INTERACTIVE LED STAIRCASE MODULES

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Abstract

The aim of the project is to motivate pedestrians to engage in more physically active transit while reducing energy normally used in electrical and mechanical devices. Additionally, the result will serve as a visually pleasing installation that can be placed in otherwise less attractive areas. Photodetectors and LEDs operate through a microcontroller to display illumination patterns as a user walks up or down the staircase. The main focal points of the project are health and fitness, energy consumption, and visual appeal.

Contents

1. Introduction

On a rudimentary level, the project consists of photodetector arrays overlaid with LED arrays. On each functioning module, or stair, the photodetectors sense the presence of the user and relay the location to the microprocessor. The microprocessor then handles illumination algorithms and outputs a signal to trigger the illumination of corresponding LEDs. Signals can also be used to trigger the illumination of other modules within the installation, employing the modular implementation of the design.

Each module features 48 Red-Green-Blue (RGB) LEDs, each with 12-bit resolution for the intensity control of each Red, Green, and Blue channels. Thus, the entire color spectrum can be reached on each LED by altering each channel individually and the LEDs can fade on and off.

In order to externally control necessary settings within the system, a switch control unit is included. This includes 2 "mode" switches, which set the illumination pattern of the system to one of up to four available modes. The external switch control also includes a calibration switch, which interrupts all illumination and detection algorithms and stores current photodetector values for a base comparison value based on the ambient light of the room. This ensures the accuracy of the system's detection array as it is moved to different locations or the background lighting of the environment changes.

Another important feature of the system is its aforementioned modular design. Dedicated signals exist within the programming, inputs, and outputs of the microprocessor to handle communication with other modules. Specifically, this implementation can be used to perform a "ripple effect" mode. In this mode, user input will trigger the sending of signals to one module both before and one module after the current step, then illuminating the modules with a predetermined delay. The two neighbor modules will then continue passing the signal in the proper directions with said delays, ultimately resulting in a full wave of illumination up and down the staircase from the user's current location. Because the modularity is handled by each unit, passed between its respective neighbors instead of control from a single "main" microcontroller, the system can be infinitely modular as long as power requirements are met for each module.

2. Design

A functional block diagram can be seen in *Appendix A,* Figure 1.

A hardware flow for the system can be seen in *Appendix A,* Figure 2.

A detailed schematic can be seen in *Appendix B,* Figure 6.

The following is a description of the project by block.

2.1 Power Supply

The power supply used is a Standard Power SPS 120-5. It is a linear power supply rated at 12A at 5V. This power supply is adequate for the initial design consisting of three modules. The power requirement calculation is:

$$P_{system} = I_{\max/LEDcontact} \bullet (\#contacts/LED) \bullet (\#LEDs/\mathrm{mod}\,ule) \bullet (\#\mathrm{mod}\,ules)$$

$$P_{system} = 25mA \bullet 3contacts \bullet 48LEDs \bullet 3\mathrm{mod}\,ules = 10.8A$$

Equation 1

Equation 1 is based on the given maximum input current for each LED and the total number of LEDs to be driven in the system. It illustrates the worst-case instantaneous power consumption of the whole system. This corresponds to all R, G, and B color leads of each LED demanding full illumination such that the entire system will illuminate white with the brightest intensity possible. While this state is not likely to be reached in actual implementation, it is important to consider for testing or errors.

A 12A supply was chosen because it surpasses the 10.8A worst case maximum of the system and is more easily obtained than an 11A supply.

Each block requiring power has the compatibility to operate on a 5V source. Thus, no voltage conversions will be necessary, reducing the total amount of circuitry. The power requirements for additional blocks are in the uA-mA range and thus are considered negligible in the maximum power supply requirement calculation.

For larger builds than a three-module system, a power supply with a larger current can be substituted as long as the voltage remains at 5V. Alternatively, multiple power supplies can be used within one system.

2.2 Photodetector Array

Photodiodes detect changes in light over points on the staircase panel to determine where the user is stepping and, thus, which LEDs will light up. There will be one photodiode per pixel used as a detector, so 12 photodiodes per module in a 2 x 6 array. It will "watch" the underside of the acrylic top case to check for changes in light as compared to a base value, which will be set upon calibration. Its signal is then sent to the microcontroller.

The photodetectors used are Advanced Photonics PDB-C156 available through DigiKey. They provide an adequate 120-degree viewing angle and output a current of 70-90µA for detection, which is readable by the microcontrollers without amplification. Their spectral response peaks at a wavelength of 900nm but provides adequate response within the visible light spectrum for the scope of this project. Their voltage output was tested between .18V for dark and .31V for white incident light.

2.3 Microcontrollers

The system uses all Microchip 16F887 microcontrollers. This decision is economical for the scope of the project since they are available for free in the Senior Design Lab and the project is heavily microcontroller-reliant. They are C-programmable and contain an adequate amount of inputs and outputs to use in conjunction with the photodiodes (inputs) and LED drivers (outputs) selected. Each PIC16F887 has 36 inputs and outputs: 14 analog/digital inputs, all of which are used as analog, and the remaining 22, which are implemented as digital I/O. These assignments are set in software. For a full schematic of each microcontroller including input and outputs, see *Appendix B,* Figure 7.

2.3.1 Microcontroller Input

The microcontroller input from the twelve photodiodes is governed by reference voltage circuitry. These are bounds on input voltages such that the maximum accuracy, with 10-bit digital resolution, can be obtained by the microprocessor. Based on maximum tested photodiode voltages, these reference voltages are set to .15V and .48V using voltage divider circuits. A basic voltage divider circuit can be seen in *Appendix B,* Figure 8. The calculation for V_{out}, the input to each reference voltage pin on the microprocessor, is shown below.

$$V_{out} = \frac{R_2}{R_1 + R_2} \bullet V_{in}$$

Equation 2

Based on the above equation and availability of parts, for V_{in} = 5.0V, for the following resistances are used:

Name	Value (Ω)
R^-_1	5.11k
R^-_2	100
R^+_1	4.7k
R^+_2	510

Table 1

2.3.2 Software Flow

For the software flow diagram, see *Appendix B,* Figure 9. The software programmed to each microcontroller determines, in short, how an input is mapped to an output pattern on the actual LED array. Several important aspects are:

Calibrate() function: Stops all illumination, stores photodetector voltages in base[] array for comparison during the running of the system. This function runs once the program first begins and can optionally run after that anytime the "calibrate" input switch on the external control board is set high.

Detection() function: Cycles through photodetectors, reading each value and comparing to the base value set in Calibrate() with a predetermined tolerance, set as variable "tolerance". For each pixel, if the photodetector value exceeds the sum of the base value and tolerance, then user input is detected.

LEDData[3][12] array: Stores 12 bits of LED output data for each of 3 channels (Red, Green, Blue). This data is manipulated within the code and later shifted out to LED drivers.

MODE variable: Determines the operation algorithm, or mode, of the system. Two switches on the external control board set the MODE variable, which is stored as an unsigned integer. Available modes are:

- Mode = 0: Basic illumination mode. Inputs are mapped directly to corresponding output pixels. Illumination lasts while input is detected.
- Mode = 1: Unused input.
- Mode = 2: Modular ripple mode. This illumination mode demonstrates the modularity of the project. It enables modular data inputs and outputs for the previous and next stairs. When a high input is received from either the previous or next stair, the entire current module illuminates and passes the illumination signal to the next stair in the proper direction.
- Mode = 3: Test algorithm mode. This mode cycles through all outputs, illuminating a pixel's LEDs with one color for 500ms, turning it off, and then moving to the next pixel. Once this is complete for one color, the next color is checked. This is a test to make sure that all outputs are mapped properly and that all LEDs are wired correctly and functioning.

In the shift output processing section of the diagram, data is shifted out one bit at a time to the LED drivers. Each of the 24 LEDs controlled by each LED driver is responsible for 12 bits. Thus, 12*24=288 bits are shifted out to the LED driver per cycle. After all of these bits are loaded into the LED driver, a latch signal is sent from the microprocessor to initiate illumination of that cycle's LED values.

2.4 LED Unit

The LED Unit consists of 6 LED drivers controlling 48 RGB LEDs for each module.

2.4.1 LED Driver

A schematic for the LED driver can be seen in *Appendix B,* Figure 10. The TLC5947 converts signals from the microcontroller into usable signals to activate the designated LEDs within the array since the microcontroller lacks the ability to supply full current to LEDs. Each LED driver has 24 channels and includes PWM functionality, so six shall be used per module – two for each color.

The chip receives a 288-bit signal serially from the PIC microcontroller, decodes the signal, and outputs a maximum of 30mA per pin where necessary. Since each LED requires three inputs, pins are grouped into threes to determine which LED they will control. The LED driver also has a constant current sink; the current is controlled by a reference resistor set at 2kΩ to yield a maximum current of 25mA at each output pin. This component was chosen because it has an appropriate number of outputs such that it can drive a significant portion of each module. Also, its maximum output current is within specifications for driving the chosen RGB LEDs. Finally, the LED driver can operate at a frequency of up to 30MHz, which well surpasses the output speed of the microprocessor, meaning timing is not an issue for this block.

2.4.2 LED Array

Each module is defined by 2 x 6 "pixels" and is controlled as such. Each pixel contains 4 RGB LEDs in a square pattern. Thus, the array is a total of 4 x 2 x 6 LEDs for a total of 48 RGB LEDs per module. For the scope of this project, 144 RGB LEDs were purchased to build 3 panels. LEDs are addressed directly based on a one-dimensional index value corresponding to the LED cluster's individual pixel as an integer between 0 and 11. No multiplexing is planned because the LED drivers support enough outputs for direct addressing.

The LEDs chosen are made and sold by Niktronix. They are the standard 5mm LED size, have an acceptable luminosity of 6000-9000mcd, a forward current range of 20-25mA, and a clear lens for maximum brightness. Each has a maximum forward voltage of 3.5V. They are common anode, so the common pin is set high and each individual R, G, or B pin is driven by the LED driver at an appropriate current to illuminate the LED. They have a 25-degree view angle, which is important because their increased directivity will keep from interference with the photodiodes. Because the LEDs are the "bulk" of the design (144 LEDs required), it was important to find them for the most reasonable price to keep within budget.

2.5 External Control Unit

The External Control Unit is a simple switching unit created from an 8-bit DIP switch to enable simple access to the function mode and calibration of the system. It uses a simple debouncing circuit to ensure that there is no oscillation when a switch changes values. For the given DIP switch, the RC time constant of the circuitry must be kept above the bounce time, which is estimated at 10ms. The equation below shows the calculation for the resistor and capacitor used.

$$R \bullet C > .01s$$
$$220k \bullet .1u = .022s > .01s$$

Equation 3

The circuitry implemented can be seen in *Appendix B,* Figure 11. This circuitry is built for three switches on an external perfboard. Two switches control the mode while one signals calibration.

2.6 Physical Design

The LED array is mounted on standard 1” spaced pegboard. 4 LEDs compromise one pixel, and thus will be laid out in a square fashion. In the center of each pixel is the photodiode that controls each pixel. The pegboard, one for each module, will consist of one 24” x 8” section. Each module is 6 pixels wide x 2 pixels long.

RGB LEDs and photodetectors are connected with 22 gauge solid wire to LED drivers and microprocessors. The LED drivers and microprocessors, along with external circuitry, are mounted on a PCB located underneath the pegboard. Thus, each module is 24” wide by 8” deep and contains 12 pixels with a total of 12 photodetectors and 48 RGB LEDs. Each module will be enclosed in a wood base enclosure. A bottom piece of plywood serves as the structural base and has dimensions of 12” x 28”. Wood siding from 2”x4” boards provide enough clearance for the circuitry on the back of the pegboard. On top, a ½” thick clear acrylic lid protects the components while allowing light through. The acrylic was purchased from the ECE parts shop and was cut to order. See Figure 3 and Figure 4 for pictures of the physical design, both illuminated and non-illuminated.

2.7 Design Changes

Most of the design changes stem from changing microcontrollers. Originally, a PIC16F877A was to be used. This chip had only 7 analog inputs, so two were to be used per module. Thus, each would have to communicate horizontally to illuminate the proper pixels in addition to vertically to properly incorporate modularity. This modularity was to be handled by a “main” microcontroller, again a PIC16F877A. However, this would have limited the modularity of the system as each microcontroller has a fixed number of usable inputs and outputs and can only process a certain amount of data comfortably at once. Also, the 877A has no internal clock, so external crystal oscillation circuitry would need to be implemented in order for it to function. Thus, the design change was made to the PIC16F887, which has an internal clock among other advanced features. Fortunately, each is made by Microchip and they have the same package and similar pinouts. The 887 has 14 analog inputs, so only one was required for each module. The design was also drastically changed to control modularity from each individual microprocessor, thus making the system infinitely modular and eliminating the need for a “main” microprocessor. Instead, power, ground, clock, and modular input and output signals are passed directly between modules.

3. Design Verification

Much of the testing and verification require one to three completed modules. They are broken up by module. Testing and verification requirements are outlined below.

3.1 Power Supply

Power Supply Requirements	Verification
1.) All powered units receive adequate power 1.Microprocessors receive 5V 2.LED drivers receive 5V 3.RGB LEDs receive no more than 3.2V	1.) 1. A voltage between 4.5 and 5.5V is measured at VDD pins. a. Measured 4.8V 2. A voltage between 4.5 and 5.5V is measured at VDD pins. a. Measured 4.7V 3. A voltage between 2 and 3.2V is to be measured from each pin to ground. a. Measured 2.0V, 3.2V, 3.2V at constant illumination
2.) Power supply ripple is less than .5V	2.) Probe power supply's output to first microcontroller with an oscilloscope a.) Ripple measured at .17V.

3.2 Photodiodes

Photodiode Array Requirements	Verification
1.) Photodetector detects user input for 100% of trials 1.) Output voltage ranges within .25V to .48V for a distance of 0-2 inches.	1.) Voltage is measured through the photodiode for placing an object directly over the photodetector at a distance of 2 inches through clear acrylic.

	1.) Measure voltage across the photodetector with a multimeter, holding a dark object at a distance of 0-2 inches. Perform 20 trials. a. 20 voltages measured, all greater than .25V and less than .48V.
2.) Photodetector does not produce false positives 1.) Photodiode voltage is under .25mV for no stimulus 2.) Photodiode voltage is under .25V for stimulus at greater distances than 6 inches.	2.) 1.) Connect an oscilloscope to the photodiode, monitor output voltage for non-stimulated photodiode under acrylic, check that it is 0-25mV. a. 20 voltages measured, all less than .25V. 2.) Connect an oscilloscope to the photodiode, monitor output voltage for photodiode under acrylic stimulated by objects 6 inches away and greater, check that it is 0-.25V. a. 20 voltages measured, all less than .25V.

3.3 Microcontrollers

Microcontroller Requirements	**Verification**
1.) PIC reference voltages are within photodiode range 1. Lower reference voltage is within spec 2. An upper reference voltage is within spec 3. Minimum photodiode voltage is > .15V 4. Maximum photodiode voltage is < .48V	1.) 1. V_{ref}^{-} <.15V must be measured with multimeter at pin A2 a. Measured .106V 2. V_{ref}^{+} >.480V must be measured at pin A3 a. Measured .489V 3. $V_{min}=V_{dark}>.15V$ a. Measured .18V when completely covered 4. $V_{max}=V_{light}<.48V$

	a. Measured .31V when under illumination by flashlight
2.) 1. Output to LED drivers is properly timed.	2.) 1. Connect oscilloscope channel 1 to XLAT on PIC output, channel 2 to LEDCLK on PIC output. Set window to display one latch cycle. Count clock signals between latches or compute by measuring time for a sample of clocks and multiplying for full cycle. Measure 288 clock pulses per one latch a. 288 clock pulses counted for one latch cycle. See *Appendix C,* Figure 12 and Figure 13 for oscilloscope readings.

3.4 LED Array

LED Array Requirements	**Verification**
1. Each pixel can be addressed individually 1. Count up through addresses from PIC, enabling each with maximum current for 500 ms.	1. 1. Implemented as test mode in code. Each pixel is illuminated individually for 500 ms. a. Test algorithm successful.

4. Cost Analysis

Cost of Labor = $80/hour x 2.5 x 144 hours = $28,800

Cost of Parts:

Part #	**Manufacturer**	**Part**	**Price**	**Quantity**	**Total Price**
½” ACRYLIC SHEET 12x24	ECE Store	Clear Acrylic panels – ½”	$9.04 / 12”x24” sheet	3	$27.12
“5MMLEDRGB COMMONANODE”	Niktronix	RGB LEDs	$0.35	144	$50.40
PDB-C156	Advanced Photonics	Photodiodes	$1.05	36	$37.80
16F887	Microchip	Microprocessor	$0.00	3	$0.00
TLC5947	TI	LED driver	$6.72	18	$120.96
-	ECE Parts Shop	PCB	$0.00	3	$0
SPS 120-5	Standard Power, Inc.	5V 12A Linear Power Supply	$35.00	1	$35.00
-	-	Misc.	$20.00	-	$20.00
				TOTAL	**$291.28**

Table 2 - Cost Analysis - Parts

Total Cost = Cost of Labor + Cost of Parts = **$29,091.28**

5. Conclusion

5.1 Accomplishments

For an individual project, the project had many successes. For one, photodetection and its analog-to-digital conversion performed perfectly in testing and the end result. Without the use of a driven signal from the photodetectors along a solid wire of up to 1 foot in length, I was initially worried about signal degradation and bleed-over from other nearby wires carrying higher currents (e.g. power to LED drivers). In the end, the photodetectors behaved exactly as initially planned. This part of the project changed very little from initial designs. LED illumination was a success as well, as each group of LEDs could be illuminated from the code for various intensities. PCB fabrication and soldering challenges were additional successes, as I learned how to solder miniscule surface-mount chips (See *Appendix A,* Figure 5 for LED driver soldering). Additionally, the project was successful in I/O routing while using a 12-bit resolution for each LED. The easy way to implement illumination would have been through multiplexing, where each LED could only be controlled as on or off, but the individual routing from LED drivers directly to LEDs made a 12-bit resolution possible, enabling a vast expanse of additional functionality.

5.2 Uncertainties

Uncertainties remain for design regarding the number of bits for which each microcontroller is responsible. Response from input to output was not always smooth and a delay was clearly visible at times. It is possible that the software could have been further optimized, but on a rudimentary level, each microcontroller is responsible for 48 LEDs x 3 channels x 12 bits of resolution = 1728 bits of data being updated rapidly, in addition to photodiode information, LED data processing algorithms, and more. Although the 16F887 chip was useful for its gratuitous number of inputs and outputs, the system would likely benefit from a more powerful microcontroller with a faster clock.

5.3 Ethical Considerations

There are no foreseeable ethical considerations to the project.

5.4 Future Work

In the future, the project could be simplified without losing much functionality by reducing the total number of LEDs used. If each pixel used 2 LEDs instead of 4, this would greatly reduce the number of soldering connections made, the amount of data processed by the microcontroller, and the number of LED drivers required. As the LEDs are bright and well directed, the brightness of the entire board is often excessive anyway. I would also like to implement a matte acrylic panel instead of clear, given that the photodetection circuitry would still work properly, mainly for visual aesthetics. Endless time can be spent implementing and perfecting different illumination algorithms, too, as the external control board can be expanded for another 5 binary bits of modes, resulting in a maximum of over 100 illumination modes. Moreover, much of the physical design could be cleaned up, including using clear acrylic or metal structural components instead of wood.

Overall, given a number of adjustments and improvements, the project could be pitched to various organizations and locations, such as malls or subway stations, as an installation. This would allow it to fulfill its purpose of promoting health and fitness, saving energy, and creating a visually appealing atmosphere.

6. References

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http://www.mikroe.com/eng/chapters/view/16/chapter-3-pic16f887-microcontroller/#c3v1

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7. Appendix A: Block Diagram and Physical Design

7.1 Block Diagram

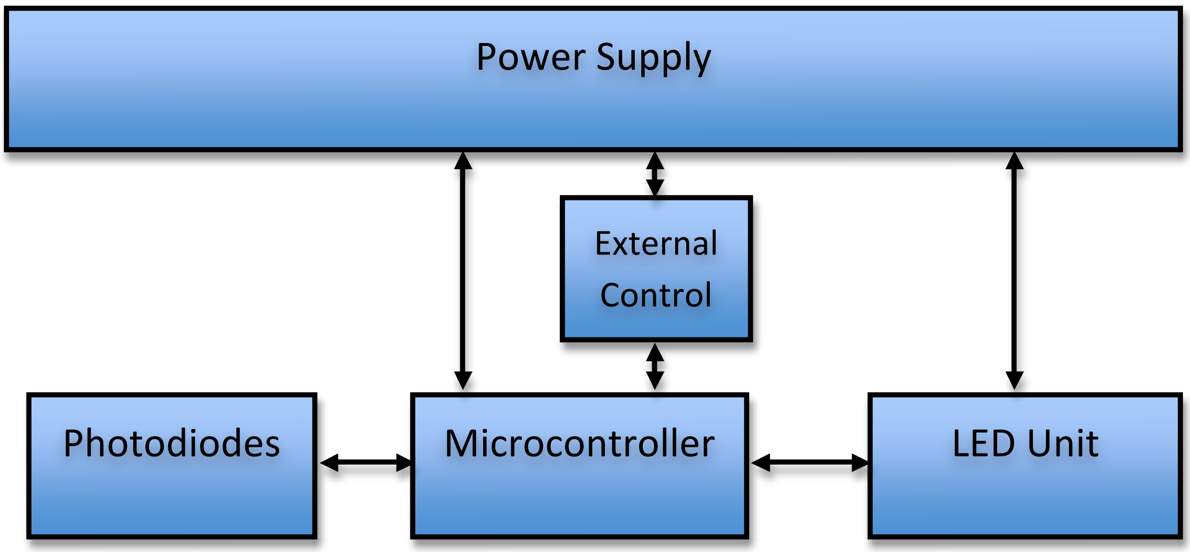

Figure 1 – Block Diagram

7.2 Hardware Flow

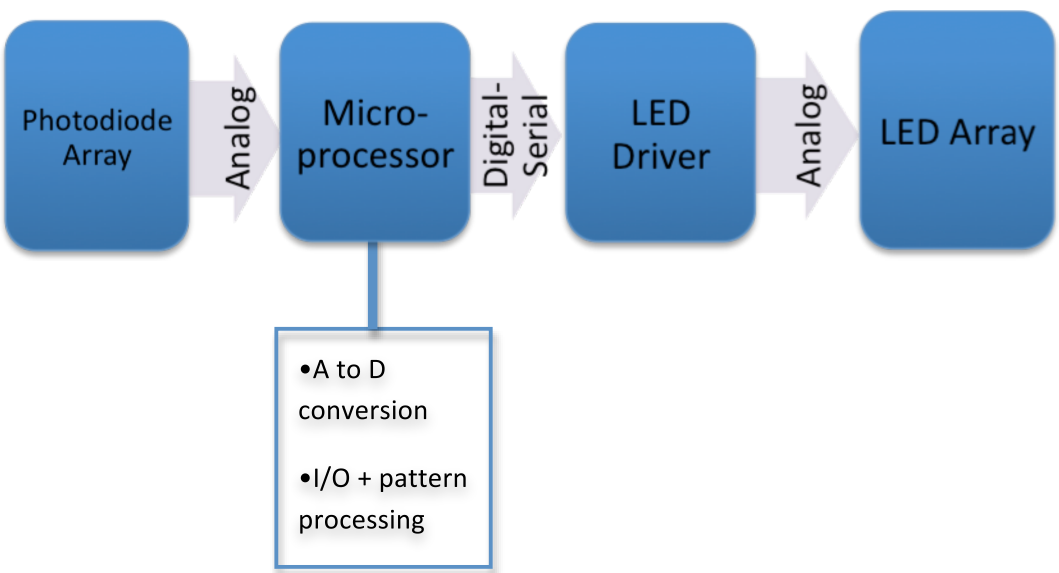

Figure 2 – Hardware Flow

7.3 Physical Design

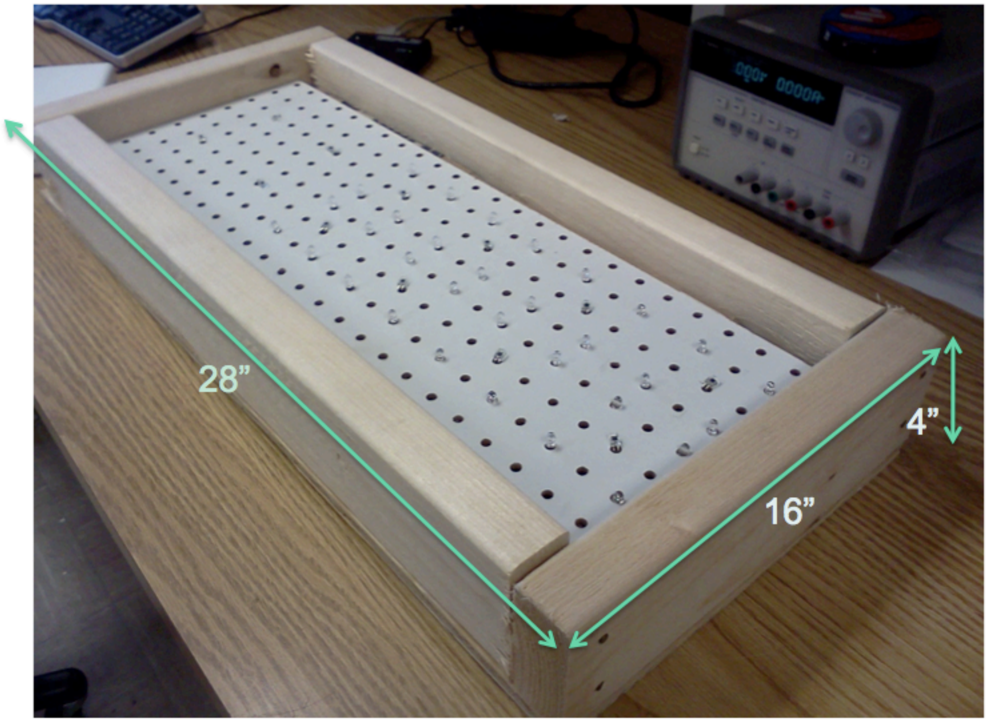

Figure 3 - Physical Design, Module Dimensions

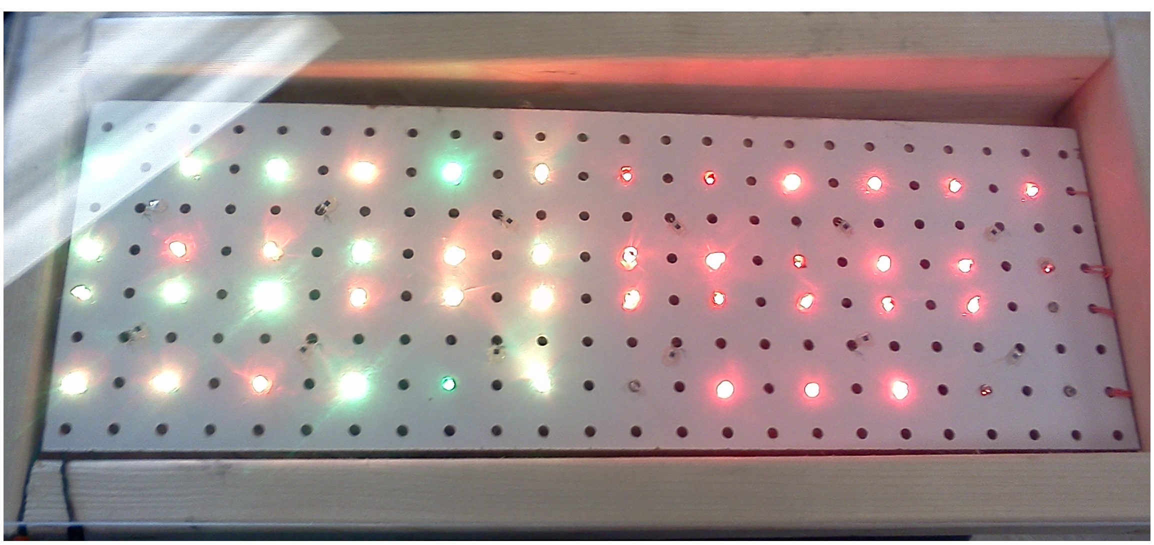

Figure 4 - Physical Design, Illuminated

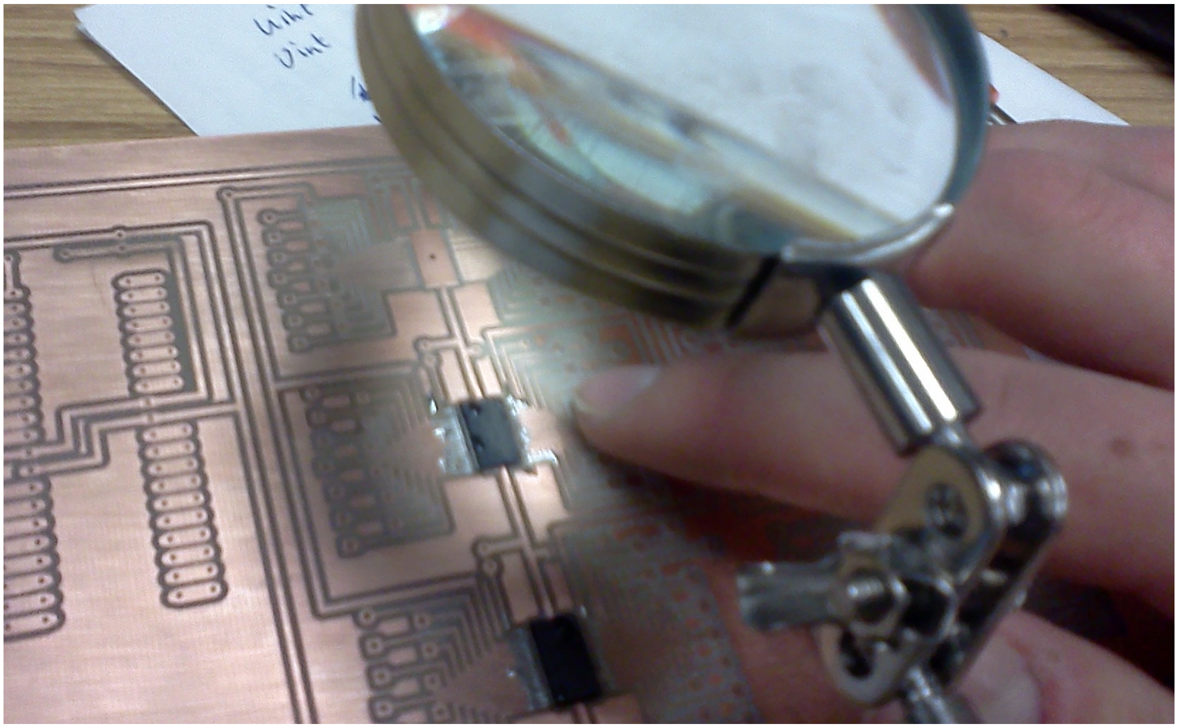

Figure 5 - Soldering Surface Mount TLC5947 Chips

8. Appendix B: Schematics

8.1 Microprocessor Schematics

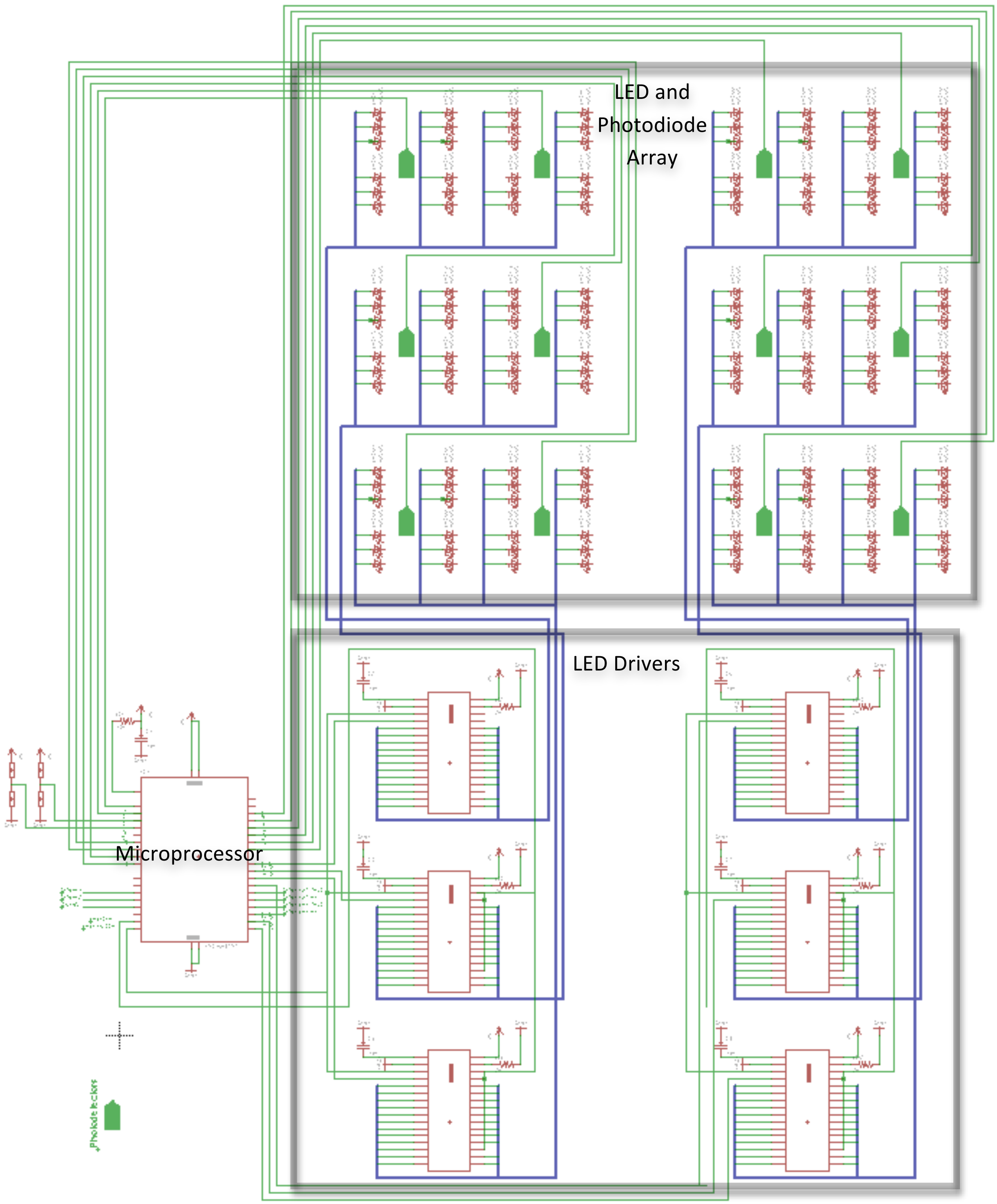

Figure 6 – Full Module Schematic

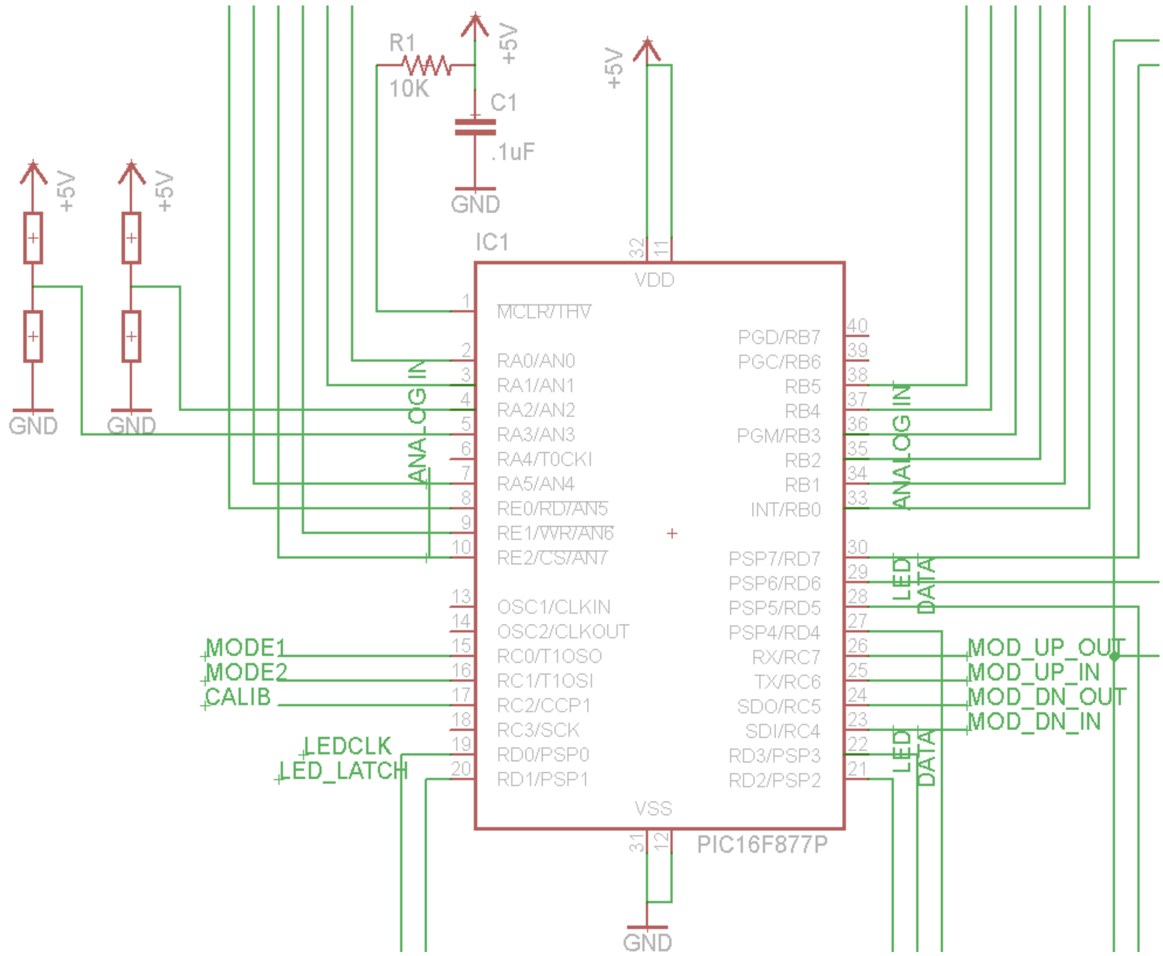

Figure 7 - Microprocessor Schematic

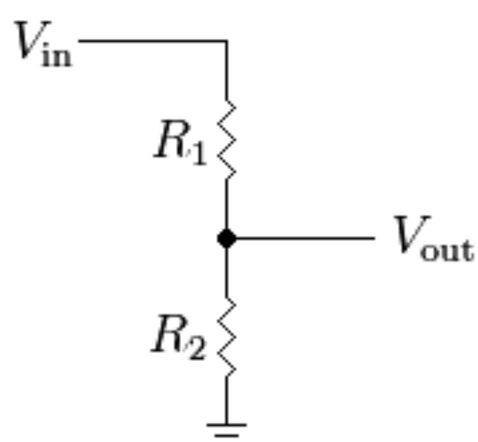

Figure 8 - Voltage Divider Circuit [1]

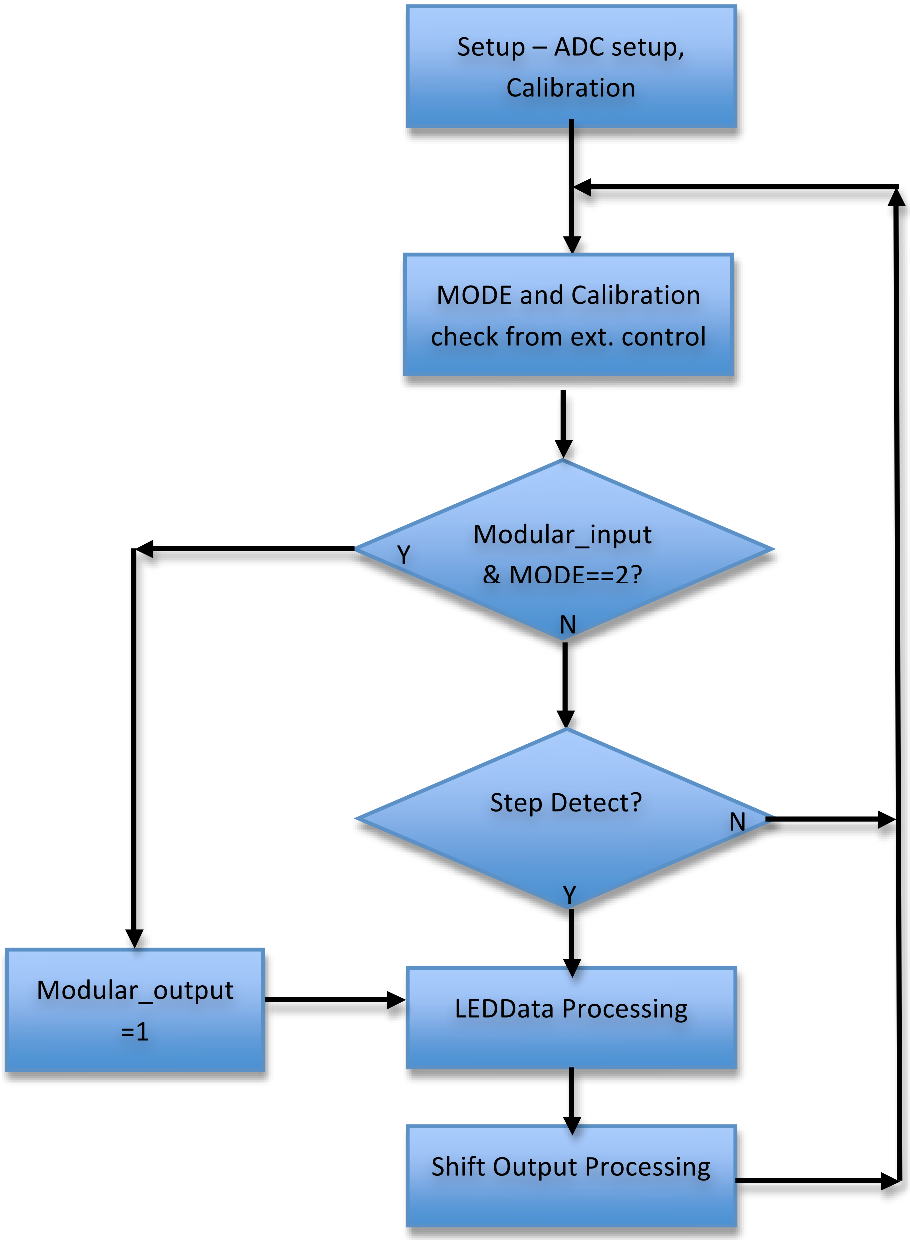

Figure 9 - Microprocessor Software Flow

8.2 LED Unit Schematics

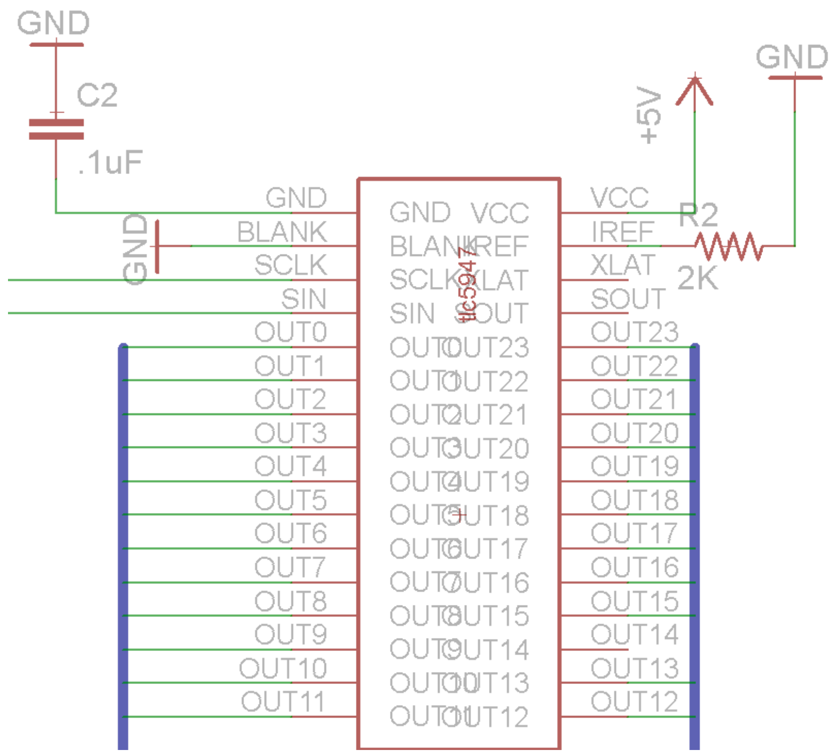

Figure 10 - LED Driver Schematic

8.3 External Control Schematic

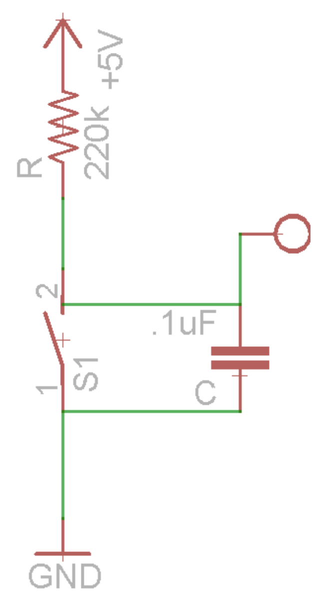

Figure 11 - External Control Switch

9. Appendix C: Simulation Outputs

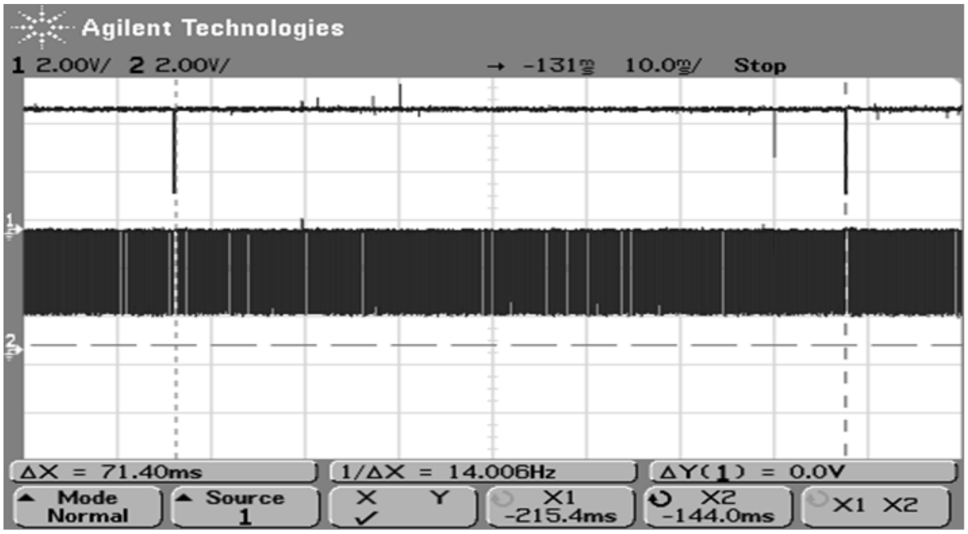

Figure 12 - LED Driver Input, One Latch per 288 Clock Cycles

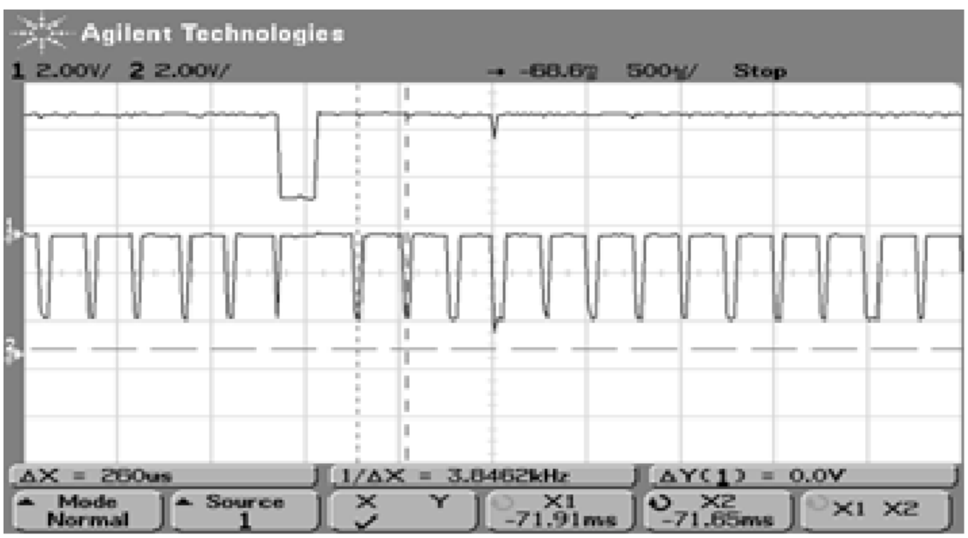

Figure 13 - LED Driver Input, Latch and Clock signals