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Design and Construction of A 16 × 16 × 16 RGB Led Cube Display

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Abstract

The paper presents the design and construction of a 16 × 16 × 16 RGB (Red-Green-Blue) Light Emitting Diode (LED) cube display. The entire hardware structure consists of 4,096 RGB LEDs formed three-dimensionally that displays the spectrogram animation of a music file. This engineering piece achieves its effect using PIC18F4620 and PIC18F2620 microcontrollers for the controller circuit and FFT algorithm respectively. Its design also includes integrated chips (ICs) such as ULN2803 driver sink, 4514 multiplexers, shift registers, ISD 17240 voice chip, and the WTV020 music chip to accomplish the seamless 3D animation of a music file in a fast-changing 3D pattern/shapes that produces a clear fanciful illusion of the spectrogram of sound.

1. Introduction

The full use of LEDs in electronic components and for lighting purposes is an accessible direction as it has become more common in recent years. The benefits of using LEDs [1] include smaller size, long-lasting lifetime, high efficiency, reduced timelines, low power consumption, etc. The most common application of LED lights [2] is display and advertising. The efficient and systematic arrangement of the LEDs in a certain order is the cause of its low power consumption. Most of the research in this field focuses on matrix LED displays [3,4] for displaying alphabets, numbers, and symbols. We can use these matrix LED devices in shopping malls to display or scroll names on the matrix. In addition, these LED lights are used for decorative purposes for buildings, shopping malls, markets, and many other places. Since the invention of the 3D LED display by Stephen W. Boyer on May 22, 2001 [6], other works on LED have been done by commercial marketers, individual producers or manufacturers as well as universities, institutes, and polytechnics all over the world [7,8]. One of such is the Cubatron - the world's largest true 3D colour graphics display from 2004—2006 [9]. It was 8 × 8 × 8 feet in size. It consisted of 729 voxels (3D pixels) arranged in a 9 × 9 × 9 matrix, spaced 10 inches apart from each other. Each voxel was a 40mm diameter ball that could be independently set to display 21-bit RGB colour. The entire display could be updated about 30 times per second. Furthermore, Adaptive Computing, cloud management and high-performance computing outfit in Utah needed something spectacular to bring to their trade show, so they built the first 16 × 16 × 16 All-Spark Cube. The All-Spark Cube was constructed using 10mm RGB LEDs wired together with three-foot lengths of 16-gauge pre-tinned copper wire.

The 16 × 16 × 16 LED display cube is one of the largest and most complicated LED display cubes ever made in any part of the world [10]. Several 16 × 16 × 16 LED cubes have been made by different persons, enterprises and institutions. One of the such few made 16 × 16 × 16 LED cube display systems by Adaptive Computing [10]. In this paper, we present the design and construction of a 16 × 16 × 16 3D RGB LED cube that displays a spectrogram animation of a music file. The aim is to design a device to display 3D images created in 3D space instead of 3D images formed in 2D space, which the viewer then interprets as 3D images [11].

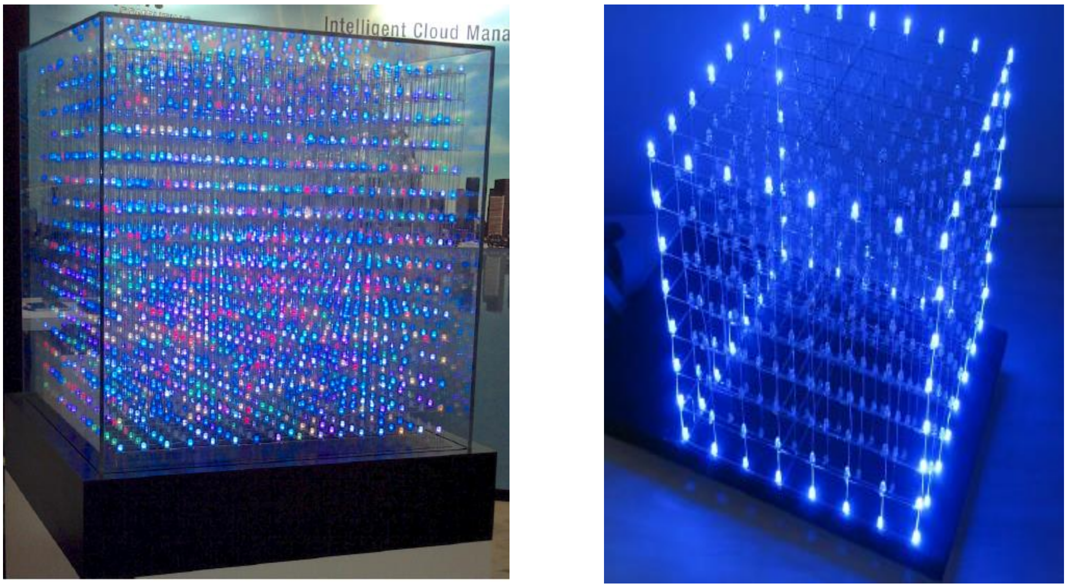

Figure 1 (a) All Spark 16 × 16 × 16 3D RGB LED Cube. (b) 8 × 8 × 8 3D Blue LED Cube [5]

To do this, a design has been made that uses a series of LEDs that will generate individual images, called frames, in such a fast way that the image looks like the animation. The cube is inspired by a project that was previously done at the University of Benin, as well as videos of commercially designed products that are available for purchase both as fully-built devices and when the end-user completes the kit form. The designs presented by both the University of Benin team and the commercial designs encouraged the design and building of a model much larger and more beautiful than any existing design.

2.0. Materials and Method

The study needed some materials for the construction of the LED cube, simulation and design of the circuit designs and PCB layout as well as the development of the firmware for controlling the microcontrollers. Primarily, as the discussion in this paper follows a chronological order, we will first present the tools and materials used for constructing the LED cube. They are the medium density fibre (MDF), 1m-3ft measuring tape, copper wire, sandpaper, soldering iron, soldering lead, lead sucker, pliers, wire cutter, pencil, digital multi-meter, knife, scissors, printed circuit board (PCB), cardboard, screwdriver, nails, Perspex sheet, drilling machine, and 9V high-voltage batteries with clips. The entire design was divided into two major sections as listed;

i) Hardware Section
    a. LED cube array
    b. Circuit design
ii) Software Section

The hardware design consists of the LED cube array and the circuit design. For the design of the 3-Dimensional LED cube array. The LED is constructed as a 16 × 16 × 16 cube with 4,096 LEDs, each with a diameter of 5mm, and each LED consists of four pins RGB LEDs. The structure of the cube follows the same arrangement as that of the 8 × 8 × 8 LED cube in [12]. Each layer of the LED cube is made up of 256 LEDs. Thereafter, these 16 layers are cascaded to form the cube. The LEDs were uniformly spaced as much as possible to achieve symmetric dimensions. The cube array was arranged and spaced within a 60cm-by-60cm-by-60cm dimension. In the design of the $16 \times 16 \times 16$ LED cube as an improvement of the $8 \times 8 \times 8$ LED cube, the changes affected two sections, the power unit and the driver unit for the display. Also, there were changes made to the program that animates the cube.

2.1. Power Unit

Since the volume of the cube has changed, the power requirement also changed. The components in the system that will drain most of the current are the LEDs. The cube utilizes multiplexing thus at any given time only one horizontal layer (plane) can be energized. A plane has a maximum of 16×16 LEDs or 256 LEDs consuming power. The super-bright LEDs that were used are rated at 30 mA. However, it is important to note here that since the human eye has different sensitivities to red, green, and blue lights, for a given current level, it is therefore imperative to ensure that the brightness levels are even by-passing different amounts of current through the red, green and blue paths in the LEDs to achieve even brightness throughout. The voltage drop for the Red LED is about 2-volts and for the Green and Blue LEDs, 2-volts and 3-volts respectively. In the power design, a desirable current of 50mA, 25mA, and 32mA to the red, green, and blue LEDs respectively were chosen to achieve even brightness. The plane of LEDs would consume a maximum current of 50mA per LED and a maximum of 256×3 LEDs (since each bulb contain 3 LEDs) being lit simultaneously. The maximum current required by the LED cube is calculated as:

$$\text{Number of LEDs in a plane} \times \text{maximum current per LED} \tag{1}$$
$$256 \times 3 \times 0.05 = 38.4\text{A}.$$

As a result, a power supply rated at 50A was chosen. The other components consuming power like the ULN2803 Sink Drivers and 748HC595 shift registers, including other peripherals, consume close to a negligible value. Therefore, the power source should provide a rating of 5V, 50A power supply for the LED cube and the ICs in the controller circuit.

2.2. Display Unit

Some resistors are needed between the cathode layers and ground and the anode columns and the negative voltage to help some currents go away after switching layers. Otherwise, these currents will go away through the LEDs and that will result in ghosting (i.e., when a layer is switched on, the previous layer is also dimly lit). So, to get rid of this ghosting, a 20 ohms resistor is added between each cathode of the LED and the corresponding pin of the ULN2803. In a $16 \times 16 \times 16$ LED cube, we have 16 anode layers and 256 cathode columns. Given the fact that the whole circuit functions at 12V, this means that the resistors between the anode layers and the ground will generate a total current consumption of $16 \times 5\ mA = 80\ mA$.

2.3. Construction of the Display Unit

The 4,096 LEDs had to be constructed into a $16 \times 16 \times 16$ LED cube and as such the same procedures as described in [12] were used with the only consideration of a higher dimension and size. The slices were of dimension 16×16 and they were combined to form the $16 \times 16 \times 16$ LED cube. The cardboard sheet used as the entry point and alignment of the 768 wires had a dimension of 60cm-by-60cm dimensions.

In mounting the circuit components and constructing the LED cube, careful consideration was taken towards soldering. All the LEDs were soldered together with the help of the copper wires that provided support to the cube. These copper wires were properly filed with sandpaper to ensure good soldering joints. Before forming the final cube array 16,384 $(4{,}096 \times 4)$ soldering points were made. In soldering, care was taken to prevent the soldering iron from staying on the board and the component for long periods. This was done to prevent damage to the components due to heat exposure. Also, IC sockets were soldered to the boards to prevent overheating of the ICs if soldered directly as they are extremely sensitive to heat. While soldering, the components were laid out for the best functionality, accessibility, and mechanical strength and using minimum space.

2.4. Software Design

The changes to the C program for the control of the display of the cube mainly consisted of optimization and change of the control unit programming logic. Whereas the FFT logic remains the same as that of the 8 × 8 × 8 LED cube. The flowgraph for the optimized control logic is shown in Figure 2.

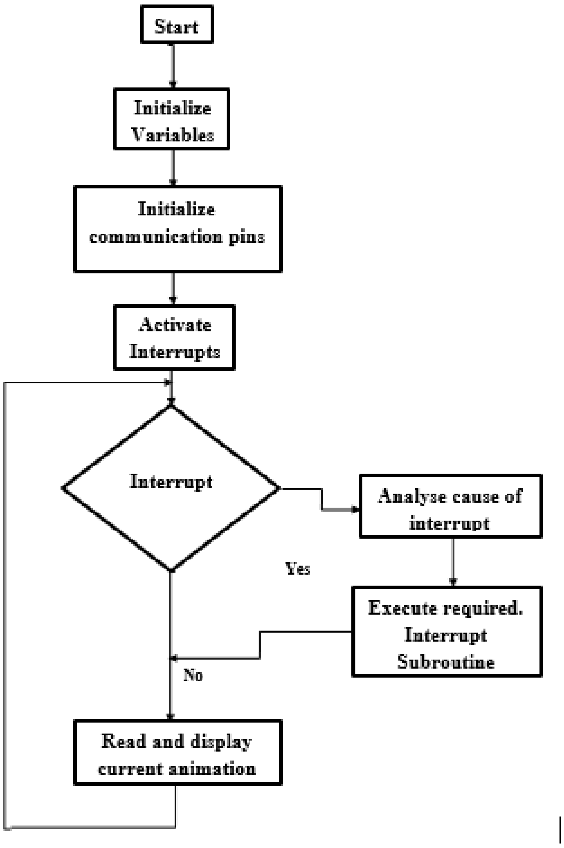

Figure 2. Flow chart for the display of the LED cube

3.0. Results and discussion

The construction of the LED cube was done in stages. Before the start of every stage, the tools needed for construction, the materials to be used, and the electrical components needed were made available. The construction stage of the LED cube was very tedious and needed patience and due diligence. During which the LEDs needed careful handling to avoid unnecessary damage to them. As stated earlier, we implemented the entire project in two main stages; hardware construction which consists of the LED array and the circuit designs and layout, and software construction. Figures 5 and 6 show the stages in the construction of the LED cube.

Figure 3. The Jig

Figure 4. A single layer/slice of the LED cube

Figure 7. shows the completely constructed LED cube. The cube was mounted onto a glass casing as shown in Figure 8 for aesthetics and protection.

Figure 5 Completely formed 16 × 16 × 16 LED cube array

Figures 6 –23 show the circuit schematics and PCB Layouts of the LC controller circuit, the cathode driver circuit, and the power supply circuit. Figures 24 and 25 are the mounted PCBs for the LED cube.

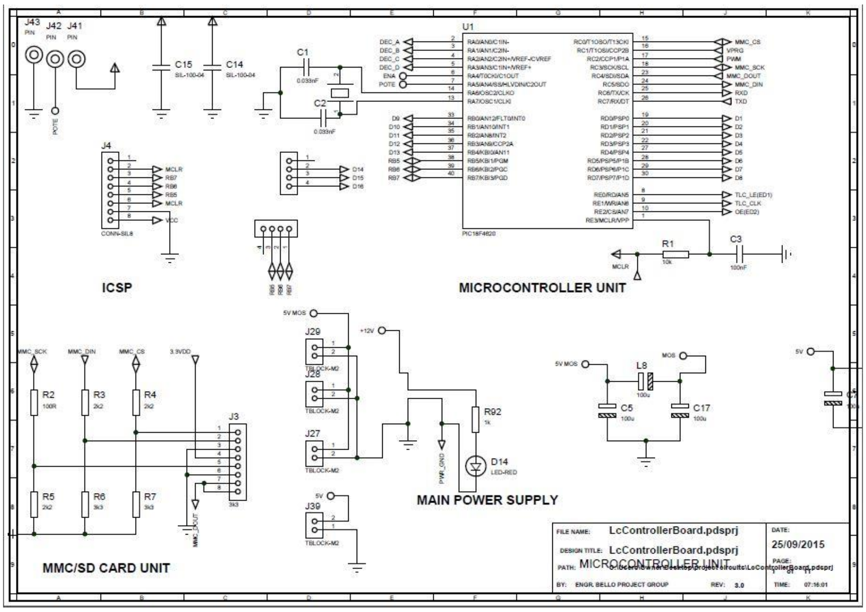

Figure 6 LC Controller Schematics (1 of 9)

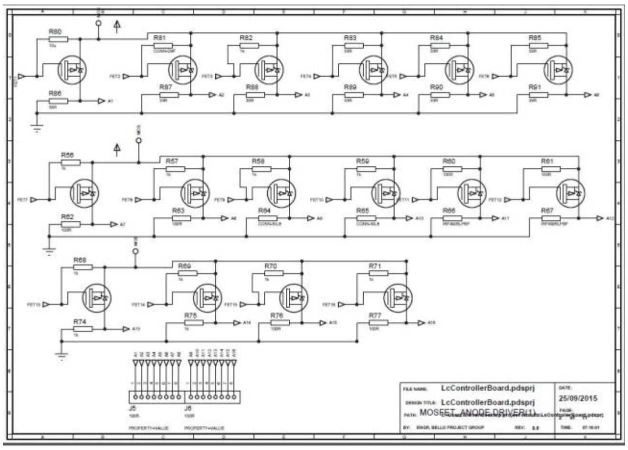

Figure 7 LC Controller Schematics (2 of 9)

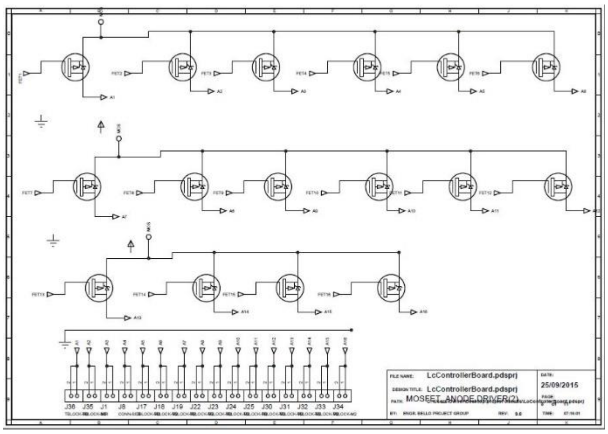

Figure 8 LC Controller Schematics (3 of 9)

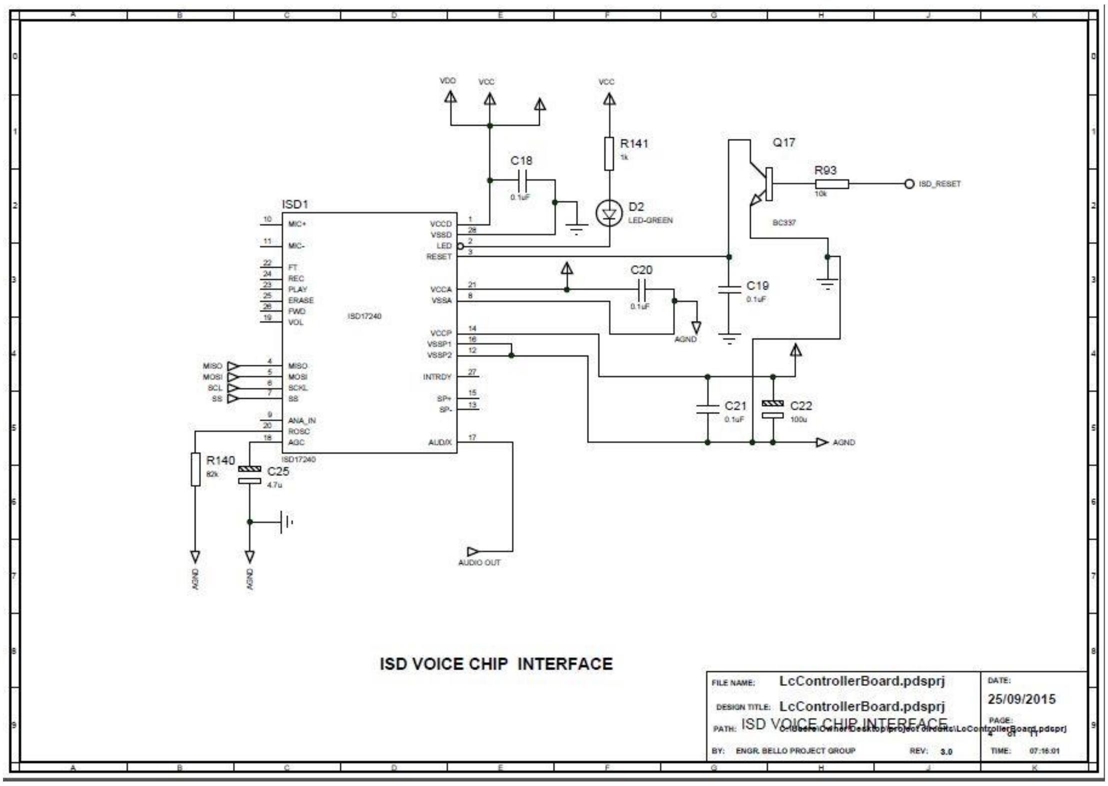

Figure 9 LC Controller Schematics (4 of 9)

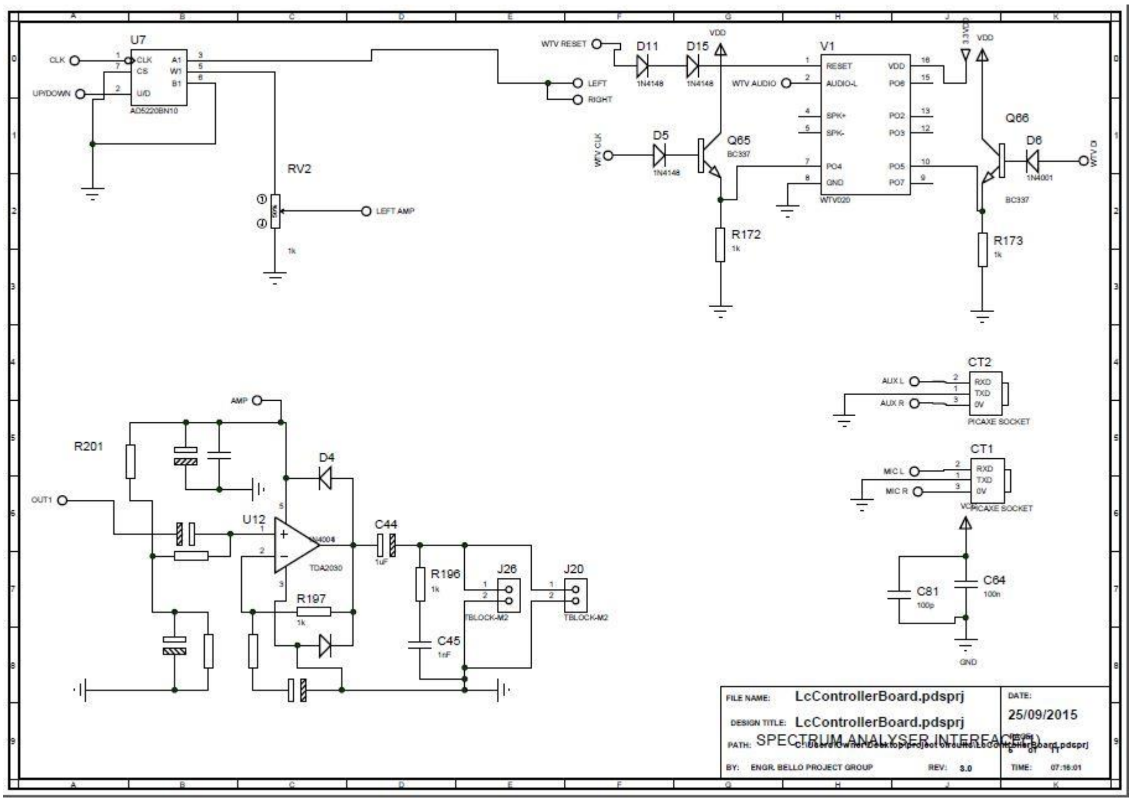

Figure 10 LC Controller Schematics (5 of 9)

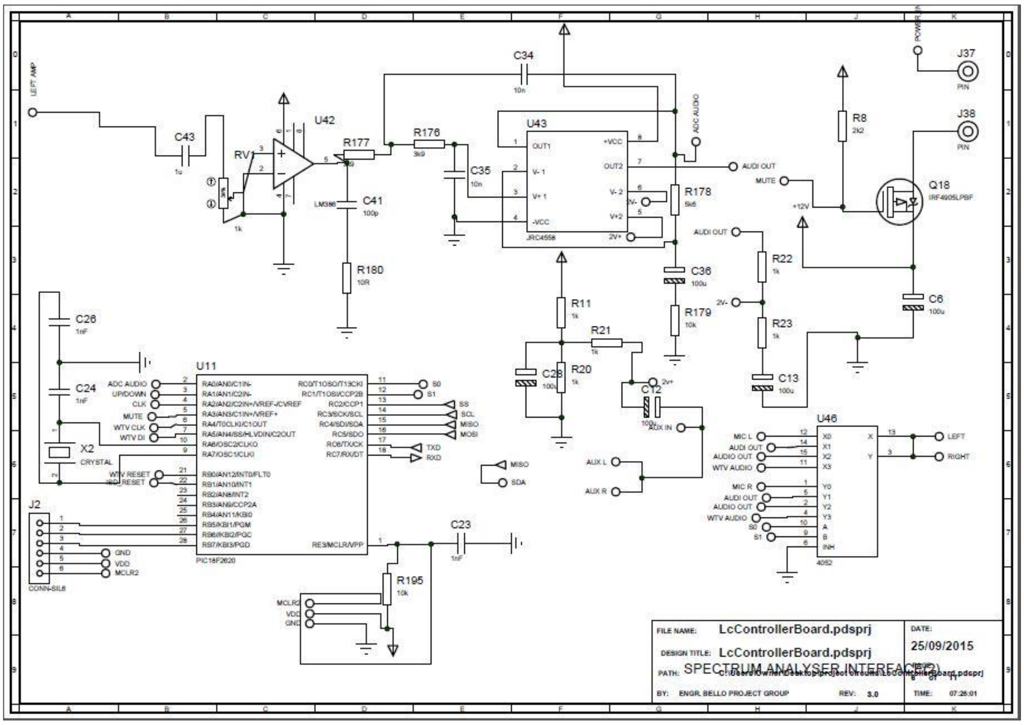

Figure 11 LC Controller Schematics (6 of 9)

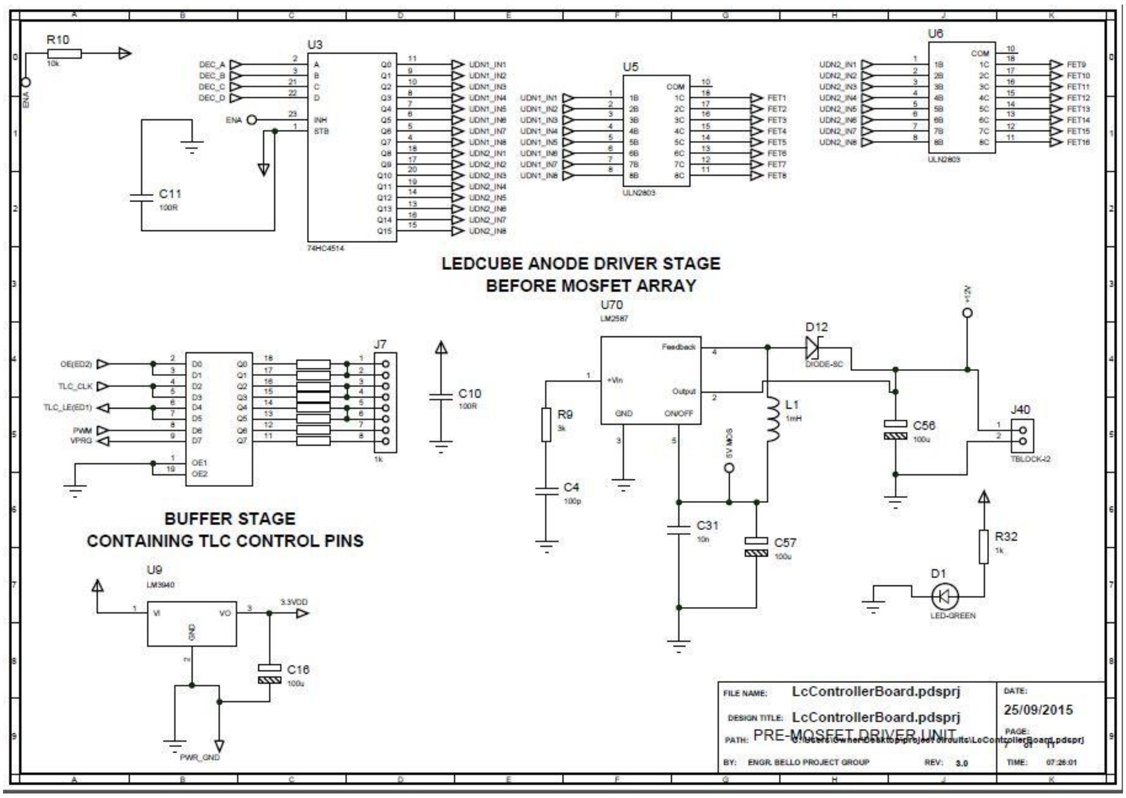

Figure 12 LC Controller Schematics (7 of 9)

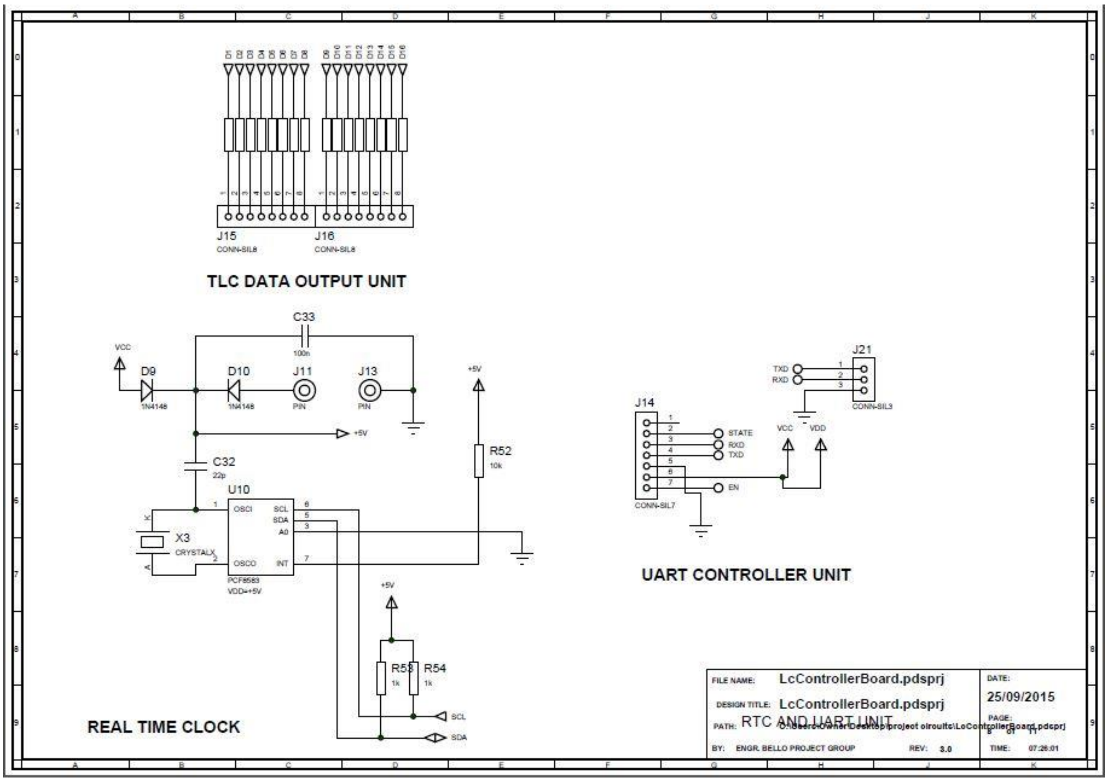

Figure 13 LC Controller Schematics (8 of 9)

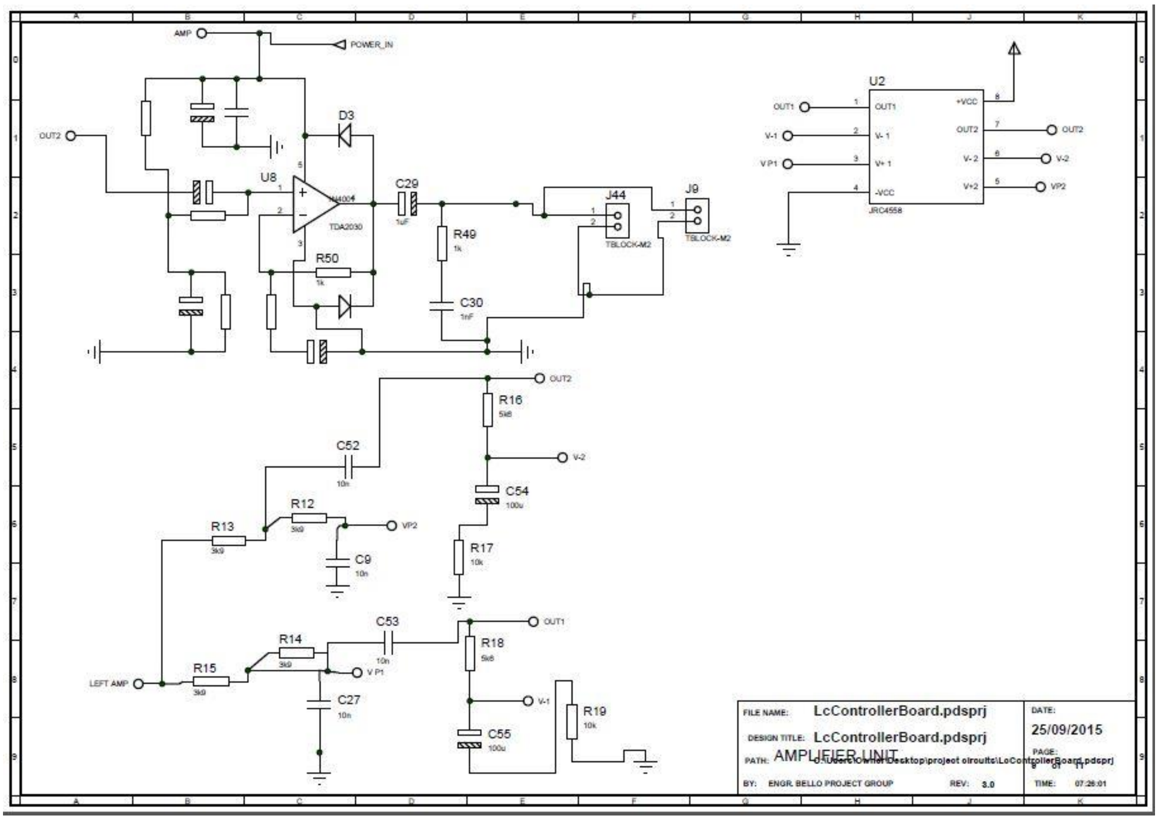

Figure 14 LC Controller Schematics (9 of 9)

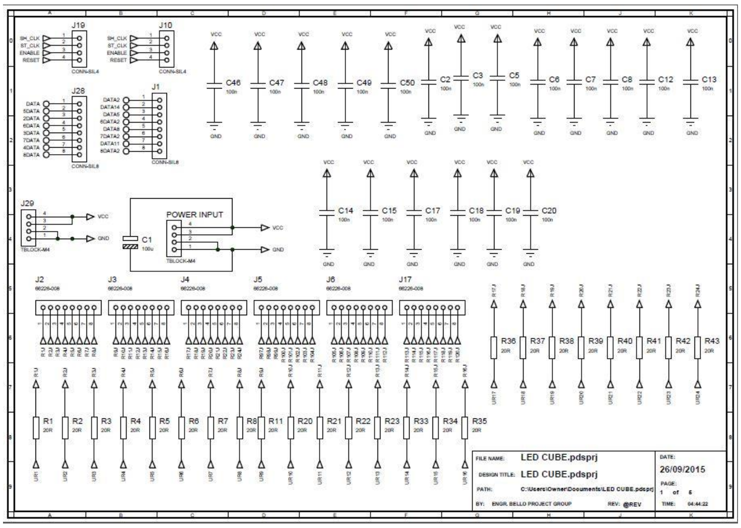

Figure 15 Cathode Driver Schematics (1 of 5)

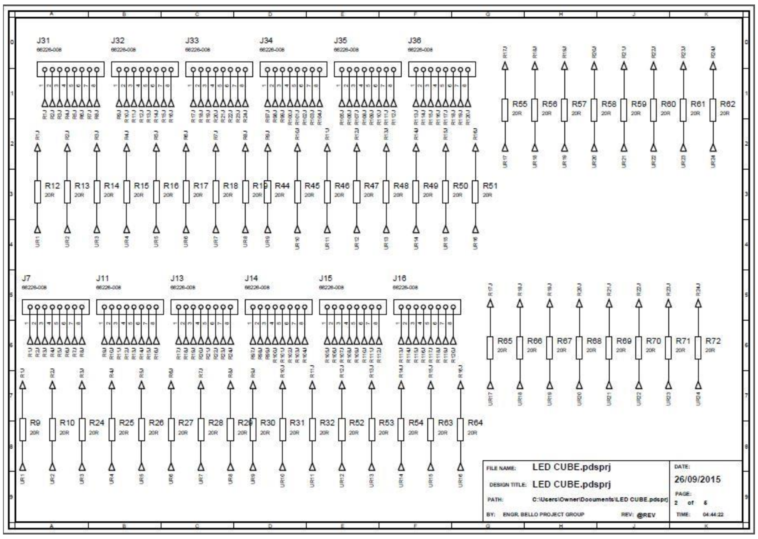

Figure 16 Cathode Driver Schematics (2 of 5)

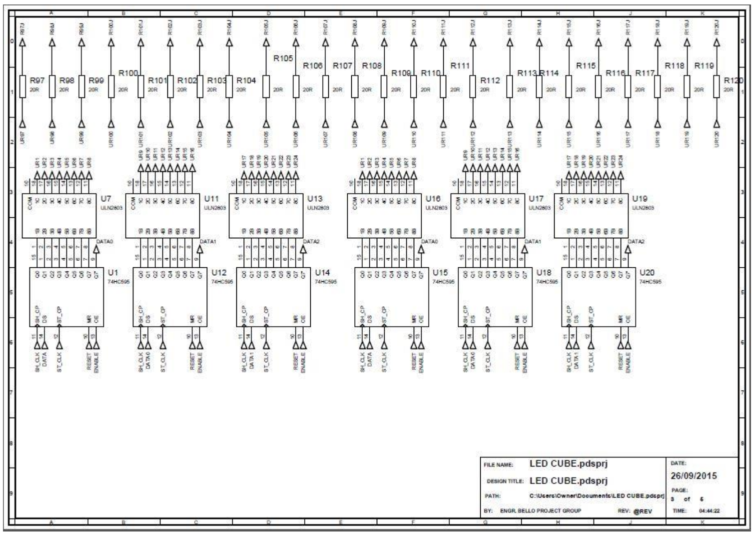

Figure 17 Cathode Driver Schematics (3 of 5)

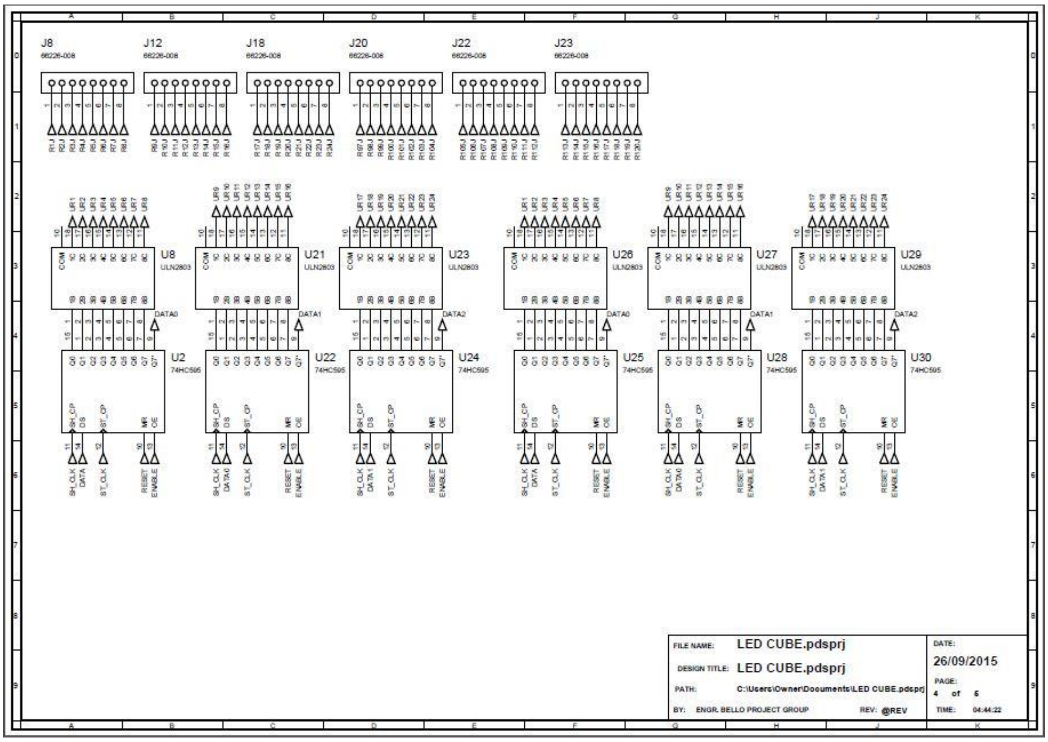

Figure 18 Cathode Driver Schematics (4 of 5)

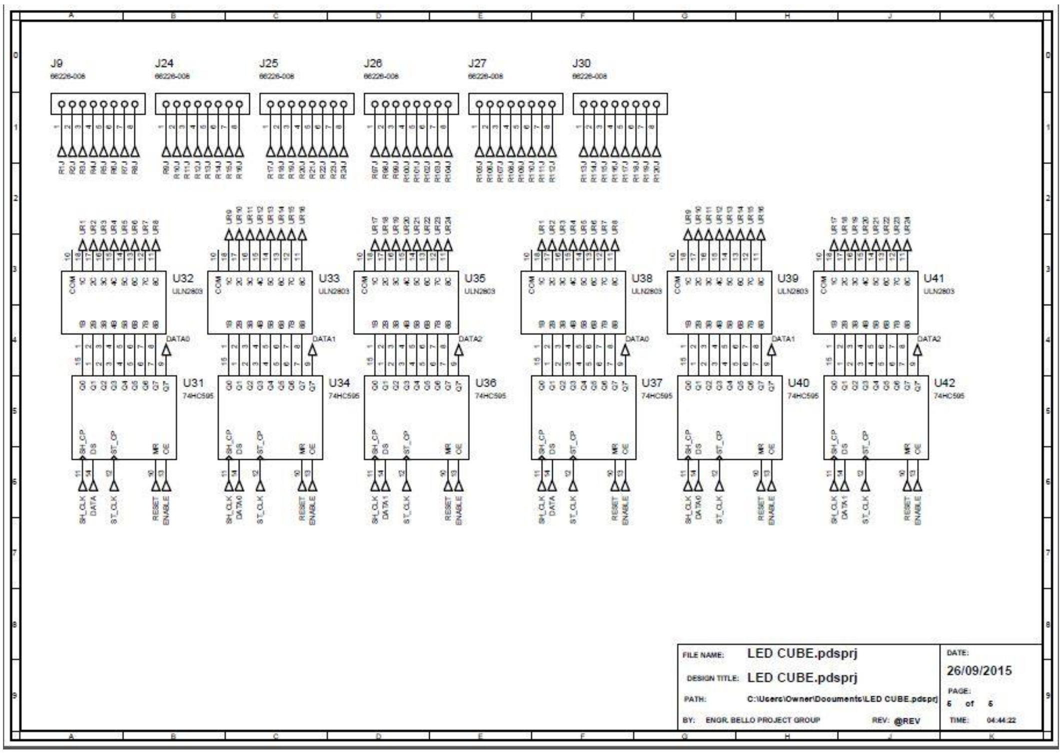

Figure 19 Cathode Driver Schematics (5 of 5)

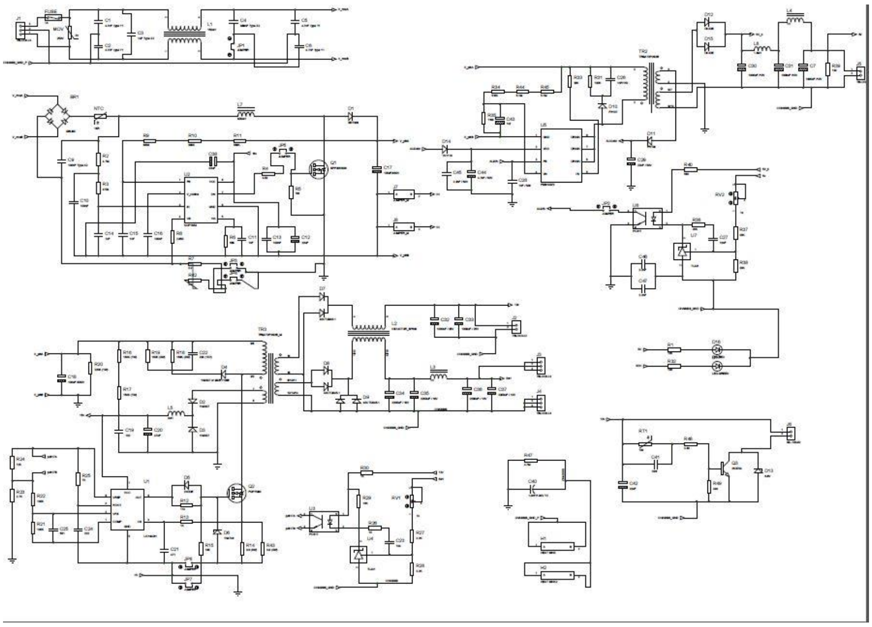

Figure 20 Power Supply Schematics

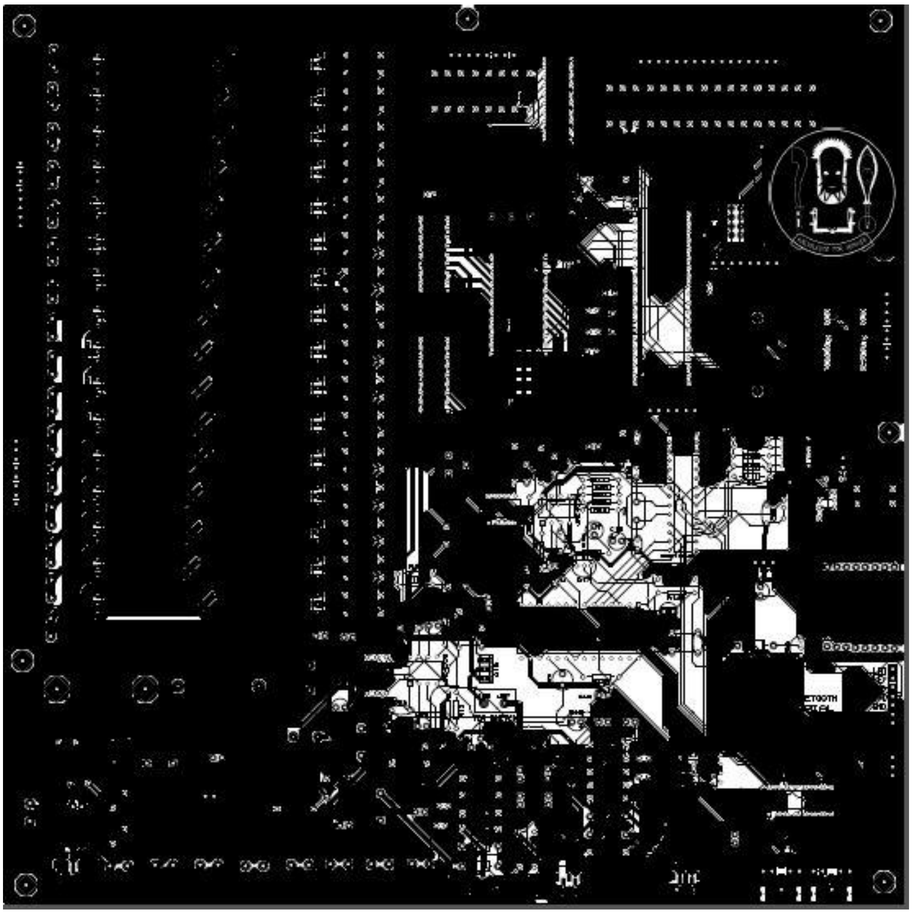

Figure 21 LC Controller PCB Layout

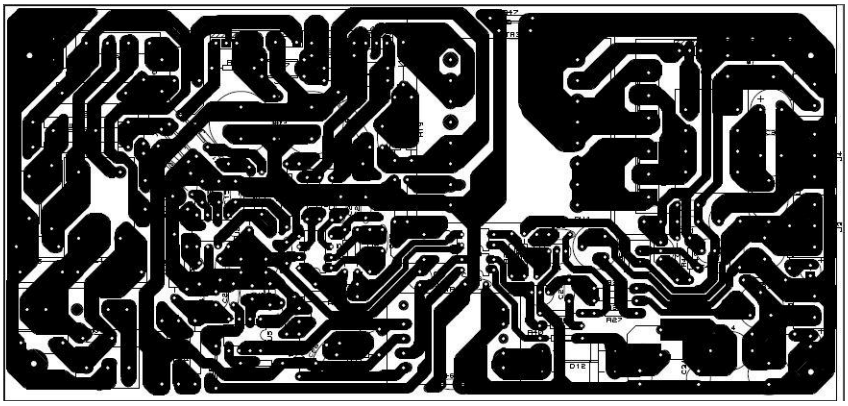

Figure 22 Power Supply PC

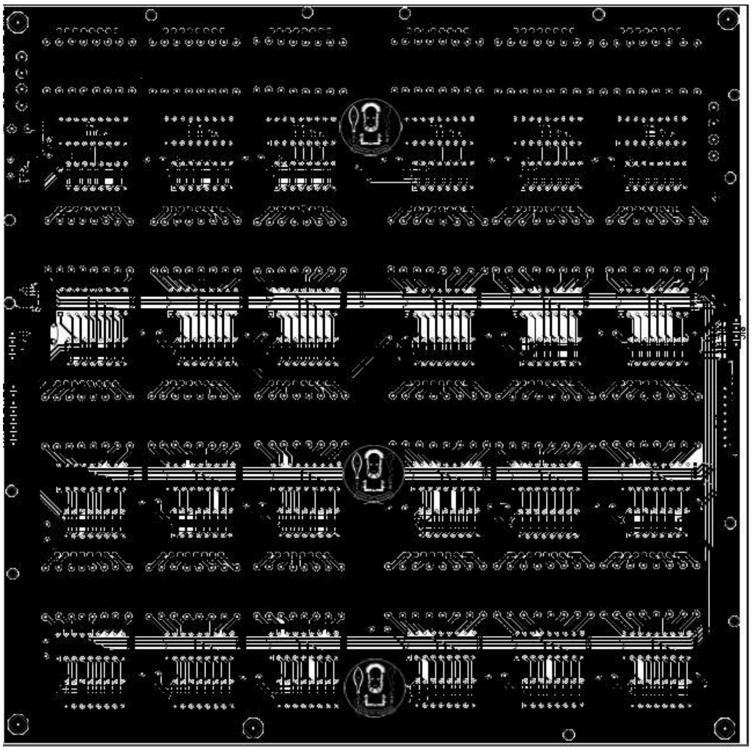

Figure 23 Cathode Driver PCB Layout

In the next stage of the development, we produced the three PCBs needed for the power supply, the cathode driver and the controller which are shown in Figures 24 and 25.

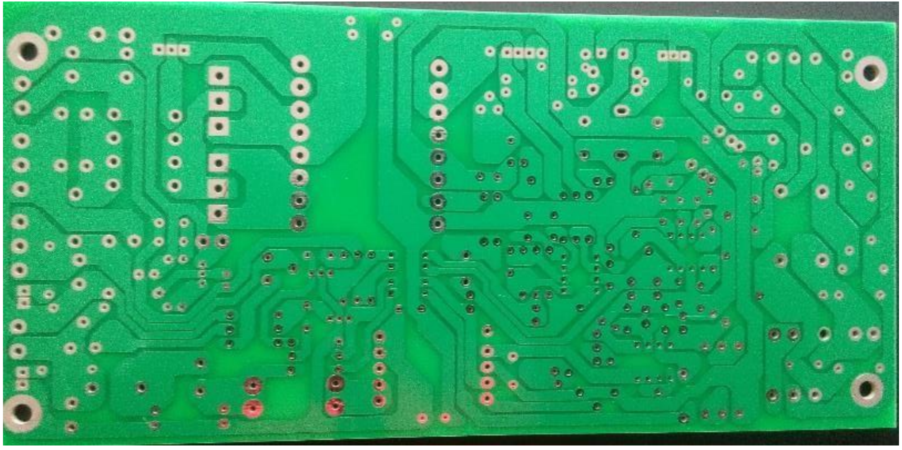

Figure 24 Power supply board

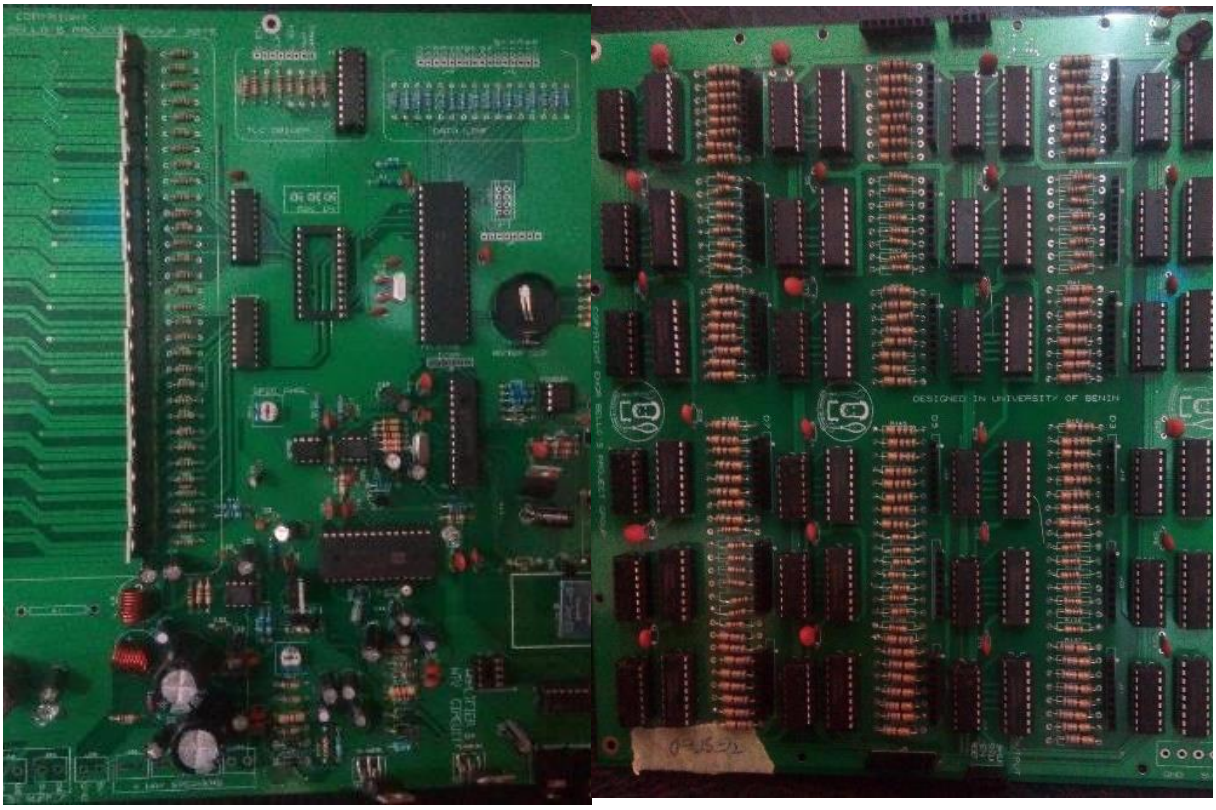

Figure 25 (a) Completely soldered LC Controller Board (b) One of the four completely soldered Cathode Driver Board

3.1. Testing

The electronic components on the PCB circuits after being soldered were tested using a digital multimeter to determine if the circuits worked satisfactorily and to check for continuity. The tests were conducted both modularly and chronologically, meaning that each specific stage of the design will be tested individually throughout the build process. This allows cascading errors (an error early in the build process causing multiple errors later on) to be entirely avoided and identify any errors to a specific hardware or software functionality concern. With this modular and chronological testing, we discovered our errors and fixed them in the most efficient method possible. The primary hardware components tested were LEDs. The LEDs were to be tested simply to confirm their functionality. Each LED test involved an "ON/OFF" check with each colour: red, green, and blue. Each LED was tested individually before being soldered to the cube and individually after soldering to the cube. This ensured that the LED is in operating condition, as well as identified any problems in the wiring of the LED cube. As the cube was soldered one plane at a time, each plane was tested before its addition to the cube structure. Finally, upon the addition of each plane to the cube, the entire cube existing then was tested.

The LC Controller board and Cathode Driver boards are key components of the LED cube, controlling current, brightness and colour. Each of these factors was tested individually from each channel. The channels were calibrated so that the same colour and brightness appear for all LEDs across each LED driver channel and device.

4.0. Conclusion

This study was an intricate one and the needed skills were inputted to achieve the desired specifications for the completed prototype. Skills needed were in several areas of electrical and computer engineering such as embedded processor development, discrete component integration, printed circuit board construction, communication protocols, embedded software development, and software design. Thus, successfully, the study completed the design and construction of a $16 \times 16 \times 16$ RGB LED cube of uniform brightness and compact design for outdoor proof to dust.

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