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November 12, 2007

Dr. Andrew Rawicz
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Re: ENSC 440 Design Specifications for the Smart Traffic Light

Dear Dr. Rawicz,

The attached document contains the design specification for the Smart Traffic Light (STL). We are designing a traffic light that is sensitive to vision limiting weather conditions such as fog and can significantly reduce automobile accidents that are caused by misinterpretation of traffic lights due to sun glare.

The design specifications provide an overview of the system and detail various aspects of its implementation.

AnoLED Technology Inc. is comprised of four senior-level engineering students, namely, Jamal Bahari, Ighodalo Iyayi, Behrad Kajbafzadeh, and Sara Rokni. Should you have any questions, feel free to contact me at 250.552.4140 or, alternatively, by email at 440-ensc-project@sfu.ca.

Sincerely,

Ighodalo Iyayi
Chief Executive Officer (CEO)
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Design Specifications for the Smart Traffic Light

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Abstract

The Smart Traffic Light (STL) addresses two visibility limiting weather-related factors, namely glare and fog. The STL significantly reduces the occurrence of glare reflections, and has the ability to adjust to weather conditions such as fog.

This document describes our design selection and methodology for the prototype model of the STL. We provide a justification for our design choices, pertinent criteria for microcontroller selection, and elaborate on the correspondence between our design and the requirements stated in the *Functional Specification for the Smart Traffic Light*.

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Glossary

Buffer. A part of RAM used for temporary storage of data that is waiting to be sent to a device [1].

Diffuser. A piece of translucent or reflective material fixed to a light source such as a lamp in order to soften or spread the light over a wide area [2].

Duty Cycle. The fraction of time during a specified time period that the module is energized, expressed as a percent of the specified time period [1].

Microcontroller. A microprocessor on a single integrated circuit intended to operate as an embedded system, and used to direct or make changes in a process or operation [1].

Metal oxide semiconductor field-effect transistor (MOSFET). A type of transistor for large-scale integrated components for computer memory units [1].

Printed Circuit Board (PCB). A thin board to which electronics components are fixed by solder [1].

Pulse Width Modulation (PWM). A form of pulse-time modulation in which the duration of pulses vary [1].

Time Division Multiplexing (TDM). A type of digital or (rarely) analog multiplexing in which two or more signals or bit streams are transferred apparently simultaneously as sub-channels in one communication channel, but physically are taking turns on the channel [3].

1. Introduction

The Smart Traffic Light (STL) reduces the occurrence of glare reflections and has the ability to adjust to weather conditions such as fog. It is based on light emitting diode (LED) technology and has the ability to sense the intensity of ambient light and adjust its lamp brightness accordingly, thereby consuming maximum power only when necessary. The STL incorporates some existing glare prevention innovations and consists of one lamp that has the ability to change colors.

1.1. Scope

This document provides design details of the STL prototype model and explains how the design conforms to the critical requirements stated in the *Functional Specification for the Smart Traffic Light*.

1.2. Intended Audience

This design specification is intended for the use of AnoLED Technology design team. The specifications detailed will serve as a guide for design engineers.

2. Lamp Circuit

There are several ways to illustrate symbols on LED displays, depending on the application, each method has its advantages and disadvantages. Two of the main factors are the cost of LED driver circuits and the output intensity of the display. We have selected the method of time domain multiplexing (TDM) to considerably reduce the number of LED driver circuits, and thus reduce cost.

The illuminated area of the STL should be able to illustrate several traffic symbols as follows:

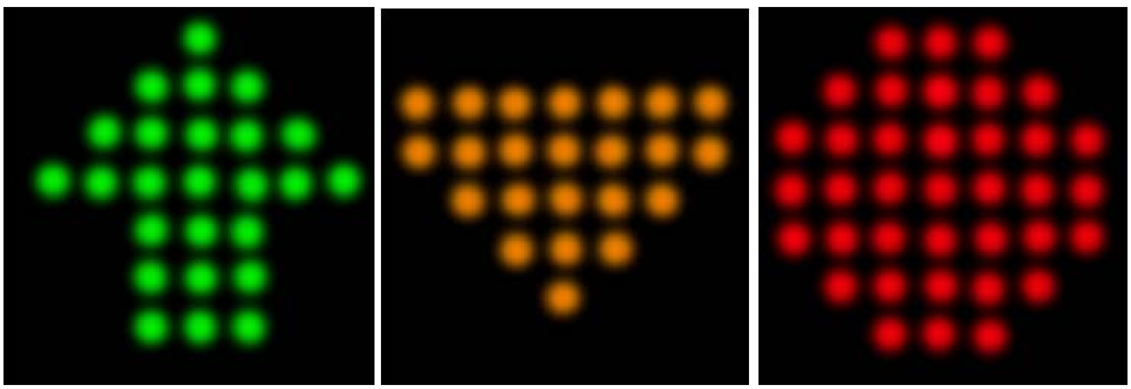

Figure 1: Traffic Symbols

Since these traffic symbols can be shown on low resolution displays, a 7×7 matrix of LEDs (49 total LEDs) is enough to accommodate all of the required symbols.

The matrix of LEDs should cover a surface area of 14”× 14”, as defined in the STL’s functional specifications. Consequently, adjacent LEDs should be separated by about 2” from each other, as illustrated in the following figure.

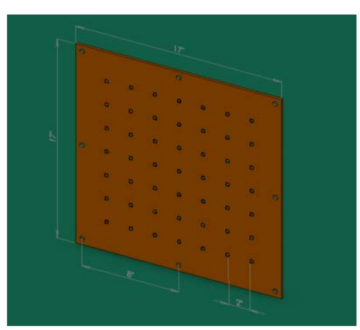

Figure 2: A View of the LED Board

3. Time domain multiplexing

The benefit of time domain multiplexing is that it reduces the number of highly efficient LED driver circuits needed, which would otherwise be equal to the number of required LEDs.

Instead of having a driver circuit for each LED, same color LEDs across a row could use the same driver circuit as their source of power, via common anodes. On the other hand, the cathode of same color LEDs along a column could be wire-ORed to be driven by a common column driver, which is active for a specific time segment.

Therefore, we require seven driver circuits for rows and seven driver circuits for columns. As each LED package has three different colors, the number of row and column driver circuits should be multiplied by three.

Each row driver circuit is initiated separately by its corresponding command from the microcontroller. At an instance of time, several rows may be simultaneously active while others are inactive. However, no two columns are active at the same time. In fact, time is divided between columns and allows only one column to be active in an instance of time. Therefore, the power consumption of system reduces by a factor of 7 by taking advantage of human visual system. Figure 3 illustrates the concept of time domain multiplexing.

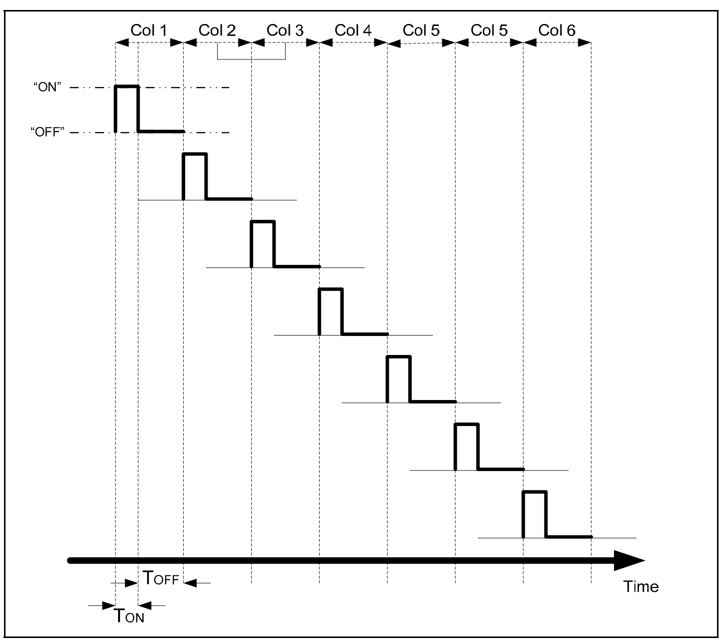

Figure 3: Time Domain Multiplexing

4. Block Diagram

Figure 4 below illustrates the block diagram of our design; a controller is responsible for analyzing the ambient light and fog sensors. Based on those inputs, the controller adjusts the intensity of the LEDs by adjusting the circuit properties to appropriate values.

RGB LEDs will enable us to mix the light produced by the LED, in order to create a variety of colors that can be utilized in displaying different images.

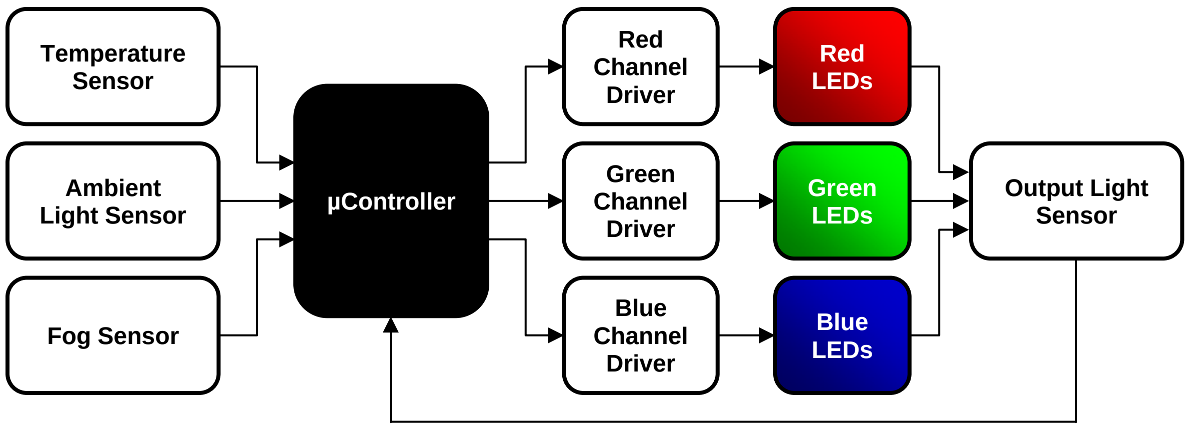

Figure 4: STL's Block Diagram

5. Circuit Diagram

5.1. Row Driver Circuit

Since the microcontroller is unable to provide the high current required by LEDs, an intermediate circuit should be used between each LED and microcontroller. If the LEDs were to consume lower than 100mA, we could simply have utilized buffers to overcome this problem. However, our LEDs need a typical current of 250mA to provide the required output light intensity. Buffers capable of providing such high currents do exist, but their price is a deterring factor ($7/chip – one buffer/per chip). Consequently, there is a need for low cost driver circuits which are able to provide a constant current of 250mA. The finalized driver circuit is shown in Figure 5 for the red color LEDs of the first row. The schematics of all other row circuits are similar to Figure 5.

Initially, we started with a switch that could toggle the LEDs on and off, according to the received command. An N-MOSFET was a good candidate for this purpose. The commands could be applied to the gate of the MOSFET while the LED was connected in series with the source lead. Unfortunately, this configuration did not provide control over the required 250mA as a result of V_{DD} variations. Therefore, we used a 1Ω current sensing resistor in series with the LED, R_{sense}, at the source of the MOSFET, and fed back the voltage sensed by the resistor to the negative input of op-amp, U1B. The sensed voltage is then compared against a reference voltage of 250mV. Thus, a negative feedback prevents excess current through LEDs by switching off the MOSFET, Q1, via op-amp, U1A.

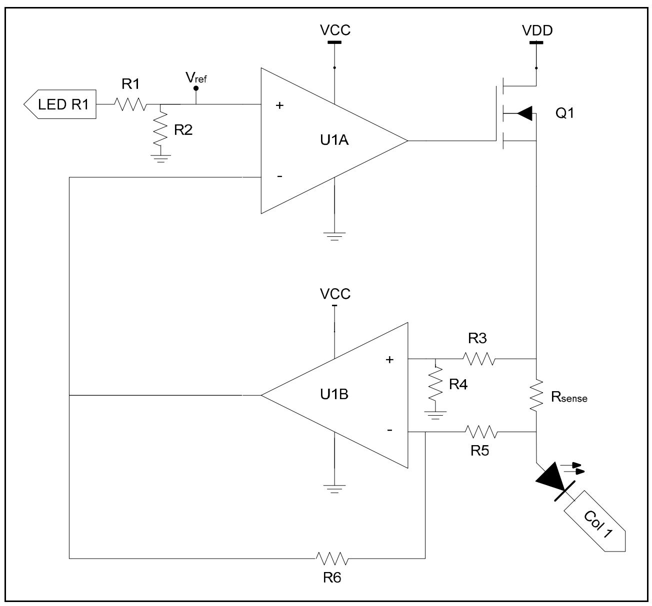

Figure 5: Row Driver Circuit Schematic

Since we are utilizing TDM, the cathode of LEDs along a column should be wire-ORed. Therefore, the sensing resistors will measure the accumulated current of all rows that sink through the corresponding column, instead of the required 250mA. The inefficiency of the initial circuit necessitated repositioning the sensing resistors in the circuit.

As Figure 5 shows, the sensing resistor is placed at the anode of the LED and current through it is measured by a difference amplifier with a unity gain. Therefore, if the output pin of U1B shows a voltage of 250mV, we are certain that current through the sensing resistor, 1Ω, and the LED, is 250mA. The difference voltage is then compared against V_{ref}, 250mV, and allows the U1A op-amp to control the operation of the MOSFET, Q1.

V_{ref} is an attenuated version of the microcontroller command through the buffer, received at LED-R1. The 250mV value of V_{ref} is set by the R_1 and R_2 voltage dividing network, as follows:

$$V_{ref} = \frac{R_2}{R_1 + R_2} V_{LED\ R1} \quad (1)$$

Assuming the value of $V_{LED\ R1}$ is 5V, forced by a buffer not shown in Figure 5, we should select a value for R_1 to be able to calculate R_2.

We set R_2 to be $1K\Omega$ so as not to introduce noise to the input of the opamp due to high value resistors, such as 1MΩ. Using Equation (1) and the above assumptions, we obtain

$$R_1 = 19K\Omega$$

To create a difference amplifier with a unity gain we should have

$$\frac{R_3}{R_5} = \frac{R_4}{R_6} \quad \text{and} \quad R_5 = R_6 \ [5]$$

Therefore, $R_3 = R_4 = R_5 = R_6 = R$. On the other hand, the input resistance of the difference amplifier is $2R$. A value of $10K\Omega$ is selected for R in order to satisfy a relatively high input impedance and prevent noise generated by high value resistors, as mentioned above.

For the STL production model, an instrumental amplifier could be used to provide an infinite input resistance. However, it will require two additional opamps, which will increase the cost of the driver circuits.

5.0.1. Determination of V_{DD} and V_{CC}

Since the MOSFET operates as a switch in the driver circuit, it should function in the triode region.

According to the datasheet of Q1 (BS 170), the typical value of its channel resistance is

$$R_{DS} = 1.2\Omega \text{ at } V_{GS} = 10\text{V and } I_D = 100\text{mA}$$

In the triode region, I_D of MOSFET can be found by

$$i_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_t)\, V_{DS} - \frac{1}{2} V_{DS}{}^2\right] \tag{2}$$

Assuming $V_{DS} \ll 2\,(V_{GS} - V_t)$, Equation (2) can be simplified as

$$i_D = \mu_n C_{ox} \frac{W}{L} V_{DS}\,, \tag{3}$$

and therefore,

$$R_{DS} = \frac{V_{DS}}{i_D} \tag{4}$$

We require i_D= 250mA and knowing R_{DS} =1.2Ω, we obtain

$$V_{DS} = 0.3\text{V}$$

By adding the voltages along the drain-source path and knowing V_{LED} = 3.5V, according to the datasheet

$$V_{DD} = V_{DS} + R_{sense} \times 250\text{mA} + V_{LED} \tag{5}$$

And therefore we obtain

$$V_{DD} = 4.05\text{V}$$

Returning to our assumption that $V_{DS} \ll 2\,(V_{GS} - V_t)$, we obtain $V_{GS} \gg 2.25$

Therefore, if we use a factor of 5 and use V_{GS} = 11.25V, V_{CC} must be 15V to allow V_G =15 V when U1A reaches the positive rail.

Column Driver Circuit

Figure 6 illustrates the complete schematic of the colomn driver circuits. Cathodes of the same colored LEDs are wire-ORed along columns. Since there are seven rows of LEDs, each column might sink a current of 0mA, when none of the rows are ON, to 7 × 250mA = 1.75A, in the case that all LEDs along a column are ON.

Thus, there is a need for a controllable switch that is capable of sinking approximately 2A. Power MOSFETs are good candidates for this purpose, as they do not draw current from the command signal due to their isolated gate structure.

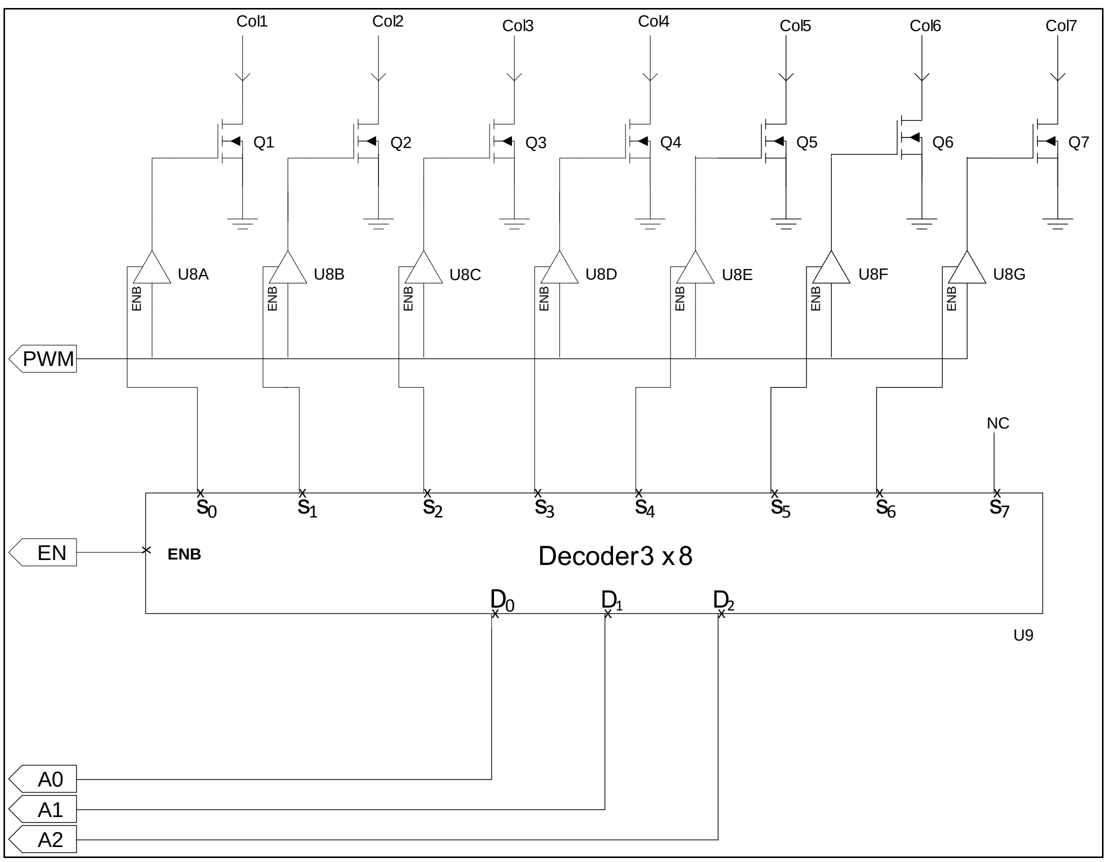

Figure 6: Column Driver Circuit

We have seven columns in the LED matrix. Though it might seem that seven MOSFETs should suffice to drive all columns, we require 21 MOSFETs, in order to isolate the sink current of R, G, and B columns.

To change the intensity of the output light, the MOSFETs should be driven by Pulse Width Modulation (PWM), the higher the duty cycle, the more intense the light output. Assuming positive values for the PWMs to actuate columns, we require N-MOSFETs whose V_{GS} are positive voltages.

Since no more than one column is ON at an instance of time, the PWM should be directed at the column which is selected to be switched ON. The 3 × 8 decoder switches between columns by activating their corresponding tri-state buffers, and is driven by three addressing signals from the microcontroller, A0-A2. The enable pin of the decoder is controlled by the microcontroller.

6. Component Selection

6.1. LED Choice

The factors considered during our LED selection are listed below:

- **Light intensity:** We required an LED that produces higher intensities than those used in existing LED traffic lights. This was necessary to increase the visibility of the STL during poor weather conditions.
- **Viewing angle:** In order to ensure equal visibility of the STL from normal viewing angles, we selected an LED with a wide viewing angle. The added benefit of selecting such an LED was that we no longer required a lens that disperses the light output.
- **Number of colors in an LED package:** A tri-color package that includes red, green and blue LEDs in a single unit was selected due to its higher reliability, reduced wiring, and elimination of diffusers to combine the light produced by primary LEDs.
- **No need for specialized heatsinks:** High power LEDs are usually mounted on a piece of metal or ceramic that require laminated PCB boards. LEDs of our choice dissipate heat via their terminals. Therefore, it is sufficient to make the PCB traces wide enough to absorb as much heat as possible.
- **Cost:** The price of the LED had to be compatible with our budget.

OVSPRGBCR4 is a full-color (R/G/B) power surface mount LED from TT Electronics, which we have selected as LEDs of our STL.

6.2. LED Layout

The LED board is a square piece of PCB with dimensions of 17", there is a distance of 5cm between LED centers. There are seven rows and seven columns of LEDs, thus, 49 LEDs in total are placed in a matrix. There are eight holes in the periphery of the board which correspond to those of the enclosure, and this enables the mounting of the board onto the enclosure. Figure below shows the front view of the LED board. At the back of the board, there are 14 connectors, seven of which send signals to the rows of the board and the remaining seven return current back through the columns.

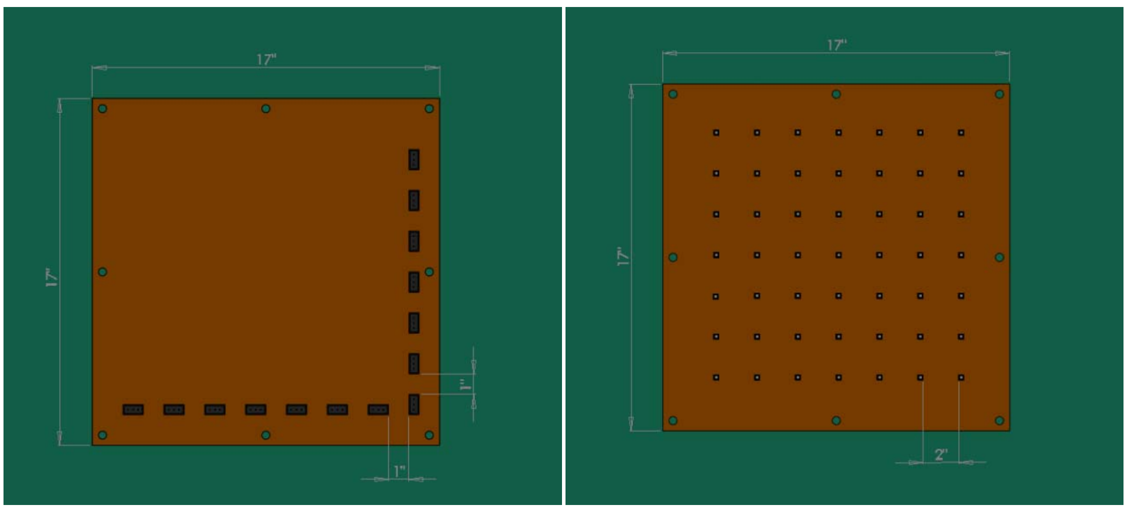

Figure 7: Back and Front View of LED Board

6.3. LED Board Circuit

Illustrated in the following figure, each LED package includes three R, G, and B LEDs. The anodes of similarly colored LEDs are connected across each row and their cathodes are connected along each column. Signals are transferred to the LED matrix via their corresponding JP connectors.

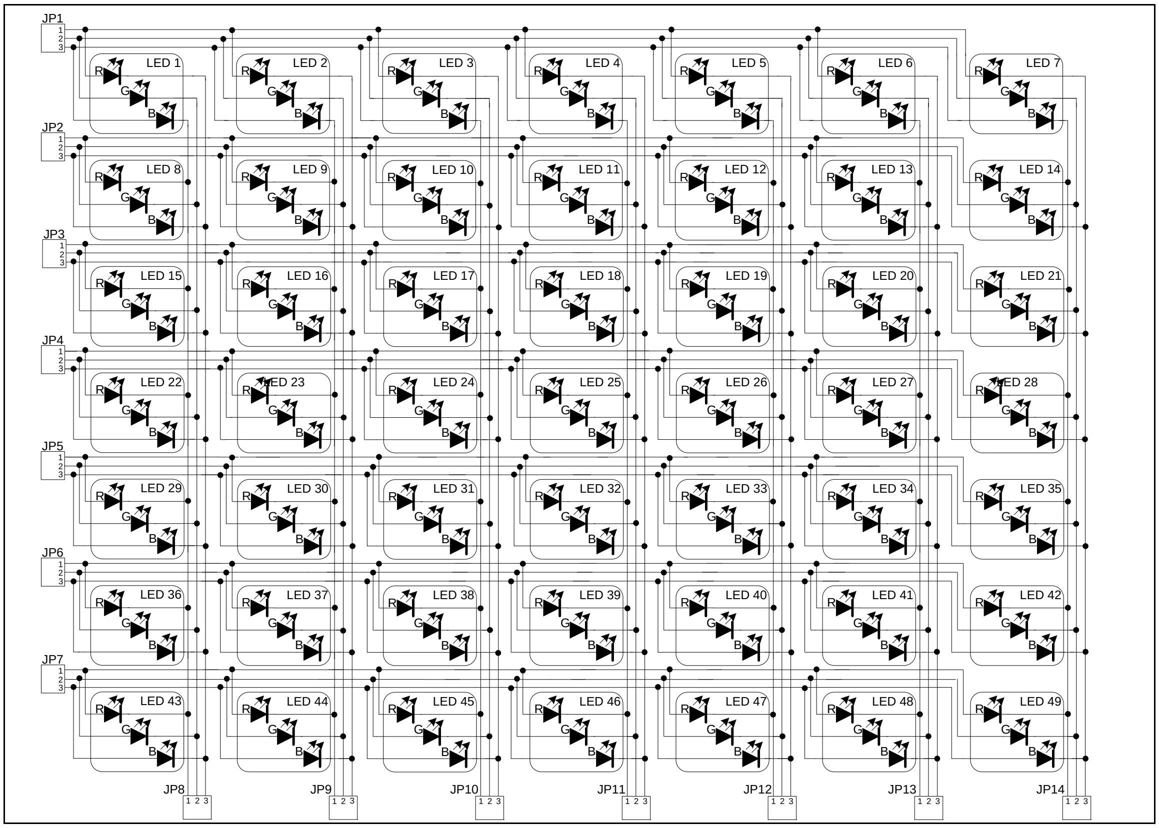

Figure 8: LED Board Circuit

6.4. Microcontroller

Figure 7 illustrates the pin configuration of the selected microcontroller. The three buffers, U1, U2, and U3 isolate the data commands of the microcontroller from the driver circuits. Therefore, in the case of any over drawn current by the driver circuits, the microcontroller is isolated.

An oscillator at pins XTAL1 and XTAL2 provides a frequency of 25 MHz, according to Table 6 of the datasheet.

Received signal from traffic light controller, namely R, A, and G are present at pins R-Sig, A-Sig, and G-Sig, respectively. Activation of any of these signals generates an interrupt to the microcontroller and will result in running its corresponding interrupt handler.

Signals SR, SG, SB, FS, and AS are continuously monitored by the microcontroller.

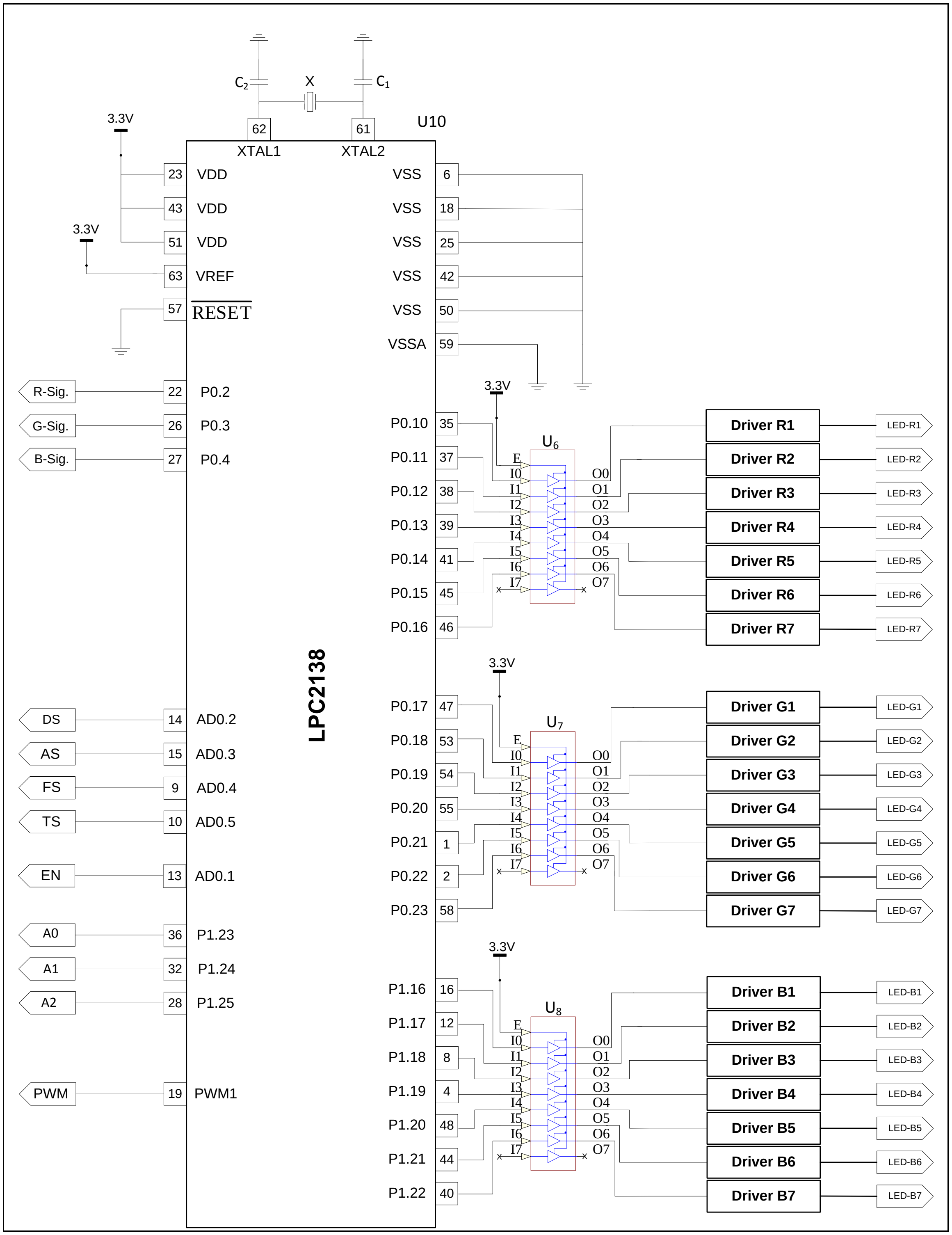

Figure 9: Microcontroller Pin Configuration

There are two methods to switch between the columns for the purpose of TDM. First, PWM1 is generated at the desired frequency and duty cycle as specified in the firmware. The desired column will then be activated using A2, A1 and A0 address pins. This method requires a technique to keep track of switching between columns at certain times.

The second and easier method is through the use of interrupts. Instead of using pins 28, 32, 36 to activate the outputs of the decoder, we can also use the internal timer of the microcontroller. In that case, the timer or the PWM can generate an interrupt to the microcontroller to update the RGB ports.

7. Power Consumption

The LED matrix of STL consumes most of the power supplied to the device. However, the average power consumption of STL is lower than regular traffic lights. The power consumed by each LED was calculated and measured experimentally. The theoretical maximum power rating of each LED and the LED display are summarized in Table 1. All these calculations are based on the characteristics provided by the manufacturer.

Table 1: Power Consumption Values

	Each LED	Display of 49 LEDs
Red	575 mW	28.17 W
Green	875 mW	42.87 W
Blue	875 mW	42.87 W

8. Power Supply

Although we require a minimum power of 114 Watts for our LED display, based on the data of Table 1, in the worst case that all colors are on at their maximum intensity, we are considering a power supply capable of producing a minimum of 150 Watts, considering the power consumption of the rest of the components.

There are several different power supplies on the market with excellent qualities which easily meet and even exceed our needs for a reasonable price. For our project, we are using a generic 152W ATX computer PSU (power supply unit), which can provide us with accurate 3.3V (12 A), ±5V (18A and 0.3A respectively), and ±12V (3A and 0.3A respectively) rail voltages.

9. Temperature Range of Operation

To ensure that overheating does not damage the STL during operation, a temperature sensing circuit is included in the device. When the temperature of the STL exceeds 85°, the temperature sensing circuit alerts the microcontroller, which then ensures that the STL is operating in its power efficient mode.

Using a thermistor as a voltage divider at the input of a voltage follower will provide us with the required circuit. RT has a value of 100Ω at 0°C. Therefore, we selected R7 to be 100KΩ to be much greater than RT to provide us with a linear relationship, according to the voltage divider equation.

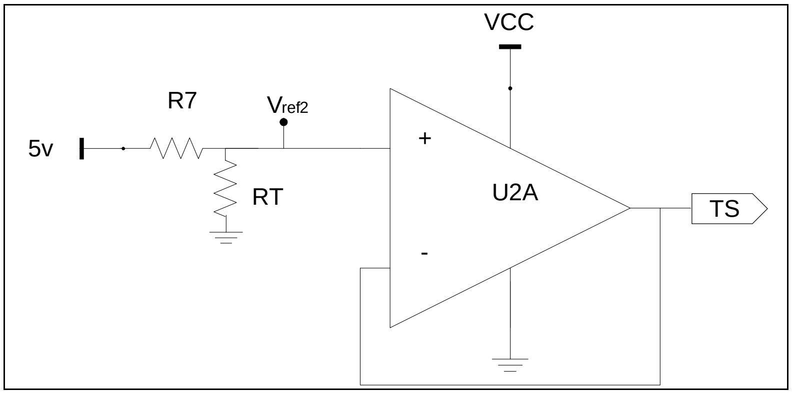

Figure 10: Temperature Sensing Circuit

10. Light Output

Each LED package is a combination of three colors, namely, red, green and blue. Therefore, primary colors can be combined within a minute surface area in cases where secondary colors such as yellow or white are required, without the use of diffusers. The maximum intensity output of each LED color is summarized in Table 2. The viewing angle of each LED is 130°, thus an additional lens which scatter narrow beams is not required. When the system enters power efficient mode, the output light intensity reduces to two lumens for green, one lumen for red, and 0.33 lumens for blue. This calculation was extrapolated from the electro-optical characteristic curve of the LED datasheet which is illustrated in the Appendix. For easier calculations, we assumed the curves were linear.

Table 2: LED Intensity Specifications

Emitter Color	Luminous Flux (lm)	On-Axis Intensity (cd)
Red	21	7
Green	32	11
Blue	7.5	2.8

11. Housing

As illustrated in Figure 11, the housing is comprised of three modules, namely, enclosure, body and visor. The dimensions of the housing unit are shown in Figure 12.

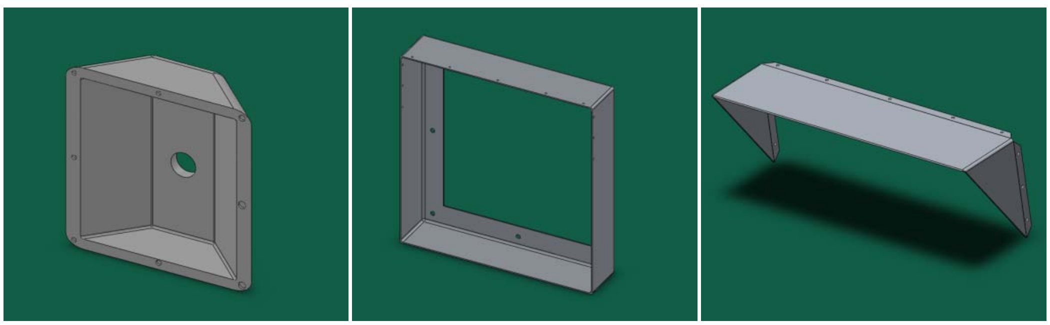

Figure 11: Enclosure Parts

The material used for the housing is UV-stabilized polycarbonate plastic; it was selected due to its stability over a wide range of temperatures, durability, ease of manufacture, and relatively low cost.

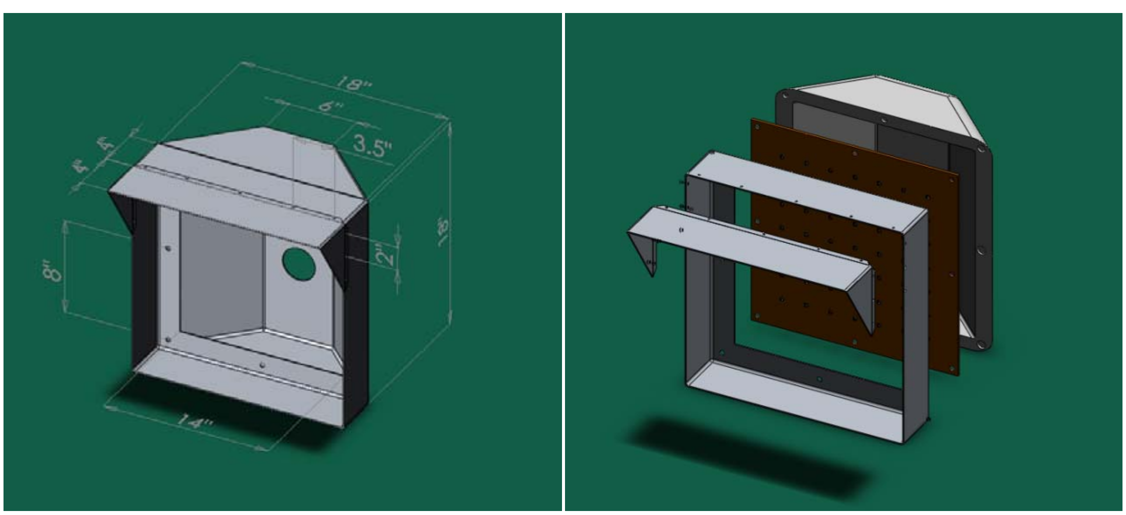

Figure 12: Enclosure Assembly

12. Safety Features

- Device enclosure is made of PVC and therefore it is a protection against electric shock hazard.
- Ambient sensor is also responsible for the internal temperature of the device and thus protects it from overheating.

13. Light sensors

The ambient light and output light sensors are similar components which generate current at their outputs corresponding to the intensity of light absorbed by them. Since A/Ds of the microcontroller measure voltage, the output current of light sensors should be converted to voltage as shown in Figure 13. In the case of the display output light sensor, AS is replaced with DS, R8 with R9, and U3 with U4.

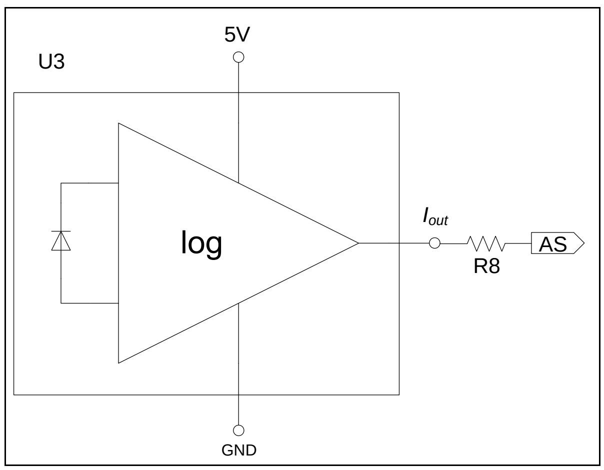

Figure 13: Light Intensity Sensor

14. Fog Detection System

Several fog detection systems have been developed and utilized in automobile industry, aviation, etc.

One method uses signal processing techniques to compare two captured pictures of a scene. Some other methods utilize moisture sensors. Simplicity of the selected technique is beneficial to our design, and we are still researching potential methods of implementing a fog detection system.

One simple method that we have proposed is the use of an ambient light sensor to measure the amount of reflected light of our device by fog; therefore, the proposed circuit is similar to that of Figure 13; however, AS is replaced with FS, R8 with R10, and U3 with U5.

15. Firmware

The algorithm for the smart detection feature of the STL is illustrated in Figure 14. The intensity of the STL is controlled by the duty cycle of the pulse input to the LED circuitry (PWM). The intensity of the STL is varied between a specified minimum and maximum threshold, its value is based on the sensor inputs.

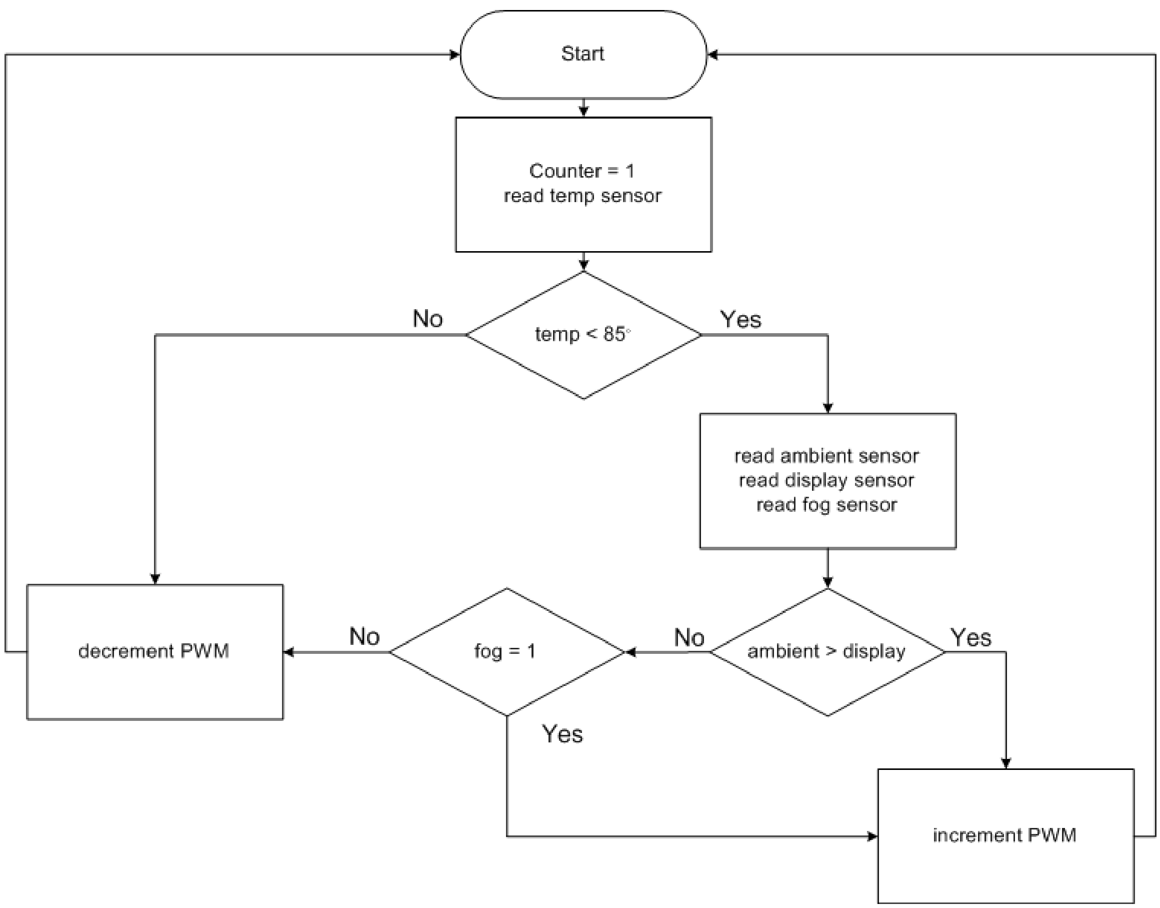

Figure 14: Intensity Flowchart

The algorithm for the STL display is illustrated in Figure 15. The traffic control signals are processed as interrupts which contain the memory address corresponding to the desired display image. A counter and a decoder are used to select which column driver is activated at a given instance, the counter is reset to 1 after counting up to 7. Upon reception of a new interrupt, the process is repeated with the new display image.

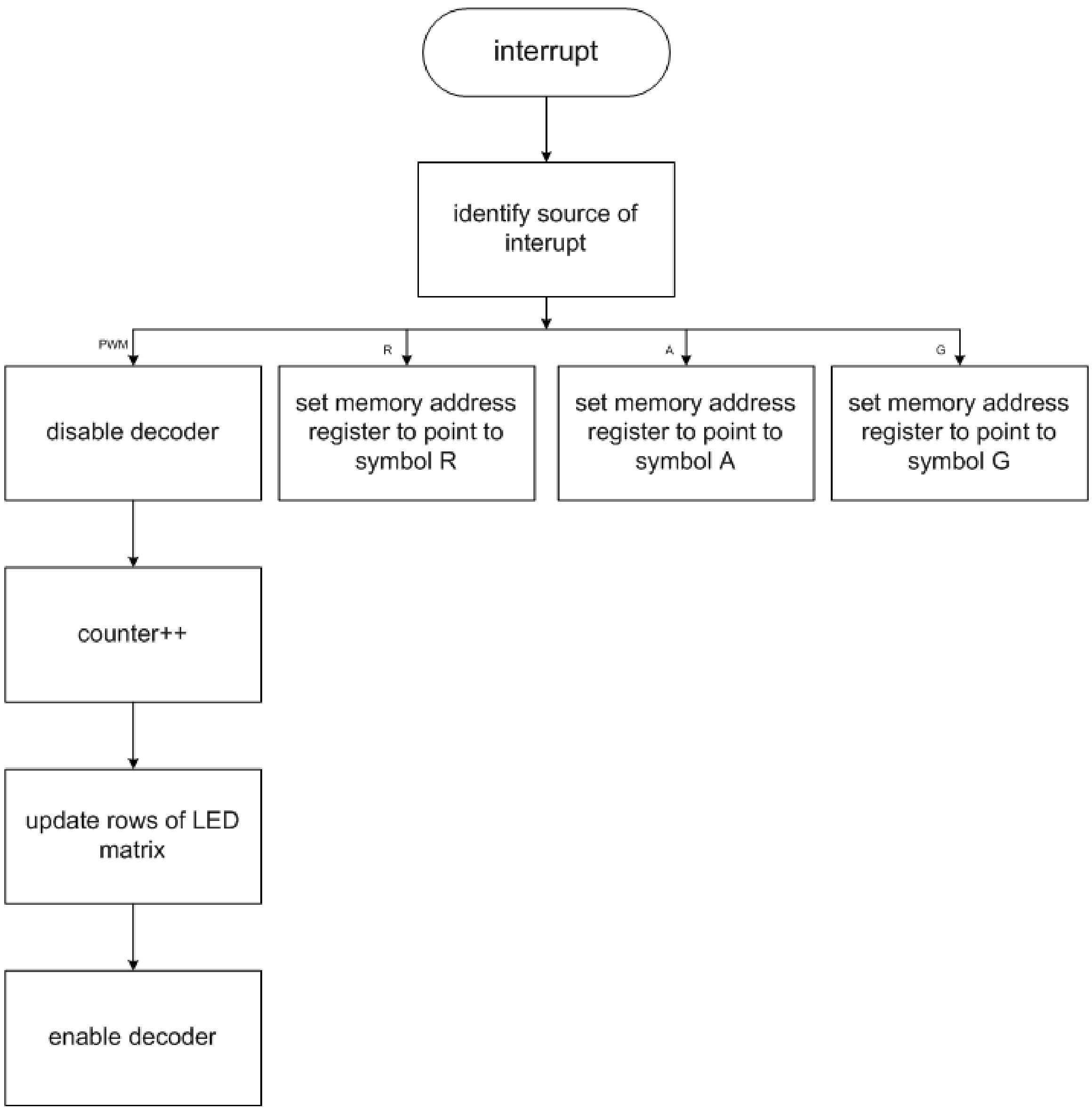

Figure 15: Display Flowchart

16. References

[1] Webster's Online Dictionary, Nov. 2007, http://www.websters-online-dictionary.org.

[2] MSN Encarta, Nov. 2007, http://encarta.msn.com/encnet/features/dictionary/dictionaryhome.aspx.

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[6] TT Electronics, "Full-color Power SMD 6mm," July 2007, http://www.optekinc.com/pdf/OVSPRGBCR4.pdf.

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Appendix

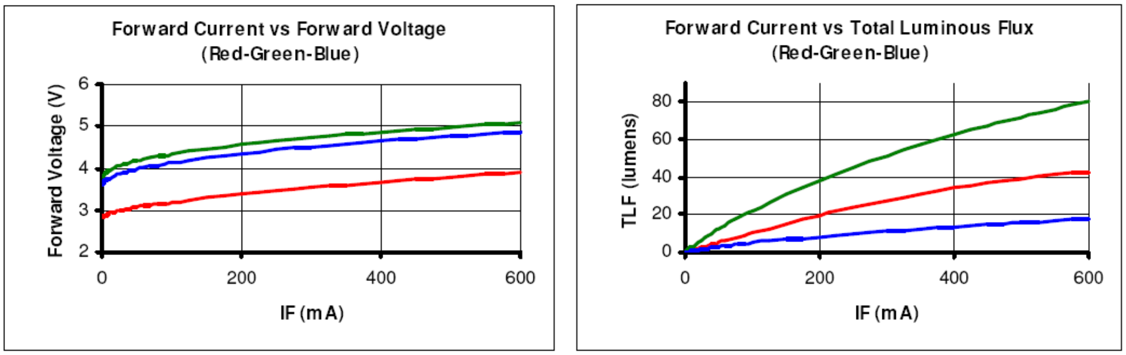

Figure 16: Typical Characteristics of the OVSPRGBCR4 LED [6]

Table 6: Recommended values for $C_{X1/X2}$ in oscillation mode (crystal and external components parameters)

Fundamental oscillation frequency F_C	Crystal load capacitance C_L	Maximum crystal series resistance R_S	External load capacitors C_{X1}, C_{X2}
1 MHz - 5 MHz	10 pF	NA	NA
	20 pF	NA	NA
	30 pF	< 300 Ω	58 pF, 58 pF
5 MHz - 10 MHz	10 pF	< 300 Ω	18 pF, 18 pF
	20 pF	< 300 Ω	38 pF, 38 pF
	30 pF	< 300 Ω	58 pF, 58 pF
10 MHz - 15 MHz	10 pF	< 300 Ω	18 pF, 18 pF
	20 pF	< 220 Ω	38 pF, 38 pF
	30 pF	< 140 Ω	58 pF, 58 pF
15 MHz - 20 MHz	10 pF	< 220 Ω	18 pF, 18 pF
	20 pF	< 140 Ω	38 pF, 38 pF
	30 pF	< 80 Ω	58 pF, 58 pF
20 MHz - 25 MHz	10 pF	< 160 Ω	18 pF, 18 pF
	20 pF	< 90 Ω	38 pF, 38 pF
	30 pF	< 50 Ω	58 pF, 58 pF
25 MHz - 30 MHz	10 pF	< 130 Ω	18 pF, 18 pF
	20 pF	< 50 Ω	38 pF, 38 pF
	30 pF	NA	NA

Table 3: Bill of Materials

Description	Mfg. Part Number	Quantity
Microcontroller	LPC2138/01	1
Op-Amp	LM734	22
Thermistor	PTS0603	1
Ambient Light Sensor	SFH5711	3
Current Sensing Resistor	FPR 2-T218	21
Tristate Buffer	SN74LVC827A	3
LineDriver	74LCX541	3
Decoder 3×8	74HC138	1
RGB LED	OVSPRGBCR4	49
Resistor 1Ω	Generic	21
Resistor 1KΩ	Generic	21
Resistor 10KΩ	Generic	44
Resistor 18KΩ *	Generic	21
Resistor 100KΩ	Generic	1
Resistor 1MΩ	Generic	3
N-Channel MOSFET	BS170	21
N-Channel Power MOSFET	FDD8750	21
Piezoelectric Crystal 30MHz	ABM3-B2-T	1
Capacitor 38pF	Generic	2
Pin Headers 1×3	Generic	14

*Instead of the nominal 19K.