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Design and Construction of a Double-Sided-Double-Line LED Matrix Display

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Abstract

This paper describes a hardware and software design of a double-sided display of a dynamic message (alphanumeric characters) in a light-emitting diode (LED) matrix, from conception, design, dimensioning to realization. The development ensured the possibility of changing the scrolling text, adjusting the brightness, speed of the scrolling and setting the time and date displayed and projected as sound from an Android application. This study explores the design of scrolling dot matrix display systems using PIC18F2620 microcontroller, ULN2803 driver and shift registers. The brilliant design allows dynamism of displayed text on two sides controlled through Bluetooth from the Android application developed with Xamarin Studio which is all basic, quick and financially savvy therefore providing a solution to the laid-back paper-based notification system.

1.0. Introduction

LED matrix displays are bringing new dimensions of versatility and eye-pleasing visual effects to a growing number of outdoor and indoor applications. From scrolling marquees to streetlights, light-emitting diodes (LEDs) have changed the world we live in. Recent advances in LED technology have even made it difficult to distinguish still images on their high-quality displays from traditional printed or painted billboards. Specifically, more power-consuming LEDs are cost-effective design alternatives to light bulbs in many applications including billboards, street signs, scoreboards, multipurpose displays etc. Analogue display of information has long been in use in various forms which include signposts for showing direction or caution signs, billboards for displaying prices and exchanging rates,scoreboards for displaying scores in games or even large boards for advertisement purposes. This involved arranging some form of lighting in a particular style to depict what is to be displayed. This style has one major challenge, no flexibility which possess numerous problemsfor the display. Due to this major setback in the analogue format of display, there is a very need for a digitalized and automated electronic display system that will solve these problems. The matrix array of LEDs is an arrangement in rows and columns. What should be noted here is that the matrix arrangement demands that LEDs be driven in a multiplex. The multiplex sequence inevitably requires more complex processing but is more efficient compared to individually driving each LED. Multiplexing is the technique employed to operate LED matrices. By multiplexing, only one row of the

LED matrix is activated at any one time. This approach is required because one end of the LED (either the anode or the cathode) is tied to a single row. This application note also describes how the brightness of each individual LED can be controlled in multiplex mode.

Frames are the final image on the display that is to be presented to the observer. Frames can be simple characters or pictures, video works. By presenting a set of frames so quickly the observer does not perceive any discontinuity. The rate at which the frames are refreshed is termed the refresh frequency and if the frequency is above a certain threshold frequency, the observer does not notice any flickering. For LED displays, a refresh rate of above 60 Hz is recommended [1].

Persistence of vision is the principle of operation of a LED matrix display. It is a human visual phenomenon that allows video images to be viewed without flicker. When the human visual system is presented with an image, that image continues to be perceived even though it is no longer in the visual field of the observer, albeit for a short time. This phenomenon thus enables flicker-free video [2].

1.1 Related Works

In the study, we will consider a couple of dot matrix display systems designed in the Faculty of Engineering, University of Benin, while pointing out their drawbacks to highlight the motivation for this research. Boi-Ukeme designed and constructed a scrolling LED matrix display [3]. The system is located at the Department of Electrical/Electronic Engineering and it was constructed using 784 yellow LEDs which constitute 56×14 yellow LEDs. Though it was a scrolling LED matrix display, it had a few limitations which include the inability to change the displayed messages, the inability to display time and date, the inability to be used as a public address system and the inability to be used to play music. These extra features were found in a 129×33 double-side LED matrix display project. Similarly, [4] aimed at creating an offline electronic display board with a differentiating characteristic of being re-programmable for an incredible number of times. Components used included transformer, diodes, capacitors, voltage regulator (7805), resistors, LEDs, microcontroller (AT89C52), crystal oscillator, shift register (78HC595) and current sinker (ULN2003). The re-programmable feature of this display board was attributed to the AT89C52 with an endurance of 1000 write/erase cycles which means that it can be erased and programmed to a maximum of 1000 times. The major drawback of this project was the limit for the number of times for the re-programming by the maximum number of times (1000 times) the AT89C52 microcontroller could be programmed. The double-sided double-line system designed in this study addresses the presented problems with existing designs in the Faculty of Engineering, University of Benin and provides a robust solution to the observed mistakes and negligence in design.

In this study, we present the design and construct a programmable electronic double-sided-double-line LED matrix display capable of showing different characters (letters, numbers and symbols) which could be changed at any time with android mobile software, giving an audio-visual idea of time and date, playing music and can also be used as a public address system.

2.0. Materials and Method

The tools used for the construction of the double-sided double-line display were the soldering iron, soldering lead, drilling machine, pliers, masking tape, measuring tape, solder sucker, wire cutter, sandpaper, and Multimeter.

The construction of the LED dot matrix requires layering, marking and soldering, therefore, to achieve a high-quality design, the best industry practices for soldering were considered. Soldering is a method of joining metal parts using an alloy of low melting point filler material (solder). In a soldering process, heat is applied to the metal parts, and the alloy metal is then pressed against the joint. The pressed alloy metal melts and is drawn into the joint by capillary action and around the materials to be joined by 'wetting action'. After the metal cools, the resulting joints are not as strong as the base metal but have adequate strength, electrical conductivity, and water-tightness for many uses [5, 6].

The model used for the design of the double-sided double-line LED matrix is presented in Figure 1. The power unit in the study considered the power requirement from all components/blocks of the model. The control unit comprises two microcontrollers (PIC18F2620); one microcontroller is meant for controlling the anode and cathode drivers while the other microcontroller is meant for controlling the real-time clock (RTC), the ISD17240 voicechip, digital potentiometer, and the analogue multiplexer/demultiplexer. Both controllers are together connected to the Bluetooth module (HC-05) [7] for communicating with Bluetooth enabled devices.

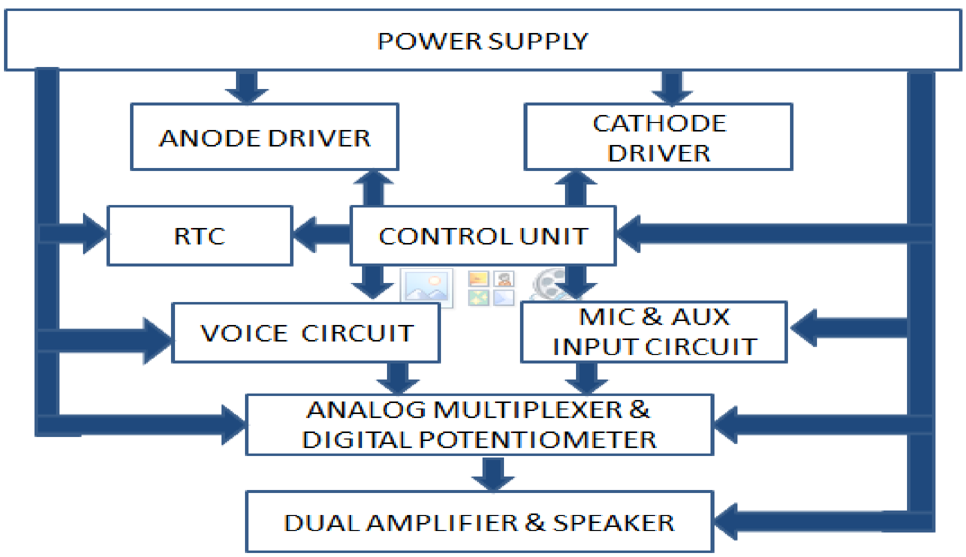

Figure 1 Block diagram of the double-sided-double-line matrix display [8]

The anode driver comprises two digital demultiplexers (74HC238), two sinking integrated circuits (IC) (ULN2803), and 16 P-channel MOSFET (IRF4905). The digital demultiplexer is meant to enable the use of a lower number of microcontroller I/O pins for interfacing with the sinking IC thus with four microcontroller pins the eight input pins of the sinking IC can be controlled. The sinking IC is meant for grounding the gate of each of the P-channel MOSFETS which is the condition for actuating the P-channel MOSFETS. The P-channel MOSFETS is meant to source or give out voltage to the anode of the LEDs [9]. The cathode driver comprises a buffer integrated circuit (IC) (74HC541), and 8 sinking integrated circuits (IC) (TLC5940). The buffer IC is meant to strengthen the signal that will be sent by the microcontroller to the sinking IC [10]. The sinking ICs are meant for sinking the current from the cathode of the LEDs. The TLC5940 is also capable of varying the intensity of the LEDs. Four of the TLC5940 controls one side of the display while the other four controls the other side of the display.

The real-time clock is an integrated circuit (PCF8583) meant for taking records of time and date. It interacts with the microcontroller through an inter-integrated circuit interface. The real-time clock has a dedicated CMOS battery to provide power for it in the event of a power failure. The voice and music circuit comprises a voice chip (ISD17240). The voice chip is meant for storing voice sound at different addresses and for reproducing them through a speaker under the control of the sub-microcontroller. The microphone and auxiliary input circuit comprise two PICAXE connectors for connecting the microphone and an auxiliary cable for the interface with the phone and computer. The auxiliary input circuit also has an amplifier circuit using one of the operational amplifiers of a dual OP-Amp IC (JRC4558) which is meant for pre-amplifying the signal before feeding it to the analogue multiplexer. The analogue multiplexer/demultiplexer (74HC4052) and digital potentiometer circuit comprise a dual analogue multiplexer and digital potentiometer (AD5220BN). The analogue multiplexer is for the selection of the output to send to the speaker pre-amplifier among the three sources of sound. The digital potentiometer is meant for varying the amplitude of the input signal that will be sent to the dual amplifier with the aid of the sub-microcontroller. The dual amplifier circuit comprises two dual amplifiers integrated circuit (IC) (TDA2030) and other components connected to it such as resistors and capacitors. The one amplifier is meant for feeding two speakers and the other amplifier is meant for feeding the other two speakers. The output is for reproducing the sound for hearing.

2.1. Power unit

The design required 32 red LED channel drivers, 64 green and 64 blue LED channel drivers. The maximum currents required by the three primary colours of LED is 60mA, 40mA and 40mA for the red, green and blue LEDs respectively. Therefore, maximum current consumptions for the respective corresponding colours of LEDs are;

Maximum consumption of red LED = $60 \times 32 = 1920mA$

Maximum consumption of green led = $40 \times 64 = 2560mA$

Maximum consumption of blue led = $40 \times 64 = 2560mA$

Total current consumption for led = 1920 + 2560 + 2560 = 7040mA

$$Power\ Consumption\ (P) = Current \times Voltage \quad (1)$$

Therefore, from Equation (1) supply consumption for all LEDs as the supply voltage is 12V = $12 \times 7\,040 = 84480mWatts = 84.480Watts$

Maximum estimated current consumption of the LED controller board = 2000mA and thus the maximum total current consumption for the project = 2000mA + 7040 = 9040mA

For the design, we used two voltage regulators; the LM2576 which is a 5V voltage regulator and the LM3940 which is a 3.3V voltage regulator.

V_{out} = 5V (Regulated Output Voltage)

Vin (Max) = 4.5V (maximum input voltage) – for LM2576

I_{LOAD} = 2000mA (maximum load current estimate for controller board)

Output Inductor (L2 in the circuit diagram) = 68uH (Recommended in the datasheet)

Output Capacitor (C1 in the circuit diagram) = 1000uF (Recommended in the datasheet)

Input Capacitor (C40 in the circuit diagram) = 100uF at voltage rating of 25V (Recommended in the LM2576 datasheet)

The latch diode (D12 in the circuit diagram) current ratio of at least 1.2 times Imax and reverse voltage rating of atleast 1.25Vmax is recommended in the datasheet and therefore 6A at 10V reverse voltage was chosen in this work.

V_{out} = 3.3V

V_{in} = 4.5 – 5.5V (for LM3940)

The crystal oscillator frequency (X1 and X3) was chosen as 24MHz since it was recommended in the datasheet of the microcontroller that the oscillator frequency should range from 32.786kHz to 40MHz [11].

Crystal oscillator capacitors (C23, C24, C5, C6) = 22pF (Recommended in the microcontroller datasheet)

Microcontrollers MCLR pin resistor (R1 and R139) = 10K (Recommended in the microcontroller datasheet)

The calculation for the current setting resistor of the sinking IC (TLC5940) include

$$Imax(\text{Maximum sinking current}) = \frac{(V(ref) \times 31.5)}{R(ref)} \qquad (2)$$

Equation (2) was gotten from TLC5940 datasheet where V(ref) = 1.24V and R(ref) is the User-selected external resistor.

The different LEDs would have different voltage drops and different sensitivity to the human eye hence the R(ref) for the red LED using Equation (2) is

$R(ref) = (1.24 \times 31.5) \times \frac{1000}{60} = 651\ \Omega$ (Closest the available resistor value is 680 Ohms)

R(ref) for the green LED is $(1.24 \times 31.5) \times \frac{1000}{40} = 976.5\ \Omega$ (Closest available resistor value is 1k Ohms)

2.2.Display unit

The LED frame design was made with Perspex measuring a 7FT by 4FT. The Perspex board was cut into 2 7FT by 2FT on each side. On both Perspex materials, we marked and drilled 8192 holes for the 8192 LEDs each of 2mm. The two Perspex were both painted black to prevent the reflection of light on the board. The LEDs were each tested before mounting and in the case of a faulty (including those with poor brightness) LED, it was promptly replaced. Each dot in the matrix was a group of four LEDs which were interconnected in series and parallel connections. The LEDs were also wired such that all anodes along a row share a common terminal and the entire cathode along a column shared a common terminal.

The current limiting resistance is given by Equation (3).

$$R = \frac{Vin - Vd}{I} \tag{3}$$

Where Vd is the voltage drop across LED, Vin =12V (Input Voltage), R is the current limiting resistance to each LED, and I is the maximum sinking current.

For the red LEDs, Vd = 1.8V so the current limiting resistance using Equation (3) is $R = (12 - 1.8) \times \frac{1000}{60} = 170\Omega$ (220 Ohms resistors were chosen)

For the green LEDs, Vd = 3.2V so the current limiting resistance is $R = (12 - 3.2) \times \frac{1000}{40} = 220\ \Omega$ (220 Ohms resistors were chosen).

For the blue LEDs, Vd = 3.2V so the current limiting resistance is $R = (12 - 3.2) \times \frac{1000}{40} = 220\ \Omega$ (220 Ohms resistors were chosen).

2.3.Control unit

A firmware is a written program that runs in a machine such as a microcontroller or a microprocessor [12, 13, 14] The control unit comprised two microcontrollers and the anode and cathode drivers. To program the microcontrollers we used MikroC compiler which is a MikroElectronika software for writing C programs. Figure 2 shows the flowchart of the written program in the C programming language that was developed for the double-sided double-line matrix system. Also, the bill of material for the completion of this work is presented in Table 4 to show the cost-effectiveness. It shows the quantity and unit cost as of the time the work was carried out. Most of the components were gotten from the local electronics store.

Table 1: Bill of materials

Category	Quantity	Unit cost	Cost
Capacitors	49	₦10	₦490
Casing, bolts and nuts			₦10000
Diode	13	₦10	₦130
Integrated circuit	26	₦753.84	₦19600
LEDs	8192	₦5	₦41000
Miscellaneous			₦6520
Perspex	4	₦2000	₦8000
Printed circuit board	1	₦5000	₦5000
Resistors	183	₦10	₦1830

Transistors	18	₦305.55	₦5500
Total			₦98070

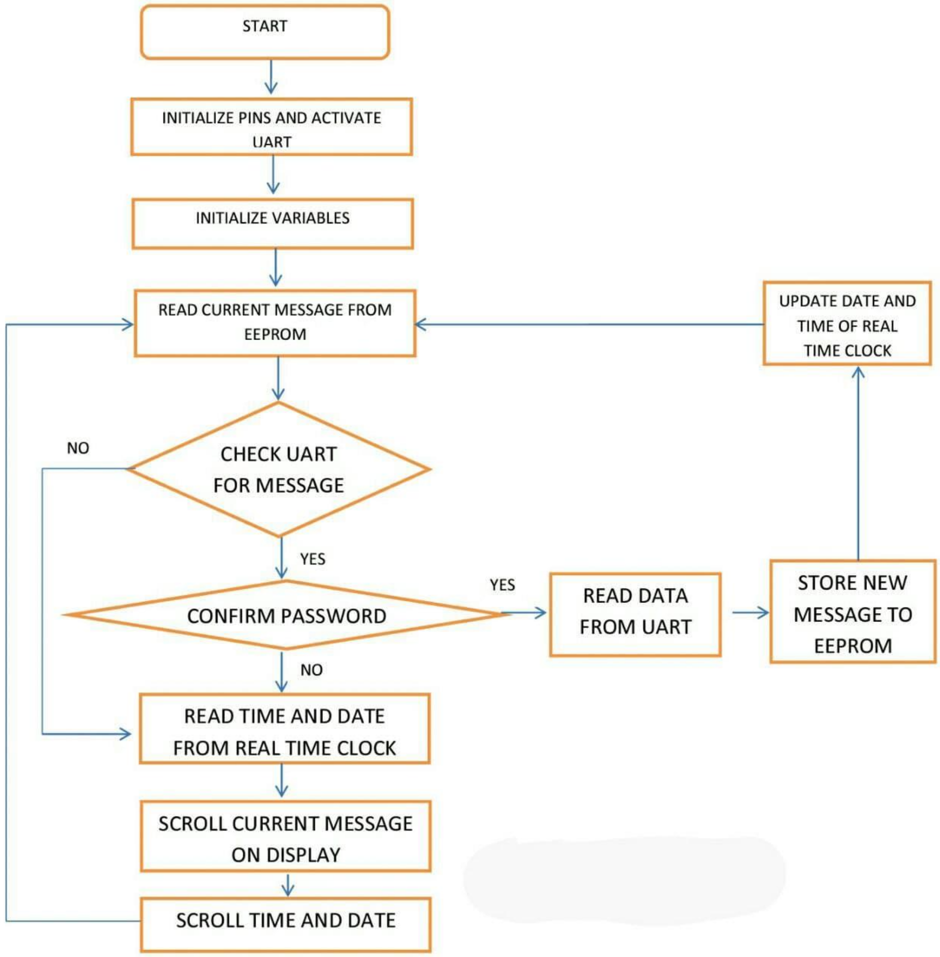

Figure 2 Flow chart for firmware development

The android application for added remote control of the system was developed in an android development environment. The application achieved the following functions; control of LED brightness level, scrolling speed control, control of the resolution of the text, setting time and date, and control of the displayed text.

3.0. Results and Discussion

Figure 3 shows the steps taken in the design and construction of the LED frame for a double-sided double-line matrix display. It shows the procedures taken in the design, starting from the marking of the Perspex material, to the painting of the Perspex before mounting the LEDs and the row and column connections. Figure 4 is the final construction showing only one side.

Figure 3 (a) Marked Perspex board (b) LED matrix board with LED (c) twisting of LED on the board the circuit and (d) LED board with soldered connectors

Figure 4 double-sided double-line LED matrix display

3.1. Mounting the power supply and controller units to the PCB

The circuit diagram was gotten after careful design and calculation had been done and respective circuits for the blocks in the model are given in Figures 5 – 13. The workability of all the discreet components and integrated circuits were verified before they were all mounted to the PCB. Also, the design, simulation and routing were carried out with Proteus before the actual components were then mounted onto the PCB. During mounting, all the IC sockets were first soldered on the PCB before all other components were soldered after being tested.

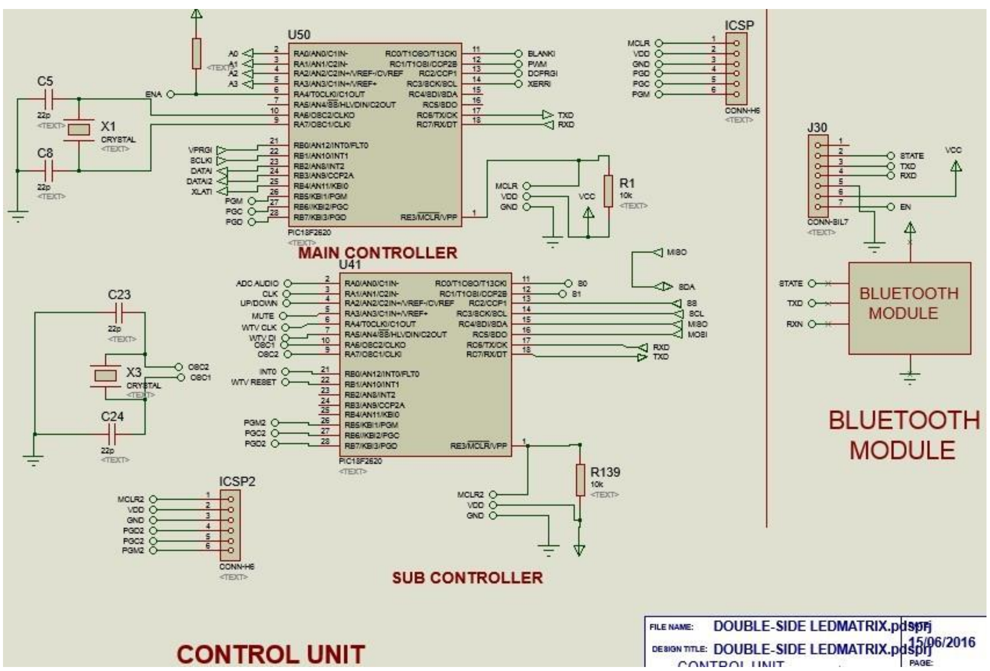

Figure 5 Control Unit

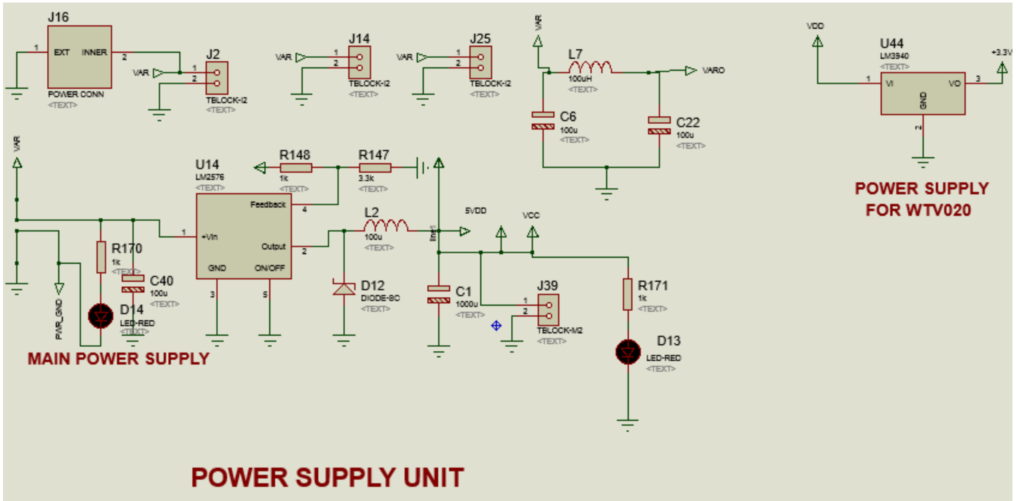

Figure 6 Power supply unit

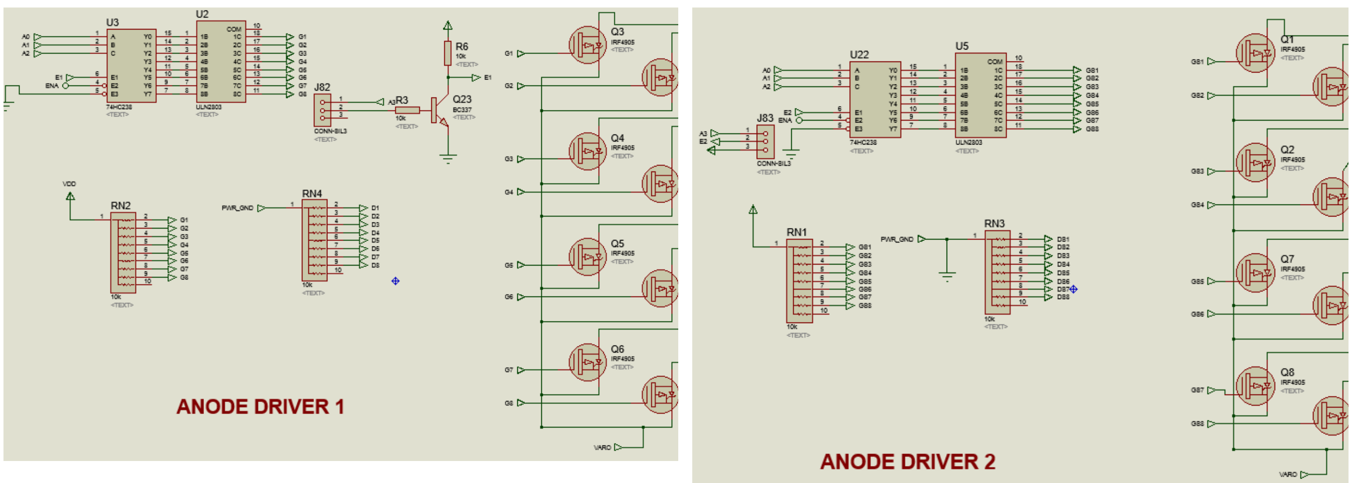

Figure 7 (a) LED anode driver 1 (b) LED anode driver 2

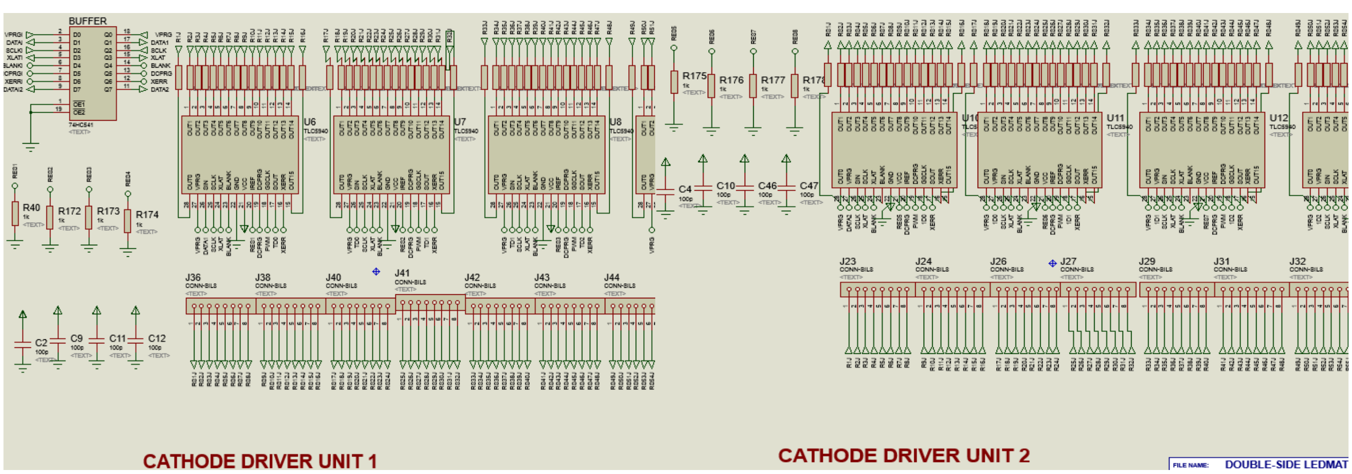

Figure 8 (a) LED cathode driver 1 (b) LED cathode driver 2

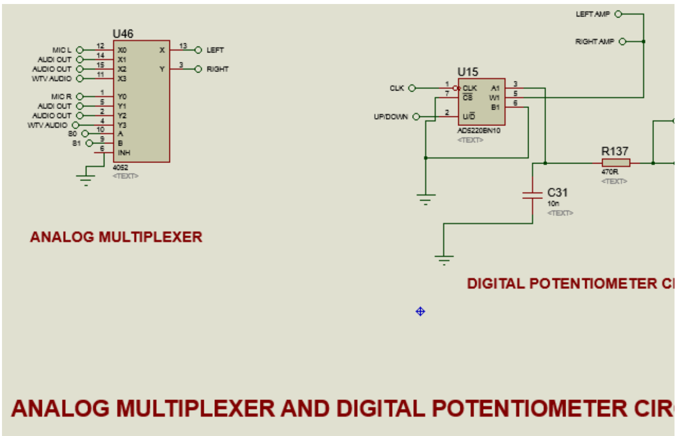

Figure 9 Analogue multiplexer and digital potentiometer circuit

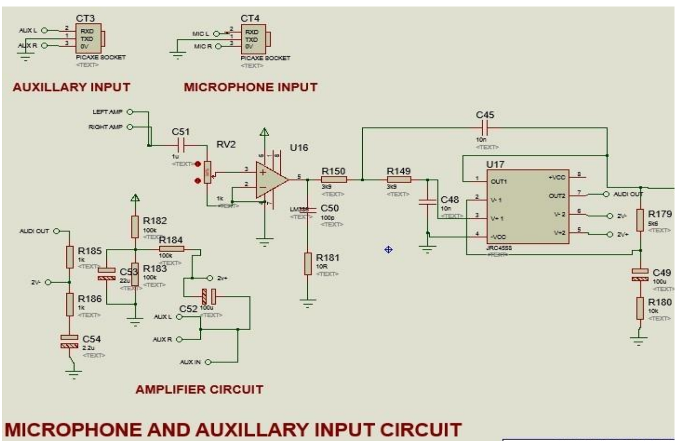

Figure 10 Microphone and auxiliary input circuit

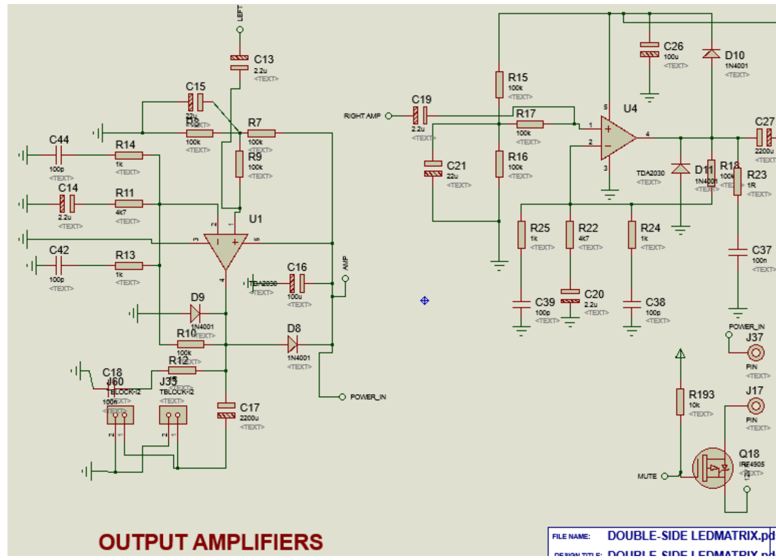

Figure 11 Output Amplifiers

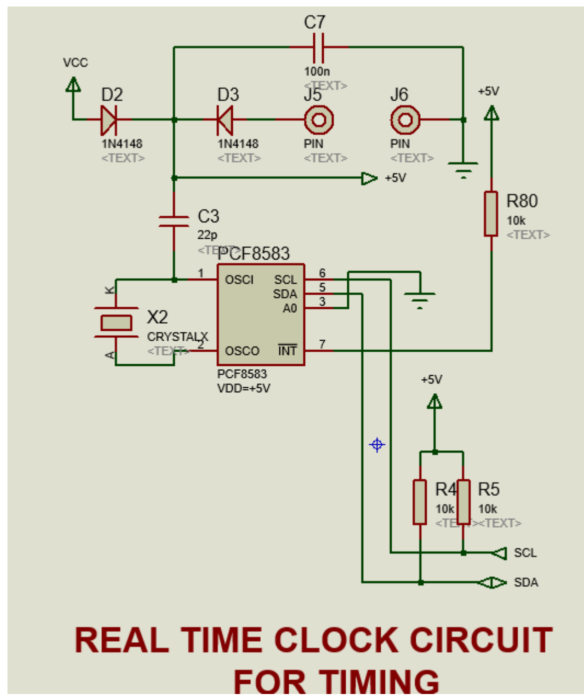

Figure 12 Real-time clock circuit unit

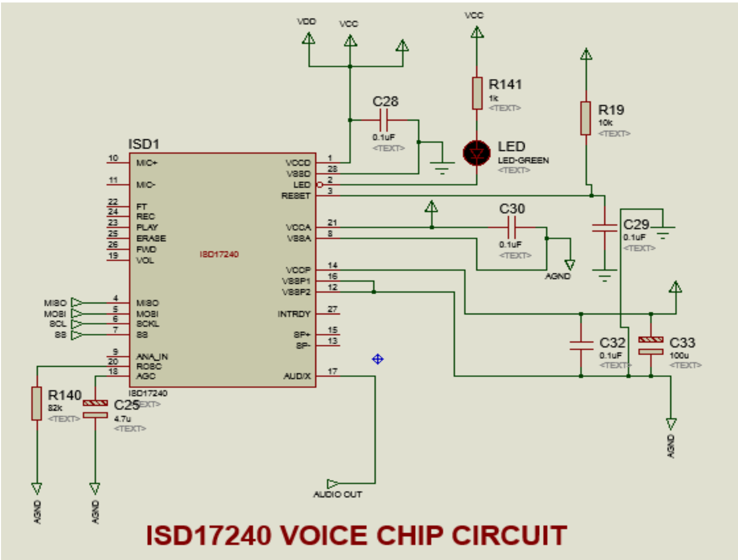

Figure 13 Voice module

Each unit/dot in the dot matrix had a serial and parallel connection and Figure 14 shows the circuit connection of the dot matrix and each unit or dot character.

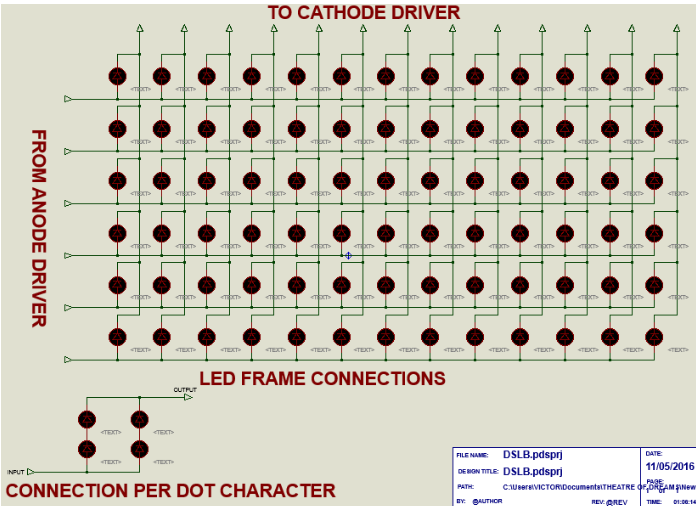

Figure 14 Dot matrix

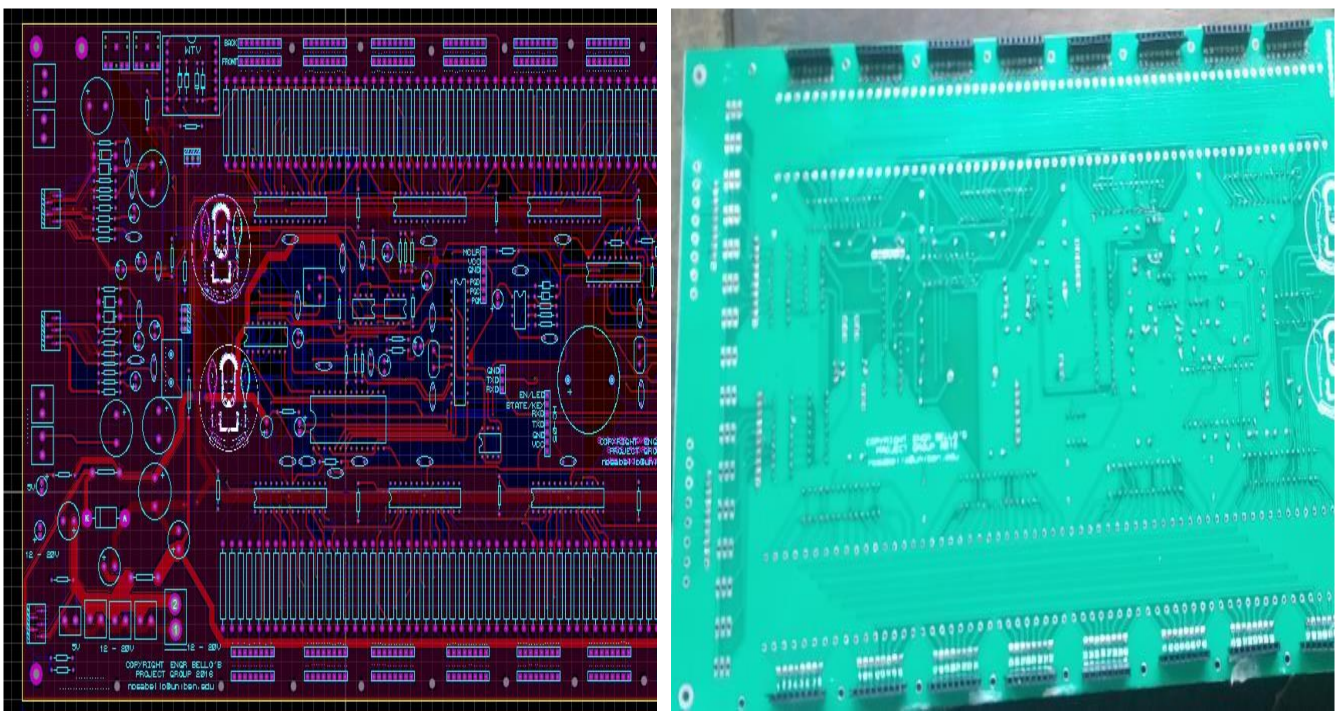

Figure 15 (a) Controller board printed circuit board design (b) Controller printed circuit board

The android development was carried out with Xamarin studio to achieve the expected features for the system any of which is only accessible with a correctly entered password. The studio during development is shown in Figure 16.

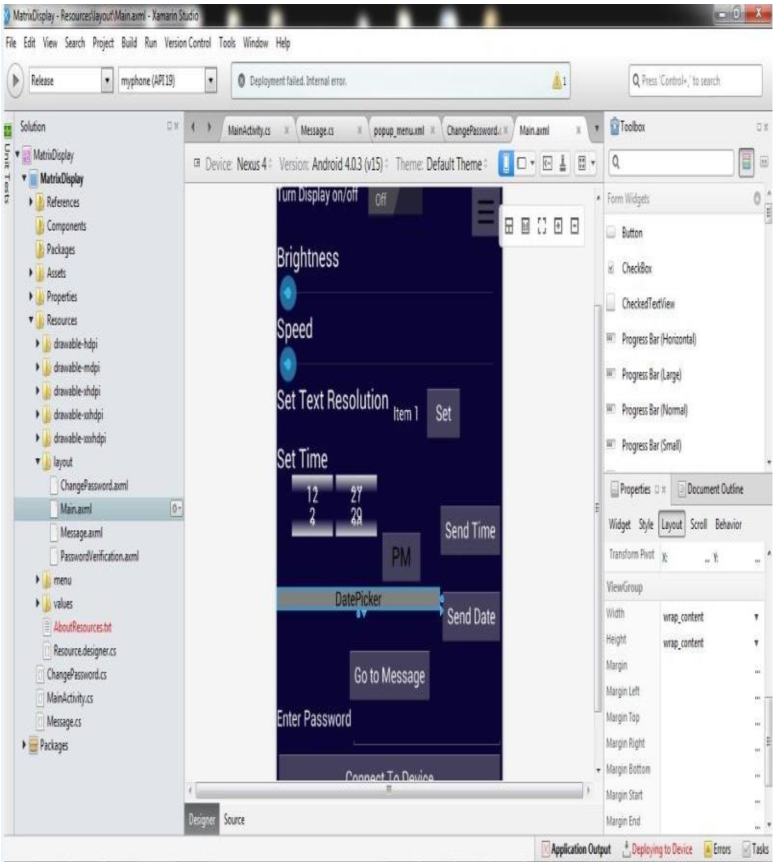

Figure 16 android software development in Xamarin Studio

At the end of the development, a test was carried out across the ICs. Table 3 presents the voltage values for some important ICs in the power supply and controller unit. It was tested with a multimeter across the VCC and VSS points in the circuit.

Table 2 voltage level tests between VCC and VSS

Component	Voltage
TLC5940	4.90V
PIC18F2620	5.00V
74HC238	4.90V
74HC541	4.90V

The voltage regulator showed a voltage of 4.92V which was 1.6% lower than specified. Similarly, from the table, the reading variations that were recorded for the microcontrollers, shift register and other ICs were approximately the same. However, the shunt LEDs gave a higher variation of up to 0.14%. The lighting across the matrix display board was uniform with mild flickering. In comparison to [14], the voltage readings for the ICs (microcontroller and shift register) were 4.85 and 4.89 respectively. These readings constitute variations of no more than 3% for a 7×50 dot matrix array. Our design outperforms theirs despite having higher dimensions of the matrix display and on both sides.

4.0.Conclusion

This paper presented an electronic display post that has the capability of "displaying information, speaking time and date, being used as a public address system and displaying messages which can be changed with an android mobile software". It eliminates the tedious traditional mean of sharing information and provides a more robust design compared to the existing designs in the Faculty of Engineering, University of Benin. It is important to mention conclusively that microcontroller based remote control LED matrix display can be widely used to display vital information in a more fancied digital and coloured form, which is a recommended means of brisk data sharing in modern society.

Nomenclature

V_d.	Voltage drop
V_{out}	Regulated output voltage
V_{in}(Max)	Maximum input voltage
$Imax$.	Maximum sinking current
V(ref)	Suitable input voltage
R(ref)	User-selected external resistor
Vd	Voltage drop across LED

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