February 17, 2012

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specification for a Smart Dimmer

Dear Dr. Rawicz,

Enclosed is our Design Specification for a Smart Dimmer, which provides technical details on the dimmer's design. The Smart Dimmer is a semi-automatic dimmer switch which reduces the problem of over-illumination of public or private spaces by compensating for changing ambient light.

This document describes the proof-of-concept design of the Smart Dimmer. However, we expect a very seamless transition from this design to the final product. Plans for the design of the final product will be discussed. Furthermore, the document discusses important choices we have made such as the usage and choice of the microcontroller, the implementation of the dimmer, the sensor setup, as well as the user interface.

Questions or concerns regarding the functional specifications may be addressed to me by email at jka37@sfu.ca or by phone at 604-291-1721.

Sincerely,

J. Kehler

Jonathan Kehler
Project Director
Smart Light Solutions

*Enclosure: Design Specification for the Smart Dimmer*

Smart Light
Solutions

# Design Specification

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***Issued Date:***

February 17, 2012

***Revision:***

1.0

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# 1 EXECUTIVE SUMMARY

This design specification outlines the technical details of the proof-of-concept prototype of our Smart Dimmer. The document discusses the design choices made in each component of our system as well as provides justification for the choices. In order to justify the designs, some sections also provide knowledge of theoretical background as well as existing solutions. Each section also discusses future plans needed to upgrade the system to a commercialized product.

The first section discusses the system overview. This section introduces the four subunits of the system: the control unit, the dimmer unit, the user interface, and the sensing unit. The block diagram and the expected functionality of each unit is introduced. The full circuit diagram of the system is also shown. The four subunits are discussed thoroughly in the following sections.

The first subunit to be discussed is the user interface. Here, it is emphasized that the user interface consists of two push buttons which send increment and decrement requests to the control unit. The measures of preventing power surge are also discussed.

The second subunit is the sensor unit. This section introduces the sensor used, the OPT101, which provides an excellent linear relationship with the light intensity up to 100k lux. The relationship between the voltage output of the OPT101 and the lux is also shown.

The dimmer unit, which dims a lamp by receiving a timed signal, is discussed next. The section introduces the concept of the TRIAC, a semiconductor device whose conduction is determined by the signal to its gate. This allows us to implement the logically controlled power-switching dimmer, whose power-saving capability is also discussed.

Lastly, the document discusses the control unit. This unit represents the central intelligence of our system. Upon receiving both user and external inputs, the control unit internally calculates the best dimming level. The algorithms for doing this as well as ensuring maximum power savings are discussed in this section.

Because it is a proof-of-concept design, this design satisfies all requirements mentioned in the functional specification *except* for [R16-1], [R13-3], and [R29-3]. These requirements are trivial and can be easily addressed in the final product. The completion date proposed in the functional specification, April 15, 2012, remains realistic [1].

## 2 GLOSSARY TERMS

AC Mains: In Canada, this is 120 V, 60 Hz alternate-current (AC) voltage source from the wall plugs

Analog-to-Digital Converter (ADC): a module used to convert analog input (voltage level) to a digital representation

Gate: in reference to electrically controlled switches, the “gate” usually refers to the terminal which is used to control (open or close) the switch

GND: Ground

GPIO: General Purpose Input/Output

Illuminance: measured in lux, light intensity per unit area, assuming human eye response (lux only has meaning in the white light region)

Intensity: spectrally neutral version of illuminance, measured in W/m^2

Interrupt (computing): a type of input requesting the processor to stop its current process and service the interrupt

ISR (interrupt service routine): a routine which is to be executed when an interrupt is received

Load: an external device which draws power from the circuit

Microcontroller Unit (MCU): a digital processor unit used to control the system

Opto-electronic: having both optical and electrical components

Photodiode: a semiconductor device which converts light to current

Plant (feedback systems): the unit which is being controlled (in our case, a dimmer)

RC circuit: circuit consisting of one or more resistors and capacitors

Responsivity: how sensitive the sensor is to light, measured in A/W

Rising/Falling Edge: the increasing and decreasing edges of a logic pulse, usually used for triggering

Spectral Response (optics): the relationship between a sensor’s responsivity and the wavelength of the light

Thyristor: a class of three-terminal semiconductor device which acts as a controllable switch

Transimpedance: current-to-voltage conversion factor

TRIAC: TRIode for Alternative Current, a type of thyristor commonly used in dimmer switches

Trigger: the act of acknowledgeing the rising edge, falling edge (edge-triggering), or a specific level (level-triggering) of some signal

Vcc: common denotation for supply DC voltage

# 3 INTRODUCTION

Designed to solve the problem of over illuminating public and private spaces, the Smart Dimmer is a semi-automatic dimmer switch which is aware of the brightness of the surroundings. Remembering the user-defined level of brightness, the Smart Dimmer will continually control the level of artificial light to compensate for varying ambient light throughout the day. In order to illustrate this, consider the usage of the Smart Dimmer in the early morning. Suppose that the user has set the brightness to the desired level and has left the room before sunrise. In this scenario, when the sun slowly rises and slightly illuminates the room, the Smart Dimmer will dim the light accordingly, but without reducing the overall brightness the sensor sees. In other words, electrical energy used to power the lamps can be saved by trading with the extremely abundant light energy directly from the sun.

## *3.1 Scope*

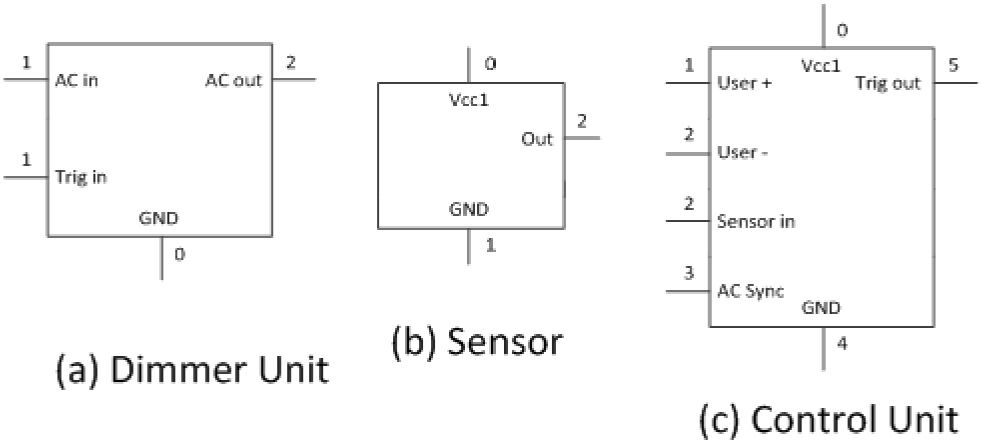
This design documentation presents a proof-of-concept prototype which may not, in part, represent the design of the final product. The prospective final product is a wall-mounted dimmer switch with a small sensor area and a simple user interface. The proof-of-concept design is a plug-in version of the same device and is connected to an external load.

## *3.2 Intended Audience*

This document is intended for compliance inspectors and employees of Smart Light Solutions Inc. The document is technical in nature, assuming some knowledge of simple electrical circuits, home hardware, semiconductor devices, and microcontrollers. While each section is explained thoroughly and with minimum technical jargon, important technical details are emphasized in tables and figures.

# 4 SYSTEM SPECIFICATIONS

The Smart Dimmer is an opto-electronic system whose function is to control the dimming of an artificial light source while adapting to dynamic ambient light. It consists of 3 main subunits: the dimmer unit, the sensor unit, and the control unit. It also contains 2 minor subunits, the user interface and the power unit. The dimmer unit, shown in Figure 4.1 (a) very closely resembles the conventional dimmer switch, but it has been modified to receive a logical control signal rather than having a mechanical control. This unit modifies the AC signal by chopping off parts of its wave-form using a microncontroller-driven TRIAC. This will be described in greater detail in Section 7.



(a) Dimmer Unit

(b) Sensor

(c) Control Unit

**Figure 4.1: Block diagrams of the (a) Dimmer Unit (b) Sensor and (c) Control Unit.**

The sensing unit, shown in Figure 4.1 (b), converts light intensity to a voltage that is understandable by the control unit. Lastly, the control unit shown in Figure 4.1 (c) represents the intelligence of our system. Being aware of both the user's desired level of brightness and the actual surrounding brightness, this unit possesses memory and computational capabilities used to maximize user's comfort and power saving. The three subunits are connected as shown in Figure 4.2.

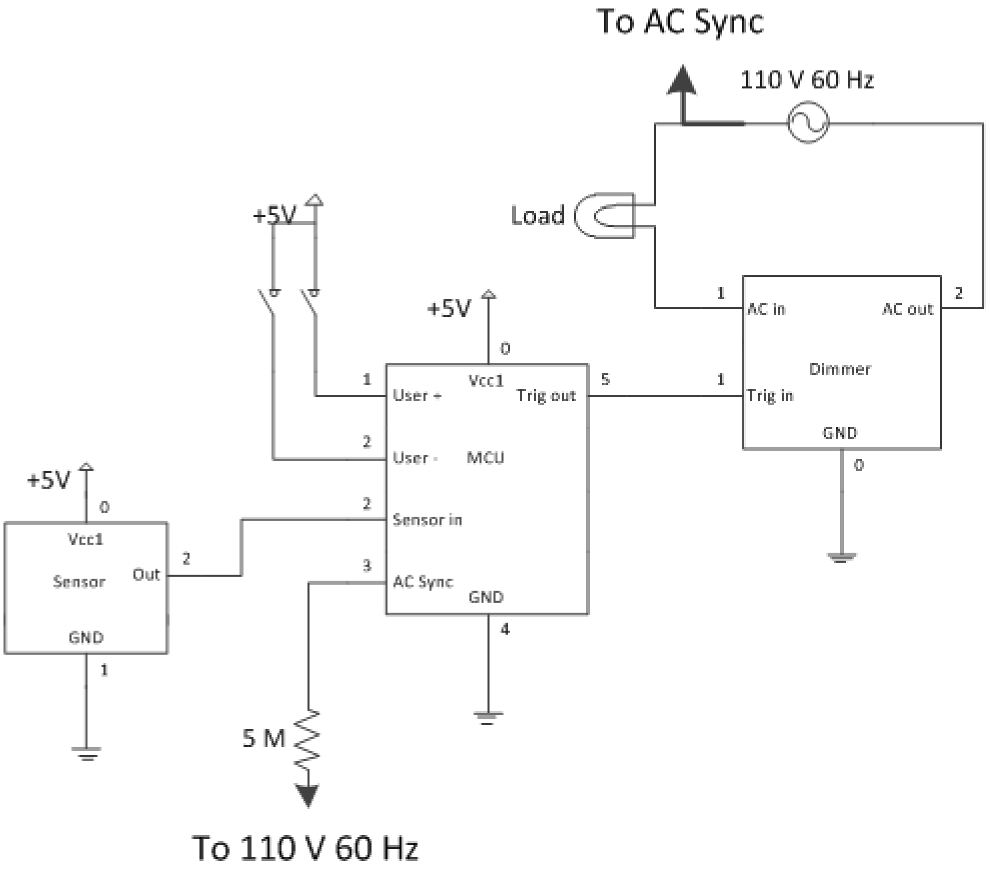


Figure 4.2: Complete Circuit diagram of our Smart Dimmer.

# 5 USER INTERFACE

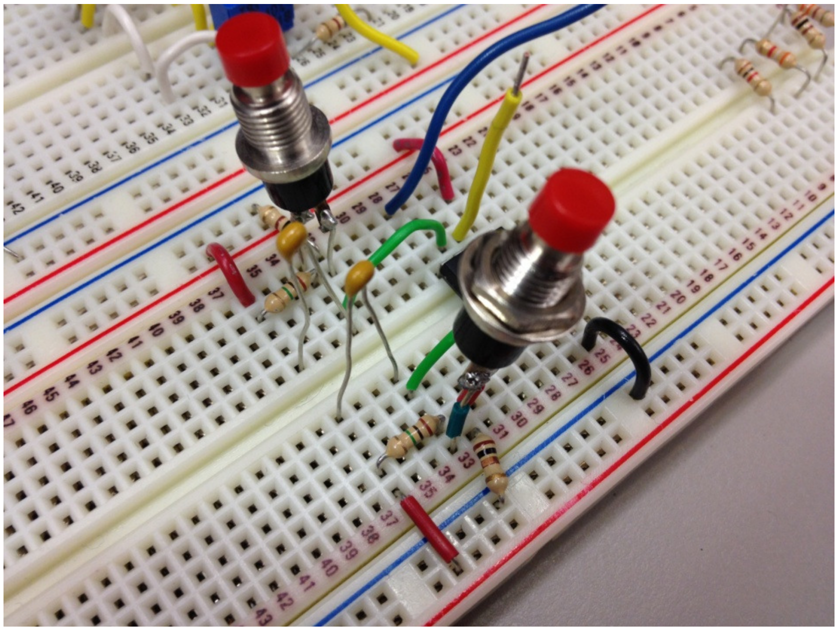


**Figure 5.1: The push buttons used to send increment- and decrement- request to the control unit.**

The user interface of the proof-of-concept prototype consists of two push buttons used for incrementing and decrementing the amount of dimming (Figure 5.1) [R17-3] [1]. In this design, the enclosure of the user interface is a metallic box which conceals all circuitry but the buttons [R03-3] [1]. The box contains an open slot in order to expose the photodiode to the environment. As shown in Figure 5.2, the push buttons go through a simple RC circuit before interfacing with the microcontroller pins. The circuit delivers a digital 'low' (0V DC) to the microcontroller pin when the button is depressed and a 'high' (5V DC) otherwise. The RC component prevents an instantaneous change in voltage to avoid causing damage to inductive components in the circuit. With $R = 1M\Omega$ and $C = 96\ pF$, the circuit spreads the instantaneous change over $RC = 0.1\ ms$ instead.

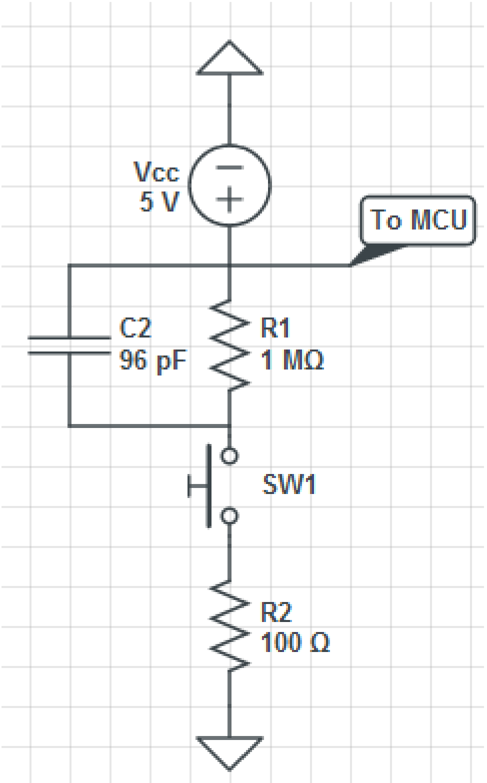


**Figure 5.2: Circuit connection of the pushbutton to the RC circuit.**

The schematic diagram of the push-button circuit is shown in Figure 5.2. The supply voltage, Vcc, in this circuit is provided by a separate power unit, which converts 120VAC to 5VDC using a rectifier.

## 5.1 Future Plans

In the final product, the user interface will have the same appearance as conventional dimmer switches as shown in Figure 5.3, except with a small area exposing the sensor to the environment. The interface will be wall-mounted.

**Figure 5.3: Possible design of the user interface in the final product. The rocker switch covers the push buttons.**

# 6 LIGHT SENSOR

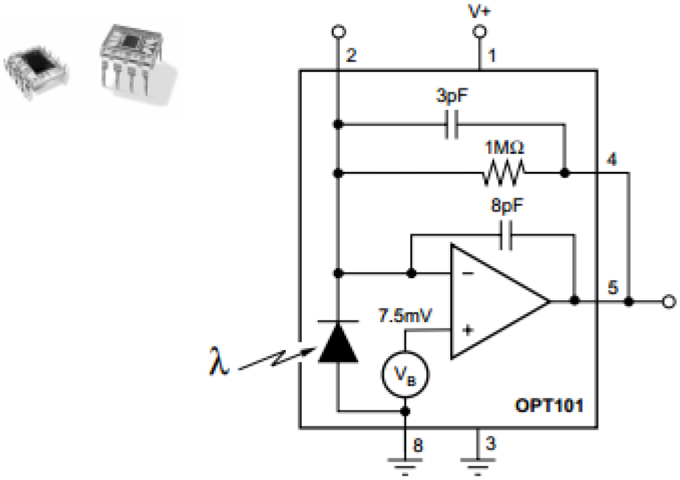


Figure 6.1: (Top Left) Image of the OPT101 and (Right) its inner circuit diagram [2]

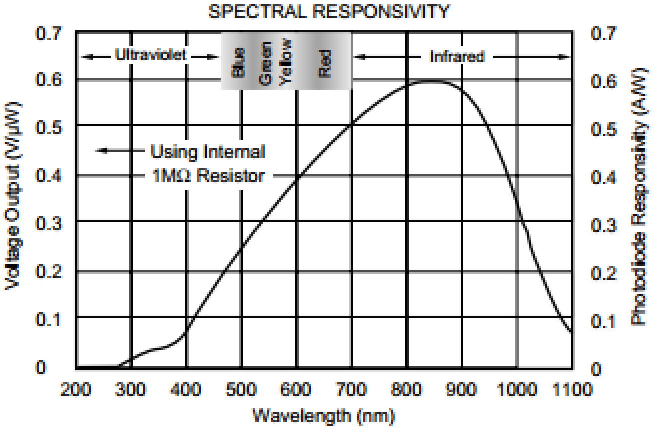


Figure 6.2: Spectral response of the OPT101 [2]

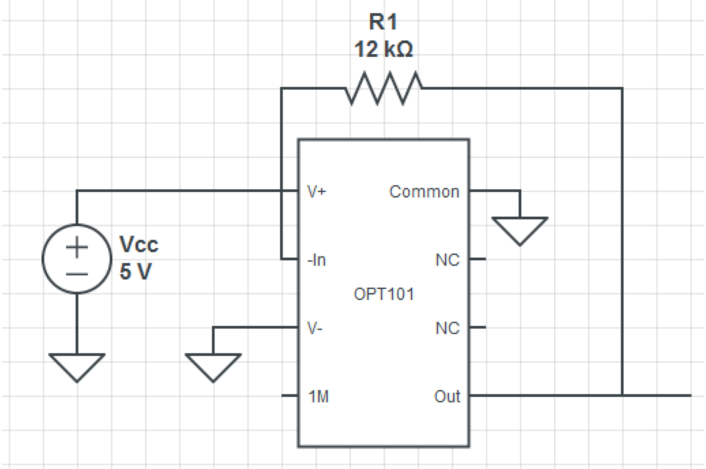


**Figure 6.3: Circuit enabling the OPT's responsivity control by changing the external resistor.**

The light sensor is the Texas Instrument OPT101 (see Figure 6.1), with an external feedback resistor. The OPT is a light-to-voltage sensor which consists of a photodiode and a transimpedance amplifier [2]. The spectral response of the OPT is shown in Figure 6.2, with a large spectral width extending from deep blue to infrared. The output voltage of this sensor is (except for the boundaries) proportional to the light intensity ($W/m^2$) which, in the visible region, is proportional to illuminance (lux) [2].

The proportionality has been experimentally tested and calibrated by a digital light meter. The circuit used to calibrate this sensor is found in Figure 6.3. As shown, the circuit is connected to an external resistor, $R_{ext}$, which dictates the gain of the amplifier. The result of this calibration is found in Figure 6.4. This allows us to obtain an equation relating the light intensity to the voltage output.

$$V_{out} = 6.67 \frac{nA}{lux} R_{ext} E$$

where E is the illuminance of the light in lux, and $R_{ext}$ is the external resistance value which scales the gain of the circuit linearly. In our case, 12 $k\Omega$ resistor was used, resulting in the slope shown in Figure 6.4.

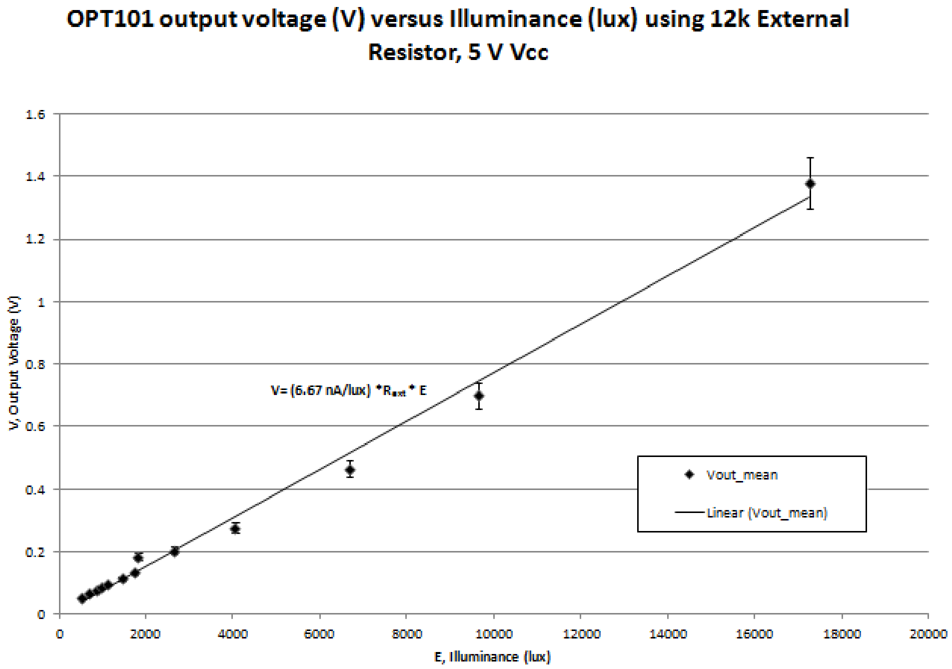


**Figure 6.4: Result of experimentally comparing the voltage output of the OPT101 to the brightness of the area (measured in lux).**

## 7 DIMMER UNIT

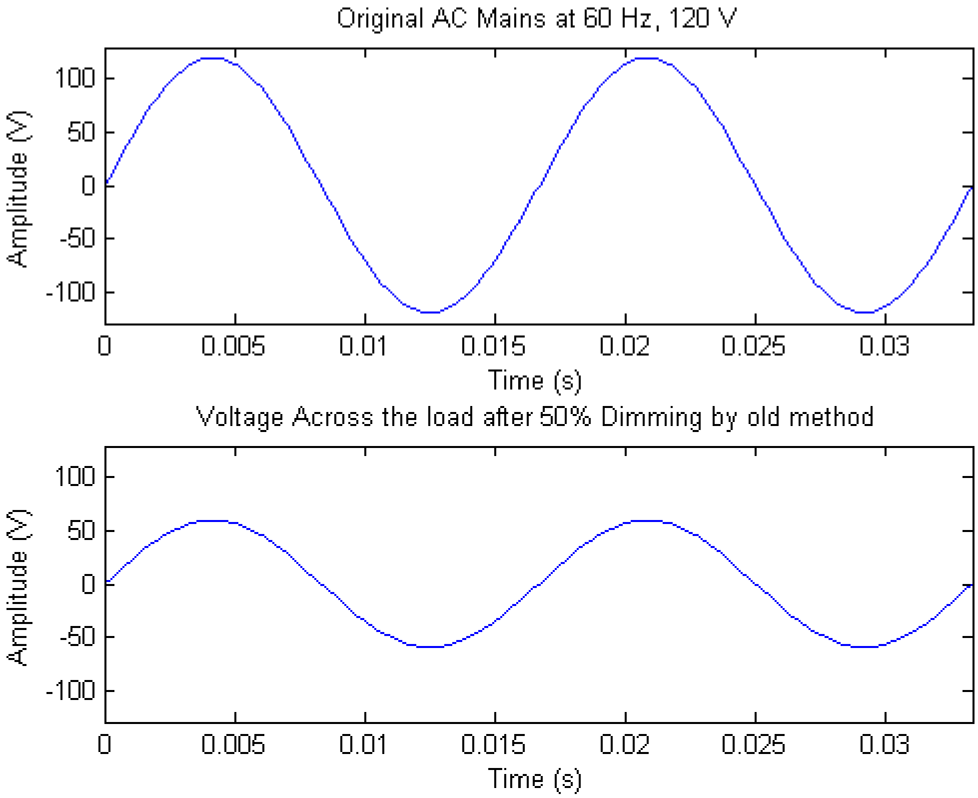
Dimmer unit is an analog circuit that is used directly to control the dimming of lamps. It is connected in series with the lamp to the AC main power supply. It takes a control signal from the control unit as input which is used to dim the light accordingly.

### 7.1 Theoretical Overview of the Thyristor Dimmer

The dimmer used in this prototype will implement the *power-switching*, or *thyristor* dimmer. Before discussing this type of dimmer, we first discuss why the old dimming method is not a good design choice.

### 7.1.1 Old Dimming Method

Before the thyristor dimmer was implemented, dimmer switches dim the light by simply reducing the current going through the load by putting a variable resistor in series with the load (resulting in attenuation as shown in Figure 7.1). This method, however, does not save energy at all. In doing this, the light energy lost from the lamp is equally dissipated as heat by the resistor. The next section discusses the thyristor dimmer, the solution to this problem.


Original AC Mains at 60 Hz, 120 V

Voltage Across the load after 50% Dimming by old method

**Figure 7.1: Old dimming method by amplitude attenuation. The bottom plot represents half-amplitude dimming.**

### 7.1.2 Thyristor Dimming (Power Switching) Method

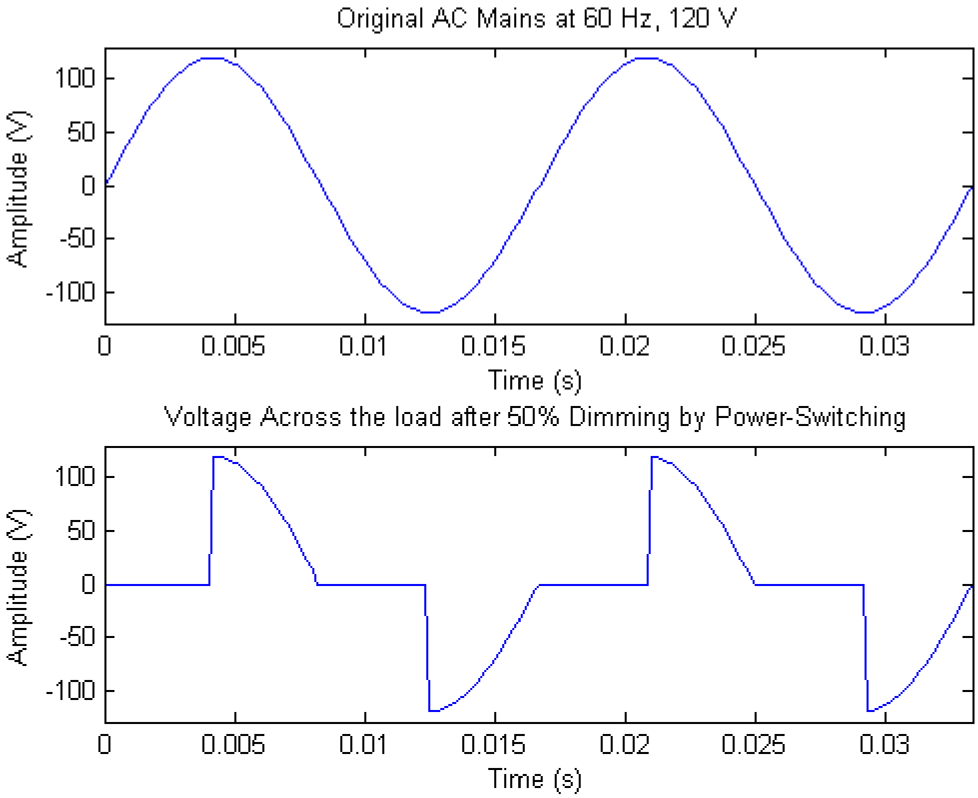


**Figure 7.2: New dimming method by power switching. The bottom plot represents half-wave dimming.**

The thyristor dimmer dims the light by periodically turning off the power by using a semiconductor device known as the TRIAC (TRIode for Alternate Current). Contrary to the traditional method, this dimmer actually saves energy, as current flow is stopped periodically, effectively cutting power consumption. This method results in the wave form shown in Figure 7.2. As shown the sinusoidal wave appears to be “chopped off’ representing the time during which no current flows. The more the wave is cut, the more the lamp appears dim. Since one of the main goals of our product is to save energy, it is imperative that our dimmer employs the power-switching method.

## 7.2 TRIAC

The TRIAC is a three terminal semiconductor device. The three terminals are MT1, MT2, and Gate. The two main terminals, called MT1 and MT2, sometimes also referred as A1 and A2, (shown in figure 1) are connected to the AC Mains, while the gate is connected to some control signal. The TRIAC’s conduction is said to be controlled by the *timing* of the gate signal [3]. This will be explained in the following section.

### 7.2.1 Timing of Gate Signal versus TRIAC Conduction

In order to illustrate the effect of the gate signal, consider this simple scenario. Without any current in the gate, the TRIAC acts like an open switch. If, however, a small pulse of current is sent to the gate, the TRIAC will conduct *until the AC Mains makes the next zero crossing* [3]. This concept is illustrated by simulation in Figure 7.3, Figure 7.4, and Figure 7.5. In Figure 7.3, the gate is pulsed at 1 ms after the AC signal starts, we can see that the TRIAC is open until 1 ms after the AC signal starts, then opens *again* after the first zero crossing, until it is pulsed. Figure 7.4 and Figure 7.5 show similar results with 4 ms and 6 ms gate delay, respectively. As expected, the longer the delay to the gate, the longer the triac acts like an open circuit reducing the duty-cycle of the AC main signal.

In short, the amount of dimming can be controlled by changing the time delay between the gate trigger and the AC Mains. This is a very important characteristic of the TRIAC that allows seamless integration with our digital control unit. Moreover, to ensure controllability of the dimming, the triggering signal has to be synchronized with the AC Mains.

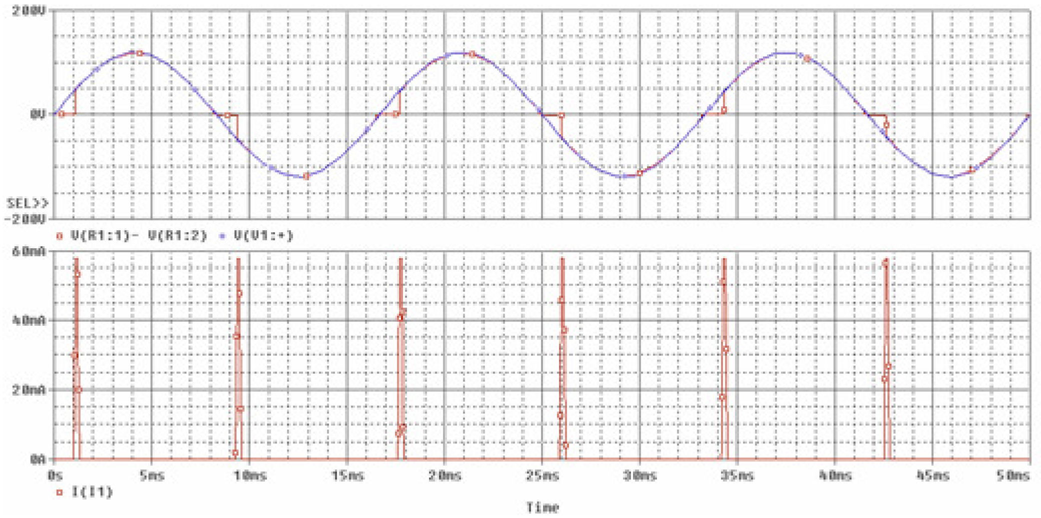


**Figure 7.3: Current output (top) of the TRIAC with AC input and gate pulsed with 1 ms delay from the AC.**

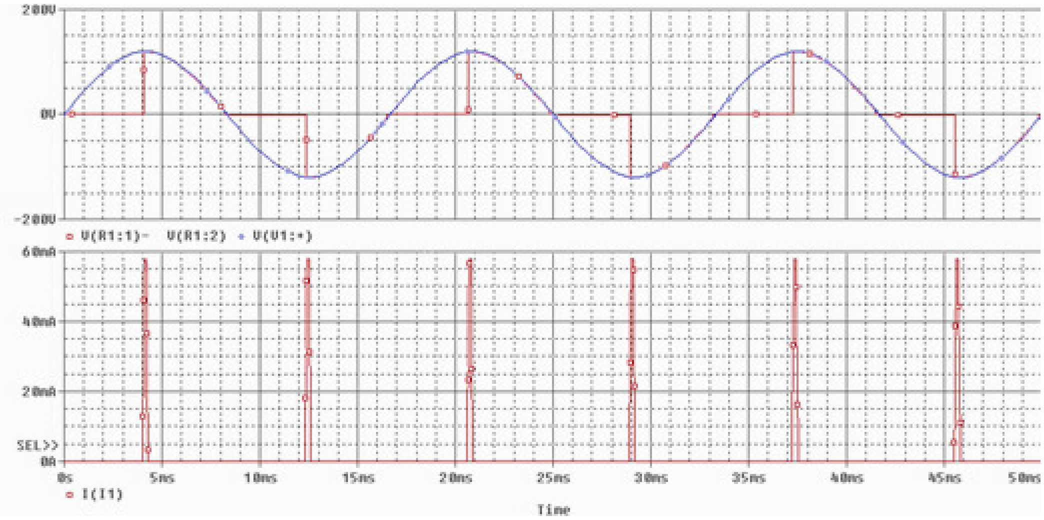


Figure 7.4: Current output (top) of the TRIAC with AC input and gate pulsed with 4 ms delay from the AC.

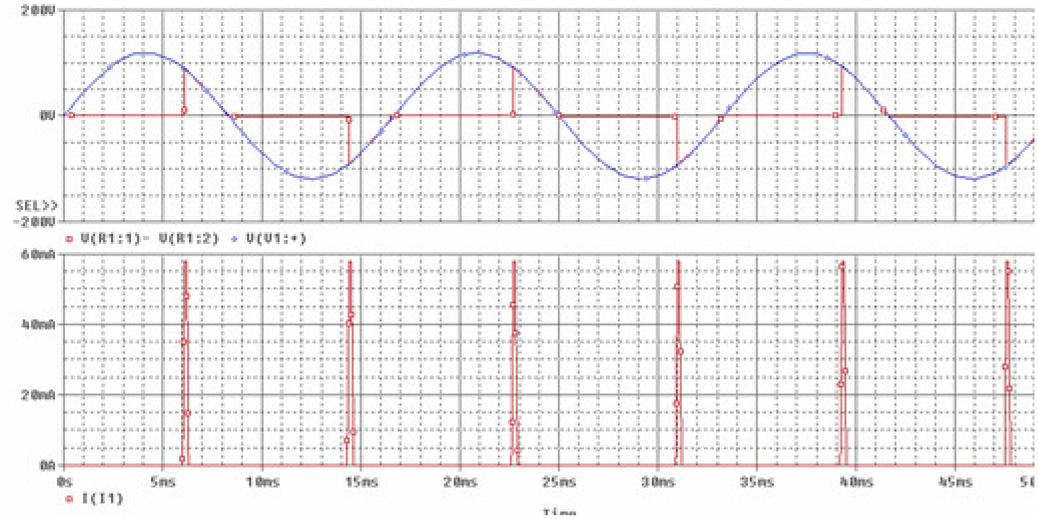
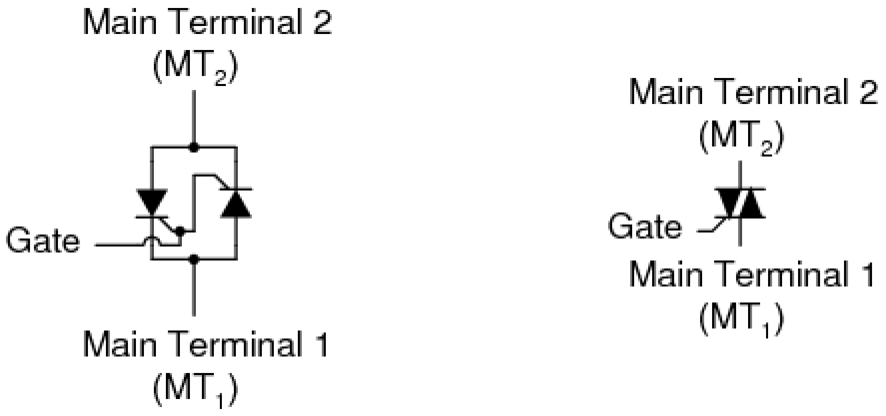


Figure 7.5: Current output (top) of the TRIAC with AC input and gate pulsed with 6 ms delay from the AC.



*TRIAC equivalent circuit* *TRIAC schematic symbol*

**Figure 7.6: (Left) SCR representation of the TRIAC and (right) the schematic symbol of the TRIAC. [4]**

## 7.2.2 Conditions for Triggering

The TRIAC is triggered (made to conduct) by a small current at the gate. The triggering can take place in any of the four quadrants as shown in Figure 7.7. For example, the triggering occurs in quadrant 1 when A2 is positive with respect to A1 and current is flowing into the gate. To trigger the TRIAC, the current flow into the gate has to reach a certain level. This gate threshold current, indicated by $I_{GT}$, is usually in the order of mA, and varies with temperature, triggering quadrant, and the voltage between the two terminals during the off-state. Our implementation alternates between quadrants 1 and 4, as the gate always receives a positive pulse from the MCU. Each quadrant differs in performance, but for our purpose, such detail is not a concern. Once the TRIAC is triggered, it will keep conducting even when the gate current is withdrawn, until the voltage across two main terminals drops below the holding level. This holding voltage is in the magnitude of tens of mV (which, compared to the large AC Mains of 120 V, can be taken as zero) [4]. For this reason, the TRIAC only stays “closed” for half a cycle, meaning it should be triggered twice in order to conduct a full cycle. The triggering signal therefore has twice the frequency of the AC current, namely 120 Hz.

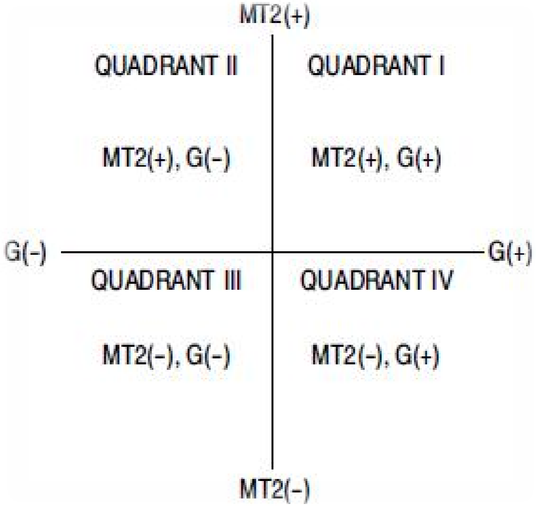


**Figure 7.7 Four triggering quadrants [4]**

## 7.3 Conventional Design: Analog-Driven Thyristor Dimmer

Before explaining the design of our dimmer, it is first necessary to introduce how the Thyristor dimmer is implemented in conventional dimmer switches. The conventional dimmer triggers the TRIAC by feeding an altered version of the AC Mains into the gate. Aside from solving synchronization problem, trigger time delay can also be effectively achieved by the usage of a simple RC circuit. The schematic diagram of such dimmer is shown in Figure 7.8. In the actual case, R5 would be a mechanically controlled variable resistor. As R is modified, the point in time at which the trigger signal reaches the current threshold is also modified. According to the theory of the TRIAC discussed above, this effectively "shifts" the gate trigger in time, causing the light to dim. This design, however, harbours a few disadvantages. Firstly, as the gate signal is modified by the RC circuit, extra heat is being dissipated by the resistor. Secondly, this implementation does not allow for electrical or digital control of the dimming. As our project focuses mostly on adding automation to the dimmer switch, a new method of implementing the Thyristor Dimmer is needed.

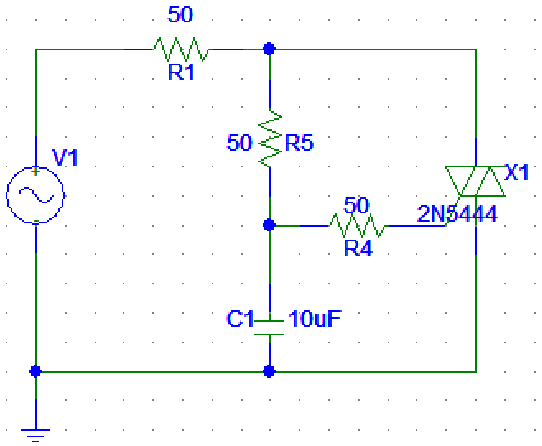


Figure 7.8 Schematic of Dimmer Switch Circuit

## 7.4 Our Design: the Logic-Driven Thyristor Dimmer

The design of our dimmer, while still dimming by the power-switching method, differs greatly from the conventional Thyristor dimmer. Instead of using an RC circuit, we trigger the gate with a microcontroller. The microcontroller will fire voltage pulse to the gate of the TRIAC periodically, with a well-controlled time delay. The circuit is shown in Figure 7.9. *Trig In* is the signal from the microcontroller, and the lamp is connected in series with *AC in*. As shown, the circuit contains the MOC3011 opto-coupler. The block diagram representation of the MOC3011 is shown in Figure 7.10. As we can see, the MOC transfers logic signal while electrically isolating the two sides [5]. This is done by firing an LED directly into a phototransistor, causing the logic signal to be converted to light pulses, and converted back immediately into logic signal.

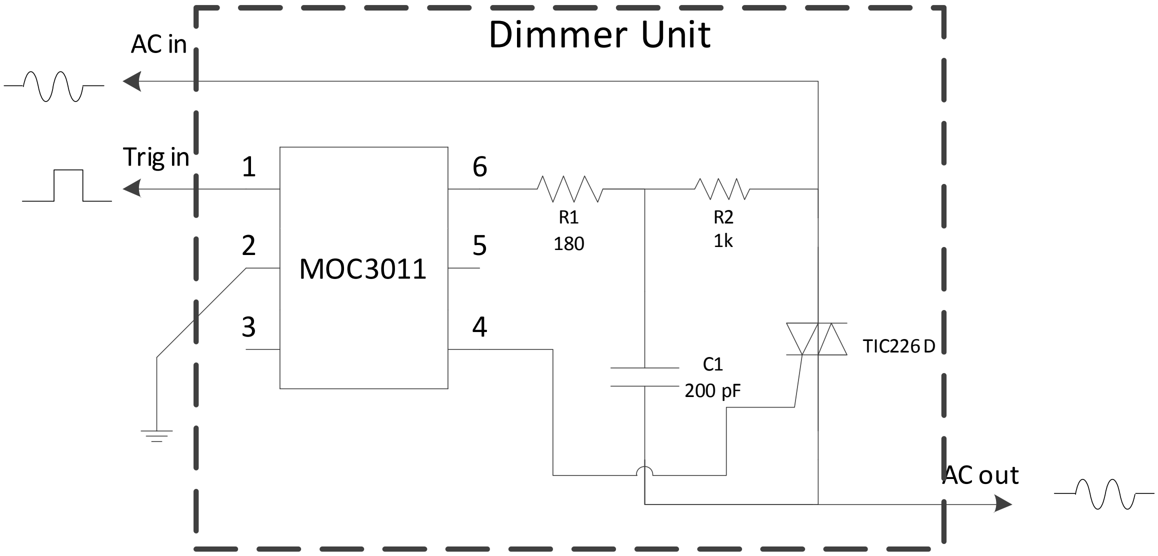


Figure 7.9: The design of our Logic-Driven Thyristor Dimmer

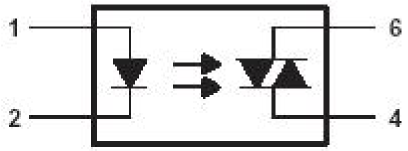


**Figure 7.10: Block diagram representation of the MOC3011[5]**

The logical signal is used to trigger the TRIAC periodically. As explained in section 7.2.1, the amount of dimming depends on the timing of the signal. Assuming 120V and 60 Hz source, the logical signal needed to dim is a 120 Hz square-wave with very small (about 1%) duty cycle. The allowable time delays are between 0 ms to 8 ms. The MCU is running at 4 MHz, allowing for adjustments in the order of micro-seconds.

# 8 CONTROL UNIT

The control unit (MCU) will take sensor readings and user interface as inputs, and provide a timed signal to the dimmer unit. It requires the AC Mains signal for synchronization and some reference voltage, Vref, to determine the resolution of the analog sensor input (this will be explained further in Section 8.2. The core of the control unit is the PIC12F675 [6]. Table 1 and Figure 8.1 lists all the pin connections of the PIC.

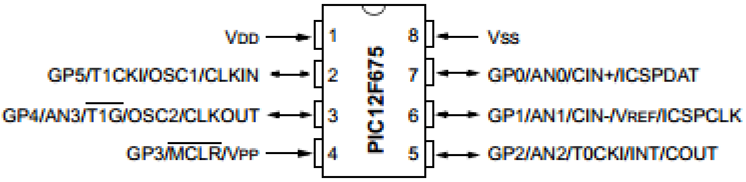


**Figure 8.1: Block diagram indicating the pins of the PIC12F675 [6]**

**Table 8.1: Microcontroller pin usage**

| Microcontroller Pins | Usage |
|---|---|
| 1 | Vcc (5V DC) in |
| 2 | TRIAC trigger signal out |
| 3 | User in (Decrement) |
| 4 | AC Mains in for synchronization |
| 5 | User in (Increment) |
| 6 | Vref in |
| 7 | Sensor in |
| 8 | GND |

The light sensor will provide an analog input to the PIC in the form of voltage level. This voltage is converted to a 10-bit digital representation using the PIC's built-in ADC. The user interface provides a pair of digital input signals, one representing an increment request, and the other representing a decrement request. Internally, the PIC services its inputs and generates an output based on a control algorithm. The nature of the output signal as well as the control algorithm will be discussed in the following sections.

## 8.1 Trigger Signal Generation

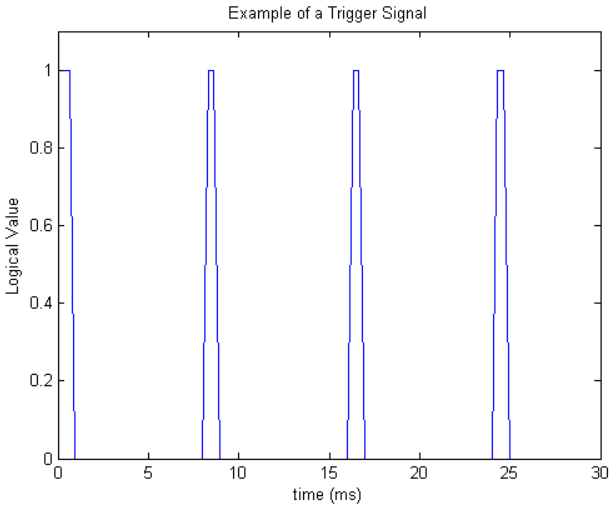


**Figure 8.2: Example of a dimming (TRIAC) trigger signal**

As explained in Section 7, the dimmer unit dims the light by “chopping off” parts of the 60 Hz power cycle thereby reducing the duty cycle of the current going into the lamp. This is done by sending a timed, logical signal to the dimmer unit (see Figure 8.2). If the MCU sends a 120 Hz trigger signal which is in phase (no delay) with the AC Mains (120 V 60 Hz), the lamp will be at full brightness. On the other hand, if the MCU sends a trigger signal which is delayed by a half-period (180° or approximately 8 ms), the lamp will be off. For this reason, it is extremely important that the trigger signal is synchronized with the AC Mains. This is the reason for synchronization signal in pin 4. This signal causes an interrupt in the MCU, allowing the generation of the trigger signal to be synchronized with the mains. The reason for the frequency to be doubled is explained in the Dimming Unit.

## 8.2 Analog-to-Digital Converter (ADC)

The Analog-to-digital converter (ADC) takes in an analog value and converts it to a 10-bit digital representation stored in a register in the MCU. The voltage level in pin 6, $V_{ref}$, determines the resolution of the ADC. $V_{ref}$ is divided by 1023 and this value is resolution of the ADC. For example, if $V_{ref}$=10V then 10/1023=9.78mV. Therefore each digit in the 10-bit value represents 9.78mV. Consqeuently, a larger $V_{ref}$ allows a larger maximum analog value but creates a more coarse resolution and vice versa.

## 8.3 Main Algorithm

As explained in Sections 7.2.1 and 8.1, the amount of dimming is controlled by the *time delay* of the trigger signal with respect to the AC Mains. This section describes the main algorithm of the MCU, which aims to accomplish two main tasks: (1) to pulse the TRIAC at the right delay time and (2) to save as much power as possible. The main algorithm is shown in Figure 8.3. Its main task is simply to wait for an interrupt while being in low-powered sleep mode.

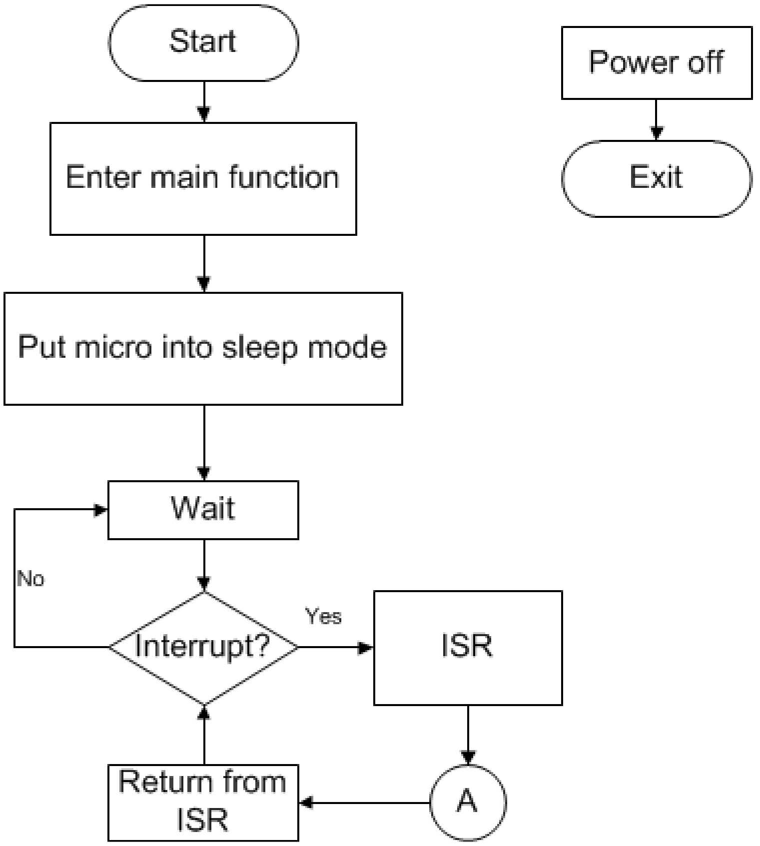


**Figure 8.3: Flowchart showing the algorithm of interrupt handling.**

In our case, our interrupt signal is the AC Mains itself, which wakes the PIC up on rising and falling edges of the Mains. When an interrupt is received, the Interrupt Service Routine (ISR) is called. The structure of ISR is illustrated in Figure 8.4. The goal of this algorithm is to determine whether or not the delay time, denoted as *DIMDELAY*, has to be updated. If *DIMDELAY* has to be updated, the system moves onto the routine shown in Figure 8.5. This routine calculates *DIMDELAY* based on some control algorithm (explained in Section 8.4), and pulses the TRIAC based on that delay. Since calculating *DIMDELAY* takes a long time (in the order of milliseconds), care has to be taken to ensure the calculation completes within the time t < *DIMDELAY*. Such is the reason for the branching in Figure 8.5, where *very short* would be defined as any time smaller than the calculation time.

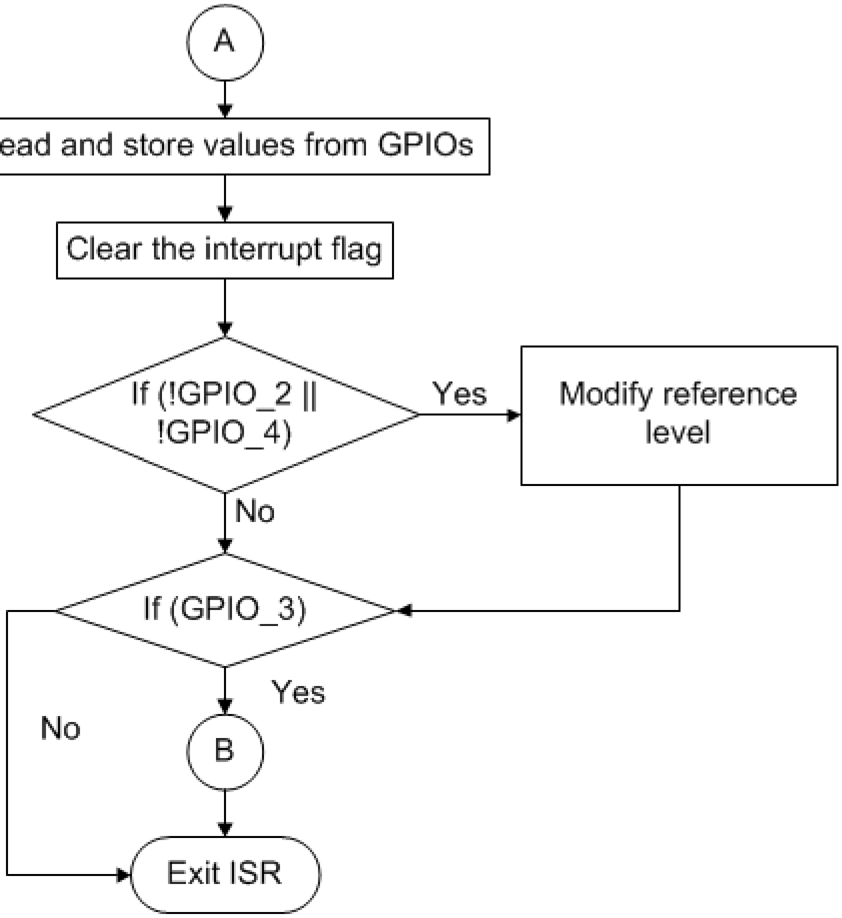


Figure 8.4: The Interrupt Service Routine (ISR)

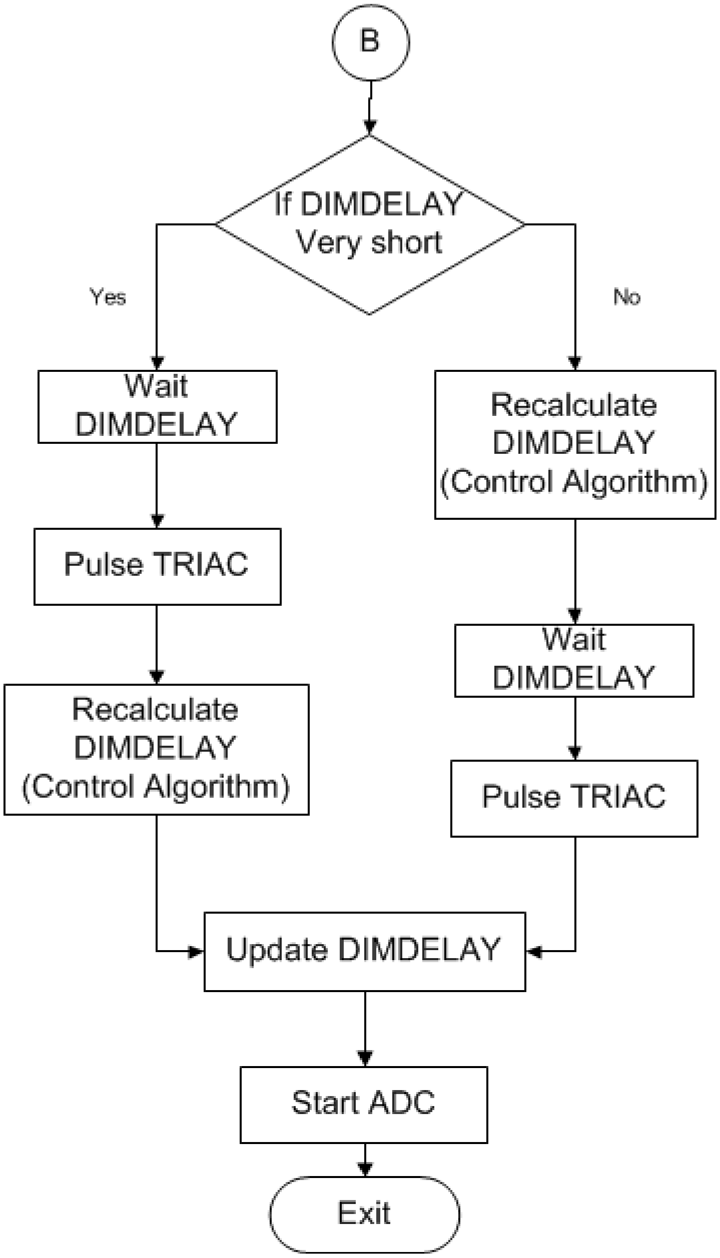


**Figure 8.5: The algorithm for maximizing power saving when performing control**

### 8.3.1 Power Saving

As explained in Section 7.1, the basic relationship between PIC's output time pulse and the brightness of the lamp is that the greater the amount of dimming, the longer PIC has to wait. Hence, as long as the brightness of the lamp is not set to its maximum, PIC will have to stay awake until it has to send a pulse. After PIC sends the pulse, it will enter sleep mode until the next interrupt signal arrives. In other words, it resumes its main wait loop (Figure 8.3). This means that the PIC will be awake only for the duration *DIMDELAY*, minimizing the current drawn by the PIC. Further development can be done by having the PIC enter sleep mode while waiting to send the pulse, and wake it up just to send the pulse. However, this requires an external timer which our PIC cannot accommodate due to lack of pins.

The next section discusses the control algorithm, which discusses how *DIMDELAY* is calculated in relation to the user and external input.

## 8.4 Control Algorithm

The control algorithm implements a feedback system (shown in Figure 8.6) which responds to the error between user reference level (R) and the sensor reading (S). Current design only involves the "proportional" (P) control, which controls the output based on the exact value of the error. The error used in this case is a percentage error, which is converted to percentage dimming, and then converted to shift in time delay in the trigger signal.

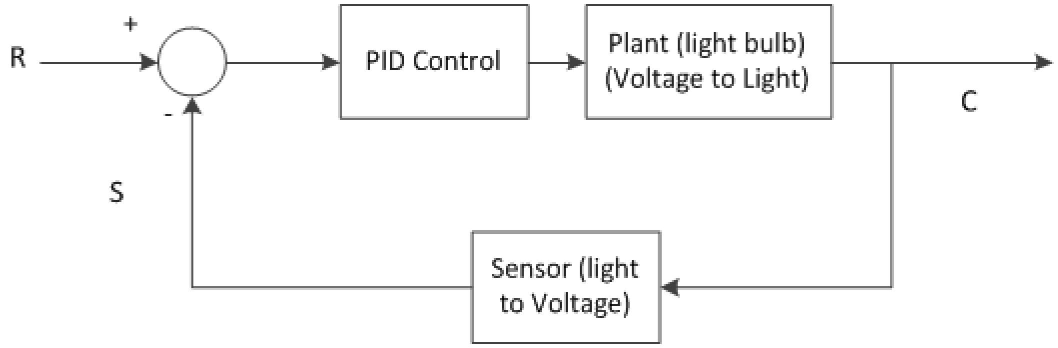


**Figure 8.6: Feedback control representation of the system.**

The flowchart showing the algorithm for digital control is shown in Figure 8.8. As shown, the system uses the percentage error and uses it to determine the percentage change of the delay of the trigger signal (DIMDELAY). The relationship between DIMDELAY and percentage dimming is actually sinusoidal, as shown in Figure 8.7. However, due to the limitation of the PIC12F675 in performing mathematical functions, the linear approximation of this relationship is used in our control algorithm. The approximation is valid for our application as long as the speed of correction is not too fast. The correction speed is determined by the proportional constant, $K_p$. This constant, whose value is between 0 and 1, determines how much the system should respond to the error *per cycle*. For example, if $K_p = 1$, the system will attempt to fix the error in one clock cycle. This is undesirable because the error in linear approximation of the sinusoid will be emphasized. In general, $K_p$ should be kept low (in the order or 0.1 or even 0.01), and the best value will be determined by trial and error. This relationship states that the percentage dimming is directly proportional to the delay time, which is implemented in Figure 8.8.

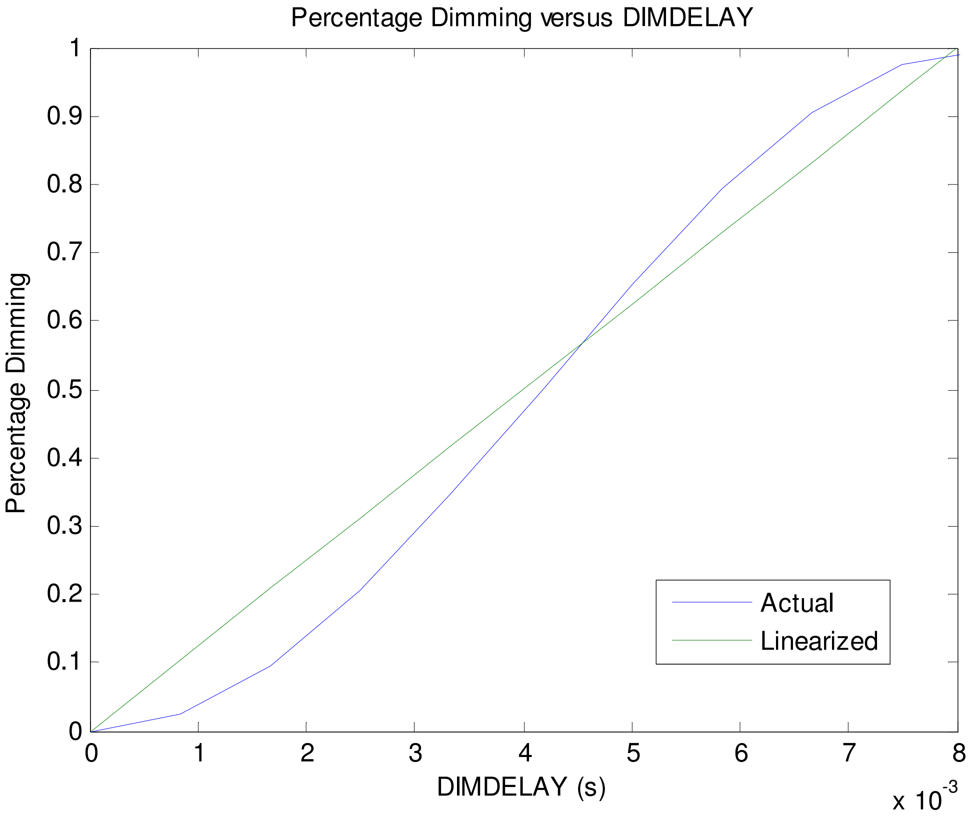


**Figure 8.7: Linearization of the relationship between dimming amount and DIMDELAY.**

The controller aims to equate the values between the sensor output and the user reference. Note that while the sensor receives feedback from the lamp, it also receives light from external sources. It is crucial that our control algorithm considers both of these light sources as a whole to be able to maintain a constant luminosity. However, one can immediately see that a “stable point” cannot be achieved by the controller alone. For example, if the reference level is lower than the sensor reading when lamps are already off, it is physically impossible for the system to achieve a stable point. For this reason, a few corner cases have to be dealt with by the MCU.

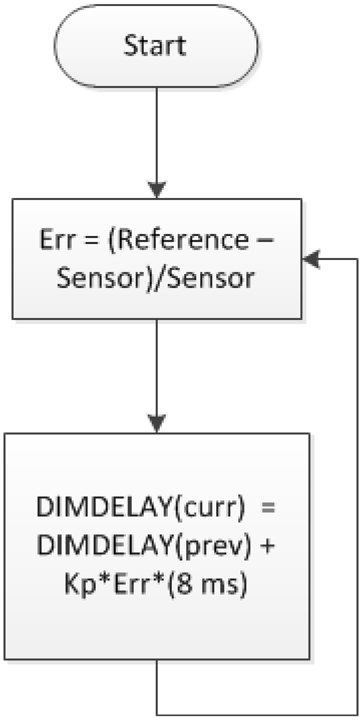


**Figure 8.8: Flowchart representation of the control algorithm.**

### 8.4.1 Corner Cases

Because our system maintains a reference level of brightness desired by the user and because the system cannot output infinite amounts or negative amounts of light there will exist situations when the desired level of brightness is not possible to achieve.
Table 8.2 shows the corner cases in which stabilization may never be reached due to the (obvious) uncontrollability of the external light.

**Table 8.2: Corner cases in which stabilization may be forced**

| Case | Behaviour |
|---|---|
| User ref > Maximum Achievable Brightness | turn light fully on, force stabilize until User Ref is updated |
| User ref < Minimum Achievable Brightness | turn light fully off, force stabilize until User Ref is updated |

In the first case, the user desired level is higher than the maximum achievable brightness. This may occur when the control unit "remembers" the level at, for example, a very bright and sunny afternoon while the light is also fully on. When the sun subsides, the system will still try to achieve the same value. In this case, the instability is inherently controlled by the "cap" of the dimmer. Referring to the trigger signal described in Section 8.1, the delay time (which corresponds to dimming) cannot be lower than 0 ms. This effectively forces the system to stabilize at maximum lamp brightness

In the second case, the user desired level is lower than the minimum achievable brithness. This may happen when the illumination due to external source exceeds the user desired brightness. Similarly to the first case, the time delay of the trigger signal is “capped” at 8 ms. When the system requests to delay greater than 8 ms, the change will be ignored, effectively forcing stabilization.

In both cases, the unrealistic reference values will be updated to match the current condition whenever the user presses a button on the system.

## 8.5 Future Plans

The control algorithm can be improved further in order to improve the stability of the feedback system by introducing Integral (I) or Derivative (D) control. Both controls require knowledge of previous errors, which is easy to be implemented on the microcontroller. If the proportional control deems inadequate, a full PID control will be implemented.

The power saving can also be improved by upgrading the PIC to receive external oscillators, giving it ability to sleep for a specified period of time, namely DIMDELAY, thereby saving power even more.

# 9 SYSTEM TEST PLAN

## 9.1 Functional Test Plan

This section lists the steps to test the Smart Dimmer system as intended to be used by the user.

### 9.1.1 Non-Corner Case

This section concerns the testing of the system under normal (non corner) cases.

#### 9.1.1.1 Increasing external light

1. Ensure no external light source is present
2. Turn the light to certain amount of lux
3. Wait for the system to stabilize
4. Introduce controlled-external light source (or open blinds)
5. The lamp should decrease in brightness to compensate

#### 9.1.1.2 Decreasing external light

1. Ensure some external light source is present
2. Make adjustments to the light (any)
3. Remove the external light source
4. The lamp should increase in brightness to match previous value

### 9.1.2 Corner Cases

#### 9.1.2.1 Reference too Large

1. Ensure large amount of external light source is present
2. Turn the light to maximum
3. Remove the external light
4. The lamp should stay maximum, system should not malfunction

#### 9.1.2.2 Reference too Small

1. Ensure no external light source is present
2. Turn the light to minimum brightness
3. Introduce some external light
4. The lamp should stay minimum, system should not malfunction

### 9.1.3 LUX Consistency Test

1. Set the device to a certain desired brightness
2. Get a time-lapse reading of illuminance using a calibrated Lux Meter
3. Modify the external light while reading
4. Ensure the lux readings tend to a constant value over time

## 9.2 Power Consumption Test Plan

1. Plug in the prototype through a power meter
2. Plug in a regular lamp (same wattage) through another power meter
3. Vary external light source from low to high over certain time period T
4. Average the power consumption over T, verify that consumption is less than regular lamp

## 9.3 Lamp Versatility Test Plan

Using all of incandescent, dimmable fluorescent, and (if available) LED bulbs, ensure that the system functions.

## 9.4 System Stability Test Plan

### 9.4.1 Response to the External Light

1. Instead of connecting the prototype to a lamp, connect it to a load resistor
2. Measure the voltage across that load $V_L$
3. Modify the external light
4. Plot $V_L$ versus time
5. Ensure the response is not fluctuating and stabilized

### 9.4.2 Response to the User

1. Instead of connecting the prototype to a lamp, connect it to a load resistor
2. Measure the voltage across that load $V_L$
3. User presses one of the buttons
4. Plot $V_L$ versus time
5. Ensure the response is not fluctuating and stabilized

## 10 CONCLUSION

The proof-of-concept design of the Smart Dimmer which is based on our functional specification has been discussed. Firstly, the overview of the system was introduced as an opto-electronic system. The system, which can be separated into sensor unit, dimmer unit, and control unit, aims to maintain a constant illumination as seen by the sensor while adapting to the dynamic external light.

The user interface of this prototype consists of two push buttons which represent increment (brighter) and decrement (dimmer) request from the user. In order to protect inductive components in our circuit from current spikes caused by the button, it is connected to an RC circuit which spreads the signal over a minimum of 0.1 ms.

The core of the sensing unit is the OPT101, which is a visible-light photodiode with a trans-impedance amplifier. The gain of the amplifier is found to be directly proportional to the external resistor, whose value in our design is 12 kΩ. The proportionality between lux level and output voltage is also calibrated using our digital light meter. The result of the calibration shows a slope of $12k\Omega \times 6.67\ nA/lux$ , which gives the dimension of volt per lux.

The dimming unit is a purely analog circuit which provides dimming given a logical input signal. The key component of this unit is the TRIAC. Knowing that the TRIAC dims the light based on the time delay of the trigger signal, the circuit is meant to receive a timed signal from the control unit. In order to isolate high power from the control unit, the logical signal passes through the MOC3011 opto-coupler, which delivers the logical signal to the TRIAC while decoupling the control side of the circuit from the unsafe 120 V.

The control unit generates the said trigger signal given a user input and an external input. Based on these values, the control unit runs an algorithm which determines the best value to dim the light to. The key component of the control unit is the PIC12F675. The algorithm aims to save the most energy by ensuring the PIC is in sleep mode as often as possible. This is done by putting the PIC to sleep whenever a trigger signal is fired

The design of this opto-electronic system will be improved during the course of our development, but this document outlines the basic design which is adequate for our requirements [1].

# 11 REFERENCES

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