DIGITAL DESIGN

Through Arduino

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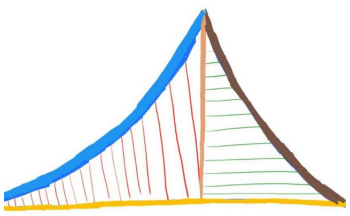


Contents

Introduction

This book introduces digital design through using the arduino framework.

Chapter 1

Installation

1.1. Termux

1. On your android device, install apkpure from

```
https://mapkpurecom/
```

2. Install Termux from apkpure

3. Install basic packages on termux

```
#Give termux access to your user directory in android
termux-setup-storage

#Upgrade packages
apt update && apt upgrade
apt install build-essential openssh

#Mandatory packages
apt install curl git wget subversion proot proot-distro python nmap neovim ranger
#--------------------End Install Termux
```

```
    ------------------------------
```

4. Install Ubuntu on termux

```
proot-distro install ubuntu
proot-distro login ubuntu
```

1.2. Platformio

1. Install Packages

```
apt update && apt upgrade
apt install apt-utils build-essential cmake neovim
apt install git wget subversion imagemagick nano
apt install avra avrdude gcc-avr avr-libc
#--------------------End Installing ubuntu on termux
    ------------------------------


#-------------------- Installing python3 on termuxubuntu
    ------------------------------
apt install python3-pip python3-numpy python3-scipy python3-matplotlib
    python3-mpmath python3-sympy python3-cvxopt
#-------------------- End installing python3 on termuxubuntu
    ------------------------------


#-------------------- Installing platformio on termuxubuntu
```

```
    ------------------------------
pip3 install platformio
#-------------------- End installing python3 on termuxubuntu
    ------------------------------
```

2. Execute the following on ubuntu

```
cd /sdcard/Download
svn co https://githubcom/gadepall/fwc-/trunk/ide/piosetup/codes
cd codes
pio run
```

3. Connect your arduino to the laptop/rpi and type

```
pio run -t nobuild -t upload
```

4. The LED beside pin 3 will start blinking

1.3. Arduino Droid

1. Install ArduinoDroid from apkpure

2. Open ArduinoDroid and grant all permissions

3. Connect the Arduino to your phone via USB-OTG

4. For flashing the bin files, in ArduinoDroid,

```
Actions->Upload->Upload Precompiled
```

then go to your working directory and select

```
pio/build/uno/firmwarehex
```

for uploading hex file to the Arduino Uno

5. The LED beside pin 3 will start blinking

Chapter 2

Seven Segment Display

We show how to control a seven segment display.

2.1. Components

Component	Value	Quantity
Breadboard		1
Resistor	$\geq 220\Omega$	1
Arduino	Uno	1
Seven Segment Display	Common Anode	1
Jumper Wires		20

Table 2.1:

2.1.1. Breadboard

The breadboard can be divided into 5 segments. In each of the green segements, the pins are internally connected so as to have the same voltage. Similarly, in the central segments, the pins in each column are internally connected in the same fashion as the blue columns.

2.1.2. Seven Segment Display

The seven segment display in Fig. 2.2 has eight pins, a, b, c, d, e, f, g and *dot* that take an active LOW input, i.e. the LED will glow only if the input is connected to ground. Each of these pins is connected to an LED segment. The *dot* pin is reserved for the $\cdot$ LED.

2.1.3. Arduino

The Arduino Uno has some ground pins, analog input pins A0-A3 and digital pins D1-D13 that can be used for both input as well as output. It also has two power pins that can generate $3.3V$ and $5V$. In the following exercises, only the GND, $5V$ and digital pins will be used.

2.2. Display Control through Hardware

2.2.1. Powering the Display

1. Plug the display to the breadboard in Fig. 2.1 and make the connections in Table 2.2. Henceforth, all 5V and GND connections will be made from the breadboard.

Arduino	**Breadboard**
5V	Top Green
GND	Bottom Green

Table 2.2:

2. Make the connections in Table 2.3.

3. Connect the Arduino to the computer. The DOT led should glow.

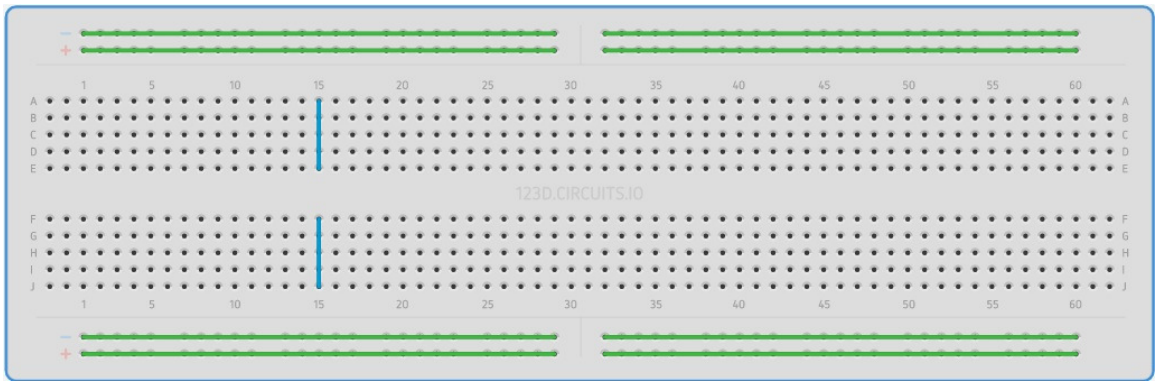


Figure 2.1:

Breadboard		**Display**
5V	Resistor	COM
GND		DOT

Table 2.3:

2.2.2. Controlling the Display

Fig. 2.3 explains how to get decimal digits using the seven segment display. GND=0.

1. Generate the number 1 on the display by connecting only the pins b and c to GND (=0). This corresponds to the first row of 2.4. 1 means not connecting to GND.

2. Repeat the above exercise to generate the number 2 on the display.

3. Draw the numbers 0-9 as in Fig. 2.3 and complete Table 2.4

a	**b**	**c**	**d**	**e**	**f**	**g**	**decimal**
0	0	0	0	0	0	1	0

Table 2.4:

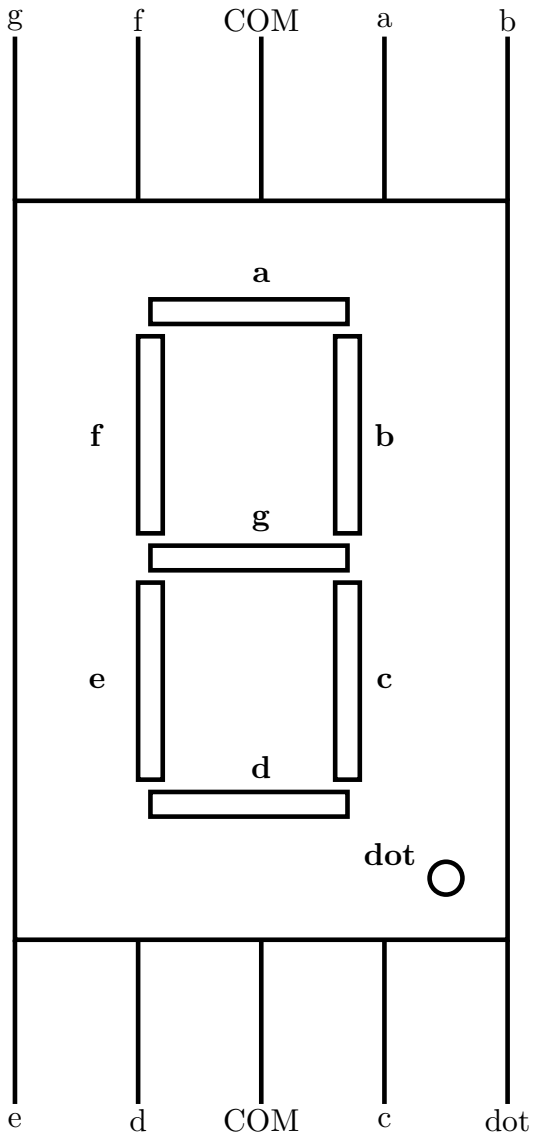


Figure 2.2:

2.3. Display Control through Software

1. Make connections according to Table 2.5

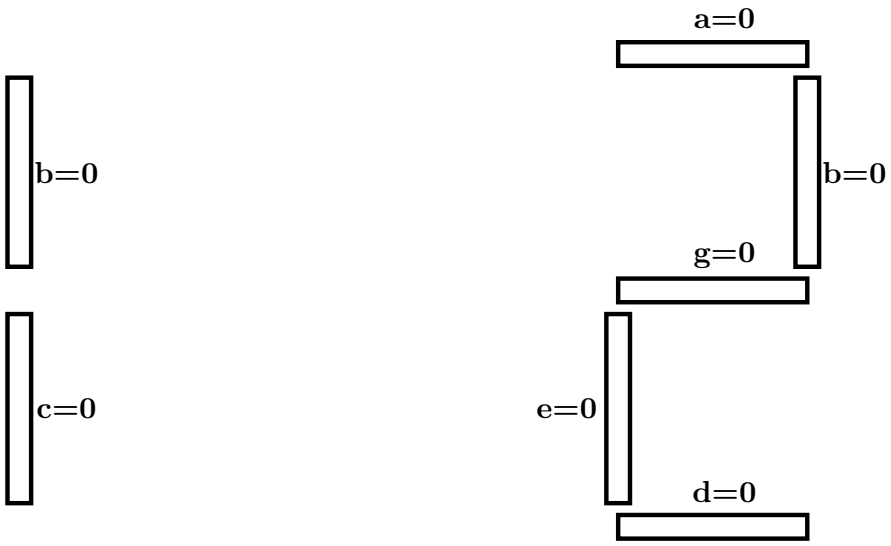


Figure 2.3:

Arduino	2	3	4	5	6	7	8
Display	a	b	c	d	e	f	g

Table 2.5:

2. Download the following code using the arduino IDE and execute

```
void sevenseg(int a,int b,int c,int d,int e,int f,int g)
{
  digitalWrite(2, a);
  digitalWrite(3, b);
  digitalWrite(4, c);
  digitalWrite(5, d);
  digitalWrite(6, e);
  digitalWrite(7, f);
  digitalWrite(8, g);
```

```
}
void loop()
{
sevenseg(1,0,0,1,1,1,1);
}
```

3. Now generate the numbers 0-9 by modifying the above program.

Chapter 3

7447

Here we show how to use the 7447 BCD-Seven Segment Display decoder to learn Boolean logic.

3.1. Components

Component	Value	Quantity
Resistor	220 Ohm	1
Arduino	UNO	1
Seven Segment Display		1
Decoder	7447	1
Jumper Wires	M-M	20
Breadboard		1

Table 3.1:

3.2. Hardware

1. Make connections between the seven segment display in Fig. 2.2 and the 7447 IC in Fig. 3.1 as shown in Table 3.2

7447	$\bar{a}$	$\bar{b}$	$\bar{c}$	$\bar{d}$	$\bar{e}$	$\bar{f}$	$\bar{g}$
Display	a	b	c	d	e	f	g

Table 3.2:

2. Make connections to the lower pins of the 7447 according to Table 3.3 and connect $V_{CC} = 5$V. You should see the number 0 displayed for 0000 and 1 for 0001.

D	**C**	**B**	**A**	**Decimal**
0	0	0	0	0
0	0	0	1	1

Table 3.3:

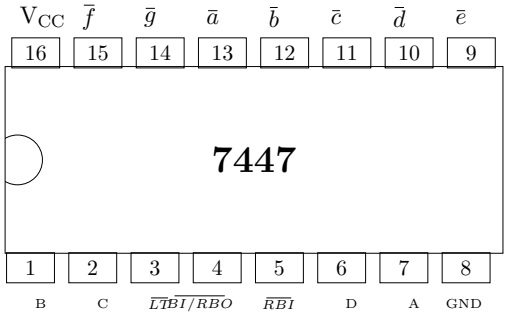


Figure 3.1:

3. Complete Table 3.3 by generating all numbers between 0-9.

3.3. Software

1. Now make the connections as per Table 3.4 and execute the following program after downloading

```
wget https://raw.githubusercontent.com/gadepall/arduino/master/7447/codes/
    gvv_ard_7447/gvv_ard_7447.ino
```

7447	D	C	B	A
Arduino	5	4	3	2

Table 3.4:

In the truth table in Table 3.5, W, X, Y, Z are the inputs and A, B, C, D are the outputs. This table represents the system that increments the numbers 0-8 by 1 and resets the number 9 to 0 Note that $D = 1$ for the inputs 0111 and 1000. Using boolean logic,

$$D = WXYZ^{'} + W^{'}X^{'}Y^{'}Z \tag{3.1}$$

Note that 0111 results in the expression $WXYZ^{'}$ and 1000 yields $W^{'}X^{'}Y^{'}Z$.

2. The code below realizes the Boolean logic for B, C and D in Table 3.5. Write the logic for A and verify.

```
//Declaring all variables as integers
int Z=0,Y=0,X=0,W=1;
int D,C,B,A;


//Code released under GNU GPL. Free to use for anything.
void disp_7447(int D, int C, int B, int A)
{
  digitalWrite(2, A); //LSB
  digitalWrite(3, B);
  digitalWrite(4, C);
```

```
  digitalWrite(5, D); //MSB


}
// the setup function runs once when you press reset or power the board
void setup() {
    pinMode(2, OUTPUT);
    pinMode(3, OUTPUT);
    pinMode(4, OUTPUT);
    pinMode(5, OUTPUT);
}


// the loop function runs over and over again forever
void loop() {
  A=0;
  B=(W&&!X&&!Y&&!Z) || (!W&&X&&!Y&&!Z) || (W&&!X&&Y&&!Z) || (!W
      &&X&&Y&&!Z);
  C=(W&&X&&!Y&&!Z) || (!W&&!X&&Y&&!Z) || (W&&!X&&Y&&!Z) || (!W&&
      X&&Y&&!Z);
  D = (W&&X&&Y&&!Z)||(!W&&!X&&!Y&&Z);


disp_7447(D,C,B,A);
}
//&& is the AND operation
// || is the OR operation
// ! is the NOT operation
```

Z	Y	X	W	**D**	**C**	**B**	**A**
0	0	0	0	**0**	**0**	**0**	**1**
0	0	0	1	**0**	**0**	**1**	**0**
0	0	1	0	**0**	**0**	**1**	**1**
0	0	1	1	**0**	**1**	**0**	**0**
0	1	0	0	**0**	**1**	**0**	**1**
0	1	0	1	**0**	**1**	**1**	**0**
0	1	1	0	**0**	**1**	**1**	**1**
0	1	1	1	**1**	**0**	**0**	**0**
1	0	0	0	**1**	**0**	**0**	**1**
1	0	0	1	**0**	**0**	**0**	**0**

Table 3.5:

3. Now make additional connections as shown in Table 3.6 and execute the following code. Comment.

```
//Declaring all variables as integers
int Z,Y,X,W;


//Code released under GNU GPL. Free to use for anything.
void disp_7447(int D, int C, int B, int A)
{
  digitalWrite(2, A); //LSB
  digitalWrite(3, B);
  digitalWrite(4, C);
  digitalWrite(5, D); //MSB


}
// the setup function runs once when you press reset or power the board
```

```
void setup() {
    pinMode(2, OUTPUT);
    pinMode(3, OUTPUT);
    pinMode(4, OUTPUT);
    pinMode(5, OUTPUT);
    pinMode(6, INPUT);
    pinMode(7, INPUT);
    pinMode(8, INPUT);
    pinMode(9, INPUT);

}

// the loop function runs over and over again forever
void loop() {

W = digitalRead(6);//LSB
X = digitalRead(7);
Y = digitalRead(8);
Z = digitalRead(9);//MSB

disp_7447(Z,Y,X,W);
}
```

Solution: In this exercise, we are taking the number 5 as input to the arduino and displaying it on the seven segment display using the 7447 IC.

	Z	Y	X	W
Input	0	1	0	1
Arduino	9	8	7	6

Table 3.6:

4. Verify the above code for all inputs from 0-9.

5. Now write a program where

   (a) the binary inputs are given by connecting to 0 and 1 on the breadboard

   (b) incremented by 1 using Table 3.5 and

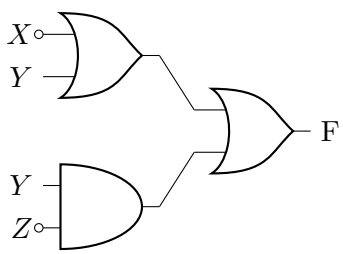
   (c) the incremented value is displayed on the seven segment display.

6. Write the truth table for the 7447 IC and obtain the corresponding boolean logic equations.

7. Implement the 7447 logic in the arudino. Verify that your arduino now behaves like the 7447 IC.

3.4. Problems

1. Obtain the Boolean Expression for the Logic circuit shown below (CBSE 2013)



2. Verify the Boolean Expression (CBSE 2013)

$$A + C = A + A'C + BC \tag{3.2}$$

3. Draw the Logic Circuit for the following Boolean Expression (CBSE 2015)

$$f(x, y, z, w) = (x' + y)z + w' \tag{3.3}$$

4. Verify the following (CBSE 2015)

$$U' + V = U'V' + U'V + UV \tag{3.4}$$

5. Draw the Logic Circuit for the given Boolean Expression (CBSE 2015)

$$(U + V')W' + Z \tag{3.5}$$

6. Verify the following using Boolean Laws (CBSE 2015)

$$X + Y' = XY + XY' + X'Y' \tag{3.6}$$

7. Write the Boolean Expression for the result of the Logic Circuit as shown in Fig. 3.2 (CBSE 2016)

8. Draw the logic circuit of the following Boolean Expression using only NAND Gates. (CBSE 2017)

$$XY + YZ \tag{3.7}$$

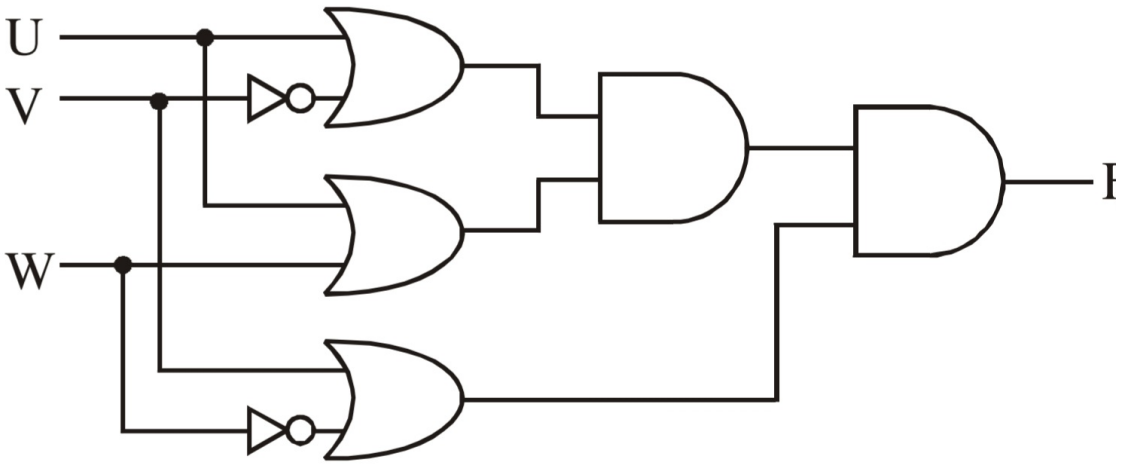


Figure 3.2:

9. Draw the Logic Circuit of the following Boolean Expression using only NOR Gates (CBSE 2017)

$$(A + B)(C + D) \tag{3.8}$$

10. Draw the Logic Circuit of the following Boolean Expression (CBSE 2018)

$$(U' + V)(V' + W') \tag{3.9}$$

11. Derive a Canonical POS expression for a Boolean function F, represented by Table 3.7 (CBSE 2019)

12. For the logic circuit shown in Fig.3.3, find the simplified Boolean expression for the output. (GATE EC 2000)

X	Y	Z	F(X,Y,Z)
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	0

Table 3.7:

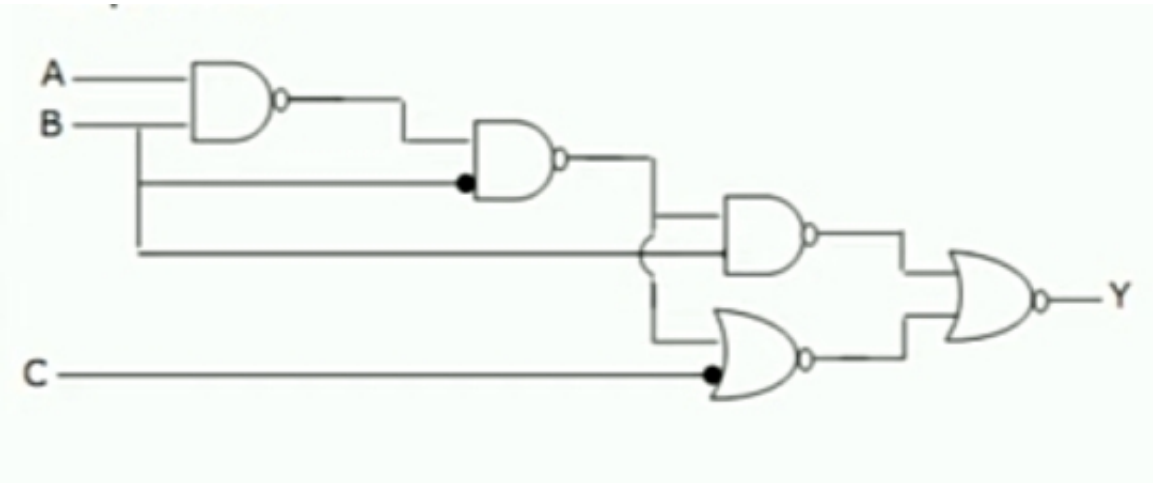
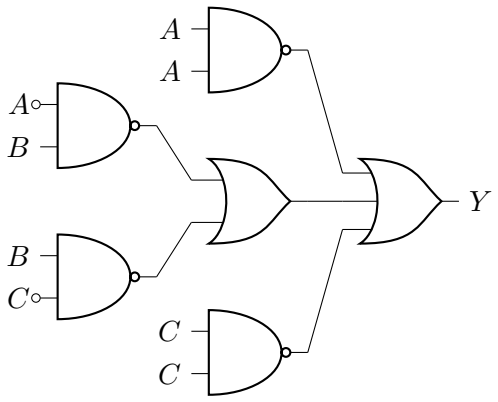


Figure 3.3:

13. Obtain the Boolean Expression for the Logic circuit shown below (GATE EC 1993)



14. Implement Table 3.8 using XNOR logic. (GATE EC 1993)

A	**B**	**Y**
0	0	1
0	1	0
1	0	0
1	1	1

Table 3.8:

15. For a binary half-sub-tractor having two inputs A and B, find the correct set of logical expressions for the outputs D (=A minus B) and X (=borrow). (GATE EC 1999)

16. Find X in the following circuit in Fig. 3.4 (GATE EC 2007)

17. A logic circuit implements the boolean function F=X'.Y+X.Y'.Z'. It is found that the input combination X=Y=1 can never occur. Taking this into account, find a simplified expression for F. (GATE IN 2007)

18. Find the Boolean logic realised by the following circuit in Fig. 3.5 (GATE EC 2010)

19. Find the logic function implemented by the circuit given below in Fig. 3.6 (GATE EC 2011)

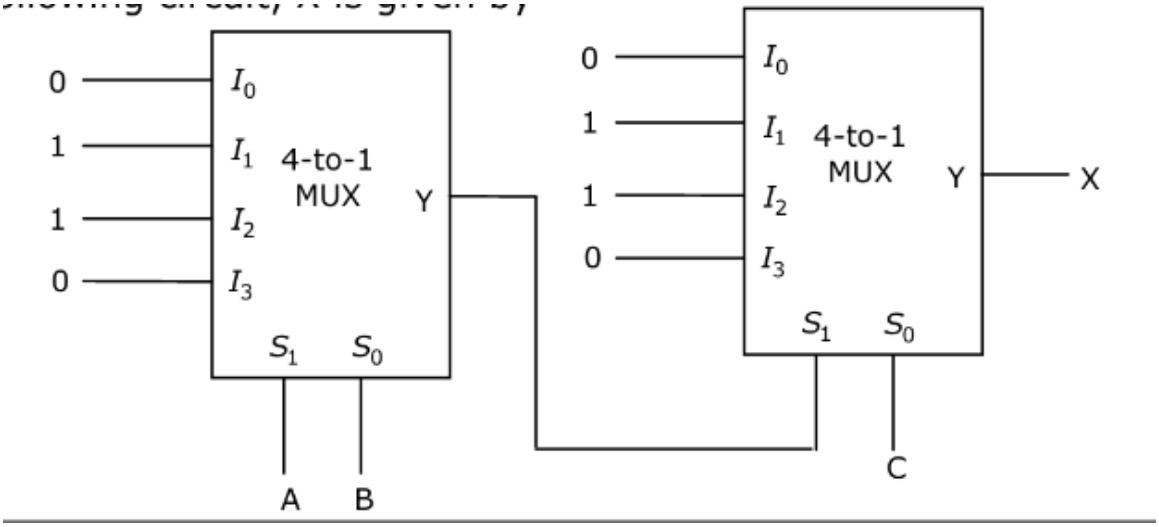


Figure 3.4:

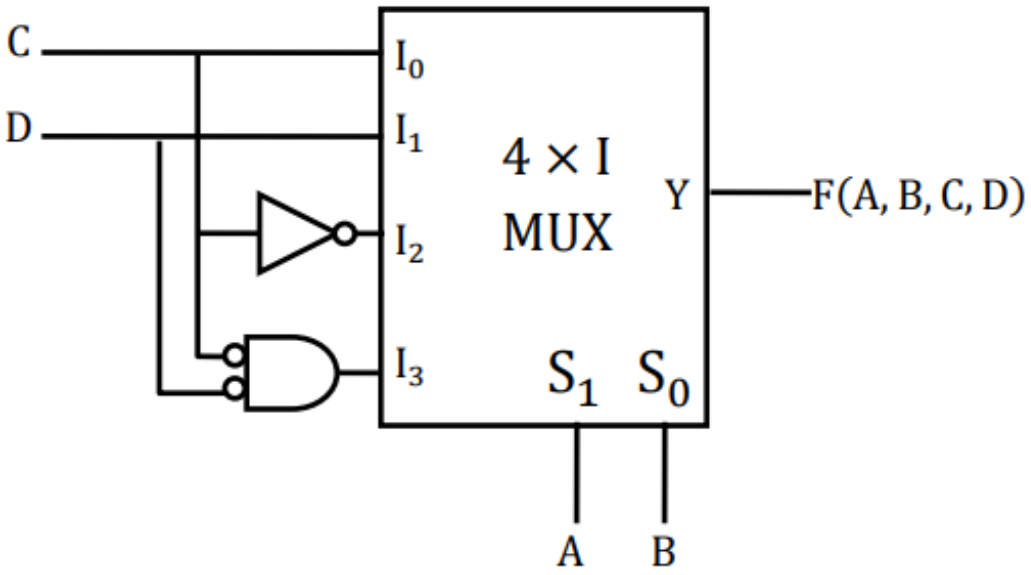


Figure 3.5:

20. Find F in the Digital Circuit given in the figure below in Fig. 3.7. (GATE IN 2016)

21. Find the logic function implemented by the circuit given below in Fig. 3.8 (GATE

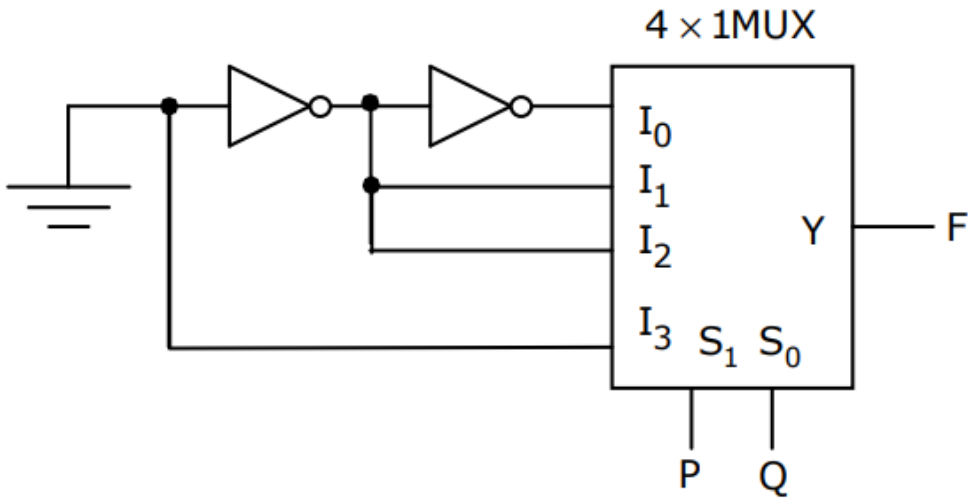


Figure 3.6:

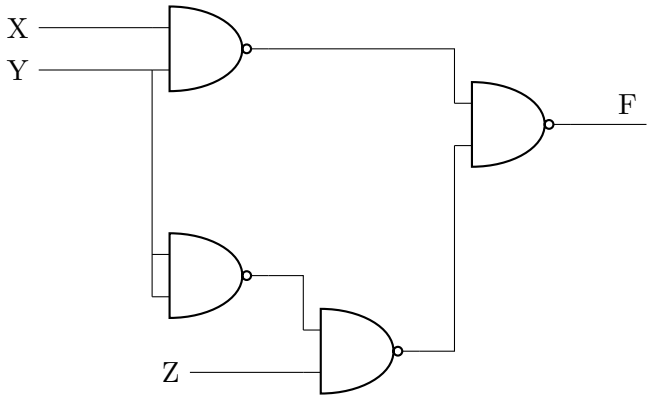


Figure 3.7:

EC 2017)

22. Find the logic function implemented by the circuit given below in Fig. 3.9 (GATE EC 2018)

23. Find the logic function implemented by the circuit given below in Fig. 3.10 (GATE EE 2018)

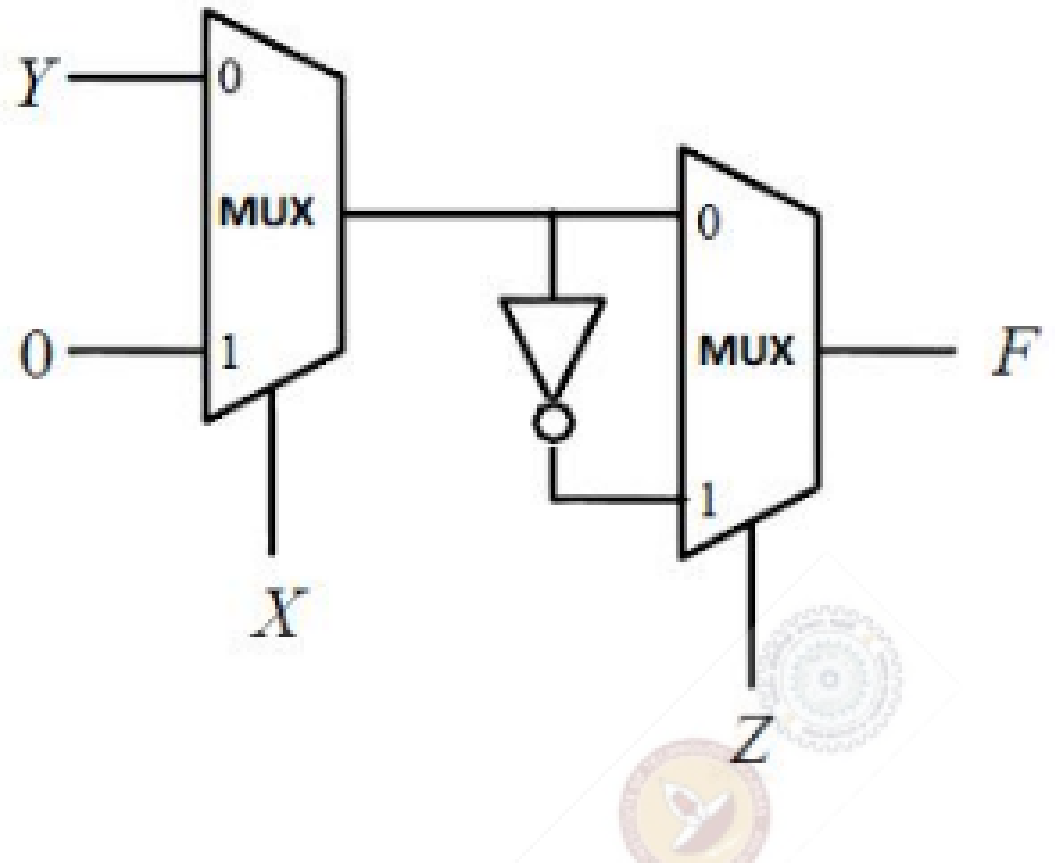


Figure 3.8:

24. Find the logic function implemented by the circuit given below in Fig. 3.11 (GATE EE 2019)

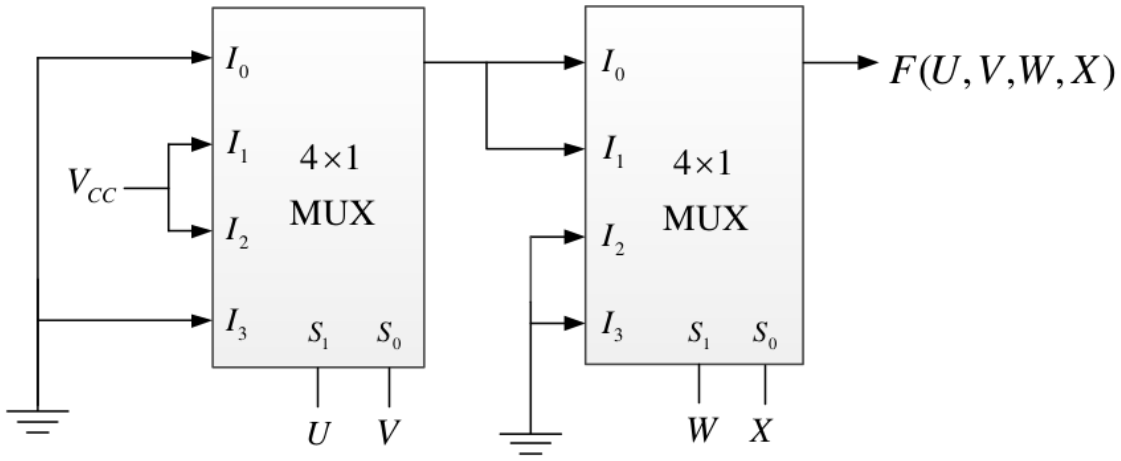


Figure 3.9:

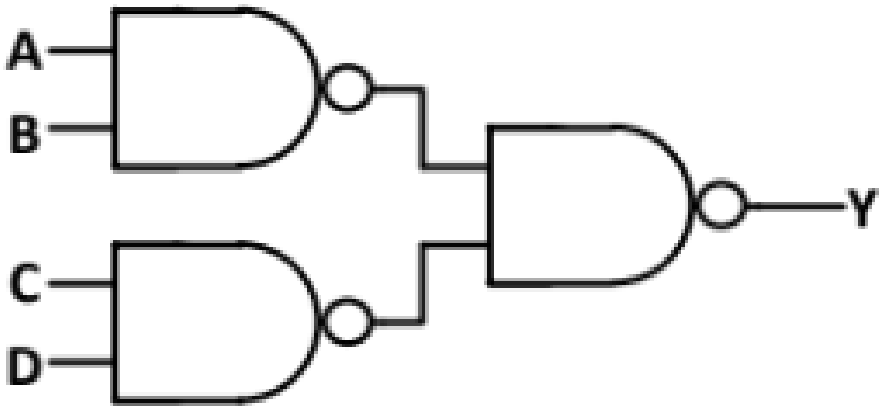


Figure 3.10:

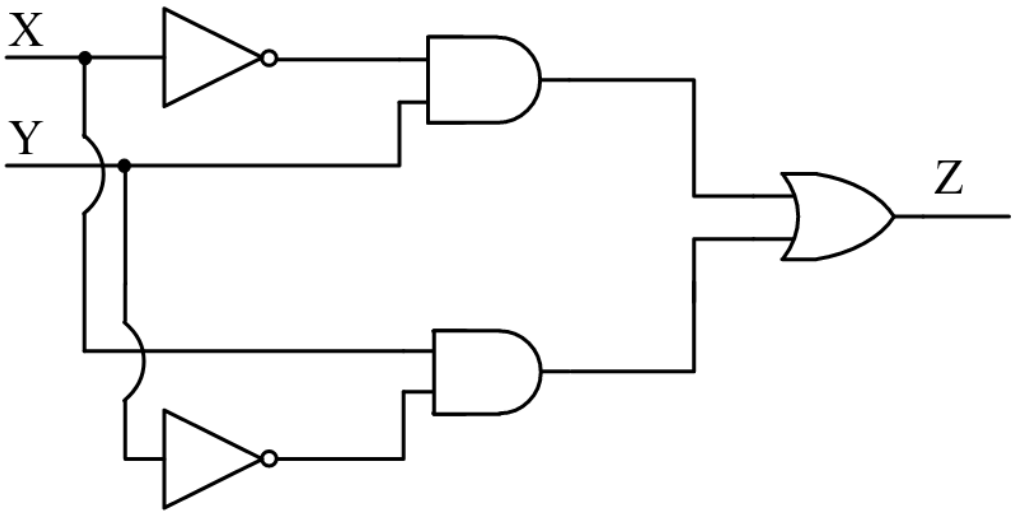


Figure 3.11:

Chapter 4

Karnaugh Map

4.1. Introduction

We explain Karnaugh maps (K-map) by finding the logic functions for the incrementing decoder

4.2. Incrementing Decoder

The incrementing decoder takes the numbers $0, , \ldots, 9$ in binary as inputs and generates the consecutive number as output The corresponding truth table is available in Table 4.1

4.3. Karnaugh Map

Using Boolean logic, output A in Table 4.1 can be expressed in terms of the inputs W, X, Y, Z as

$$A = W'X'Y'Z' + W'XY'Z' + W'X'YZ' + W'XYZ' + W'X'Y'Z \quad (4.1)$$

Z	Y	X	W	**D**	**C**	**B**	**A**
0	0	0	0	**0**	**0**	**0**	**1**
0	0	0	1	**0**	**0**	**1**	**0**
0	0	1	0	**0**	**0**	**1**	**1**
0	0	1	1	**0**	**1**	**0**	**0**
0	1	0	0	**0**	**1**	**0**	**1**
0	1	0	1	**0**	**1**	**1**	**0**
0	1	1	0	**0**	**1**	**1**	**1**
0	1	1	1	**1**	**0**	**0**	**0**
1	0	0	0	**1**	**0**	**0**	**1**
1	0	0	1	**0**	**0**	**0**	**0**

Table 4.1:

1. K-Map for A: The expression in (4.1) can be minimized using the K-map in Fig 4.1 In Fig 4.1, the implicants in boxes 0,2,4,6 result in $W'Z'$ The implicants in boxes 0,8 result in $W'X'Y'$ Thus, after minimization using Fig 4.2, (4.1) can be expressed as

$$A = W'Z' + W'X'Y' \tag{4.2}$$

   Using the fact that

$$\begin{aligned} X + X' = \\ XX' = 0, \end{aligned} \tag{4.3}$$

   derive (4.2) from (4.1) algebraically

2. K-Map for B: From Table 4.1, using boolean logic,

$$B = WX'Y'Z' + W'XY'Z' + WX'YZ' + W'XYZ' \tag{4.4}$$

   Show that (4.4) can be reduced to

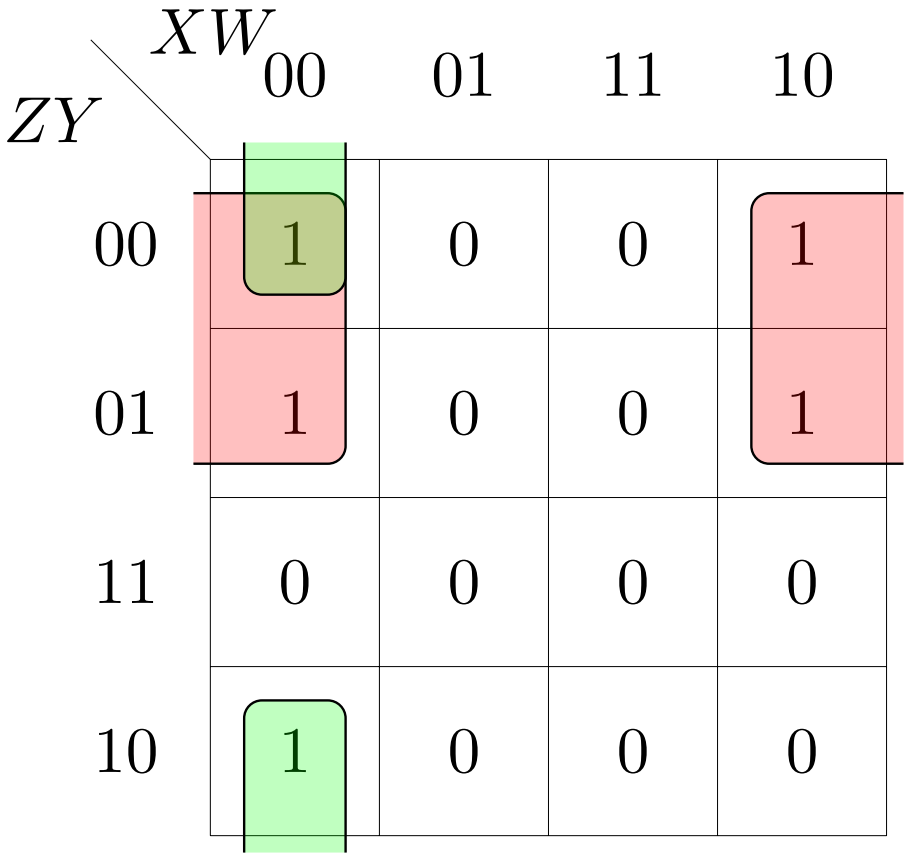


Figure 4.1: K-map for A

$$B = WX'Z' + W'XZ' \tag{4.5}$$

using Fig 4.2

3. Derive (4.5) from (4.4) algebraically using (4.3)

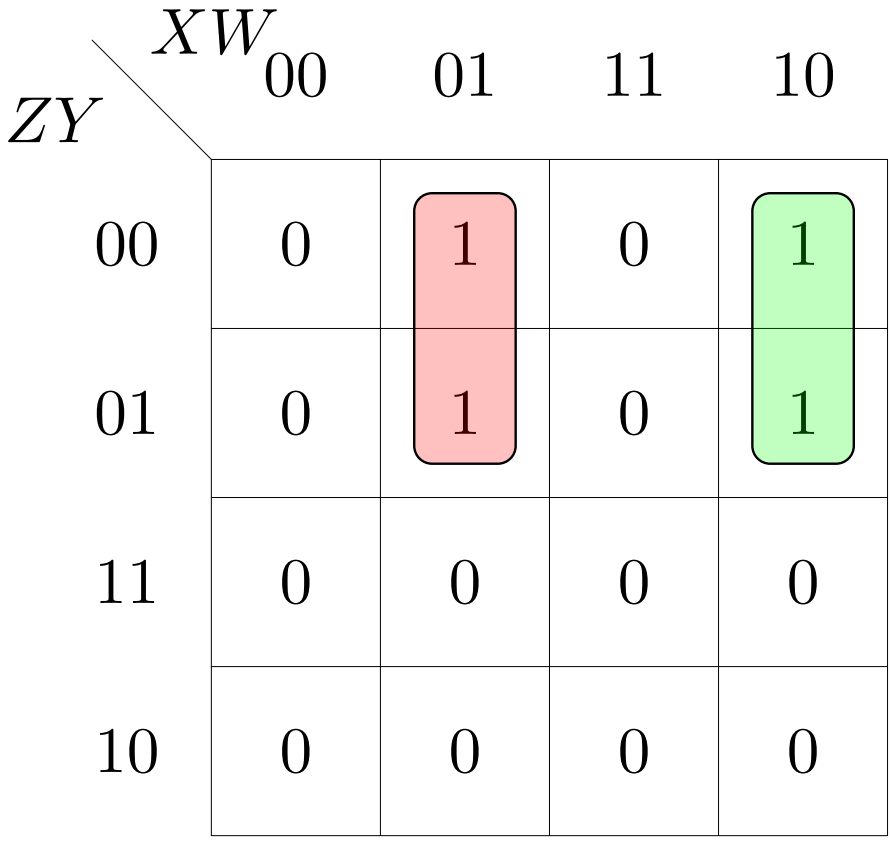


Figure 4.2: K-map for B

4. K-Map for C: From Table 4.1, using boolean logic,

$$C = WXY'Z' + W'X'YZ' + WX'YZ' + W'XYZ' \tag{4.6}$$

Show that (4.6) can be reduced to

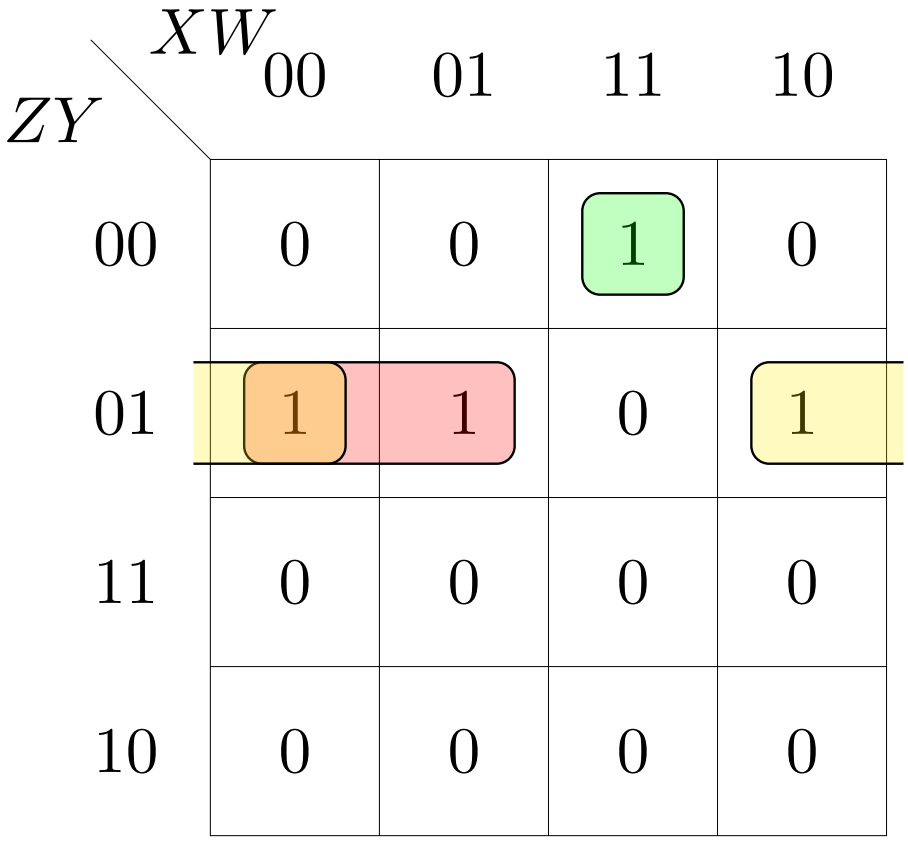


Figure 4.3: K-map for C

$$C = WXY'Z' + X'YZ' + W'YZ' \tag{4.7}$$

using Fig 4.3

5. Derive (4.7) from (4.6) algebraically using (4.3)

6. K-Map for D: From Table 4.1, using boolean logic,

$$D = WXYZ' + W'X'Y'Z \tag{4.8}$$

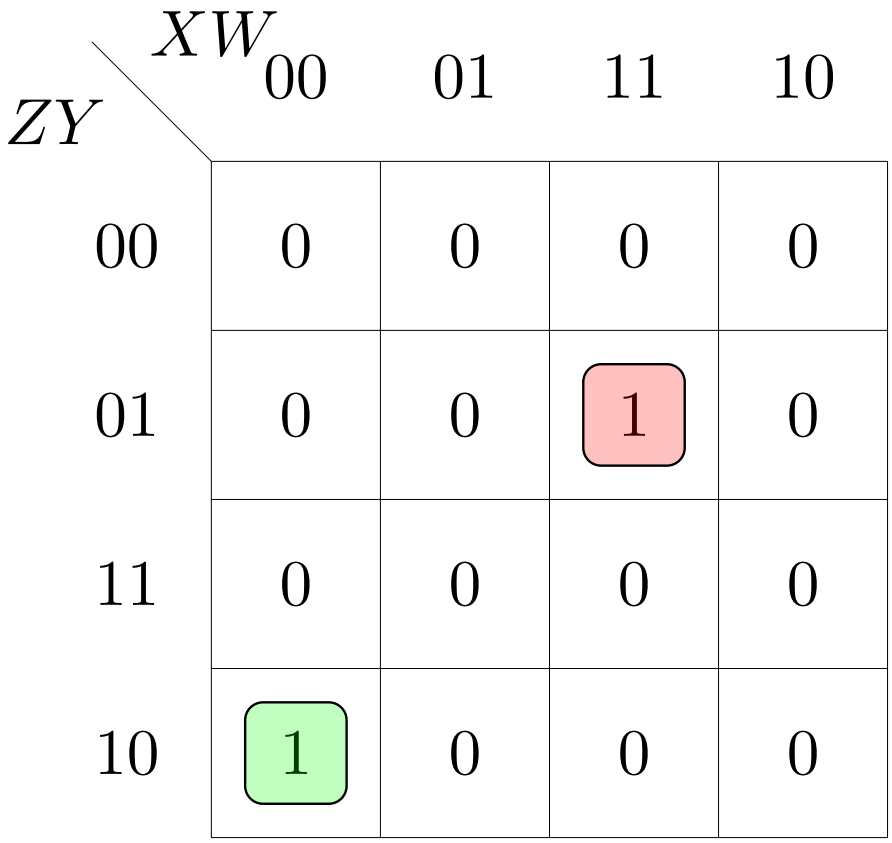


Figure 4.4: K-map for D

7. Minimize (4.8) using Fig 4.4

D	C	B	A	**a**	**b**	**c**	**d**	**e**	**f**	**g**	Decimal
0	0	0	0	**0**	**0**	**0**	**0**	**0**	**0**	**1**	0
0	0	0	1	**1**	**0**	**0**	**1**	**1**	**1**	**1**	1
0	0	1	0	**0**	**0**	**1**	**0**	**0**	**1**	**0**	2
0	0	1	1	**0**	**0**	**0**	**0**	**1**	**1**	**0**	3
0	1	0	0	**1**	**0**	**0**	**1**	**1**	**0**	**0**	4
0	1	0	1	**0**	**1**	**0**	**0**	**1**	**0**	**0**	5
0	1	1	0	**0**	**1**	**0**	**0**	**0**	**0**	**0**	6
0	1	1	1	**0**	**0**	**0**	**1**	**1**	**1**	**1**	7
1	0	0	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	8
1	0	0	1	**0**	**0**	**0**	**1**	**1**	**0**	**0**	9

Table 4.2: Truth table for display decoder.

8. Download the code in

```
wget https://rawgithubusercontentcom/gadepall/arduino/master/7447/codes/
    inc_dec/inc_decino
```

and modify it using the K-Map equations for A,B,C and D Execute and verify

9. Display Decoder: Table 4.2 is the truth table for the display decoder in Fig. 3.1. Use K-maps to obtain the minimized expressions for a, b, c, d, e, f, g in terms of A, B, C, D with and without don't care conditions

4.4. Dont Care

We explain Karnaugh maps (K-map) using don't care conditions

4.5. Don't Care Conditions

1. Don't Care Conditions: 4 binary digits are used in the incrementing decoder in Table 4.1. However, only the numbers from 0-9 are used as input/output in the decoder and we don't care about the numbers from 0-5 This phenomenon can be addressed by revising the truth table in Table 4.1 to obtain Table 4.3

Z	Y	X	W	**D**	**C**	**B**	**A**
0	0	0	0	**0**	**0**	**0**	**1**
0	0	0	1	**0**	**0**	**1**	**0**
0	0	1	0	**0**	**0**	**1**	**1**
0	0	1	1	**0**	**1**	**0**	**0**
0	1	0	0	**0**	**1**	**0**	**1**
0	1	0	1	**0**	**1**	**1**	**0**
0	1	1	0	**0**	**1**	**1**	**1**
0	1	1	1	**1**	**0**	**0**	**0**
1	0	0	0	**1**	**0**	**0**	**1**
1	0	0	1	**0**	**0**	**0**	**0**
1	0	1	0	**-**	**-**	**-**	**-**
1	0	1	1	**-**	**-**	**-**	**-**
1	1	0	0	**-**	**-**	**-**	**-**
1	1	0	1	**-**	**-**	**-**	**-**
1	1	1	0	**-**	**-**	**-**	**-**
1	1	1	1	**-**	**-**	**-**	**-**

Table 4.3:

2. The revised K-map for A is available in Fig 4.5. Show that

$$A = W' \tag{4.9}$$

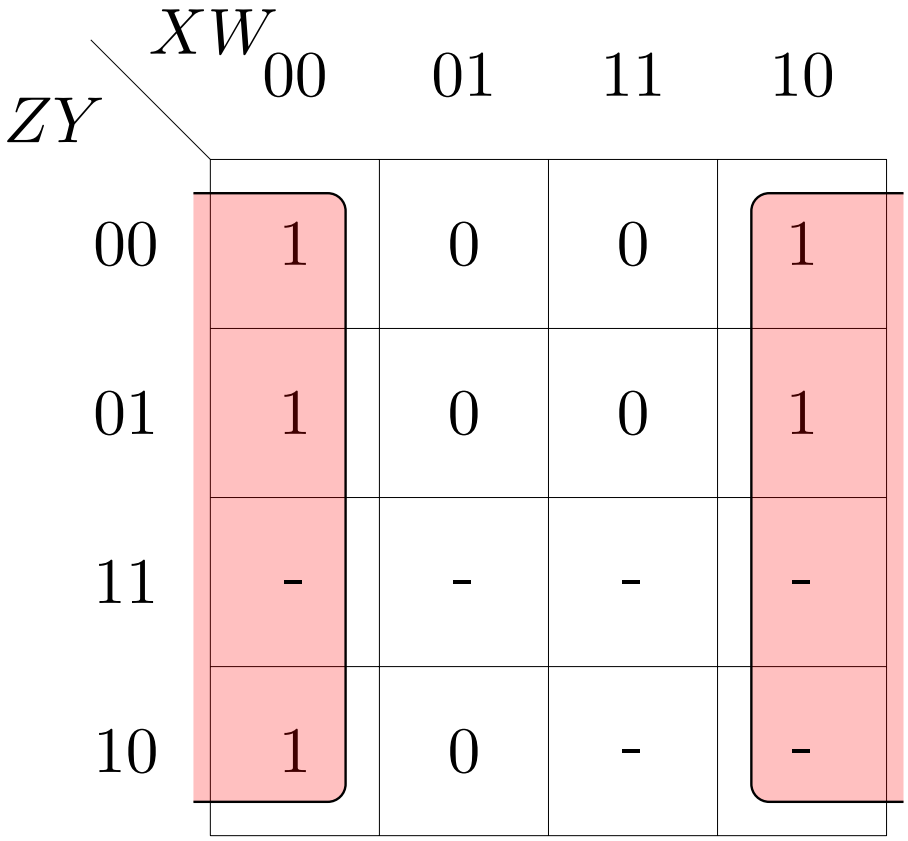


Figure 4.5: K-map for A with don't cares

3. The revised K-map for B is available in Fig 4.6 Show that

$$B = WX'Z' + W'X \tag{4.10}$$

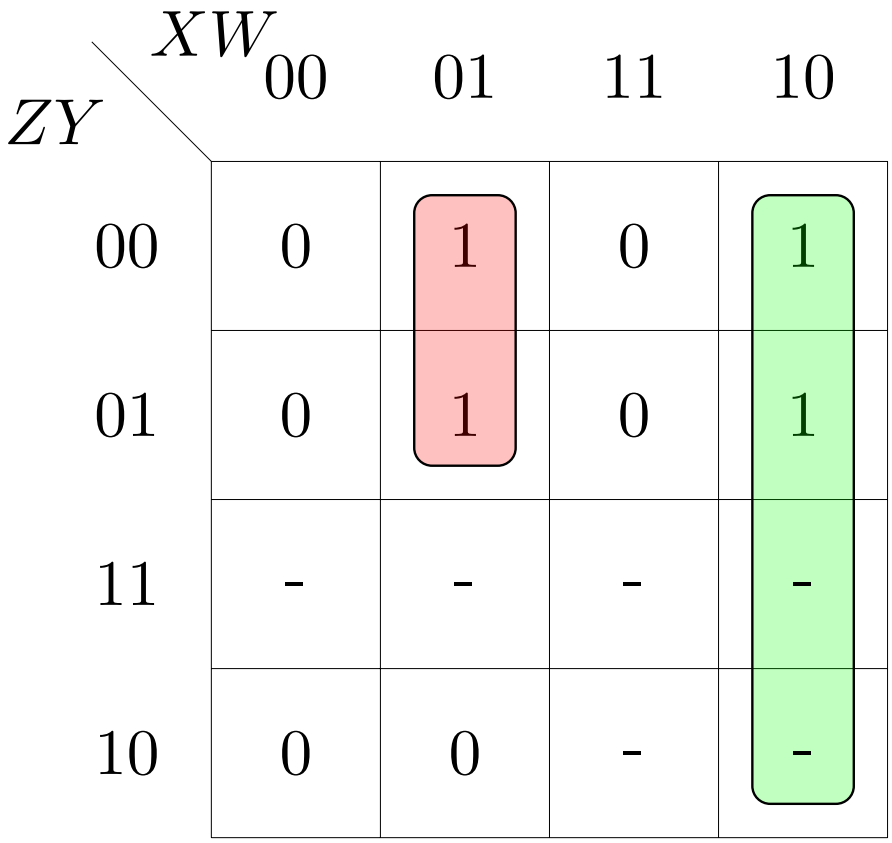


Figure 4.6: K-map for B with don't cares

4. The revised K-map for C is available in Fig 4.7 Show that

$$C = X'Y + W'Y + WXY' \tag{4.11}$$

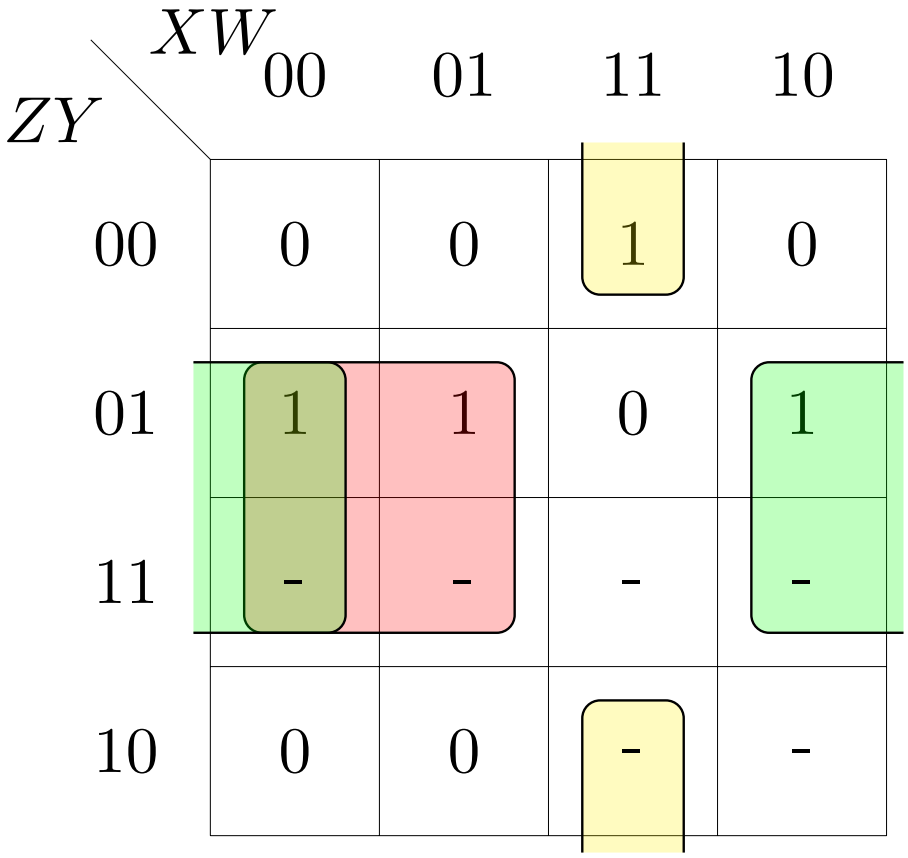


Figure 4.7: K-map for C with don't cares

5. The revised K-map for D is available in Fig 4.8 Show that

$$D = W'Z + WXY \tag{4.12}$$

6. Verify the incrementing decoder with don't care conditions using the arduino

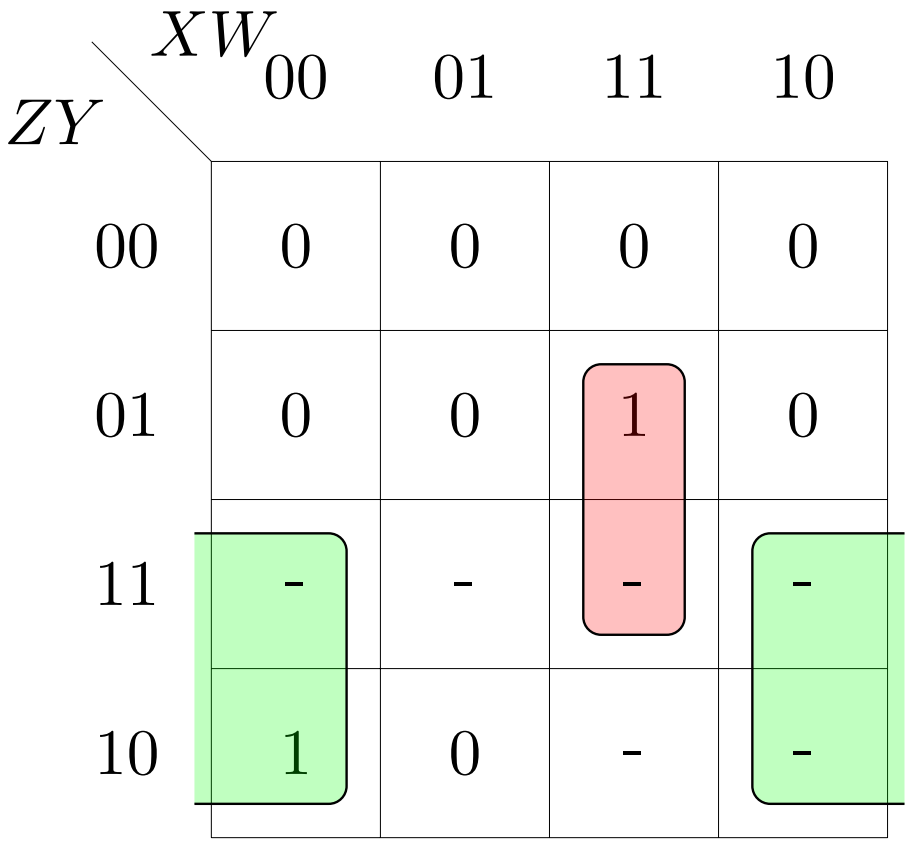


Figure 4.8: K-map for D with don't cares

7. Display Decoder: Use K-maps to obtain the minimized expressions for a, b, c, d, e, f, g in terms of A, B, C, D with don't care conditions

8. Verify the display decoder with don't care conditions using arduino

4.6. Problems

1. Obtain the Minimal Form for the Boolean Expression (CBSE 2013)

$$H(P, Q, R, S) = \sum(0, 1, 2, 3, 5, 7, 8, 9, 10, 14, 15) \tag{4.13}$$

2. Write the POS form for the function G shown in Table 4.4. (CBSE 2013)

U	V	W	G
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

Table 4.4:

3. Reduce the following Boolean Expression to its simplest form using K-Map (CBSE 2015)

$$F(X, Y, Z, W) = (0, 1, 4, 5, 6, 7, 8, 9, 11, 15) \tag{4.14}$$

4. Derive a Canonical POS expression for a Boolean function F, represented by the following truth table (CBSE 2015)

5. (CBSE 2015) Reduce the following Boolean Expression to its simplest form using

X	Y	Z	F
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

Table 4.5:

K-map

$$F(X, Y, Z, W) = \sum(0, 1, 6, 8, 9, 10, 11, 12, 15) \tag{4.15}$$

6. Reduce the following Boolean Expression to its simplest form using K-map. (CBSE 2016)

$$F(X, Y, Z, W) = \sum(2, 6, 7, 8, 9, 10, 11, 13, 14, 15) \tag{4.16}$$

7. Derive a Canonical POS expression for a Boolean function F, represented in Table 4.6 (CBSE 2016)

8. Verify the following (CBSE 2016)

$$A' + B'C = A'B'C' + A'BC' + A'BC + A'B'C + AB'C \tag{4.17}$$

9. Reduce the following boolean expression to it's simplest form using K-Map (CBSE

P	Q	R	F(P, Q, R)
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	1

Table 4.6:

2017)

$$F(X, Y, Z, W) = \sum(0, 1, 2, 3, 4, 5, 10, 11, 14) \tag{4.18}$$

10. Reduce the following Boolean Expression to its simplest form using K-Map. (CBSE 2017)

$$E(U, V, Z, W) = (2, 3, 6, 8, 9, 10, 11, 12, 13) \tag{4.19}$$

11. Derive a canonical POS expression for a Boolean function G, represented by Table 4.7 (CBSE 2017)

12. Derive a canonical POS expression for a Boolean function FN, represented by Table 4.8. (CBSE 2018)

13. Reduce the following Boolean expression in the simplest form using K-Map.

$$F(P, Q, R, S) = \sum(0, 1, 2, 3, 5, 6, 7, 10, 14, 15) \tag{4.20}$$

X	Y	Z	G(X,Y,Z)
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	1

Table 4.7:

X	Y	Z	FN(X,Y,Z)
0	0	0	1
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

Table 4.8:

(CBSE 2019)

14. Fig. 4.9 below shows a muliplexer where S0 and S1 are the select lines, I0 to I3 are the input lines, EN is the enable line and F(P,Q,R) is the output. Find the boolean expression for output F as function of inputs P,Q,R using K-map.

(GATE EC 2020)

15. The four variable function f is given in terms of min-terms as

$$f(A, B, C, D) = \sum m(2, 3, 8, 10, 11, 12, 14, 15) \tag{4.21}$$

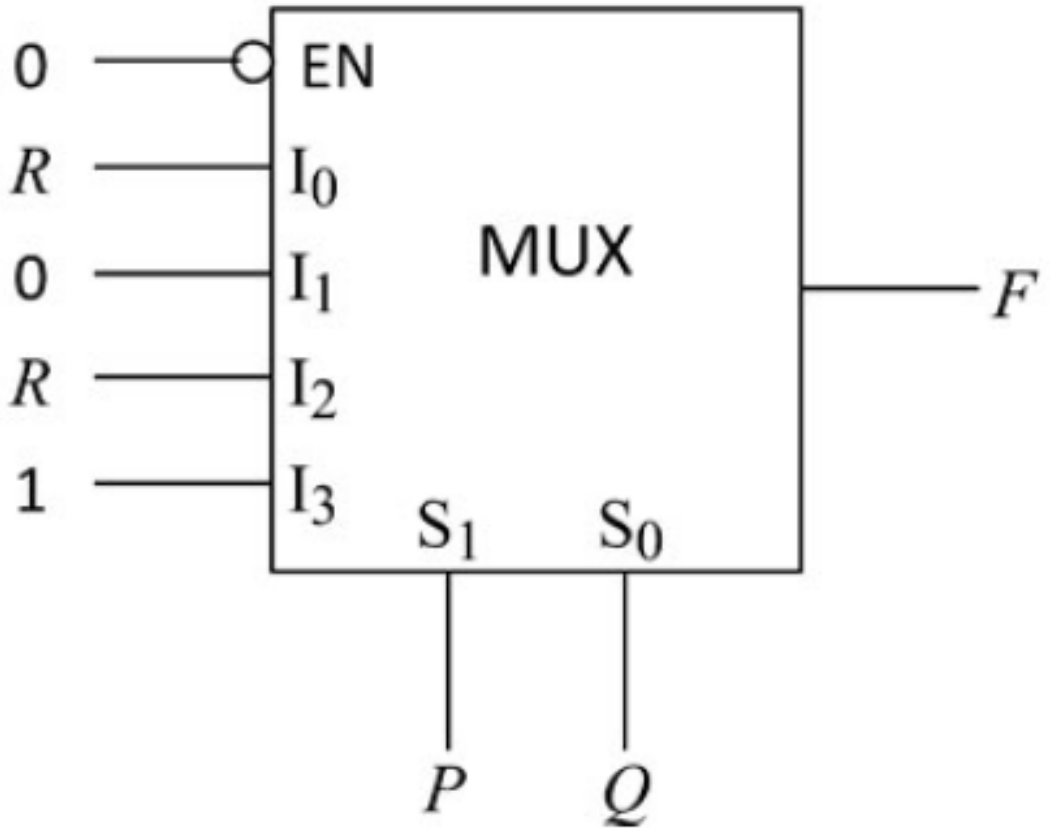


Figure 4.9:

Using the K-map minimize the function in the sum of products form. (GATE EC 1991)

16. Find the logic realized by the circuit in Fig. 4.10. (GATE EC 1992)

17. A combinational circuit has three inputs A, B and C and an output F. F is true only for the following input combinations. (GATE EC 1992)

    (a) A is false and B is true

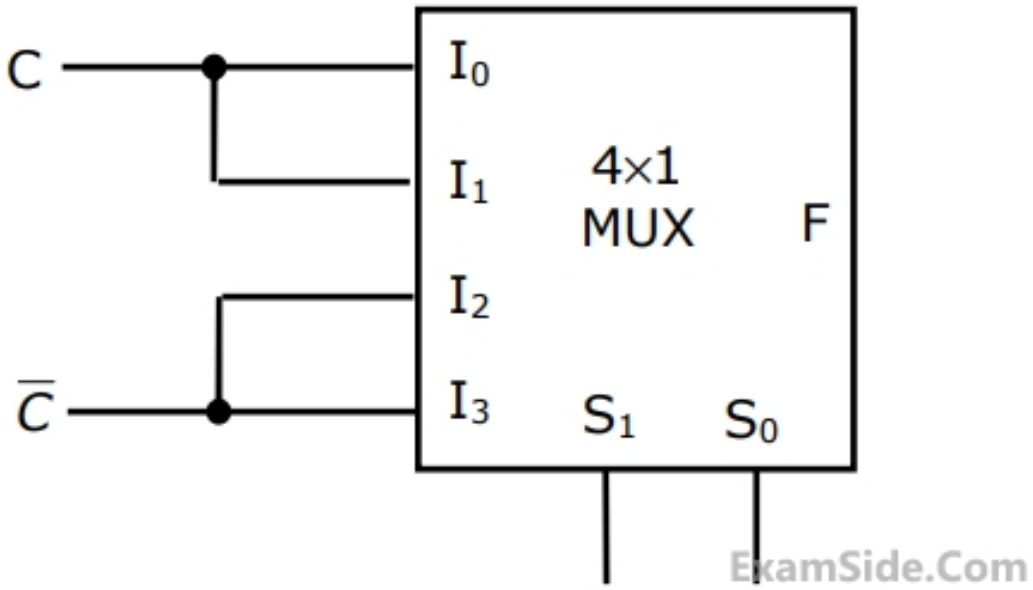


Figure 4.10:

(b) A is false and C is true

(c) A, B and C are all false

(d) A, B and C are all true

(a) Write the truth table for F. use the convention, true = 1 and false = 0.

(b) Write the simplified expression for F as a Sum of Products.

(c) Write the simplified expression for F as a product of Sums.

18. Draw the logic circuit for Table 4.9 using only NOR gates. (GATE EC 1993)

C	B	A	Y
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

Table 4.9:

19. Implement the following Boolean function in a 8x1 multiplexer. (GATE EC 1993)

$$Q = BC + ABD' + A'C'D \tag{4.22}$$

20. Minimize the following Boolean function in 4.23.

$$F = A'B'C' + A'BC' + A'BC + ABC' \tag{4.23}$$

21. Find the Boolean expression for Table 4.10. (GATE EC 2005)

A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

Table 4.10:

22. Minimize the logic function represented by the following Karnaugh map. (CBSE 2021)

X \ YZ	00	01	11	10
0	1	1	1	0
1	0	0	1	0

23. Find the output for the Karnaugh map shown below (GATE EE 2019)

RS \ PQ	00	01	11	10
00	0	1	1	0
01	1	1	1	1
11	1	1	1	1
10	0	0	0	0

Chapter 5

7474

We show how to use the 7474 D-Flip Flop ICs in a sequential circuit to realize a decade counter.

5.1. Components

Component	Value	Quantity
Breadboard		1
Resistor	$\geq 220\Omega$	1
Arduino	Uno	1
Seven Segment Display	Common Anode	1
Decoder	7447	1
Flip Flop	7474	2
Jumper Wires		20

Table 5.1:

5.2. Decade Counter

1. Generate the CLOCK signal using the **blink** program.

	INPUT				**OUTPUT**				CLOCK		5V			
	W	X	Y	Z	A	B	C	D						
Arduino	D6	D7	D8	D9	D2	D3	D4	D5	D13					
7474	5	9			2	12			CLK1	CLK2	1	4	10	13
7474			5	9			2	12	CLK1	CLK2	1	4	10	13
7447					7	1	2	6			16			

Table 5.2:

2. Connect the Arduino, 7447 and the two 7474 ICs according to Table 5.2 and Fig. 5.2.

   The pin diagram for 7474 is available in Fig. 5.1

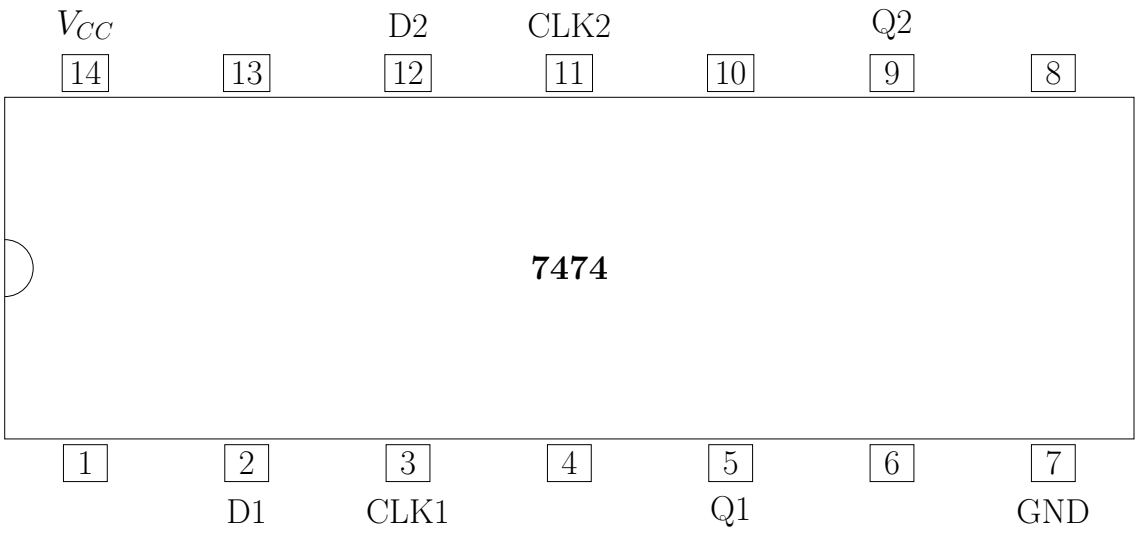


Figure 5.1:

3. Realize the decade counter in Fig. 5.2.

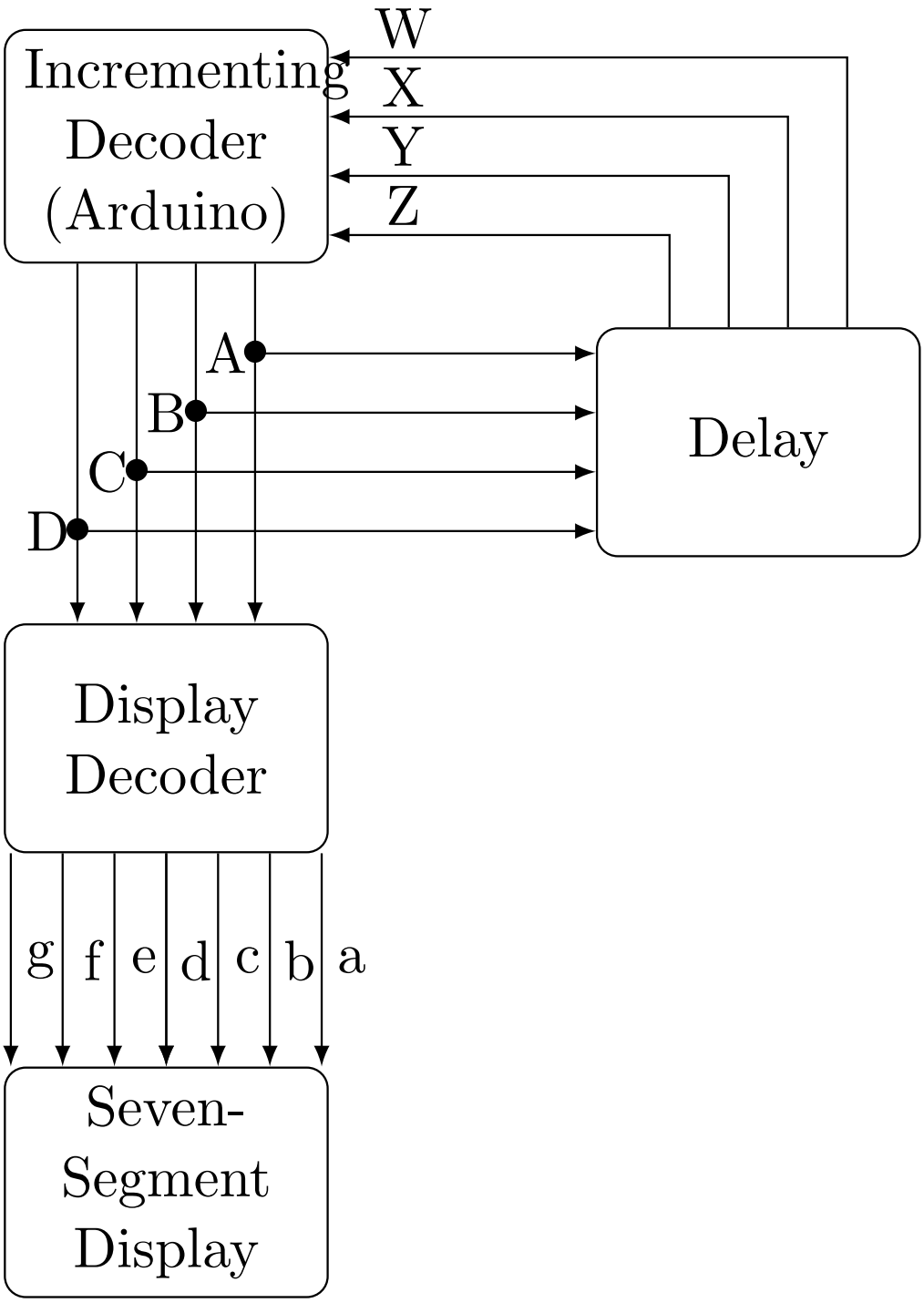

Incrementing
Decoder
(Arduino)
W
X
Y
Z
A
B
C
D
Delay
Display
Decoder
g
f
e
d
c
b
a
Seven-
Segment
Display

Figure 5.2:

Chapter 6

Finite State Machine

We explain a state machine by deconstructing the decade counter

6.1. The Decade Counter

The block diagram of a decade counter (repeatedly counts up from 0 to 9) is available in Fig 5.2 The incrementing decoder and display decoder are part of combinational logic, while the delay is part of sequential logic

6.2. Finite State Machine

1. Fig 6.1 shows a finite state machine (FSM) diagram for the decade counter in Fig 5.2 s_0 is the state when the input to the incrementing decoder is 0 The state transition table for the FSM is Table 4.1, where the present state is denoted by the variables W, X, Y, Z and the next state by A, B, C, D.

2. The FSM implementation is available in Fig 6.2 The flip-flops hold the input for the time that is given by the clock This is nothing but the implementation of the Delay block in Fig 5.2

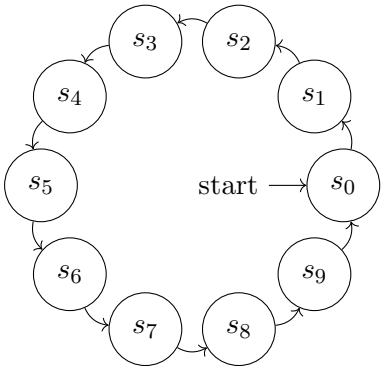


Figure 6.1: FSM for the decade counter

3. The hardware cost of the system is given by

$$\text{No of D Flip-Flops} = \lceil \log_2 (\text{No of States}) \rceil \tag{6.1}$$

   For the FSM in Fig 6.1, the number of states is 9, hence the number flipflops required = 4

4. Draw the state transition diagram for a decade down counter (counts from 9 to 0 repeatedly) using an FSM

5. Write the state transition table for the down counter

6. Obtain the state transition equations with and without don't cares

7. Verify your design using an arduino

6.3. Problems

1. The digital circuit shown in Fig. 6.3 generates a modified clockpulse at the output. Sketch the output waveform. (GATE EE 2004)

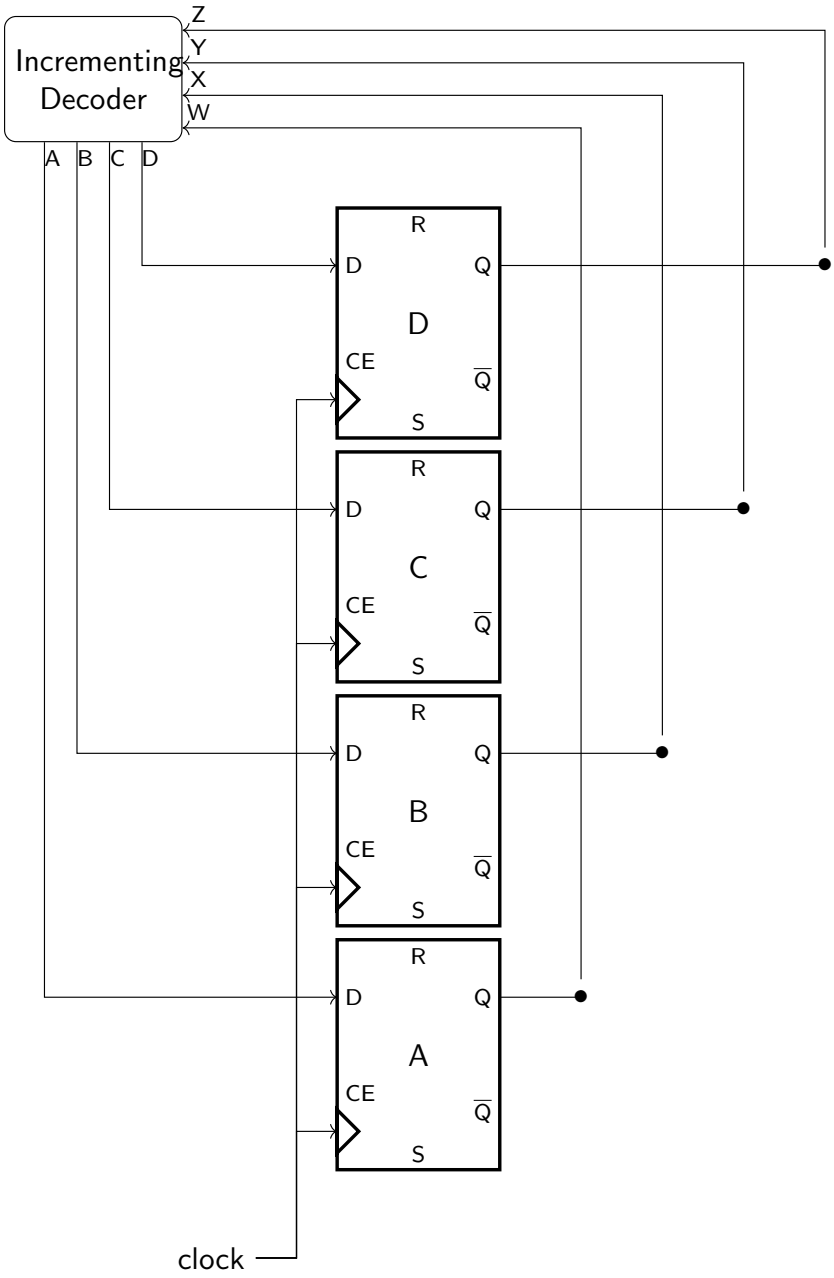


Figure 6.2: Decade counter FSM implementation using D-Flip Flops

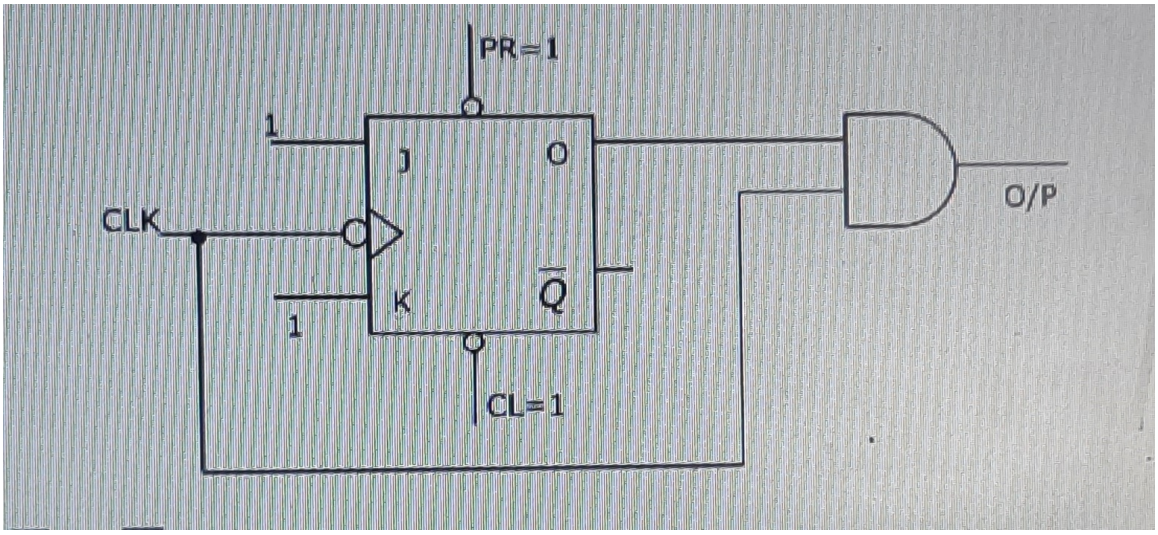


Figure 6.3:

2. The circuit shown in the figure below uses ideal positive edge-triggered synchronous J-K flip flops with outputs X and Y. If the initial state of the output is X=0 and Y=0, just before the arrival of the first clock pulse, the state of the output just before the arrival of the second clock pulse is (GATE IN 2019)

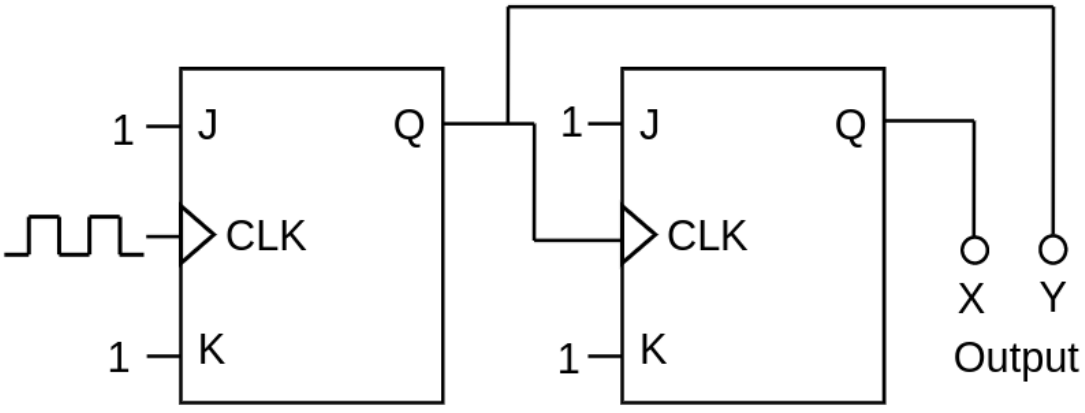


Figure 6.4:

3. A counter is constructed with three D flip-flops. The input-output pairs are named (D0, Q0), (D1, Q1), and (D2, Q2), where the subscript 0 denotes the least significant bit. The output sequence is desired to be the Gray-code sequence 000, 001, 011, 010, 110, 111, 101, and 100, repeating periodically. Note that the bits are listed in the Q2 Q1 Q0 format. Find the combinational logic expression for D1. (CBSE 2021)

Chapter 7

Assembly Programming

T:his manual shows how to setup the assembly programming environment for the arduino.

7.1. Software Installation

1. Find the USB port to which arduino is connected.

```
%Finding the port


sudo dmesg | grep tty
%The output will be something like
[ 6.153362] cdc_acm 1-1.2:1.0: ttyACM0: USB ACM device
%and your port number is ttyACM0
```

2. Copy the .inc file to your home directory

```
cp assembly/setup/m328Pdef/m328Pdef.inc ~/
```

3. Execute

```
avra assembly/setup/codes/hello.asm
```

as

4. Then flash the .hex file

```
hello.hex
```

5. You should see the led beside pin 13 light up.

6. Now edit **hello.asm** by modifying the line to

```
ldi r17,0b00000000
```

   Save and execute. The led should turn off.

7. What do the following instructions do?

```
ldi r16,0b00100000
out DDRB,r16
```

   Solution: The Atmega328p microcontroller for the arduino board has 32 internal 8-bit registers, R0-R31. R16-R31 can be used directly for i/o. The first instruction loads an 8-bit binary number into R16. The second instruction loads the value in R16 to the DDRB register. Each bit of the DDRB register corresponds to a pin on the arduino. The second instruction declares pin 13 to be an output port. Both the instructions are equivalent to pinMode(13, OUTPUT).

8. What do the following instructions do?

```
ldi r17,0b00100000
out PortB,r17
```

   Solution: The instructions are equivalent to digitalWrite(13).

T:he objective of this manual is to show how to control a seven segment display through the AVR-Assembly.

7.2. Seven Segment Display

1. See Table 2.1 for components.

2. Complete Table 2 for all the digital pins using Fig. 2.

Port Pin	Digital Pin
PD2	2
PB5	13

Table 2:

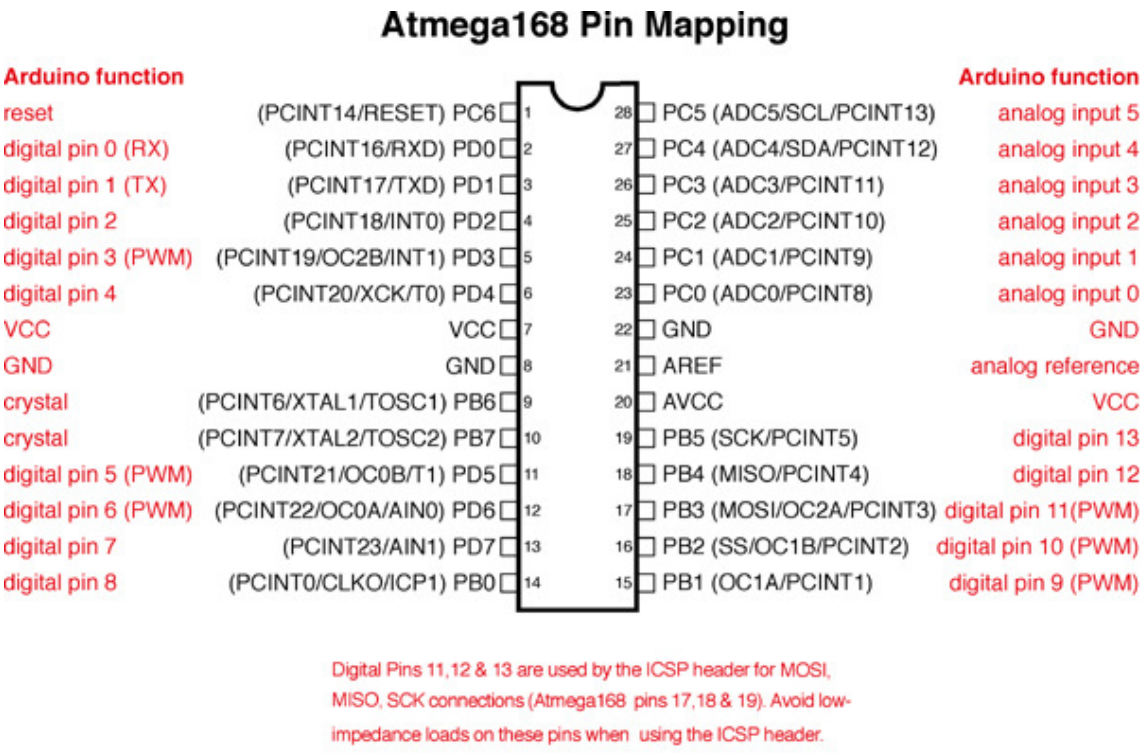


Figure 2:

3. Make connections according to Table 3.

Arduino	2	3	4	5	6	7	8
	PD2	PD3	PD4	PD5	PD6	PD7	PB0
Display	a	b	c	d	e	f	g
2	0	0	1	0	0	1	0

Table 3:

4. Execute the following code. The number 2 should be displayed.

```
;using assembly language for
;displaying number on
;seven segment display

.include "/home/gadepall/m328Pdef.inc"



;Configuring pins 2–7 (PD2–PD7) of Arduino
;as output
  ldi r16,0b11111100
  out DDRD,r16
;Configuring pin 8 (PB0) of Arduino
;as output
  ldi r16,0b00000001
  out DDRB,r16
;Writing the number 2 on the
;seven segment display
  ldi r17,0b10010000
  out PortD,r17
```

```
  ldi r17,0b00000000
  out PortB,r17
Start:
  rjmp Start
```

5. Now generate the numbers 0-9 by modifying the above program.

7.3. 7447

This manual shows how to program the 7447 BCD-Seven segment display decoder through AVR-Assembly.

7.3.1. Components

Component	Value	Quantity
Resistor	220 Ohm	1
Arduino	UNO	1
Seven Segment Display		1
Decoder	7447	1
Jumper Wires	M-M	20
Breadboard		1

7.3.2. Boolean Operations

1. Verify the AND,OR and XOR operations in assembly using the following code and making pin connections according to Table 1.

```
wget https://raw.githubusercontent.com/gadepall/arduino/master/assembly/7447/
    count/codes/and_or_xor.asm
```

7447	D	C	B	A
Arduino	5	4	3	2

Table 1:

2. Suppose R20=0b00000010, R16=0b00000001. Explain the following routine

```
loopw: lsl r16    ;left shift
        dec r20    ;counter --
        brne loopw ;if counter != 0
        ret
```

Solution: The routine shifts R16 by 2 bits to the left (the count in R20=2). At the end of the routine, R16=0b00000100.

3. What do the following instructions do?

```
rcall loopw
out PORTD,r16  ;writing output to pins 2,3,4,5
```

Solution: rcall calls for execution of the **loopw** routine, which shifts R16 by 2 bits to the left and writes R16 to the display through PORTD.

4. Use the following routine for finding the complement of a number.

```
wget https://raw.githubusercontent.com/gadepall/arduino/master/assembly/7447/
    count/codes/complement.asm
```

5. Write an assembly program for implementing the following equations. Note that ZYXW is the input nibble and DCBA is the output nibble. Display DCBA on the seven segment display for each input ZYXW from 0-9.

$$A = W' \tag{7.1}$$

$$B = WX'Z' + W'X \tag{7.2}$$

$$C = WXY' + X'Y + W'Y \tag{7.3}$$

$$D = WXY + W'Z \tag{7.4}$$

6. Repeat the above exercise by getting ZYXW as manual inputs to the arduino from the GND and 5V pins on the breadboard.