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A digital indicator system with 7-segment display

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Abstract. This paper presents the design and implementation of a digital system that uses a 7-segment display to indicate the number of drug tablets in a tablet-bottling assembly line. As well as display the number of tablets in a bottle (from 0 – 9), the display can also indicate the name of the vitamin tablet being assembled (Vitamin A, b, C, d, E). This work presents the digital implementation comprising the logic expression, logic circuit and VHDL code for the Vitamin type in the bottle. A digital implementation to display the number of Vitamins in the tablet bottle as well as the Vitamin type with a BBC microbit microcontroller is presented. The application of this work can be extended to give a visual indication of any industrial application that requires indication of the current production stage/phase.

1. Introduction

Seven segment displays are made up of LEDs combined such that they can be used to display numbers and letters. As their name implies, they are made of seven LEDs plus an additional LED for a dot. Led dot matrix displays, on the other hand, are made up of LEDs in a square matrix form to give an indication of a letter, number or symbol [1]. Seven segment displays can be in form of common anode or common cathode. They can also be in form of single digit or multi digit seven segment displays.

Seven-segment displays are used in many types of everyday products, for example, in a tablet-bottling system [2], to give an indication of measurement types such as temperature or a reading on calculator or meters [3]. The 7-segment display for the bottling system is controlled by logic circuits which encodes a decimal number in binary form consequently activating suitable LEDs of the display. 7-segment displays cannot only indicate numbers (0 to 9), they can also display some alphabets.

The application of 7-segment display in this paper is to give a visual indication of the number of tablets in a drug bottling assembly line as well as give a visual indication of the Vitamin type being assembled. The digital drug tablet-bottling assembly line works by grouping and assembling a particular Vitamin tablet in a bottle along a production line after these tablets have been manufactured. In this paper, we design a digital system to indicate the alphabets (A, b, C, d, and E) which is used to categorise the kind of vitamin tablet that is assembled in a drug bottling production line. The design of numbers 0 – 9 using a single digit 7-segment display is also developed to give an indication of the number of tablets in the bottle. In this paper, the decoding logic for indicating A, b, C, d, and E letters is presented in detail.

2. Single Digit Displays

Light Emitting Diodes (LEDs) and Liquid Crystal Displays (LCDs) are the two common types of digital visual displays. For 7-segment displays, seven light-emitting diodes are arranged in such a way as to give



light whenever current flows through the powered circuit. An LCD, on the other hand, works on the principle of polarized light which gets activated when light is not reflected, thereby the letters, alphabets, numbers and characters appears black. However, inactivation causes incident reflected light to be invisible. The LED segments in 7 segments displays are organised as shown in Figure 1 and characterized as a, b, c, d, e, f, g and dp as indicated. When chosen LED segments are turned ON or OFF, certain alphabetical letters or numbers are created.

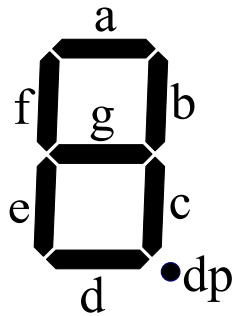


Figure 1: 7 segment display lettering

Common Anode (CA) displays have the anode of all LED pins connected together to 5v, therefore, a LOW voltage applied individually on each pin will light up the LED of that particular pin. Conversely, Common Cathode (CC) displays have the cathode of all LED pins connected together to ground, therefore, a HIGH voltage applied individually on a given pin will turn ON the LED of that particular pin Figure 2 shows the internal structure of a single digit 7-segment display.

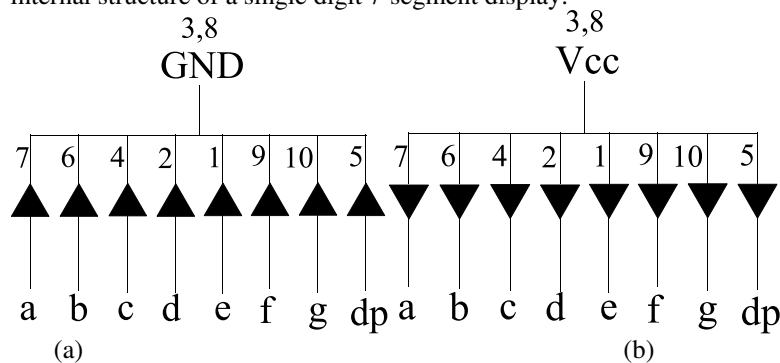


Figure 2: Internal structure of 1-digit 7 segment displays. (a) Common Cathode (CC) (b) Common Anode (CA)

7 segment displays normally have 8 pins which represent the each LED on the display (7 segment plus the dot making 8 LEDs) (Figure 3a and b). However, there is also a 7 segment display called a Binary Coded Display (BCD) that has only 4 pins (Figure 3c. In this case, the binary combination as shown in Table 1 will produce numbers 0 - 9 and letters A - F as shown.

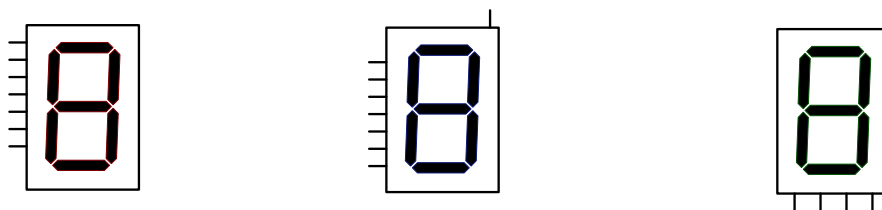


Figure 3: Single-digit 7 segment displays; (a) Generic 7-segment display (b) Common anode/ cathode 7-segment display (c) Binary coded (BCD) 7-segment display

Table 1: Binary Coded Display pin configuration

	Pin 1	Pin 2	Pin 3	Pin 4	binary
0	0	0	0	0	0000
1	0	0	0	1	0001
2	0	0	1	0	0010
3	0	0	1	1	0011
4	0	1	0	0	0100
5	0	1	0	1	0101
6	0	1	1	0	0110
7	0	1	1	1	0111
8	1	0	0	0	1000
9	1	0	0	1	1001
A	1	0	1	0	1010
b	1	0	1	1	1011
C	1	1	0	0	1100
d	1	1	0	1	1101
E	1	1	1	0	1110
F	1	1	1	1	1111

For common anode 7-segment displays, Table 2 shows the binary and hexadecimal value that would produce numbers 0 - 9 and alphabets A - F, this can be traced by using Figure 2. For common cathode 7-segment displays, the binary and hexadecimal values are shown in Table 3 for numbers 0 - 9 and alphabets A - F. Notice that the binary values can also be produced by carrying out a NOT operation on the respective common anode binary value. For example, number '2' is formed by the following segments: a, b, d, e, and g; number '5' is formed by the following segments: a, c, d, f and g; alphabet 'A' is formed by the following segments: a, b, c, e, f and g; letter 'E' is formed by the following segments: a, d, e, f and g. As shown in both Tables 2 and 3, there is no one segment that is shared by all digits but segment "e" is shared to all alphabets that can be displayed by the 7-segment.

Table 2: Common Anode

	<i>d</i>	<i>p</i>	<i>g</i>	<i>f</i>	<i>e</i>	<i>d</i>	<i>c</i>	<i>b</i>	<i>a</i>	binary	hexadecimal
0	1	1	0	0	0	0	0	0	0	0b11000000	0xc0
1	1	1	1	1	1	0	0	0	1	0b11111001	0xf9
2	1	0	1	0	0	1	0	0	0	0b10100100	0xa4
3	1	0	1	1	0	0	0	0	0	0b10110000	0xb0
4	1	0	0	1	1	0	0	1	1	0b10011001	0x99
5	1	0	0	1	0	0	1	0	0	0b10010010	0x92
6	1	0	0	0	0	0	1	0	0	0b10000010	0x82
7	1	1	1	1	1	0	0	0	0	0b11111000	0xf8
8	1	0	0	0	0	0	0	0	0	0b10000000	0x80
9	1	0	0	1	0	0	0	0	0	0b10010000	0x90
A	1	0	0	0	1	0	0	0	0	0b10001000	0x88
b	1	0	0	0	0	0	1	1	1	0b10000011	0x83
C	1	1	0	0	0	1	1	0	0	0b11000110	0xc6
d	1	0	1	0	0	0	0	1	1	0b10100001	0xa1
E	1	0	0	0	0	1	1	0	0	0b10000110	0x86
F	1	0	0	0	1	1	1	0	0	0b10001110	0x8e
OFF	1	1	1	1	1	1	1	1	1	0b11111111	0xff

Table 3: Common Cathode 7 segment display:

	<i>d</i>	<i>p</i>	<i>g</i>	<i>f</i>	<i>e</i>	<i>d</i>	<i>c</i>	<i>b</i>	<i>a</i>	binary	hexadecimal
0	0	0	1	1	1	1	1	1	1	0b00111111	0x3f
1	0	0	0	0	0	1	1	1	0	0b00000110	0x06
2	0	1	0	1	1	0	1	1	1	0b01011011	0x5b
3	0	1	0	0	1	1	1	1	1	0b01001111	0x4f
4	0	1	1	0	0	1	1	1	0	0b01100110	0x66
5	0	1	1	0	1	1	0	1	1	0b01101101	0x6d
6	0	1	1	1	1	1	0	1	1	0b01111101	0x7d
7	0	0	0	0	0	1	1	1	1	0b00000111	0x07
8	0	1	1	1	1	1	1	1	1	0b01111111	0x7f
9	0	1	1	0	1	1	1	1	1	0b01101111	0x6f
A	0	1	1	1	0	1	1	1	1	0b01110111	0x77
b	0	1	1	1	1	1	0	0	0	0b01111100	0x7c
C	0	0	1	1	1	0	0	1	1	0b00111001	0x39
d	0	1	0	1	1	1	1	1	0	0b01011110	0x5e
E	0	1	1	1	1	0	0	1	1	0b01111001	0x79
F	0	1	1	1	0	0	0	1	1	0b01110001	0x71
OFF	0	0	0	0	0	0	0	0	0	0b00000000	0x00

3. Logic Design for Display

7-segment displays have their segments designed in order that the formations of various letters shown in Table 4 are obtained. Activation of each segment is through a decoding circuit that distinguishes the code for each alphabet in which that particular segment is utilized. Because a CA display is used, the segments are activated with a LOW voltage and deactivated with a positive HIGH voltage.

Table 4: Segments activated for each of the five alphabets used in the 7 segment displays.

Letter	Activated Segment
A	A, B, C, E, F, G
b	C, D, E, F, G
C	A, D, E, F
d	B, C, D, E, G
E	A, D, E, F, G

A 7-segment display truth table for producing the alphabets is indicated in Table 5. 4 hexa-decimal inputs and 7 outputs can be seen for each segment as part of the logic. Since the alphabet F is not utilized as part of the inputs, therefore, all outputs for F are all fixed to 1.

Table 5: Hexadecimal-to-7-segment decoder for letters A through E

Letter	Hexadecimal Inputs	Segment Outputs
	$H_3H_2H_0H_1$	$abcdefg$
A	1 0 1 0	0 0 0 1 0 0 0
b	1 0 1 1	1 1 0 0 0 0 0
C	1 1 0 0	0 1 1 0 0 0 1
d	1 1 0 1	1 0 0 0 0 1 0
E	1 1 1 0	0 1 1 0 0 0 0
F	1 1 1 1	1 1 1 1 1 1 1

3.1 Karnaugh Maps

In order that simplified logic are developed for each segment, the truth table in Table 5 is drawn using Karnaugh maps. Numbers that will not be shown on the display are invalid and therefore ‘X’ is entered on the Karnaugh maps.

3.2 Expressions for the Segment Logic

Using the table in Table 4, a standard Sum-of-Products (SOP) expression was written for each segment and then simplified with the use of K-map. Entries corresponding to chosen outputs from the table are written into the suitable cells representing the hex inputs. The 1s and Xs are clustered in order to achieve the simplified SOP expressions for the display logic.

Segment a: Segment a is used for the alphabets A, C and E. The Boolean expression for segment a is:

$$a = H_3\bar{H}_2H_1\bar{H}_0 + H_3H_2\bar{H}_1\bar{H}_0 + H_3H_2H_1\bar{H}_0$$

Simplified expression for segment a is shown in Figure 4:

$H_3H_2 \setminus H_1H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	0	1	1	0
10	X	X	1	0

Figure 4: K-map simplification of segment a

$$a = H_0$$

Segment b: Segment b is used for the alphabets A and d. The Boolean expression for segment b is:

$$b = H_3\bar{H}_2H_1\bar{H}_0 + H_3H_2\bar{H}_1H_0$$

Simplified expression for segment b is shown in Figure 5:

$H_3H_2 \setminus H_1H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	1	0	1	1
10	X	X	1	0

Figure 5: K-map simplification of segment b

$$b = \bar{H}_1\bar{H}_0 + H_1H_0 + H_2H_1$$

Segment c: Segment c is used for the alphabets A, b and d. The Boolean expression for segment c is:

$$c = H_3\bar{H}_2H_1\bar{H}_0 + H_3\bar{H}_2H_1H_0 + H_3H_2\bar{H}_1H_0$$

Simplified expression for segment c is shown in Figure 6:

$H_3H_2 \setminus H_1H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	1	0	1	1
10	X	X	0	0

Figure 6: K-map simplification of segment c

$$c = \bar{H}_1\bar{H}_0 + H_2H_1$$

Segment d: Segment d is used for the alphabets b, C, d and E. The Boolean expression for segment d is:

$$d = H_3\bar{H}_2H_1H_0 + H_3H_2\bar{H}_1\bar{H}_0 + H_3H_2\bar{H}_1H_0 + H_3H_2H_1\bar{H}_0$$

Minimization of the expressions for segment d is shown in Figure 7:

$H_3H_2 \setminus H_1H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	0	0	1	0
10	X	X	0	1

Figure 7: K-map simplification of segment d

$$d = H_3 H_2 H_1 + \overline{H_3} H_2 \overline{H_1}$$

Segment e: Segment e is present in alphabets A, b, C, d and E. The Boolean expression for segment e is:

$$e = H_3 \overline{H_2} H_1 \overline{H_0} + H_3 \overline{H_2} H_1 H_0 + H_3 H_2 \overline{H_1} H_0 + H_3 H_2 \overline{H_1} \overline{H_0} + H_3 H_2 H_1 \overline{H_0}$$

Minimization of the expressions for segment e is shown in Figure 8:

$H_3 H_2 \backslash H_1 H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	0	0	1	0
10	X	X	0	0

Figure 8: K-map simplification of segment e

$$e = H_2 H_1 H_0$$

Segment f: Segment f is present in alphabets A, b, C and E.. The Boolean expression for segment f is:

$$f = H_3 \overline{H_2} H_1 \overline{H_0} + H_3 \overline{H_2} H_1 H_0 + H_3 H_2 \overline{H_1} H_0 + H_3 H_2 H_1 \overline{H_0}$$

Minimization of the expressions for segment f is shown in Figure 9:

$H_3 H_2 \backslash H_1 H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	0	1	1	0
10	X	X	0	0

Figure 9: K-map simplification of segment f

$$f = H_2 H_0$$

Segment g: Segment g is found in alphabets A, b, d and E. The Boolean expression for segment g is

$$g = H_3 \overline{H_2} H_1 \overline{H_0} + H_3 \overline{H_2} H_1 H_0 + H_3 H_2 \overline{H_1} H_0 + H_3 H_2 H_1 \overline{H_0}$$

Minimization of the expressions for segment g is shown in Figure 10:

$H_3 H_2 \backslash H_1 H_0$	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	1	0	1	0
10	X	X	0	0

Figure 10: K-map simplification of segment g

$$g = H_2 H_1 H_0 + \overline{H_1} H_0$$

3.3. The Logic Circuits

From the minimum expressions, the logic circuits for each segment can be implemented. The logic diagram of segment a, b and c is shown in Figure 11

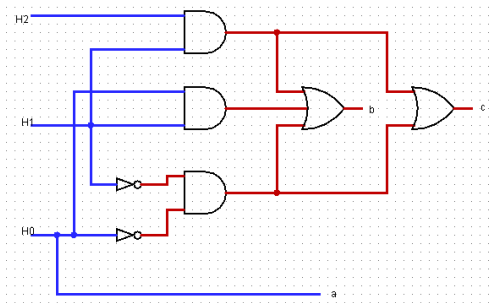


Figure 11: Logic diagram of segment a, b and c
For segment d, the logic diagram is shown in Figure 12:

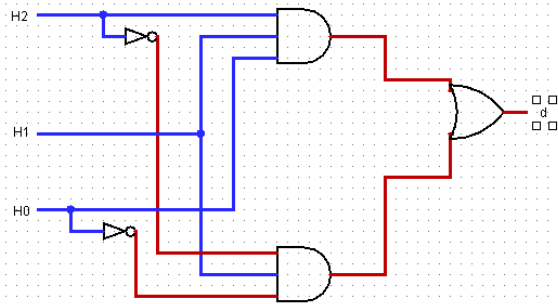


Figure 12: Logic diagram of segment d
For segment e, the logic diagram is shown in Figure 13:

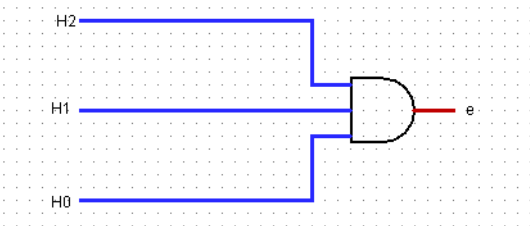


Figure 13: Logic diagram of segment e
For segment f, the logic diagram is shown in Figure 14:

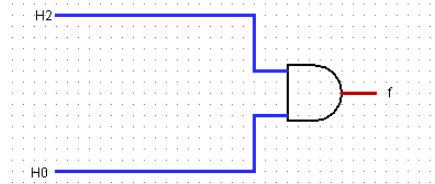


Figure 14: Logic diagram of segment f
For segment g, the logic diagram is shown in Figure 15:

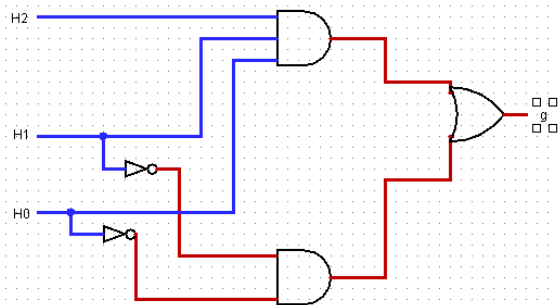


Figure 15: Logic diagram of segment g

VHDL implementation of the 7-segment decoding logic in a programmable logic device (PLD) is described using the following code.

Segment ais implemented with the VHDL code:

```
port (H0: in bit; SEGa: out bit);  
SEGa <= H0;
```

Segment bis implemented with the VHDL code:

```
port (H0, H1, H2: in bit; SEGb: out bit);  
SEGb <= (not H1 and not H0) or (H1 and H0) or (H2 and H1);
```

Segment cis implemented with the VHDL code:

```
port (H0, H1, H2: in bit; SEGc: out bit);  
SEGc <= (not H1 and not H0) or (H2 and H1);
```

Segment dis implemented with the VHDL code:

```
port (H0, H1, H2: in bit; SEGd: out bit);  
SEGd <= (H2 and H1 and H0) or (not H2 and H1 and not H0);
```

Segment eis implemented with the VHDL code:

```
port (H0, H1, H2: in bit; SEGe: out bit);  
SEGe <= (H2 and H1 and H0);
```

Segment fis implemented with the VHDL code:

```
port (H0, H2: in bit; SEGf: out bit);  
SEGf <= (H2 and H0);
```

Segment gis implemented with the VHDL code:

```
port (H0, H1, H2: in bit; SEGg: out bit);  
SEGg <= (H2 and H1 and H0) or (not H1 and not H0);
```

4. Results and Discussion

The digital indicator system with a 7-segment display was physically implemented using a BBC Microbit microcontroller and a single digit 7-segment display to produce numbers 0 – 9 as well as letters A, b, C, d and E. These numbers and letters give a visual indication for the digital drug bottling system in an assembly process. The results are presented in the following sections.

4.1 Simulation

The decoder simulation is shown in Figure 4 with the letter C selected. The purpose of simulation is to verify proper operation of the circuit.

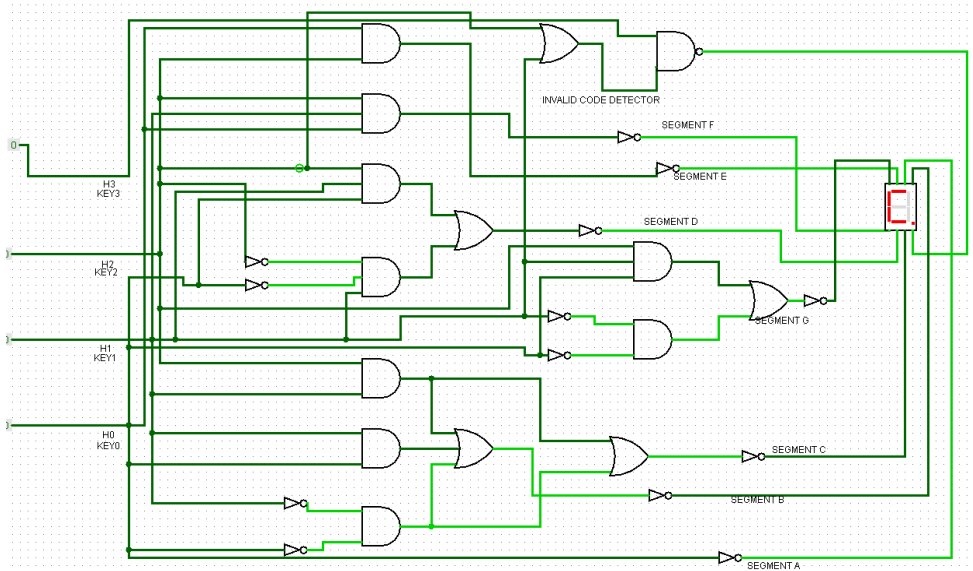


Figure 16: Decoder Simulation for letter C

4.2 Microcontroller Implementation

The implementation of the digital system that displays the count from 0 to 9 as well as the letters A, b, C, d and E was carried out on a BBC Mibrobot microcontroller as shown in Figure 17.





Figure 17: A blue 7 segment display displays number 0 – 9, A – F

4.3 Multi-digit displays

Multi-digit displays do not have pins equal to $8 \times$ number of digits, instead, their number of pins equals $8 +$ number of digits as shown in Figure 18.

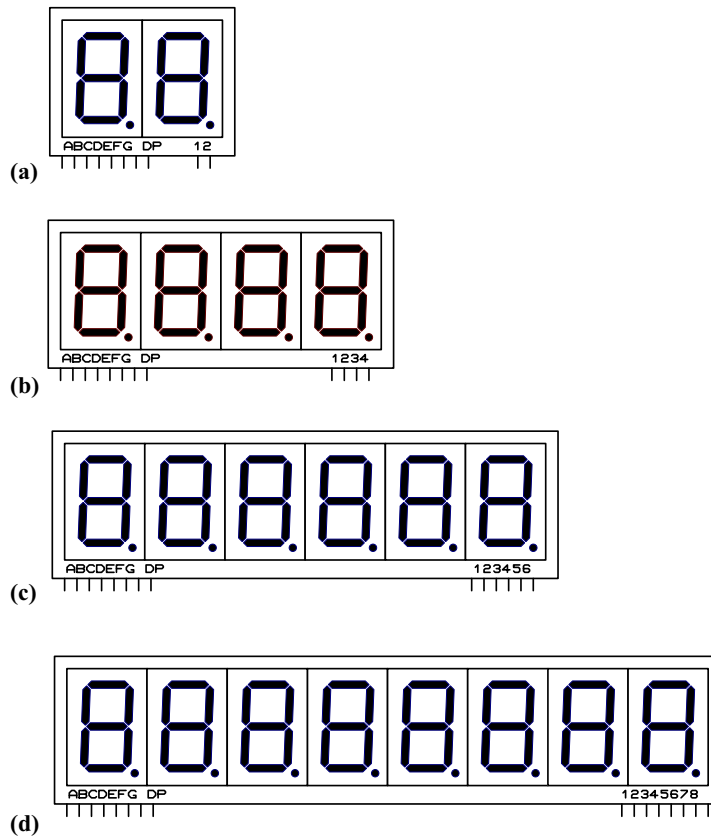


Figure 18: Multi-digit 7 segment displays; (a) 2-digit, 7-segment display (b) 4-digit, 7-segment display (c) 6-digit, 7-segment display and (d) 8-digit, 7-segment display

7 segment displays can be connected directly to a microcontroller. 74HC573 Latch IC can likewise be used to drive 7 segment displays, the advantage of using a latch is that only 8 digital pins of a microcontroller can be used for multi-digit displays. If a latch is not used, the number of pins that is equal to the number of pins the LED display has will be used by the microcontroller.

4-digit 7-segment displays

The internal structure of a 4-digit 7-segment common cathode display is shown in Figure 19. The cathode of each digit are connected together, a LOW voltage on the cathode will light up the corresponding LED if its anode is HIGH while a HIGH voltage on the cathode will turn off the LEDs.

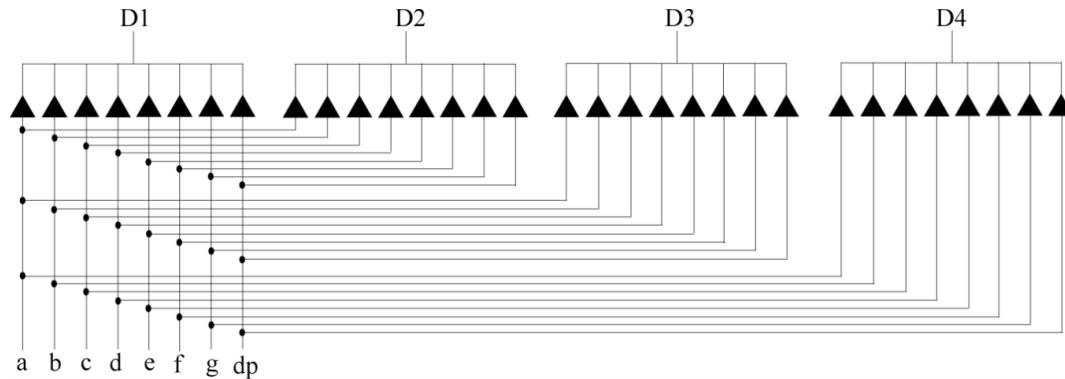


Figure 19: Internal structure of 4-digit 7 segment display common cathode display

The internal structure of a 4-digit 7-segment common anode display is shown in Figure 20. The anode of each digit are connected together, a HIGH voltage on the anode will light up the corresponding LED if its cathode is LOW while a LOW voltage on the anode will turn off the LEDs of the corresponding digit.

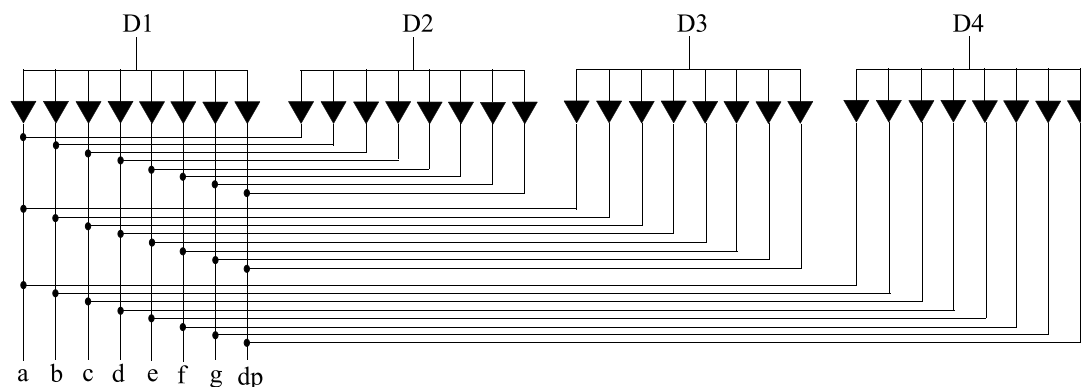


Figure 20: Internal structure of 4-digit 7 segment display common anode display

The pinout for 1-digit and 4-digit 7-segment displays is shown in Figure 21a. For 1-digit displays (Figure 21b), pin 3 and 8 are the power pins: in common anode, these pins should be connected to Vcc while for common cathode, they should be connected to GND.

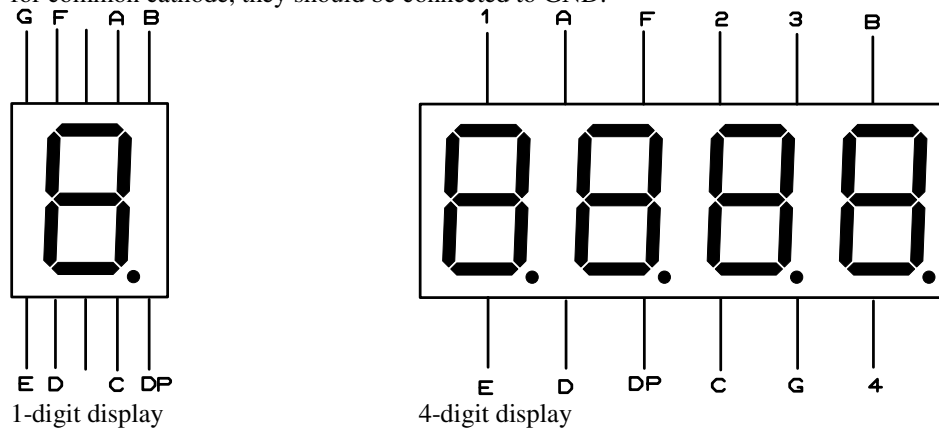


Figure 21: Pinout for 1-digit and 4-digit displays

5. Conclusion

This work provided a proper understanding of seven segment displays. A digital implementation to display letters and numbers on a single digit seven segment display has been implemented using logic expressions, logic gates, VHDL implementation and a physical implementation on a microcontroller. The application of this system is to a drug tablet bottling which displays the count number as well as the Vitamin type being bottled. The application was also extended to a multi-digit seven segment display in order to increase the count range. Further work will involve the design and implementation of a four-digit display as a clock to give an indication and update of the hour, minute and second. The clock will have alarm capability so as to beep when the alarm goes off as well as set and reset inputs.

Acknowledgment

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