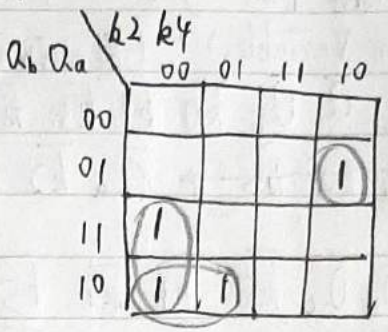
~~$Q_e = Q_c Q_b Q_a$~~

$$Q_e = (\bar{Q}_c \bar{Q}_b \bar{Q}_a\ \bar{k0}\ \bar{k1}\ \bar{k2}\ \bar{k3}\ \bar{k4}\ \bar{k5}\ \bar{k6}\ \bar{k7}\ \bar{k8})$$
$$\cdot (\bar{Q}_e Q_d k9 + Q_e \bar{Q}_d \bar{k9} + Q_e Q_d \bar{k9})$$

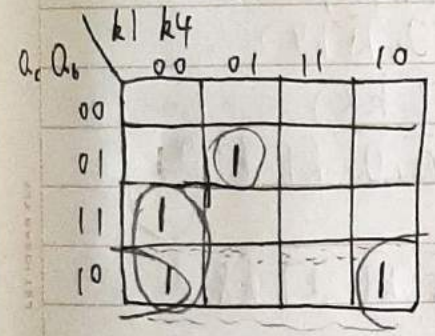
K-maps of remaing variables:



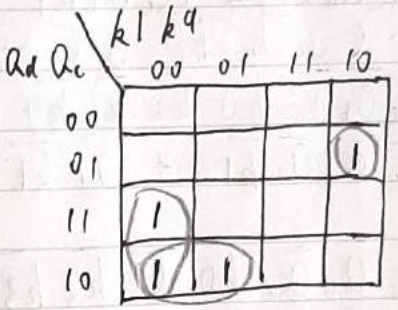
Transition Logic for Q_a



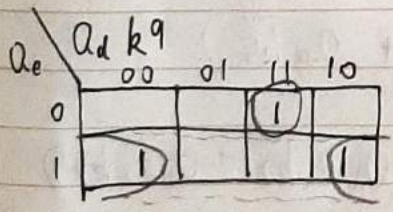
Transition Logic for Q_b



Transition Logic for Q_c



Transition Logic for Q_d



Transition Logic for Q_e

Q_a(Remaining Variables) $= Q_a\bar{k5} + \bar{Q}_a\bar{k2}k5$

Q_b(Remaing Variables) $= Q_b\bar{k2}\bar{k4} + Q_b\bar{Q}_a\bar{k2} + \bar{Q}_bQ_ak2\bar{k4}$

~~(Remaining) $Q_c = Q_b\bar{k1}\bar{k4} + Q_c\bar{Q}_b\bar{k4}$~~

(Remaining) $Q_d = Q_d\bar{Q}_c\bar{k1} + Q_d\bar{k1}\bar{k9} + \bar{Q}_dQ_ck1\bar{k9}$

(Remaining) $Q_e = \bar{Q}_eQ_dk9 + Q_e\bar{k9}$

(Remaing) $Q_c = Q_c\bar{Q}_b\bar{k4} + Q_c\bar{k1}\bar{k4} + \bar{Q}_cQ_bk1k4$

Then we ~~can't~~ can get:

(Common Variables) · (Remaining Variables)

$$Q_a = (\bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{k0} \bar{k1} \bar{k3} \bar{k4} \bar{k6} \bar{k7} \bar{k8} \bar{k9}) \cdot (\cancel{Q_a k2 k5} + \bar{Q}_a \bar{k2} k5 + Q_a \bar{k5})$$

$$Q_b = (\bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{k0} \bar{k1} \bar{k3} \bar{k5} \bar{k6} \bar{k7} \bar{k8} \bar{k9}) \cdot (\bar{Q}_b Q_a k2 \bar{k4} + Q_b \bar{Q}_a \bar{k2} + Q_b \bar{k2} k4)$$

$$Q_c = (\bar{Q}_e \bar{Q}_d \bar{Q}_a \bar{k0} \bar{k2} \bar{k3} \bar{k5} \bar{k6} \bar{k7} \bar{k8} \bar{k9}) \cdot (\cancel{Q_c Q_b k1 \bar{k4}} Q_c \bar{Q}_b \bar{k4} + Q_b \bar{k1} \bar{k4}) \cdot (Q_c \bar{Q}_b \bar{k4} + Q_c \bar{k1} \bar{k4} + \bar{Q}_c Q_b \bar{k1} k4)$$

$$Q_d = (\bar{Q}_e \bar{Q}_b \bar{Q}_a \bar{k0} \bar{k2} \bar{k3} \bar{k4} \bar{k5} \bar{k6} \bar{k7} \bar{k8}) \cdot (Q_d \bar{Q}_c \bar{k1} + Q_d \bar{k1} \bar{k9} + \bar{Q}_d Q_c k1 \bar{k9})$$

$$Q_e = (\bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k0} \bar{k1} \bar{k2} \bar{k3} \bar{k4} \bar{k5} \bar{k6} \bar{k7} \bar{k8}) \cdot (\bar{Q}_e Q_d k9 + Q_e \bar{k9})$$

Removing common variables of all transition equations:

$$Q_a = (\bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{Q}_b \bar{k1} \bar{k4} \bar{k9}) \cdot (\bar{Q}_a \bar{k2} k5 + Q_a \bar{k5})$$

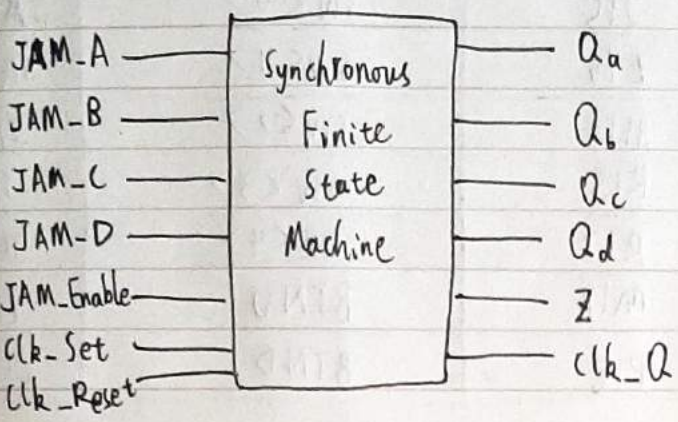
$$Q_b = (\bar{Q}_e \bar{Q}_d \bar{Q}_c \bar{k1} \bar{k5} \bar{k9}) \cdot (\bar{Q}_b Q_a k2 \bar{k4} + Q_b \bar{Q}_a k2 + Q_b \bar{k2} \bar{k4})$$

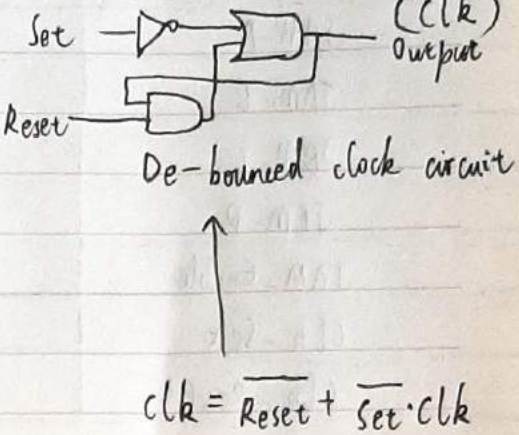
$$Q_c = (\bar{Q}_e \bar{Q}_d \bar{Q}_a \bar{k2} \bar{k5} \bar{k9}) \cdot \cancel{(Q_c \bar{Q}_b \bar{k4} + Q_b \bar{k1} \bar{k4})} \cdot (Q_c \bar{Q}_b \bar{k4} + Q_c \bar{k1} \bar{k4} + \bar{Q}_c Q_b \bar{k1} k4)$$

$$Q_d = (\bar{Q}_e \bar{Q}_b \bar{Q}_a \bar{k2} \bar{k4} \bar{k5}) \cdot (Q_d \bar{Q}_c \bar{k1} + Q_d \bar{k1} \bar{k9} + \bar{Q}_d Q_c k1 \bar{k9})$$

$$Q_e = (\bar{Q}_c \bar{Q}_b \bar{Q}_a \bar{k1} \bar{k2} \bar{k4} \bar{k5}) \cdot (\bar{Q}_e Q_d k9 + Q_e \bar{k9})$$

Implementation: (Synchronous)



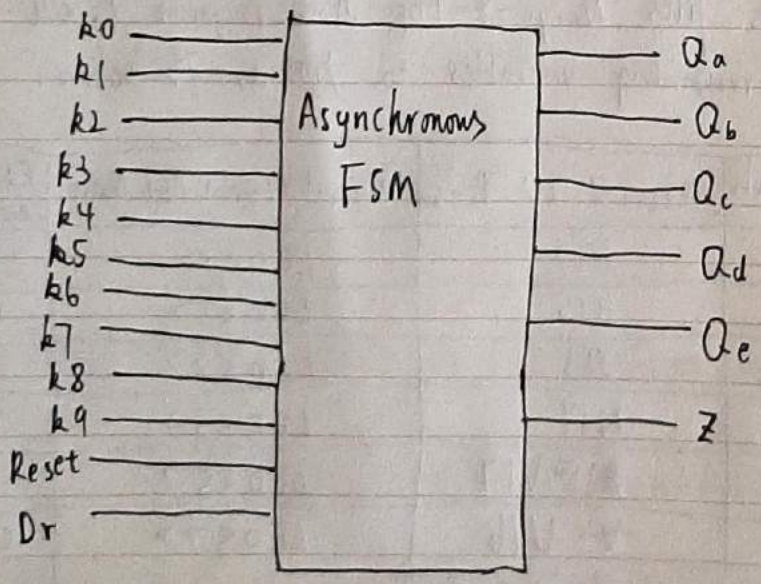


Editing the constraints files "Nexys-4-DDR_Msc_Fragment_1.xdc" and map the name of corresponding variables to pins as ~~th~~ below.

(output) Synchronous FSM Signals	Artix-7 IO Pins	Original Digilent Net Name	Edited Digilent Net Name
Qa	H17	LED<0>	Qa
Qb	K15	LED<1>	Qb
Qc	J13	LED<2>	Qc
Qd	N14	LED<3>	Qd
Z	~~R18~~ V17	LED<5>	Z
clk_Q	~~V~~ U16	LED<7>	clk_Q

(Input) Synchronous FSM Signal	Artix I/O Pins	Original Digilent Nee Name	Edited Digilent Nee Name
JAM-A	J15	SW<0>	JAM_A
JAM-B	L16	SW<1>	JAM_B
JAM_C	M13	SW<2>	JAM_C
JAM-D	R15	SW<3>	JAM_D
JAM_Enable	R17	SW<4>	JAM_Enable
Clk_Set	M18	BTNU	Clk_Set
Clk_Reset	P18	BTND	Clk_Reset

Implementation: (Asynchronous)



Editing the constraints files as below

(output) Asynchronous FSM Signal	Artix I/O Pins	Original Digilent Net Name	Edited Digilent Net Name
Q_a	H17	LED <0>	Q_a
Q_b	K15	LED <1>	Q_b
Q_c	J13	LED <2>	Q_c
Q_d	N14	LED <3>	Q_d
Q_e	R18	LED <4>	Q_e
Z	U16	LED <7>	Z

(Input) Asynchronous FSM Signal	Artix I/O Pins	Original Digilent Net Name	Edited Digilent Net Name
k0	J15	SW<0>	k0
k1	L16	SW <1>	k1
k2	M13	SW<2>	k2
k3	R15	SW<3>	k3
k4	R17	SW <4>	k4
k5	T18	SW <5>	k5
k6	U18	SW <6>	k6
k7	R13	SW <7>	k7
k8	T8	SW <8>	k8
k9	U8	SW <9>	k9
Dr	T13	SW <11>	Dr
Reset	U12	SW<13>	Reset

Summary

① map names of variables and pins in the constraints files

② Ignore the combinational loop alert by adding
'set property ALLOW_COMBINATIONAL_LOOPS TRUE [get_nets]'

③ wire ——— assign
reg ——— always

④ initial { sequential execution } ——— Test

always { parallel execution } ——— Design

⑤ Edit ~~for~~ source files properties,
clear 'implementation' and 'synthesis' for Test_Bench

⑥ Synchronous: clock

Asychronous: race hazard