Design, Construction and Operation of a 4-Bit Counting Circuit

Brian E. Usibe* and Julie C. Ogbulezie

Department of Physics, University of Calabar P.M.B. 1115 Calabar, Nigeria

Abstract: *A four-bit binary counting circuit was designed and constructed. The materials used were; PIC Microcontroller, Seven-segment LED, Printed Circuit Board, LEDs, Transistors, 9v DC power source (Battery), and other passive components. The method adopted for this counter makes use of a microcontroller as the backbone of the design, which holds the command for every action that is to occur during an operation. The output (results) of the circuit was indicated by four Light Emitting Diodes (LEDs) with counts; 0000, 0001, 0010, 0011, 0100, 1010, 0110, 0111, 1000, 1001, 1010, 1011, 1100, 1101, 1110 and 1111. These binary outputs were further converted to decimal equivalent through a reprogrammable microcontroller and then displayed using a dual seven-segment display device.*

Keywords: *Counting circuit, PIC microcontroller, seven-segment display, logic systems.*

I.   INTRODUCTION

An instrument which, in its simplest form, provides an output that corresponds to the number of pulses applied to its input is termed a digital counter. In digital logic, a counter is a device which stores (and sometimes displays) the number of times a particular event or process has occurred, often in relationship to a clock signal. A circuit which performs this function and has these characteristics is generally referred to as a digital counter [1].

Counting circuits belong to a particular class of sequential circuits. Each has one particular input and a number of outputs which follows some digital codes. The counter itself is a J-K flip-flop. Two major types of counting circuits exist; the Batch and the Measurement types [2].

Digital counters operate in the binary number system. This is so because binary system is easily and quickly carried out with electronic circuitry. Computer information is expressed in binary form (bits) because of the convenience of handling two clearly-defined states. Each bit is either a ZERO or a ONE, OFF or ON, LOW or HIGH, etc [3]. Fig 1 and table 1 illustrate a 4–bit binary counter that can count from 0 to 15. The 16th count input causes the counter to return to the 0 output and generate a carry pulse. This action of a counter to return to the 0 state with a carry output on every 16th pulse makes the 4–bit binary a modulo-16 (mod 16) counter. Modulus counter means it operates the predetermined state. For example, in mod-10 counter, it counts only 10 states.
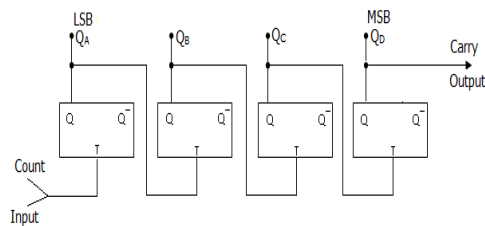

Fig. 1: Schematic symbol

The four binary outputs: Q_D, Q_C, Q_B and Q_A in figure.1 are said to have an 8-4-2-1 weighting because if QD through QA are all 1_s, then the binary counter output would be;
$1111_2 = (1x2^3) + (1x2^2) + (1x2^1) + (1x2^0) = 8 + 4 + 2 + 1 = 15_{10}$
The subscripts indicate the base of the system.

Table 1: Counter output in various number systems

No. of count pulse	Binary output	Octal (Base 8)	Decimal (Base 10)	Hexadecimal (Base 16)
0	0000	0	0	0
1	0001	1	1	1
2	0010	2	2	2
3	0011	3	3	3
4	0100	4	4	4
5	0101	5	5	5
6	0110	6	6	6
7	0111	7	7	7

8	1000	10	8	8
9	1001	11	9	9
10	1010	12	10	A
11	1011	13	11	B
12	1100	14	12	C
13	1101	15	13	D
14	1110	16	14	E
15	1111	17	15	F
16	0000	0	0	0

II.   THEORY

Every counting circuit consists of four basic units –the sensing unit, the signal conditioning unit, the counter unit and the output unit [4]

The sensing unit is usually made of a photoelectric device or a switch or a capacity pick-up or an interruptible jet. Its function is to detect what needs to be counted. The signal-conditioning unit is usually an interfacing device such as R-C Discriminator circuit. Its function is to arrange the 'sensed' signal or object into a countable form. The counter, which is usually the shift register of a J-K flip-flop records the event or object time-wise. The out put device can be an indicating visual meter or an audible beep producer. However, in this work, a PIC microcontroller would be used in place of the traditional J-K flip-flop.

The primary Boolean rule applicable for the manipulation of this counting circuit is the Exclusive-OR (**XOR**).

Table 2: Truth table for XOR Gate

A	B	P
0	0	0
0	1	1
1	0	1
1	1	0

III.   MATERIALS AND METHODS

1.   Materials used in the construction

The materials used during the construction of the circuit include; soldering iron, soldering lead, soldering pump, side cutter, digital multi-meter, sand paper and electrician knife, as well as plastic Perspex for the casing.

The binary counting circuit comprises of four (4) distinct sections. The hardware is a collection of Light Emitting Diodes, Seven Segment Display and some resistors that limit current for both the Light Emitting Diodes and the seven segment display. These components are interfaced to the microcontroller in order to output the required result in a more interpretable format.

The method adopted for this counter makes use of a microcontroller as the backbone of the design, which holds the command for every action that is to occur during an operation. Reason for this method is to reduce number of components and improve the functionality of the circuit. Figure 2 shows the block diagram of the counting circuit.
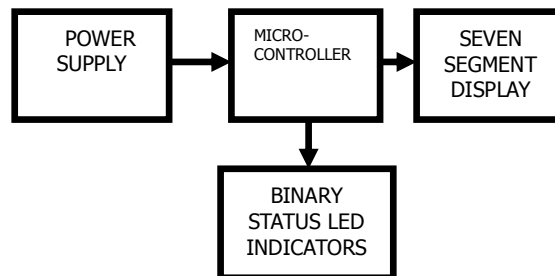

Fig. 2: Block diagram of a 4-bit binary counting circuit

2.   Design stage

The design stages for the 4-bit binary counter comprises the sequential connection of the power supply, the seven segment display, the binary status LED indicators and the Microcontroller. The various units that constitute the system would be built onto a Printed Circuit Board, tested and then eventually inter-connected. For reasons of operational flexibility, reliability, and reproducibility, specialized integrated circuit like microcontroller would be

used.

The microcontroller is the heart of the entire design. It processes the binary information and displays it on the four Binary Status LED indicators, at the same time, converts the generated binary to decimal value then displays it on the seven segment display. The microcontroller also manages the dual seven segment display by way of multiplexing the displays which helps in reducing complex wiring in the diagram.
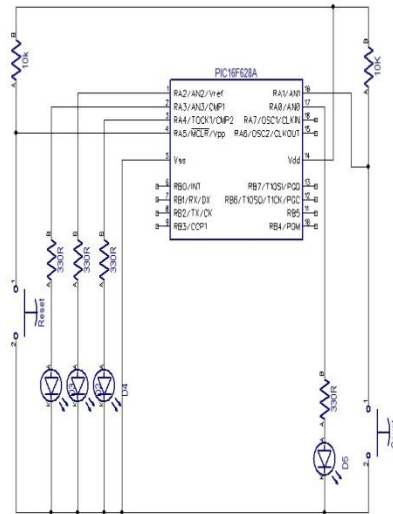

Fig. 3: Circuit for the binary LED and the Microcontroller stage

The voltage drop across the seven segments LED is 2V [6]. Since a 5V supply is used in powering both the seven segments LED display and the LEDs, this leaves 3V across their respective resistors. Therefore, current through the seven segment LED display is:

$$I = V/R = 3/150 = 0.02A. \qquad (1)$$

While that of the LED is:

$$I = V/R = 3/330 = 0.009A \qquad (2)$$

Equations 1 and 2 can be written as

$$R = VS - VD / I \qquad (3)$$

Where V_S is supply voltage and V_D is LED voltage drop. [7]

From equation 3, resistor value for seven segment display is

$$R = 5 - 2/0.02 = 3/0.02 = 150\Omega$$

Switching transistor

Using transistor BC 548, Supply voltage, $V_s = 9V$

The load driven by the transistor is the relay Load resistance, $R_L = 150\Omega$

$$\text{Load current } LI = Vs/RL = 9/150 = 60mA \qquad (4)$$

Since Load current L_I (max) must be greater than I_C and from the data sheet Ic (max) = 100mA

The Base Resistor, R_B

$$RB = Vcc \times hfe \quad 5 \big/ \times Ic \qquad (5)$$

Where

I_C = collector current

V_{cc} = supply voltage [8]

Therefore R_B $= 9 \times 400 \big/ 5 \times 100 = 7.2$ KΩ

Where the typical h_{fe} = 400 (from data sheet). Therefore, the closet value for the base resistor is selected to be 10KΩ.

3. Schematic and Printed Circuit Board
The effective and reliable design and production of the schematic and PCB creates better performance and consistent results. The software used in creating the PCBs and schematic diagram is Dip Trace, which was downloaded from www.diptrace.com. Crosschecking of footprints and design procedures was necessary to ensure a favourable outcome. After converting the schematic into PCB, a laser jet printer was used in the printing of the converted design into a special material known as Press and Peel sheet, a transparent film used in PCB production.

IV. RESULTS AND DISCUSSIONS
The binary to decimal and all the algorithm conversions and counting are implemented in the firmware of PIC16F628. The result is finally displayed on the Dual Seven Segment LED display. The software was compiled with the mikroC Pro for PIC compiler from mikroElektronika. The firmware was compiled into a machine code using the same Editor, and programmed into the microcontroller. The simulation of the algorithm of the detector system was done using Proteus software from Lab Center Electronics. Figure 5 shows the constructed circuit.

Fig. 5: The constructed 4-bit binary counter

The following results were obtained at each count pulse.

Table 10: Counter output obtained at each count pulse

Pulse No/ SSD	LED 1	LED 2	LED 3	LED 4
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0

9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1

4.1   Mode of operation of the counter

A multiplex dual 7-segment display was employed in order to display the binary equivalent that is generated at a time. The Microcontroller used in the design is a type PIC16F628. This is one of the most recent Microcontrollers and has a built-in oscillator and can be reprogrammed. The reset pin (4) of the microcontroller is made positive by the 10KΩ pull-up resistor and a switch in order for the PIC to function properly. If the counter is to be reset, the switch can be pressed, pulling pin 4 to 0V for a moment. The "trigger reaction" signal from the push button is fed to the pin RA1 of the microcontroller. The 10KΩ resistors pull these inputs to +5V and 0V when the push button is pressed, in which case the appropriate input is made negative (logic 0). The LEDs are driven from the microcontroller pins RA0, RA2, RA3 and RA4, respectively, via 10KΩ pull-up resistors. Pins RB0, RB1, RB2 and RB3 provide a Binary Coded Decimal (BCD) output equivalent to the number that will be displayed on the Seven Segment Display. This binary is converted to a seven-segment output by the microcontroller and the outputs to the dual seven segment display are delivered from pins RB0 to RB7 via 330Ω current limiting resistors. The complete circuit diagram for the 4-Bit Binary Counter is shown in figure 4.

There is insufficient power from the microcontroller to drive the dual displays, and in any case, it is customary to use "strobes" (multiplexing) to drive two displays from one set of segment outputs. Virtually all displays are driven in this way. This explains why calculators and other digital electronic devices often appear to flicker when filmed with a video camera. Strobe is achieved by careful programming, and the use of microcontroller pin RA7 and RA8 to control which display is lit at any one time.

When RA7 and RA8 are at logic 1, current flows through the 10kΩ current limiting resistor into the base of the two transistors. Hence the transistor switches on, and their collectors are effectively pulled to 0V, via their emitters. The collectors of the transistors are connected to the display common cathode Pins and so the display is able to light up according to the binary coded output. However, when RA7 and RA8 are at logic 0 (0V), the two transistors turned off, and so no current will flow to the display and hence the display stays off. Decoupling of the supply is provided by electrolytic capacitors and a 9V PP3 battery provides the necessary power supply.
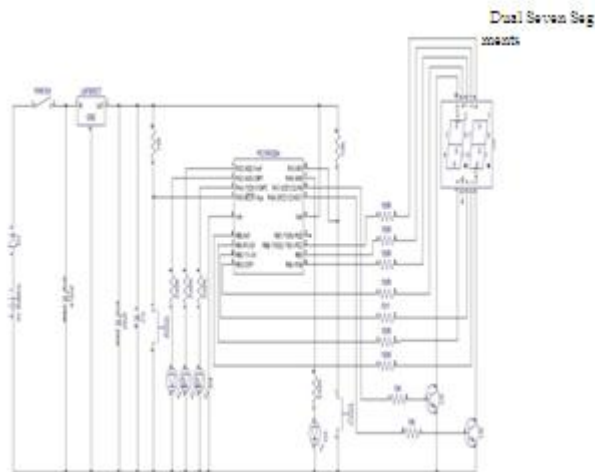

Fig. 4: Schematic Layout of the 4-Bit Binary Counter

4.2 Applications of the circuit

The designed and constructed 4-bits counter can find application in the following areas:
(1)   It is used essentially in digital computers and other digital devices for memory storage and counting in different bases.
(2)   The binary counting circuit can be modified and used in radioactivity Rate Meter for count rate per record.
(3)   It can be modified and applied in frequency-dividing operations.
(4)   It can be used in digital clocks and timers for counting events.

V. CONCLUSION

Digital counting circuits are vital in everyday Electronics. They are used not only in counting, but in the conversion from one number base to another. Although, counters can also be designed/constructed using multi-vibrators, this research has used the PIC Microcontroller, showing that it is the best method, as it makes use of a firmware for its operation, at the same time reducing the number of components in the circuit. Again, the chip could be reprogrammed for the realization of other types of counters.

REFERENCES

[1]. Menkiti, A.I. Computer Logic and Architecture. University of Calabar Press, Calabar, Nigeria, 2011.
[2]. Bozie, S.M. Electronics and switching circuits. Edward Arnold Publication, London, 1979.
[3]. Givant, S. and Halmos, P. Introduction to Boolean Algebra. Undergraduate Text in Mathematics, Sprinter Pub., 2009.
[4]. Hill, J.F. and Peterson, G.R. Introduction to switching theory and logical design. John Wiley and Sons, New York, 1974.
[5]. Patton, A. An introduction to digital logic. Macmillan Books, London, 1973.
[6]. Mandll, M. Directory of electronics circuits with glossary of terms. Eaglewood Cliffs, New Jersey, 1978.
[7]. Jaegar, R. C. Microelectronics circuit design. McGraw Hill. pp.226-233, 1997
[8]. Haykinl, S.S. Transistor circuits in electronics. Liffer Books, London, 1971.