DESIGN AND CONSTRUCTION OF A LIGHT ACTIVATED REMOTE CONTROLLED FAN REGULATOR

BY

ABDU-AGUYE UMAR-FARUK

A thesis submitted to the postgraduate school of the Ahmadu Bello University,
Zaria, in partial fulfillment of the requirements for the award of Master of Science
(M.Sc.) in Electrical Engineering

CERTIFICATION

This thesis entitled “Design and Construction of a Light Activated Remote Controlled Fan Regulator” by ABDU-AGUYE, UMAR-FARUK meets the regulations governing the award of the degree of Master of Science (Electronics and Telecommunications) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literature presentation.

__________________________ Date: _________________

Dr. D. D. Dajab
(Major Supervisor)

__________________________ Date: ________________

Dr. M.B. Mu’azu
(Minor Supervisor)

__________________________ Date: ________________

Dr. M. B. Mu’azu
(Head of Department)

__________________________ Date: _______________

Prof. S. Nkom

Dean, Postgraduate School

DECLARATION

I hereby declare that this thesis work was carried out by ABDU-AGUYE, UMAR-FARUK under the supervision of Dr. D. D. Dajab and Dr. M. B. Mu'azu of the Department of Electrical Engineering, Ahmadu Bello University, Zaria, as part of the requirements for the award of the degree of Master of Science (M.Sc.) in Electronics & Telecommunications Engineering.

This is an original work which has never been submitted elsewhere for any degree. All literature consulted have been duly specified by means of references.

______________________________ ______________

ABDU-AGUYE, UMAR-FARUK Date

DEDICATION

This project is dedicated to Allah and then my entire family – my source of inspiration.

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to my project supervisors Dr. D. D. Dajab and Dr. M. B. Mu’azu, for their invaluable guidance and support.

My deep appreciation goes to my brothers Shittu, Mustapha, Abdullahi & Mubarak, my sisters Ramatu, Fatima, Zainab & Samira and my course mates, colleagues and friends, Suleiman Garba, Abdullahi Abubakar Mas’ud, Yahaya Bello and Paul Onyabe. Their moral support has been an invaluable source of motivation during the whole Masters Degree program.

I shall forever be grateful to my wife Munirat O. Momoh for her encouragement, support and sacrifice.

To my parents, words are not enough to express my gratitude – only Allah can reward you.

ABSTRACT

For several reasons, invisible electromagnetic signals in the RF and infrared frequency spectra are preferred for the remote control of consumer electronics. However, a niche exists for the use of visible light for the remote control of domestic electrical fittings which require simple power control operations. Electrical fitting controllers like light switches, light dimmers, power sockets and ceiling fan regulators can be remotely controlled by an ordinary flashlight focusing its light beam on the detector for the fitting. The remote control signal detector compares the luminous intensity on a light beam detector with that on an ambient luminous intensity detector and, given a sufficient difference, initiates a cyclic controller output sequence. The output cycles, changing the state of the controlled fitting from OFF to ON (at different ON states if applicable) and back OFF. The design of a simple and sufficiently sensitive light beam detector that can function properly and reliably in all indoors ambient lighting conditions was the main focus of this thesis. The luminous intensity difference detector designed uses two light dependent resistors (LDRs) in special enclosures which increased their sensitivity to a focused light beam in high levels of ambient illumination. A UA741C Op-Amp IC based comparator is used to detect a difference in illuminance between the ambient illumination and the extra illuminance as a result of a focused light beam on the light beam detector. The light remote controlled ceiling fan regulator realized using the luminous intensity difference detector has a control range which competes favorably with infra-red remote controlled systems. The luminous intensity difference detector can be used in security systems, motion sensing, robotics, sunlight tracking systems and many emerging applications of optoelectronics.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The remote control of household and industrial electronics and electrical devices and systems by means of wireless handheld controllers is not uncommon today. These controllers make use of electromagnetic waves of different spectra. Usually the frequency of the electromagnetic waves used for control is selected from the ranges of frequencies that are not generated internally by the controlled device or externally in the ambient surroundings of the target environment where the controlled device is to be used.

The control signals are restricted to narrow bandwidths and are expected to be of very specific format at the receiver of the controlled device. These measures are taken to ensure that the controlled device does not respond to random electromagnetic phenomena, to ensure reliability in operation of the controlled system and for control instruction differentiation.

The most popular and widely used spectrum for remote control systems today is the infra-red range of frequencies. Most consumer electronics and electrical devices in use today are of the infrared type. Infrared signals are invisible to the naked eyes and so the signals are not focused into a narrow beam when used in remote control systems. Therefore accurate pointing of the remote controller to the detector of the controlled device is not necessary, making them easier and more convenient to use.

Examples of consumer electronics that commonly have remote control facility are television sets, video cassette recorders, and compact disc players. Electrical products with remote control facility are less common and include mostly climate control equipment like fans and air conditioners. Each of these electrical systems is purchased with its own very specific remote controller. It is not uncommon to have up to five different remote controllers in a residential sitting room alone.

Electromagnetic waves of the visible light spectrum is generally not used for remote control systems for several obvious reasons which include the high likelihood of interference from natural and man made light sources which exist in almost all environments where electrical equipment are deployed, the higher power for visible light generation and preference for unobtrusive, discrete and invisible control signals.

However, a small niche exists for the use of visible light for the remote control of electrical and electronics systems, this includes simple power “on” and “off” operations, speed or intensity control of multiple home electrical fittings using a single controller.

Picture a scenario whereby one can put the bedroom lights on and off, turn the ceiling fan on to any of the preset speeds and also turn the air conditioning unit on and off from ones bed, using the same remote control device – a flashlight, just by focusing the beam of light on the detector of the device to be controlled.

1.2 THESIS MOTIVATION

This work aims at developing a means of incorporating a remote control alternative into electrical fitting controllers, namely light switches, power outlets (sockets), dimmer switches and ceiling fan speed regulators. Lower levels of illumination in the interior usually characterize homes, unlike office buildings, even when artificial light sources are used. This is logical as our homes serve as a shelter from the extremes of the outdoor physical conditions. The desire is to develop a reliable, yet simple means of controlling all the lights, ceiling fans and some other selected electrical fittings connected to wall sockets, for example air-conditioners. Remote control is not desirable for devices like electric stoves, deep freezers and refrigerators, which are best manually controlled.

A single controller is desired for the control of all the electrical fittings. This will prevent the unnecessary clutter of specialized controllers for similar devices.

1.3 LITERATURE REVIEW

The use of remote control for electrical fittings lacks a concise history. Often, manufacturers and consumers deem the inclusion of extra intelligence and the associated cost of remote control for simple routines like powering On/Off of light switches, air-conditioners and ceiling fan regulators as economically unjustifiable. At present, infra-red remote control of lights, power switches and ceiling fans are available. They are available mostly only on special request and require a separate controller (transmitter) for each fitting.

Layton [1] revealed that the world's first remote controls were radio-frequency (RF) devices that directed German naval vessels to crash into Allied boats during World War I. In World War II, remote controls detonated bombs for the first time. The dominant remote-control technology in home-theater applications is infrared (IR). Infrared light is also known as plain-old "heat." The basic premise at work in an IR remote control is the use of light to carry signals between a remote control and the device it's directing. Infrared light is in the invisible portion of the electromagnetic spectrum. An IR remote control (the transmitter) sends out pulses of infrared light that represent specific binary codes. These binary codes correspond to commands, such as power on/off and volume up. The IR receiver in the TV, stereo or other device decodes the pulses of light into the binary data (ones and zeroes) that the device's microprocessor can understand. The microprocessor then carries out the corresponding command.

Brain [2] gave a detailed description of a typical TV infrared remote controller with emphasis on its internal physical structure and its operation.

The focus of this work, the use of visible light as a pointing device for the remote control of power to multiple electrical fittings in the home is not rich in precedence.

Visible light is commonly used to activate or deactivate electrical/electronic processes through the use of Photodiodes, Photocells/Light Dependent Resistors (LDRs) and Phototransistors as light sensors. The LDR is the most popular for ambient illumination level sensing.

In an optoelectronics experiment by **Phillips [3]**, it was stated that an LDR must be part of a voltage divider network in order to give an output voltage, which changes with illumination. It was shown that there are just two ways of constructing the voltage divider network, with the LDR at the top, or with the LDR at the bottom of the voltage divider. It concluded that the optimum value of fixed resistor, that gives the biggest changes in the output voltage, is when the fixed resistor value is equal to the resistance of the LDR.

Collinson [4] used a single LDR, the popular ORP12, in a potential divider network to activate an external light or buzzer whenever the LDR is exposed to dark ambient lighting conditions. The UA741 Operational Amplifier IC, powered by a single polarity DC supply, was used for the voltage comparison and subsequent activation.

Similarly **Van Roon [5]** used a single LDR in a voltage divider network to bias an NPN transistor, which controls the On/Off state of a relay. The circuit is light activated when the LDR is placed at the top of the potential divider network and is dark activated when the LDR is placed at the bottom.

It is important to note that all light and/or dark activated or light controlled systems use a single LDR in a potential divider network and are either threshold systems, where the activation/deactivation of a process is based on a particular level of illumination, or proportional systems, where the magnitude of the output variable is directly or inversely proportional to the level of illumination.

This thesis undertakes the design of a simple luminous intensity difference detector circuit than can be used to detect a beam of light for visible light remote control system. The circuit will use two light dependent resistors in a voltage divider network to detect a visible light remote control signal. The design objective is to use the LDRs in a comparative configuration. That is, a circuit which will use the LDRs in a non-threshold or proportional manner. The activation/deactivation of the output of the detector will depend on the difference between the levels of illumination on two different surfaces. This thesis also undertakes the design of a special enclosure for the LDR to improve its sensitivity to a focused light beam in the presence of high levels of ambient illumination. The comparative circuit configuration and the special LDR enclosure are intended to make the remote control signal detector to be very sensitive and reliable in a wide range of ambient illumination This work, therefore, presents a third way of using LDRs in a potential divider network.

1.4 PROBLEM DEFINITION

To realize a simple remote control system for electrical fittings which uses visible light as the control signal, many questions need to be asked like; Why visible light?, How reliable would the system be?, Will the system work in the presence of bright light as well as in the dark?, etcetera.

A room in a typical home could have at least two electrical fitting controllers for lights and a ceiling fan, and for wiring conveniences these controllers are usually placed close together. Fittings like air-conditioners are usually provided with dedicated power outlets (sockets). Since this equipment require only simple power control instruction, and given the desire for a single controller, it would be necessary for the controller to be able to select the device it is controlling at any point in time. Otherwise an "on" instruction from the controller will turn on all the remotely controlled equipment simultaneously.

A focused beam of light in a pointing device, like a flashlight, can be pointed to the detector of the particular fitting to be controlled. Since the beam of light can be seen, it can be brought to focus on any selected surface, individual devices can be separately controlled by focusing the beam on its detector only. Battery powered flashlights (torchlight) are ubiquitous, cheap and can be easily obtained. Most households have a couple of them.

In order to use a focused beam of light for remote control, the light sensor of the controller must be sensitive to the beam of light from a reasonable distance even in the presence of high level of ambient illumination as is obtainable indoors in residential buildings. The system must be designed to be reliable, free from false triggering by random light sources and power line voltage fluctuations. These are the challenges that must be overcome in the realization of a practicable luminous intensity difference remote controlled system.

1.5 METHODOLOGY

The design of the luminous intensity difference remote controlled electronic ceiling fan regulator will be carried out by:-

a) Designing an electronic circuit that can detect a difference between the ambient illumination and the illumination as a result of a focused beam of light from the controller and use this detection to initiate a simple control process. The light beam detector circuit is expected to be sensitive to the beam of light from a distance of about 4.0m in daytime illumination and even farther in the dark of night.

b) Selecting a light sensitive electronic component, studying its electrical characteristic and finding a means of improving its sensitivity, in the presence of high levels of ambient illumination, if necessary.

The emphasis of the design of the luminous intensity difference detector is;

i) Simplicity and Economy, it should use as few components as possible to make a simple and direct comparison between the light intensities reaching two different light sensitive devices,

ii) Selectivity, in terms of its ability to respond only to the control signal and not random or transient light sources

iii) Reliability, in terms of its ability to respond to the control signal correctly and without failure and,

iv) Noise Immunity, in terms of its freedom from the negative effects of power fluctuations and random physical phenomena in the semi-conductor material that make up the light sensitive components.

Finally, an equally reliable electronic circuit that will control the electrical appliance, in this case a ceiling fan regulator will be designed.

1.6 THESIS OUTLINE

This thesis consists of six chapters. Chapter One is an introduction to the topic of wireless remote control of electronic/electrical systems. Chapter Two is a description of the observations, investigations and experimentation that were carried out on the Light Dependent Resistor (LDR). Chapter Three describes the design of the timer and counter based electronic ceiling fan regulator circuit. In Chapter Four, three parts of the system are coupled together. The circuit diagram of the assembly of these parts of the system is presented and the explanation of its operation is provided. Chapter Five provides the power consumption estimation for the Light Activated Remote Controlled Fan Regulator; it discusses the systems construction and testing. Chapter Six is a conclusion of the work done in the thesis, it presents results obtained and proffers general recommendations and suggestions for further work.

CHAPTER TWO

LUMINOUS INTENSITY DIFFERENCE DETECTOR DESIGN

2.1 INTRODUCTION

At this juncture, before considering the design of the luminous intensity difference detector, the physical nature of visible light and definitions of terms used to qualify and quantifying light will be discussed.

In some ways, visible light behaves like a wave phenomenon, but in other respects it acts like a stream of high-speed, submicroscopic particles. Isaac Newton was one of the first scientists to theorize that light consists of particles. Modern physicists have demonstrated that the energy in any electromagnetic field is made up of discrete packets. The term *photon* (meaning 'visible-light particle') has been coined for these energy packets. Particle-like behavior is not restricted to the visible-light portion of the electromagnetic radiation spectrum, however. Radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays all consist of photons, each of which contains a particular amount of energy that depends on the wavelength. The electromagnetic spectrum is shown in Appendix I.

Photons travel through empty space at a speed of approximately 299,792 kilometers per second. This is true no matter what the electromagnetic wavelength. In media other than a vacuum, the speed is reduced. For example, visible light travels more slowly through glass than through outer space. Radio waves travel more slowly through the polyethylene in a transmission line than they do through the atmosphere. The ratio of the speed of the photons in a particular medium to their speed in a vacuum is called the *velocity factor*.

This factor is always between 0 and 1 (or 0 and 100 percent), and it depends to some extent on the wavelength.

The shorter the wavelength of an electromagnetic disturbance, the more energy each photon contains. In fact, this relationship is so precise that a mathematical formula applies. If e represents the energy (the unit of measurement is the joule) contained in each photon and s represents the electromagnetic wavelength (in meters), then

$$e = h \cdot c / s \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2.1$$

where h is *Planck's constant* (approximately equal to 6.626 times 10^{-34} joule-second) and c is the speed of electromagnetic-field propagation in the medium in question (approximately 2.998 times 10^{8} meters per second in a vacuum). A simpler formula applies to frequency. If f represents the frequency of an electromagnetic field (in hertz), then

$$e = h \cdot f \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2.2$$

The energy contained in a single photon does not depend on the intensity of the radiation. At any specific wavelength, say the wavelength of light emitted by a helium-neon laser, every photon contains exactly the same amount of energy, whether the source appears as dim as a candle or as bright as the sun. The intensity is a function of the number of photons striking a given surface area per unit time.

Luminous intensity is an expression of the amount of light power emanating from a point-source within a solid angle of one steradian (abbreviation, sr). For reference, a frequency of 540 terahertz (540 THz or 5.40 x 10^{14} Hz) is specified. A frequency of 540 THz corresponds to a wavelength of about 555 nanometers (nm), which is in the middle of the visible-light spectrum, and is generally accepted as the frequency and wavelength at which the average human eye is most sensitive. A steradian is the standard unit solid angle; a sphere encloses 4π (approximately 12.57) steradians.

Late in the 20th century, the candela was defined and adopted as the standard unit of luminous intensity. The candela (abbreviation, cd) is the standard unit of luminous intensity in the International System of Units (SI). It is formally defined as the magnitude of an electromagnetic field, in a specified direction, that has a power level equivalent to a visible-light field of 1/683 watt (1.46 x 10^{-3} W) per steradian at a frequency of 540 THz.

The lumen (abbreviated, lm) is the International Unit of luminous flux. It is defined in terms of candela steradians (cd·sr). One lumen is the amount of light emitted in a solid angle of 1 sr, from a source that radiates to an equal extent in all directions, and whose intensity is 1 cd.

One lumen is the equivalent of 1.46 milliwatt (1.46 x 10^{-3} W) of radiant electromagnetic (EM) power at a frequency of 540 THz. Reduced to SI base units, one lumen is equal to 0.00146 kilogram meter squared per second cubed (1.46 x 10^{-3} kg m^2/s^3). [6]

Illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of the intensity of the incident light. Similarly, luminous emittance is the luminous flux per unit area emitted from a surface. Luminous emittance is also known as luminous exitance. [7]

In SI derived units, these are both measured in lux (abbreviated, lx). The lux is defined in terms of lumens per meter squared ($lm·m^{-2}$ or $cd·sr·m^{-2}$). Reduced to SI base units, one lux is equal to 0.00146 kilogram per second cubed (1.46×10^{-3} kg / s^3).

One lux is the equivalent of 1.46 milliwatt (1.46×10^{-3} W) of radiant electromagnetic (EM) power at a frequency of 540 THz, impinging at a right angle on a surface whose area is one square meter. The lux is a small unit. An alternative unit is the watt per meter squared (W / m^2). To obtain lux when the illuminance in watts per meter squared is known, multiply by 683. To obtain watts per meter squared when the illuminance in lux is known, divide by 683 or multiply by 0.00146.

Illuminance varies inversely with the square of the distance from the source. [6] Illuminance was formerly often called brightness, but this leads to confusion with other uses of the word. "Brightness" should never be used for quantitative description, but only for nonquantitative references to physiological sensations and perceptions of light. [7]

The objective of the design of the detector circuit is to arrive at a circuit which will compare the luminous intensity on the remote control detector with the ambient luminous intensity. When the intensity on the detector is higher than the ambient, to a preset (adjustable) extent, the detector circuit is expected to initiate the control action in the controlled device. To achieve this at least two different light sensors will be required, one positioned to detect ambient lighting conditions and the other to detect a higher than ambient luminous intensity, caused by the beam of light from the remote controller.

There is a wide range of light sensitive electronic devices. Among the most common are:-

a) Photodiode - A light-controlled variable resistor. In total darkness, it has a relatively high resistance and therefore conducts little current. However, when the PN junction is exposed to an external light source, internal resistance decreases and current flow increases. The photodiode is operated with reverse-bias and conducts current in direct proportion to the intensity of the light source. Current flow is unidirectional. The circuit symbols for the photodiode are shown in Fig. 2.1.

Fig. 2.1 Photodiode Symbols

b) Photocells or Light Dependent Resistors - Like the photodiode, the photocell is a light-controlled variable resistor. However, a typical light-to-dark resistance ratio for a photocell is 1:1000. This means that its resistance could range from 1000Ω in the light to 1000kΩ in the dark, or from 2000Ω in the light to 2000kΩ in the dark, and so forth. Of course, other ratios are also available. Photocells are used in various types of control and timing circuits as, for example, the automatic street light controllers in most cities. Current flow is bidirectional. Photocells/light dependent resistors are represented in circuits using the symbols shown in Fig. 2.2.

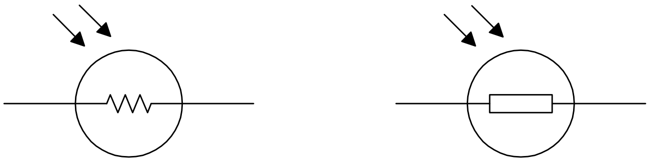


Fig. 2.2 Photocell/Light Dependent Resistor Symbols

c) Phototransistors - A phototransistor is much more sensitive to light and produces more output current for a given luminous intensity than does a photodiode. It is made by placing a photodiode in the base circuit of an NPN transistor. Light falling on the photodiode changes the base current of the transistor, causing the collector current to be amplified. Phototransistors may also be of the PNP type, with the photodiode placed in the base-collector circuit. Phototransistors may be of the two-terminal type, in which the luminous intensity on the photodiode alone determines the amount of conduction. They may also be of the three-terminal type, which have an added base lead that allows an electrical bias to be applied to the base. The bias allows an optimum transistor conduction level, and thus compensates for ambient (normal room) luminous intensity. The circuit symbols for phototransistors are shown in Fig. 2.3. [8]

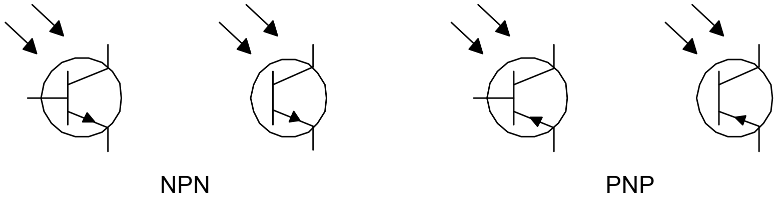


Fig. 2.3 Phototransistor Symbols

2.2 THE LIGHT SENSOR

The light dependent resistor was chosen for this work because; its sensitivity was deemed to be sufficient to detect the luminous intensity differences expected in the proposed application, its response time is adequate for the intended application, it is the most suitable for use in a voltage divider network at the input to a voltage comparator circuit, it is cheaper and more readily available than other light sensitive devices.

Packaged in either hermetically sealed cans, plastic case or coated in moisture resistant epoxy, LDRs are ideal for daylight sensing and switching applications. They can also be used in position sensing applications. The LDR chosen for this work is the SILONEX MPY54C569, Cadmium Sulphide (CdS) photoconductive cell in epoxy coated package, supplied by Farnell® Electronic Components.

Technical Specifications

Peak Spectral Response	550nm
Cell Resistance at 10 lumens	20kΩ - 100kΩ
at 1000 lumens	500Ω - 2kΩ
Dark resistance (min.)	20MΩ*
Dark resistance (max.)	Infinite
Max. Voltage	100 V D.C. / A.C. (peak)
Max. Dissipation at $30^{O}C$	60mW
Typical resistance rise time	75ms
Typical resistance fall time	350ms

* After 10 seconds [9]

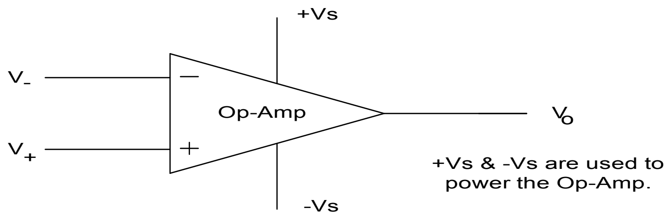
2.3 THE OPERATIONAL AMPLIFIER

The UA741C Operational Amplifier (Op-Amp) Integrated Circuit (IC), a linear IC, was used in the design of the comparator based detector circuit. The UA741C is a high performance Op-Amp with high open loop gain, internal compensation, high common mode range and exceptional temperature stability. The UA741C is short circuit protected and allows for nulling of offset voltage.

The Op-Amp has two inputs: one inverting, or (-) input, and the other non-inverting, or (+) input. It has a single output. The Op-Amp is powered normally by a dual polarity power supply, typically in the range of ±5 to ±15 Volts. The particular member of the UA741C family used is the 8-pin “mini-DIP (Dual-in-line Package)” or “V” package. Refer to the datasheet in Appendix II for the UA741C Op-Amp I.C. schematic symbol, pin configuration and detailed characteristics.

2.4 THE OP-AMP COMPARATOR

The Op-Amp can be used as an analogue voltage comparator. This is a circuit which compares two signals or voltage levels. The basic comparator circuit is shown in Fig. 2.4.



+Vs & -Vs are used to power the Op-Amp.

Fig. 2.4 The Basic Op-Amp Comparator Circuit

It is very simple and requires no additional external components. If V- and V+ are equal in magnitude, then Vo should, ideally, be zero. Even if V- differs from V+ by a very small amount, Vo is large because of the amplifiers high gain. [10]

It is especially useful in systems that contain both analogue voltages as well is digital components. If the voltage on the non-inverting (+) input is greater than the voltage on the inverting (-) input, the output is HIGH. If the voltage on the inverting (-) input is greater than the voltage on the non-inverting (+) input, the output is LOW. The input to a comparator can be thought of as analogue inputs, but the output is digital since it will always be either HIGH or LOW. For this reason, the comparator is often referred to as a one-bit analogue-to-digital (A/D) converter. [11]

2.5 THE DESIGN OF THE LUMINOUS INTENSITY DIFFERENCE DETECTOR

Of the several alternatives, the basic circuit configuration of the detector circuit decided upon is shown in Fig. 2.5.

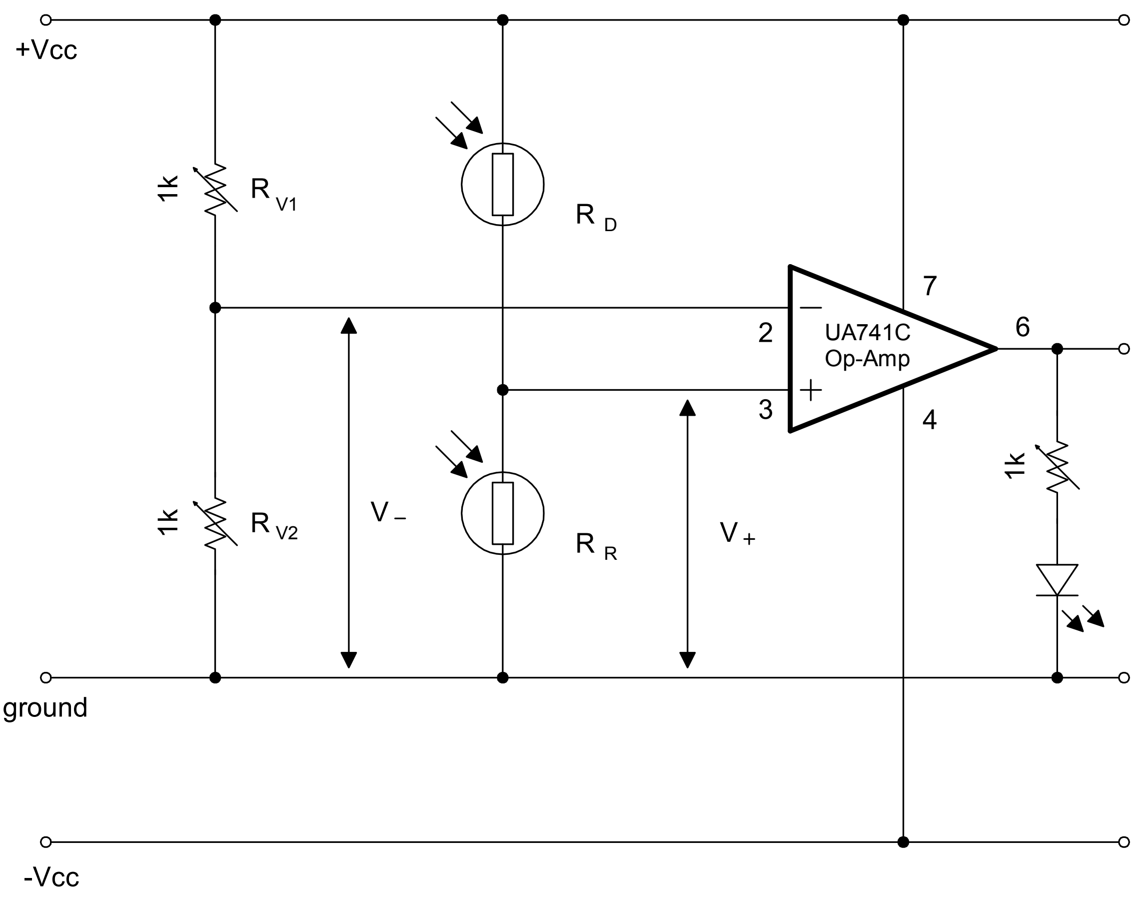


Fig. 2.5 The Ideal Light Beam Detector

R_D and R_R are Light Dependent Resistors; R_R is positioned to receive ambient illumination and is not intended as the control signal detector, R_D is positioned as close to R_R to receive approximately the same amount of ambient radiation, but far enough to be separately illuminated by the flashlight's light beam from at least 4.0m away. They are both of the same make in order to have similar electrical characteristics.

When LDRs R_D (Detector) and R_R (Reference) are exposed to equal amounts of light intensities, the voltage input to the non-inverting input to the Op-Amp, V+, will be approximately equal to Vcc/2. Though, resistances of two identical LDRs at equal levels of illumination are not usually equal. The voltage at the inverting input, V-, can be varied between Vcc and ground by adjusting variable resistors R_{V1} and R_{V2}. Resistors R_{V1} and R_{V2} are both 0 – 1kΩ variable. Ideally, in order to preserve power, they should be much higher values say 0 – 500kΩ since their voltage divider action is all that is required. All they need do is to divide the voltage to provide the required adjustable voltage level to the inverting input and supply the minimum input bias current. However, the higher their value the less precisely adjustable they become. Fine adjustment is required to control the sensitivity of the comparator to the beam of light. V- is adjusted to be slightly higher (more positive) than V+, the extent of which determines the sensitivity of the comparator. With V- slightly higher than V+, the output of the Op-Amp comparator, measured between pin 6 of the IC and ground, is LOW. LOW here refers to a negative voltage approximately equal to –Vcc.

LDR R_D is designated as the detector of the control light beam. When the illumination on R_D is greater than that on LDR R_R, as a result of say a focused beam of light, its resistance will fall and as a result, the voltage on the non-inverting terminal, V+, will rise. From the voltage divider rule, V+ can be calculated as:-

$$V+ = \frac{R_R}{R_R + R_D} \times V_{CC} \quad \cdots\cdots\cdots\cdots\cdots \quad 2.3$$

From equation (2.1), it can be readily seen that if $R_R = R_D$ (at equal levels of illumination),

$$V+ = \frac{V_{CC}}{2} \qquad \text{..........} \qquad 2.4$$

but if $R_R > R_D$ (When R_D is at a higher illumination than R_R) then,

$$V+ > \frac{V_{CC}}{2} \qquad \text{..........} \qquad 2.5$$

Consequently, when the illumination of R_D is sufficient to make V+ greater than V-, the output of the comparator becomes HIGH. HIGH here refers to a positive voltage approximately equal to +Vcc.

However, immediately the illumination of R_D returns to same level as that on R_R, as a result of retracting the beam of light focused on R_D, the output from the Op-Amp comparator will go back LOW.

Thus the basic circuit which can detect the control signal, a focused beam of light on the detector, differentiate it from the ambient lighting conditions and produce an output which can be used to initiate the control action in the controlled device has been designed.

In reality, however, the circuit designed here is ideal and impractical because of some drawbacks. Perfecting the detector circuit by studying these drawbacks and modifying the design accordingly will form the main focus of this work.

2.6 INPUT BIAS CURRENT REQUIREMENTS

For the Op-Amp IC to work properly the input elements must be able to supply a certain minimum amount of current into both inverting and non-inverting inputs for proper bias, otherwise the input terminals will be seen to be unconnected (open). The average of the currents flowing into both inputs is known as the input bias current (I_B). Available data sheet do not state a minimum value. For example, from the data sheet for the UA741C Op-Amp in Appendix II, at a power supply voltage, Vs = ± 15V and ambient temperature, $T_A = 25^{O}C$, the input bias current (I_{IB}) is given a typical value of 10nA, and a maximum of 200nA. No minimum value was stated. Also these ratings vary according to power supply voltage and temperature.

It can be observed, from Fig. 2.5 The Ideal Light Beam Detector, that the input voltage to the non-inverting input of the Op-Amp is supplied from the junction between two LDRs R_D and R_R in series. Which are themselves connected between +Vcc and ground. In relatively bright light this arrangement works well to bias the input to the Op-Amp allowing it to function properly. In the dark, however, the steady state resistance of an LDR is virtually infinite. As a result, the arrangement would not be able to supply the Input Bias Current to the Op-Amp.

Effectively, in the dark, the non-inverting input is seen to be an open input and, as a result of internal bias, the output from the Op-Amp IC is permanently HIGH.

The circuit of Fig. 2.5 was built and the input bias current requirement problem was discovered in the course of testing. It was experimentally discovered, by varying the amount of ambient illumination, that the resistance of the LDRs when the detector circuit resumed proper operation was approximately 690kΩ. At this value of resistance the output of the Op-Amp (Indicated by a red LED) returned to the LOW level in the presence of equal levels of ambient illumination on both LDRs.

2.7 INPUT BIAS RESISTORS VALUE DETERMINATION

In order for the luminous intensity difference detector to function properly both in the light and in the dark, a means by which the non-inverting input to the Op-Amp would always be supplied with sufficient input bias current had to be found. The circuit was modified to include two biasing resistors, R_B, in parallel with the LDRs as shown in Fig. 2.6. For symmetry and maximum sensitivity, both biasing resistors were chosen to be the same value and were designated R_{B1} (in parallel with R_D) and R_{B2} (in parallel with R_R). The value of R_{B1} and R_{B2} which are equal will be referred to as R_B.

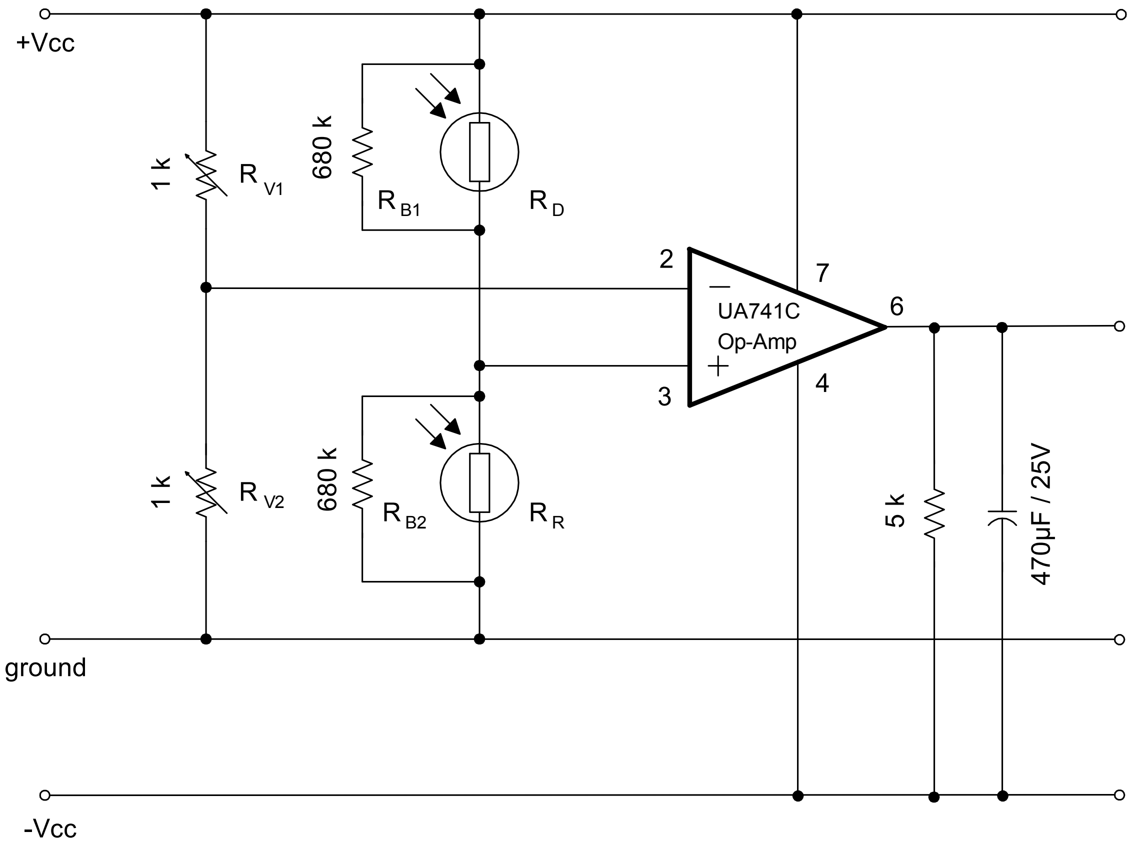


Fig. 2.6 Light Beam Detector Circuit with Biasing Resistors

The experimentally determined value of the resistance of the LDRs when the detector resumed proper operation, 690kΩ, is obviously the maximum value that can be used as the biasing resistors. Recall that in complete darkness the LDRs have infinite resistance. In absolute darkness the bias current will be supplied through these resistors.

Lower resistance values can be used to supply the input bias current, but as can be seen from Fig. 2.6 the biasing resistors are placed each in parallel with one LDR, since the circuit is to be activated/deactivated by varying the effective resistance of R_D in parallel R_{B1} with respect to R_R in parallel with R_{B2}, the value of the biasing resistors have to be chosen carefully.

If a smaller value of resistance say 10kΩ is chosen for R_B, the effective change of resistance from the parallel arrangement as a result of the illumination of the LDRs will be less than if a higher value of R_B, say 680kΩ, is chosen. As an illustration, Fig. 2.7 shows a fixed resistor connected in parallel with an LDR. For different values of the fixed resistance, the effective value of the parallel arrangement will vary for a fixed range of LDR resistance variation as shown in Table 2.1. This table was mathematically derived.

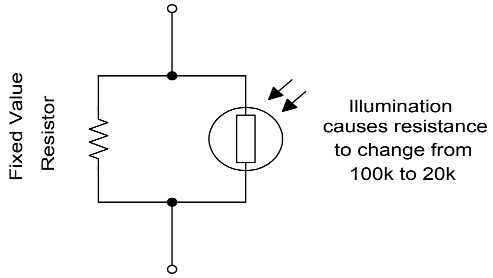


Fig 2.7 Parallel Arrangement of Fixed Resistor and Light Dependent Resistor

Table 2.1 shows the change of effective resistance of the parallel arrangement of an LDR and a fixed resistor as a result of a fixed change of LDR resistance due to illumination. The table shows the nominal value of change in resistance and gives percentage change of resistance for five values of fixed resistors when the light dependent resistor's resistance changes from 100kΩ to 20kΩ as a result of illumination. The five values of fixed Resistors used are 10kΩ, 180kΩ, 350kΩ, 500kΩ and 680kΩ.

Percentage change of resistance is calculated using:-

$$\text{Percentage Change of Resistance} = \frac{\text{Final Resistance - Initial Resistance}}{\text{Initial Resistance}} \quad \ldots\ldots\ldots\ldots\ldots \quad 2.6$$

Table 2.1 Effect of Fixed Resistor Value on Change of Effective Resistance of Parallel Connection of Fixed Resistor and LDR

Fixed Resistor Value (Ohms)	Initial Effective Resistance when LDR=100kΩ	Final Effective Resistance when LDR=20kΩ	Change of Resistance (Negative) (Ohms)	Percentage Change (Negative) (%)
10kΩ	9.091kΩ	6.667kΩ	2.424kΩ	26.67%
180kΩ	64.280kΩ	18.000kΩ	46.280kΩ	72.00%
350kΩ	77.777kΩ	18.919kΩ	58.858kΩ	75.68%
500kΩ	83.333kΩ	19.230kΩ	64.103kΩ	76.92%
680kΩ	87.179kΩ	19.429kΩ	67.750kΩ	77.71%

As can be seen from Table 2.1, the higher the value of the fixed resistor used to ensure proper input bias, the higher the percentage change in effective resistance of the parallel arrangement when the LDR resistance changes by a constant amount, from 100kΩ to 20kΩ, due to a fixed change of illumination. In other words, the ability of the LDR to influence a change in the effective resistance of the LDR and Fixed Resistor in parallel arrangement is enhanced by using the highest possible Fixed Resistor Value.

Since the detector is designed to compare the relative levels of voltage at its inverting and non-inverting inputs, the percentage change of resistance in the two halves of the voltage divider network created by the LDRs is more important for illumination level difference detection than the actual resistance values.

As a result of the preceding analysis, the value for R_{B1} and R_{B2} was chosen to be the highest standard value of commercially available resistors lower than or equal to 690kΩ which is 680kΩ.

When implemented, in practice, the effect of the infinite resistance of the LDRs in darkness and subsequent malfunction of the Op-Amp comparator due to input bias current insufficiency was completely eliminated.

2.8 LIGHT DEPENDENT RESISTOR SENSITIVITY IMPROVEMENT

In complete darkness, direct illumination perpendicular to the light sensitive surface of the LDRs by a flashlight powered by 3V (two 1.5V cells in series) and using a 2.5V/ 0.4W bulb can change the resistance of the LDRs from its infinite value to any value between 180kΩ and 400kΩ from a distance of 4.0m. When the detector LDR is illuminated in this situation, the voltage at the non-inverting input to the Op-Amp comparator rises steeply to a value between 4.00V to 5.85V. With the voltage at the inverting input set at just above 3.0V (user adjustable), the output of the detector would be HIGH (activated). In other words, in darkness the percentage change of the resistance of the LDR is very high and the light beam can be easily detected.

In bright ambient lighting conditions, as obtains indoors during the daytime or when electrical lights are on (day or night); the exposed LDR can have a resistance as low as 8kΩ, depending on its location with respect to the light sources. In such high levels of ambient illumination, the same flashlight from the same distance of 4.0m and illuminating the LDR in the same manner as described above, would change an LDR resistance of 8kΩ to about 7.9kΩ, this represents a very small percentage change in resistance. As a result, the resultant percentage change of the resistance of the detector LDR (in parallel with the bias resistor R_{B1}) with respect to the reference LDR (in parallel with R_{B2}) is very low and insufficient to increase the voltage at the non-inverting input to a value higher than that set at the inverting input. In other words, in high ambient light, the percentage change of the resistance of the exposed LDRs is too small for the flashlight beam, from a distance of 4.0m, to be detected.

In order for the detector to detect the flashlight beam from a distance of up to 4.0m in a reasonably wide range of ambient illumination, some investigations were carried out on the LDR as a device to find out how its sensitivity to a focused beam of light from a flashlight in the presence of high levels of ambient illumination can be improved.

Given the almost perfect response of the detector in darkness, a means by which the high percentage change of resistance can be achieved in high level ambient illumination was sought.

It was found that by encasing the LDR in a specially designed white translucent cylindrical case and positioning it, within the case, in such a way that its light sensitive surface does not receive any direct illumination from the exterior, the sensitivity of the system to the flashlight beam was improved very significantly. Within the casing, the LDR receives only reflected light. By mimicking darkness, the casing enabled the LDR to maintain dark sensitivity (percentage change of resistance as a result of the illumination) and improved its sensitivity in high levels of ambient light.

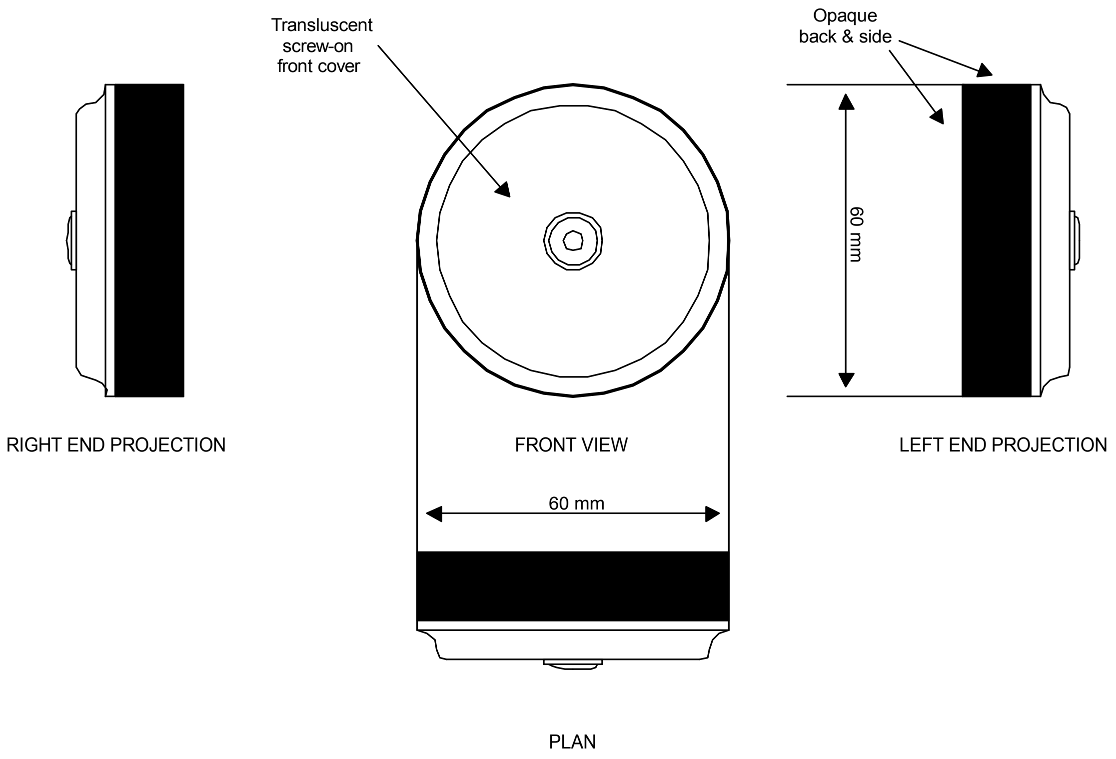


Fig. 2.8 Light Dependent Resistors Enclosure

The casing designed for the LDRs for improved sensitivity is shown in Fig. 2.8. The placement of the LDR within the case is also illustrated in Fig. 2.9.

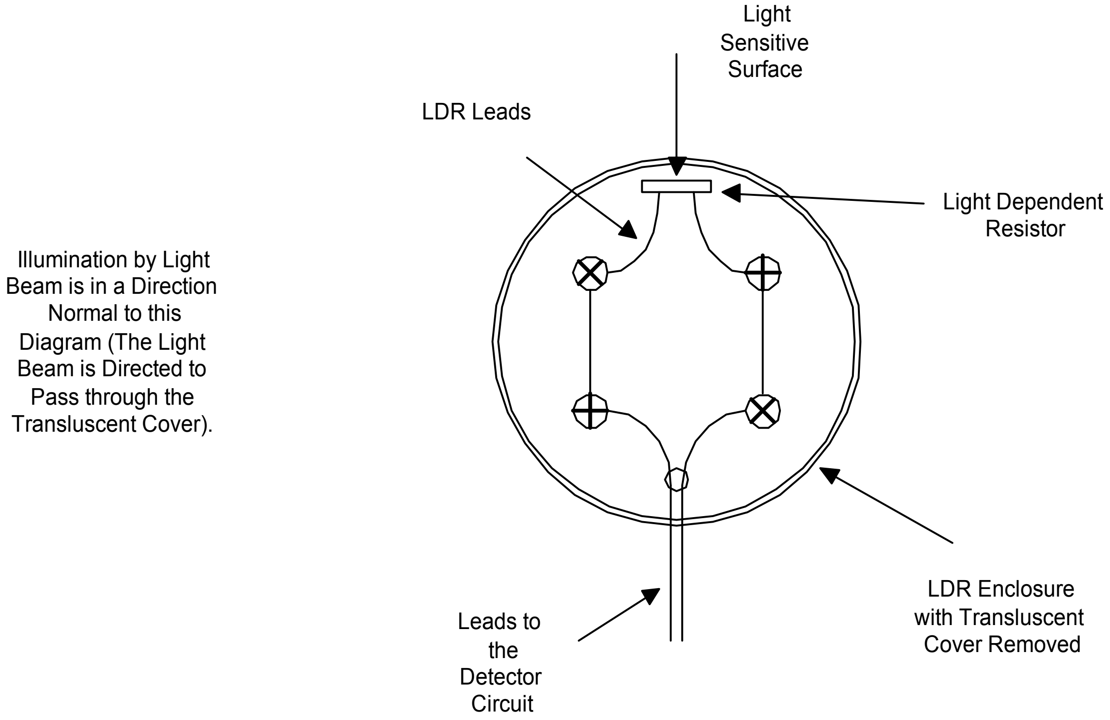


Fig. 2.9 Placement of the LDRs within the Enclosure

Tables 2.2 – 2.9 present values of LDR resistances before and after illumination by the controller, a 3V flashlight using a 2.5V/0.4W bulb, and shows the calculated percentage change of resistance when illuminated from 1.0, 2.0, 3.0, 4.0 and 5.0m respectively in four levels of ambient illumination.

By placing the LDR (exposed and then encased) at four fixed distances (from a 220V/60W incandescent light bulb), the four levels of ambient illumination are created. Distances of 1.0, 2.0, 3.0, and 4.0m were used. The readings were carried out at night in a closed room where no other light sources were present. Ambient Illumination Level 1 (A.I.L. 1) indicates the brightest ambient illumination level, which is when the LDR is only 1.0m away from the powered 220V/60W incandescent light bulb; Ambient Illumination Level 2 (A.I.L. 2) indicates that the LDR is 2.0m away from the bulb, Ambient Illumination Level 3 (A.I.L. 3) indicates that the LDR is 3.0m away from the bulb and Ambient Illumination Level 4 (A.I.L. 4) indicates that the LDR is 4.0m away from the bulb.

Because of the wide variation of parameters of identical LDRs and lighting conditions within buildings, actual illuminance readings using a photometer were not used because the resistance readings and the percentage change of resistance calculations where indicative enough of the effectiveness of the encasing of the LDRs.

The exposed LDR is illuminated by the remote flashlight directly (perpendicular to the light sensitive surface).

The encased LDR is placed in specially designed case as shown in Fig. 2.8 and Fig. 2.9 and the casing is illuminated by the flashlight in the direction perpendicular to the front cover of the casing so that the light beam passes through the translucent cover.

Table 2.2 Percentage Change of Resistance of the Exposed LDR in A.I.L 1

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	25.3	3.5	86.16
2.0	25.3	8.4	66.80
3.0	25.3	12.4	50.99
4.0	25.3	18.5	26.88
5.0	25.3	21.0	17.00

Table 2.3 Percentage Change of Resistance of the Encased LDR in A.I.L. 1

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	12350	358	97.10
2.0	12350	635	94.86
3.0	12350	1140	90.77
4.0	12350	1450	88.26
5.0	12350	1535	87.57

Table 2.4 Percentage Change of Resistance of the Exposed LDR in A.I.L. 2

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	54.1	10.9	79.85
2.0	54.1	18.5	65.80
3.0	54.1	25.2	53.42
4.0	54.1	31.2	42.33
5.0	54.1	33.9	37.34

Table 2.5 Percentage Change of Resistance of the Encased LDR in A.I.L. 2

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	26280	416	98.42
2.0	26280	720	97.26
3.0	26280	1699	93.54
4.0	26280	3078	88.29
5.0	26280	6787	74.17

Table 2.6 Percentage Change of Resistance of the Exposed LDR in A.I.L 3

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	120	4.2	96.50
2.0	120	15.5	87.08
3.0	120	24.2	79.83
4.0	120	35.7	70.25
5.0	120	49.1	59.08

Table 2.7 Percentage Change of Resistance of the Encased LDR in A.I.L. 3

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	26300	465	98.23
2.0	26300	780	97.03
3.0	26300	1825	93.06
4.0	26300	4010	84.75
5.0	26300	7370	71.98

Table 2.8 Percentage Change of Resistance of the Exposed LDR in A.I.L. 4

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	145.5	6.4	95.60
2.0	145.5	11.6	92.03
3.0	145.5	20.7	85.77
4.0	145.5	32.1	77.94
5.0	145.5	52.6	63.85

Table 2.9 Percentage Change of Resistance of the Encased LDR in A.I.L 4

Illumination Distance in meters (m)	LDR Initial Resistance (kΩ)	LDR Final Resistance (kΩ)	Percentage Change Of Resistance (%)
1.0	26305	470	98.21
2.0	26305	944	96.41
3.0	26305	1945	92.61
4.0	26305	4055	84.58
5.0	26305	7394	71.89

From a comparison of Table 2.2 with Table 2.3, Table 2.4 with Table 2.5, Table 2.6 with Table 2.7, and Table 2.8 with Table 2.9 it is obvious that the specially designed enclosure for the LDR is very effective in increasing the sensitivity of the LDR in the presence of high levels of ambient illumination. It can also be observed that as the ambient illumination level reduces from A.I.L. 1 to A.I.L. 4 the percentage change of resistances get closer in value whether the LDR is exposed or encased. The casing has a reduced effect as the ambient illumination level reduces.

The effect of the enclosure is most evident in the brightest ambient illumination, A.I.L 1. In a comparison of Table 2.2 with Table 2.3, it can be seen that when exposed the percentage change of resistance falls from 86.16% at 1.0m illumination distance to just 17.00% at 5.0m. When encased however, the percentage falls from 97.10% at 1.0m illumination distance to 87.57% at 5.0m. This implies that encasing the LDR makes the detector system "see" the control light beam better in high ambient illumination levels.

To further emphasize the effectiveness of the enclosure, Fig. 2.10 shows a graph of the Percentage Change of Resistance vs. Illumination Distance of 3.0m for the exposed and encased LDR for the four ambient illumination levels.

Table 2.10 was obtained by extracting the required values from Table 2.2 to Table 2.9. The graph in Fig. 2.10 is a plot of the values in Table 2.10.

Table 2.10 Percentage Change of Resistance of Exposed and Encased LDRs when illuminated from Three meters in A.I.L. 1 – 4

Ambient Illumination Level A.I.L.	Percentage Change of Resistance of Exposed LDR (%)	Percentage Change of Resistance of Encased LDR (%)
1	50.99	90.77
2	53.42	93.54
3	79.83	93.06
4	85.77	92.61

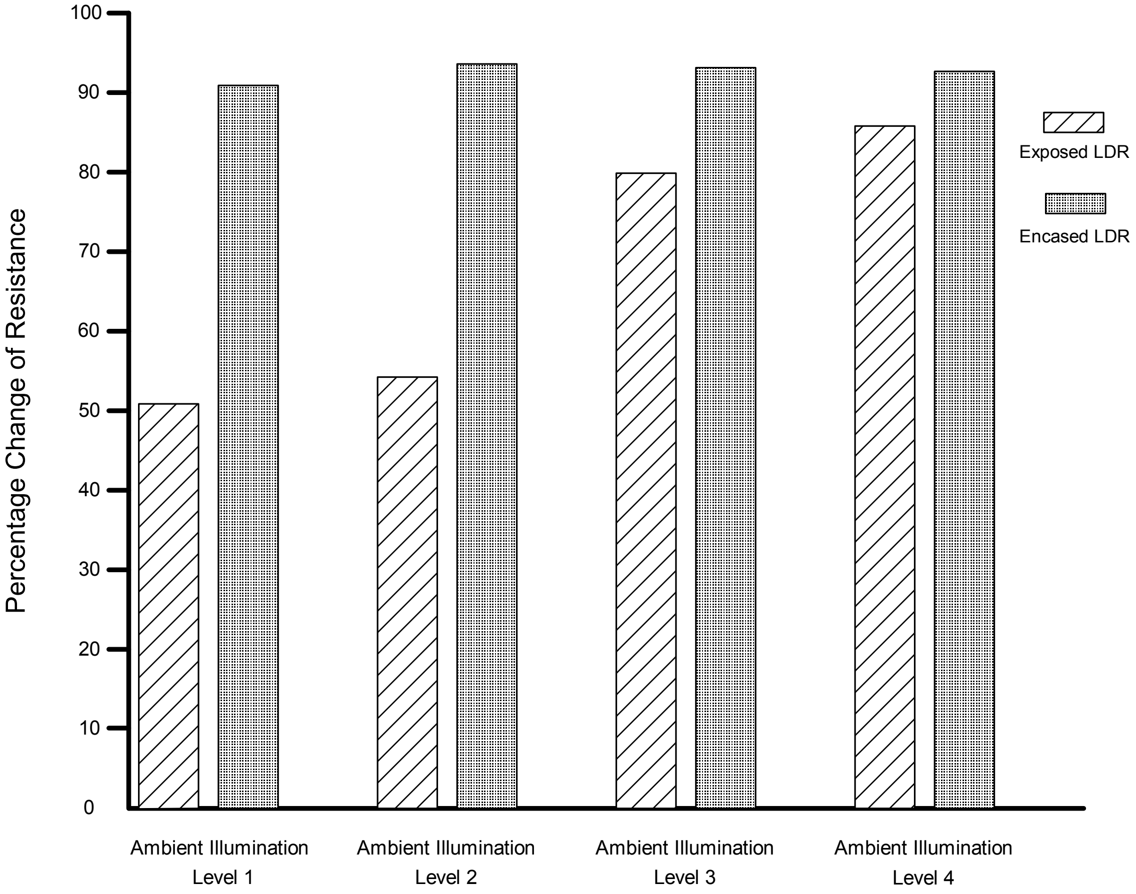


Fig. 2.10: Plot of Percentage Change of Resistance of Exposed and Encased LDRs when illuminated from Three meters in A.I.L. 1 – 4

It can be seen from the graph in Fig 2.10 that the percentage change of resistance is higher for the encased LDR than for the exposed LDR for all ambient illumination levels. However, it can also be observed that the higher the ambient illumination level, the lower the percentage change of resistance for both exposed and encased LDRs. (Recall, Ambient Illumination Level 1 is the brightest and Ambient Illumination Level 4 is the least bright). This indicates that even when the LDRs are placed in the special casing, the distance from which the control beam can be detected will reduce with increasing ambient illumination.

The foregoing analysis explains the need for placing the LDRs in specially designed enclosures. In fact, without the enclosure the system would mainly be effective in the dark where the focused flashlight beam can be detected from distances even greater than 4.0m. Without the special enclosure, in indoors daytime illumination, the flashlight beam would only be detectable from a short distance depending on the ambient illumination level. This distance is typically not more than 1.5m.

The main effect of the special casing of the LDRs is to allow the system to be sensitive to the flashlight beam (the control signal) from distances up to 4.0m in the daytime as well as at night. If the detector was designed for night time (darkness) use only, the casing of the LDRs would be unnecessary. This is evident from the graph as the percentage change of resistance of the exposed or encased LDRs become closer in value as the ambient illumination level decreases to A.I.L. 4.

2.9 LUMINOUS INTENSITY DIFFERENCE DETECTOR OUTPUT STABILIZATION

After solving the problem of input bias current requirements by the inclusion of bias resistors (R_{B1} and R_{B2}) in parallel with the LDRs and encasing the LDRs in specially designed enclosures, the detector circuit was constructed and tested. It proved to be very effective and reliable at detecting the focused beam of light from the specified flashlight (3V power source, 2.5V/0.4W bulb). The beam was detectable from an average distance of 4.0m, daytime (indoors) and 8.0m at night (dark).

Using the red LED at the output to observe the change of state from LOW (LED off) to HIGH (LED on), when the detector LDR is illuminated, and HIGH to LOW, when the light beam is withdrawn, indicated a perfect operation. However, on observing the output using an oscilloscope, occasionally, the following waveforms, as reproduced from an oscilloscope, were observed.

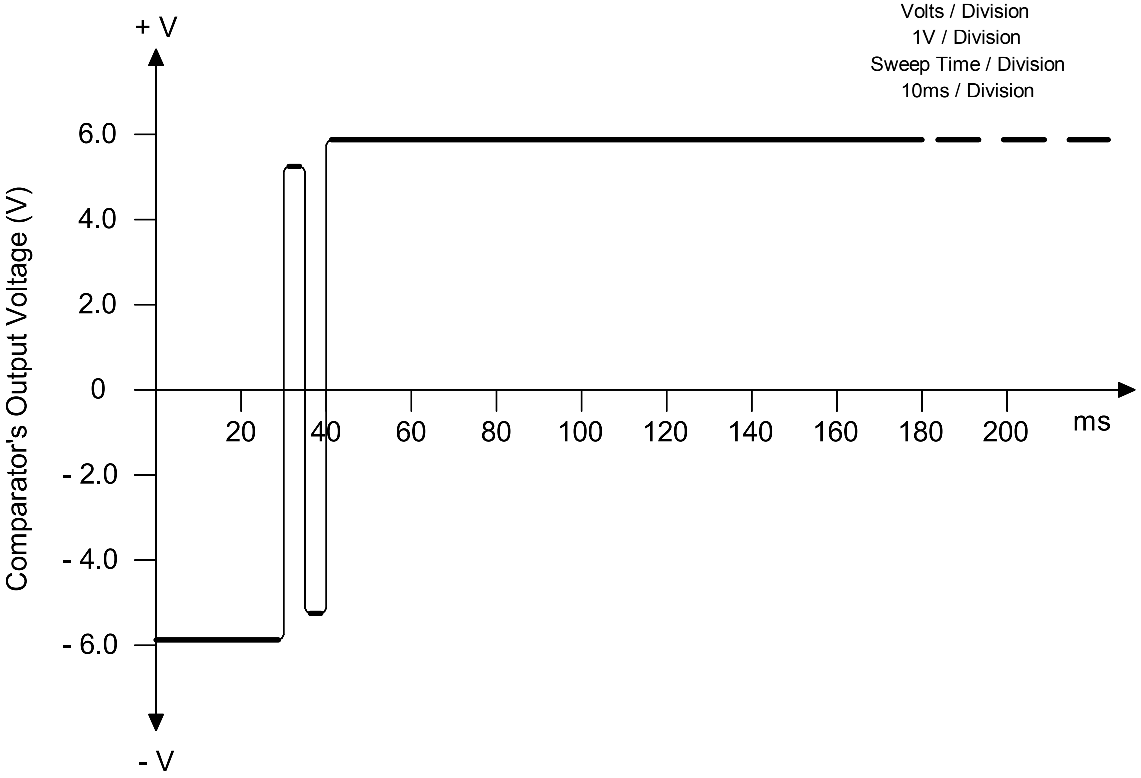


Fig.2.11 Transient in Detector's Output during Level Change on Detection of the Light Beam

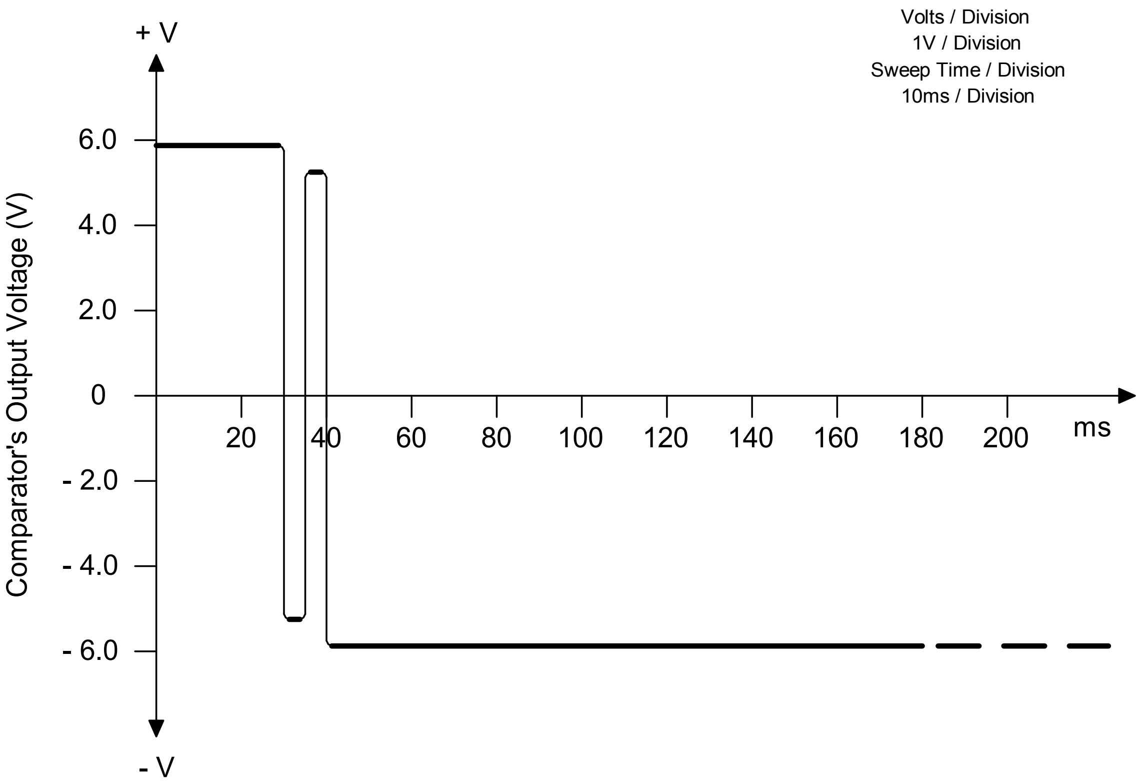


Fig.2.12 Transient in Detector's Output during Level Change on Withdrawal of the Light Beam

As seen from the Fig.2.11, occasionally, when the detector LDR is illuminated, the output of the Op-Amp which is initially LOW, changes state (LOW-HIGH-LOW) before rising to the final steady HIGH state and remains HIGH as long as the LDR is illuminated. Also, in Fig.2.12, occasionally, when the light beam is suddenly withdrawn, the output, which is initially HIGH, changes state (HIGH-LOW-HIGH) before settling to the final LOW state. This transient behavior is undesirable as it could cause the subsequent stages of the controller to malfunction since it relies on a steady HIGH state to initiate the control action and steady LOW state to stop the control action.

The cause of this transient unsteady behavior was investigated and it was concluded, among other reasons, that the response of the resistance of the LDR to luminous intensity changes is not linear from initial value to final value.

The LDR is a semiconductor device made of cadmium sulphide, when illuminated by visible light; it absorbs photons of light energy. This energy from the light is used to liberate electrons from the outer shell of the molecules; this creates electron-hole pairs, with the liberated electrons free to conduct current. The amount of free electrons is proportional to the amount of light energy the material is exposed to. A high number of free electrons in the material implies a high conductivity. The higher the conductivity of the material, the lower its resistance. In complete darkness, its resistance is infinite because, then, there are no free electrons to carry current.

The process by which electrons are liberated by or recombine with molecules when the LDR is exposed to different levels of illuminance takes place randomly and over time. This fact explains why the resistance does not change linearly or immediately.

The typical resistance rise time is quoted for the LDR used in this work as 75 milliseconds. This value depicts the time required for the resistance to change from its initial low steady value to its final high steady value when the illuminance suddenly falls to a lower value.

The typical resistance fall time is 350 milliseconds. This value depicts the time required for the resistance to change from its initial high steady value to its final low steady value when the illuminance suddenly increases to a higher value.

Comparing these two values shows that it takes a shorter time for the electrons to be liberated from the molecules than it takes for them to recombine with the molecules.

In either case, the process by which the resistance value changes is not linear, the possession of a response time by LDRs indicates that they have capacitive properties.

The resistance actually increases and decreases in a fashion similar to the charging and discharging of a capacitor. However, its response to luminous intensity changes is not as smooth as a capacitors charging or discharge curve. This occasionally results in the toggling of the comparator's output before the final LOW or HIGH state is reached.

Another reason for this transient in the output of the light beam detector is that the beam is pointed at the detector by hand, unless the beam is held very steadily, its intensity at the detector would vary with the slight movements of the hand while pointing the beam at the detector. This is almost inevitable.

It should also be noted that the light energy delivered by a flashlight beam does not have an even intensity along the cross-section of the beam and as a result slight movements of the hand while pointing the beam at the detector or retracting the beam from the detector can cause these output transients.

To prevent these transients from causing unsteady operation of the subsequent circuitry which controls the ON/OFF state of the to the oscillator circuit, a filter would be needed. This filter would reduce the magnitude of the transient voltages to a level where they would not be able to cause the relay contacts of the oscillator power controller to switch off or on in response to the transients.

A simple filter capacitor was decided upon. A capacitor could be placed across the detector LDR, but this would cause a slow response of the system to a retraction of the beam of light. The response will be slow because of the time it would take for the capacitor to charge or discharge through the high value resistance of the parallel arrangement of bias resistors and LDR. For the purpose of the kind of control intended for this system, where the power or speed control is achieved through toggling, a quick response to the retraction of the beam of light is of paramount importance.

Consequently, it was decided that the filter capacitor would be placed at the output of the comparator to filter out the transients and allow the change of state of the output from HIGH to LOW and vice versa to be smoother.

A 470µF/25V capacitor and a 5kΩ resistor in parallel placed across the output and

–Vcc was used. The 5kΩ resistor serves as a pull down resistor to reduce the time the output returns to the LOW state from the temporary HIGH state which exists only when the beam of light is detected. The resistor also does this by providing a path for the filter capacitor to discharge.

With the filter capacitor in place, the occasional transients waveform in the transition of the output from LOW to HIGH and HIGH to LOW as shown in Fig. 2.11 and Fig. 2.12 respectively were reduced in shape and magnitude in the manner shown in the Fig. 2.13 and Fig. 2.14. Both figures were also reproduced from the output of an oscilloscope.

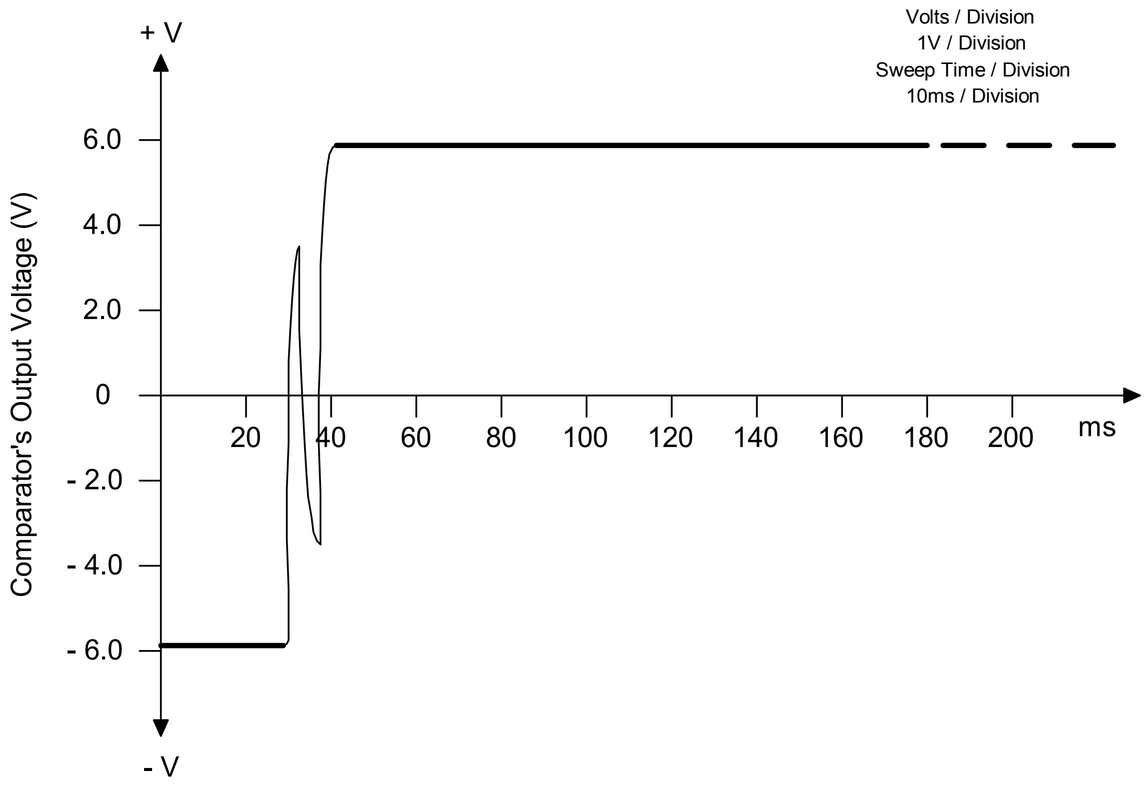


Fig. 2.13 Filtered Output of the Detector on Detection of the Light Beam

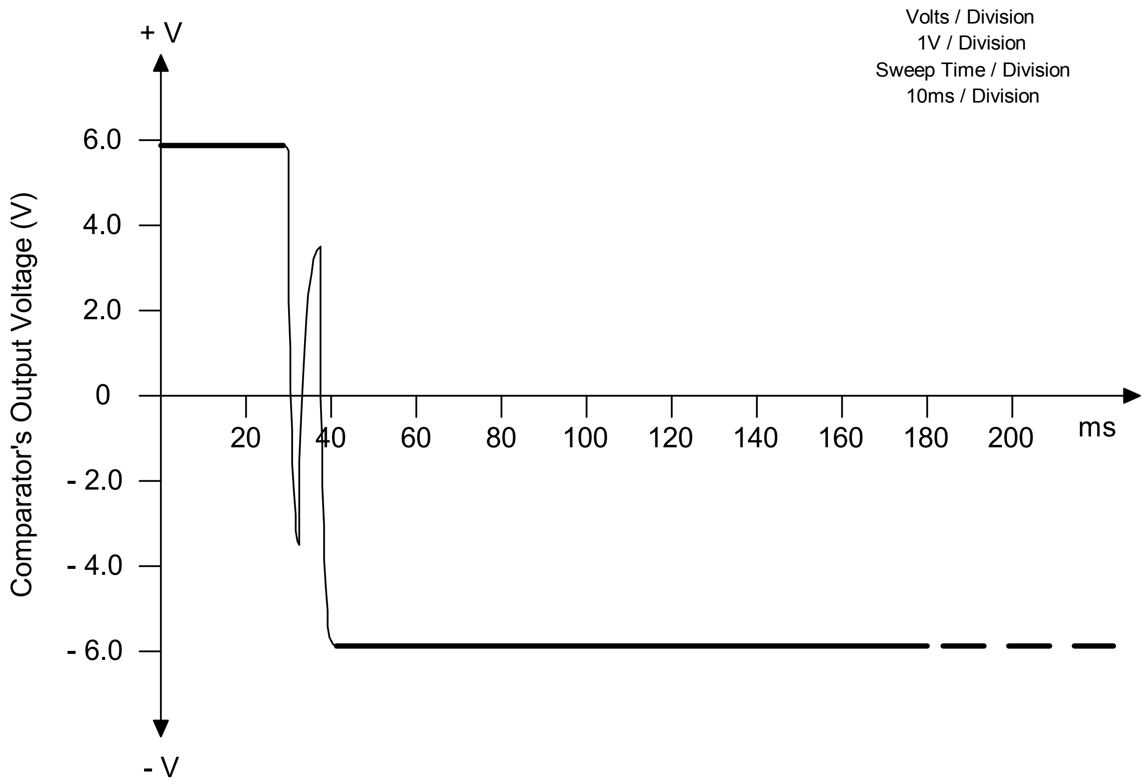


Fig. 2.14 Filtered Output of the Detector on Withdrawal of the Light Beam

It is important to note that, the transients discussed here occur only occasionally. Most of the time, the transition of state at the output from the light beam detector circuit takes place smoothly from LOW to HIGH (When the light beam is detected) and HIGH to LOW (When the light beam is withdrawn from the detector LDR). The filter capacitor placed at the output of the light beam detector (in conjunction with that placed across the oscillator switch's relay coil of the subsequent stage) serve only to improve the reliability of switching by filtering out these occasional transients.

The final circuit of the luminous intensity difference detector is shown in Fig.2.15. This circuit was found to be very reliable, has a good response time and is free from false triggering from random light sources and power supply fluctuations.

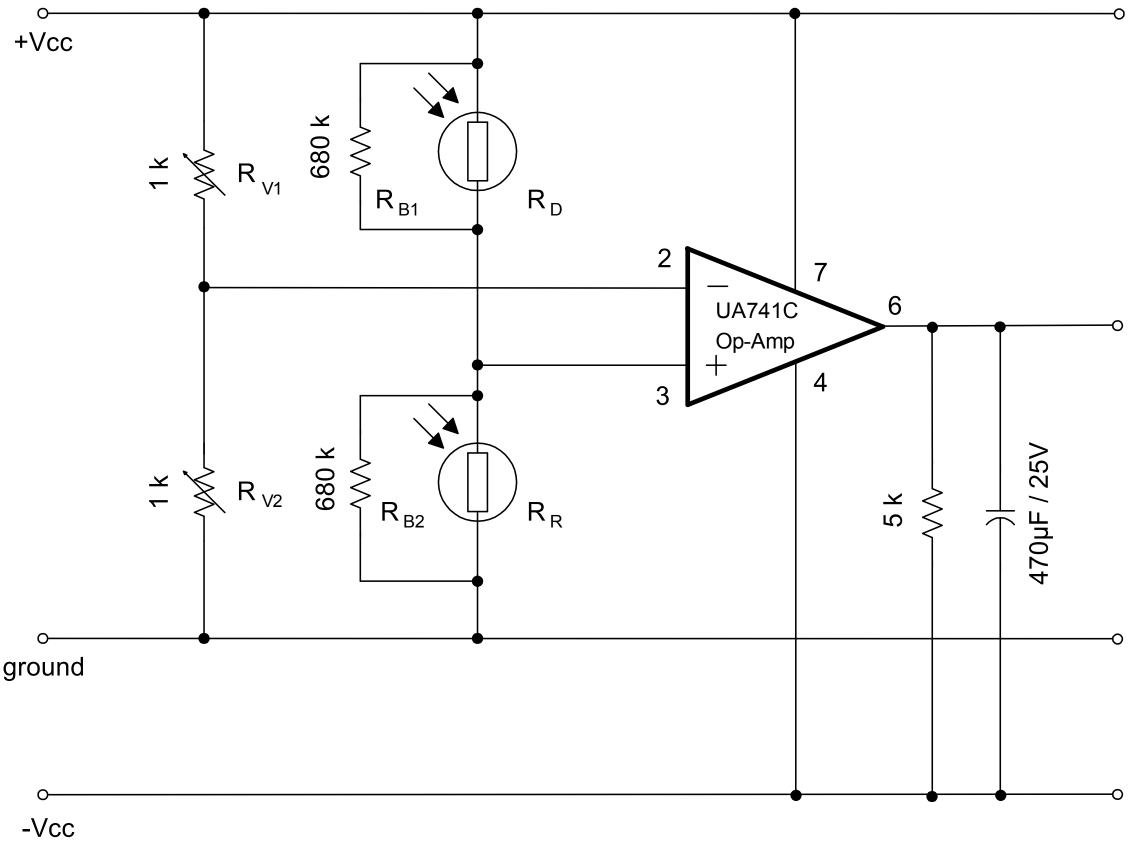


Fig 2.15 The Final Luminous Intensity Difference Detector Circuit

In summary, for the luminous intensity difference detector shown in Fig. 2.15 to function properly in a wide range of ambient illumination there has to be;

1) Biasing Resistor R_{B1} and R_{B2}. The value of these resistors:-

    a) Will depend on the particular type of comparator IC to be used.

b) Should be experimentally determined, for the particular comparator IC to be used, using the procedure described in section 2.7, since datasheet do not specify a minimum value for the input bias current I_B.

c) Should be the maximum possible values (and equal) for maximum sensitivity. (The LDRs should also be of the exact same type).

2) The LDRs must be encased to increase their ability to detect the light beam (the control signal). The following should be noted about the enclosure;

a) The design presented in Fig. 2.8 and Fig. 2.9 is a basic design. For example, in order to have a better response in a room with a high ambient illumination, the diameter of the translucent path, through which ambient light can pass, can be reduced by making the outer circumference of the translucent cover opaque.

b) The enclosure can be realized in an infinite number of shapes and sizes as long as they shield the LDRs from as much ambient illumination as possible while still allowing a focused light beam, perpendicular to the translucent cover, to pass through.

2.10 THE OSCILLATOR SWITCH

The detection of the beam is indicated by the HIGH output from the comparator circuit. To use this ‘beam detected’ state to initiate the control action to be carried out by the subsequent stages of the system, it would be used to turn the power to the oscillator ON.

The oscillator is a square wave generator that produces a continuous train of clock pulses which would be used to change the state of the output of the ceiling fan regulator.

Among the several alternatives that could be used to make the HIGH state of the comparators output to turn on the clock pulse generator, a relay switch was decided upon. This has the disadvantage of higher power consumption than a transistor switch, but unlike a transistor switch its output can only assume one of two states, on or off and no state in between. The relay also has an advantage of the sound it makes when the switch contacts were closed and opened, this helps the human controller know when the beam has been detected. Fig. 2.16 shows section of circuit used to switch the oscillator circuit on whenever the control light beam is detected.

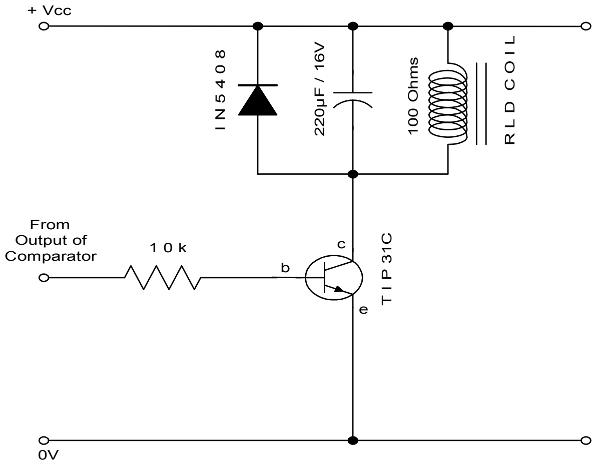


Fig. 2.16 The Oscillator Switch

When the output from the light beam detector is LOW, the transistor TIP31C is off and is operating in the cut-off region of its operating characteristics. The entire +6V supply voltage is applied across the transistor. $V_{CE} = +6V$.

The TIP31C transistor is a silicon NPN transistor, its common use is for the power stages in audio frequency applications. Some of its specifications include V_{CE} (max.) of 55V, I_C (max.) of 3A and P_{TOT} (max. permissible device dissipation) = 40W at 25^{O}C. [12]

When a light beam is detected and the output from the comparator is set HIGH, the transistor is turned on through the 10kΩ current limiting resistor. The transistor is saturated and its collector-emitter voltage, V_{CE}, is approximately equal to 0V. Consequently, the entire positive supply voltage, +6V, is applied across the relay's coil. The relay coil is fully powered after a very short delay as the 220μF/16V capacitor charges across it. When sufficient power is applied across the relay coil, its switch contacts close. The closing of the relay's switch contacts is used to supply power to the subsequent circuit, the oscillator. The diode, in parallel with the relay's coil and the 220μF/16V capacitor, is connected in reverse bias as a free-wheeling diode to drain the high current that is created when the energy stored in the magnetic field of the relay coil returns to the circuit whenever the transistor switches off. This protects the transistor from damage.

The combination of the 470μF/25V capacitor at the output of the comparator and the 220μF/16V across the relay RLD coil help to filter out detection transients and cause the relay contacts to close and open after a small delay on the detection and withdrawal of the light beam to ensure reliability of detection in the light beam detector system.

2.11 THE POWER SUPPLY UNIT

Use of the UA741C Op-Amp as a voltage comparator requires a bi-polar power supply. Pin 7 is supplied a positive supply voltage +Vcc and pin 4 is supplied a negative voltage

–Vcc. The +Vcc, -Vcc, inverting input, non-inverting input and output voltages are referenced to the ground power terminal.

The ceiling fan and its regulator coil are A.C. powered hence it is expedient to modify the same A.C. supply to power the electronic circuitry.

The circuit diagram of the power supply unit for the electronic ceiling fan regulator is shown in Fig. 2.17.

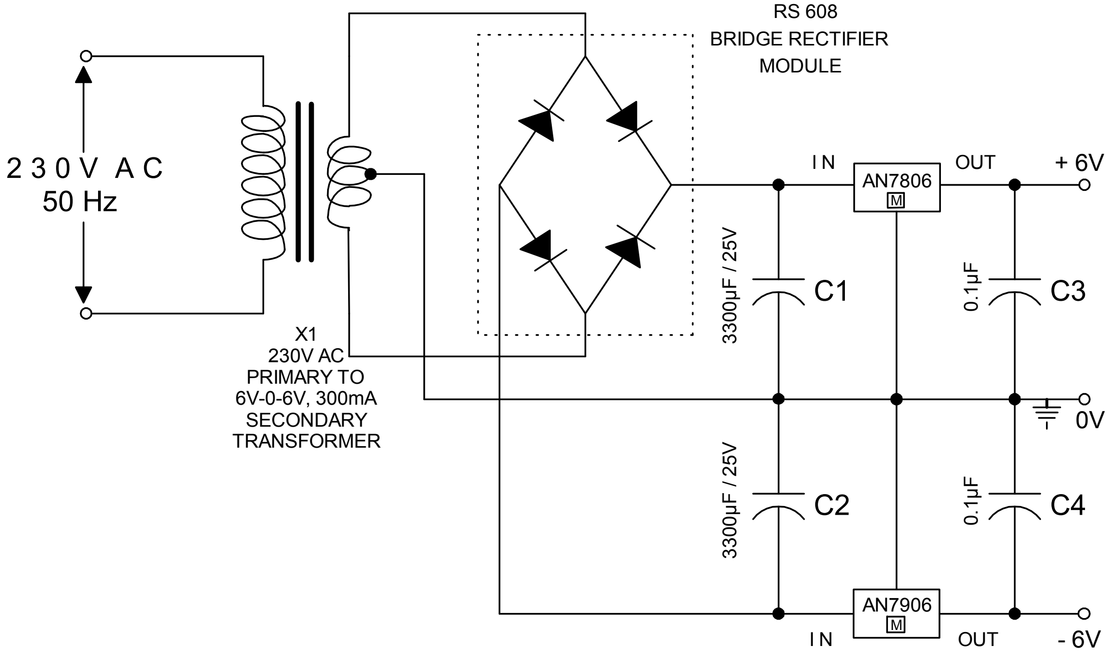


Fig. 2.17 The Power Supply Unit.

This circuit uses a 50Hz/230V AC primary to 6V-0-6V, 300mA secondary step-down transformer, the AC output from the transformer is rectified across the complete secondary coil (12V) using a modular bridge rectifier unit the RS 608 Bridge Rectifier. Two AC filter capacitors C1 and C2 both 3300µF/25V are connected in series across the output from the bridge rectifier. The center-tap connection from the transformer is connected to the junction between the two filter capacitors, this serves as the ground connection for the bipolar DC supply output.

The DC voltage between the positive output from the bridge rectifier and the ground is +8.46V. This is obtained by multiplying the AC voltage 6V by a factor of 1.41 as a result of full-wave rectification. Similarly, the voltage between the negative output from the bridge rectifier and the ground is -8.46V.

Two voltage regulator modules, the AN7806 a positive 6V regulator and AN7906 the negative voltage equivalent, are used across capacitors C1 and C2 to produce a smooth regulated DC +6V and -6V output from the filtered DC supply.

Two 0.1µF capacitors, C3 and C4, are used to further enhance the stability of the DC voltages.

CHAPTER THREE

TIMER AND COUNTER BASED SWITCHING CIRCUIT

3.1 INTRODUCTION

After the control beam has been detected, a simple means by which the ceiling fan can be activated, change speeds and be deactivated needs to be devised. This can be achieved by a simple cycle whereby, when the control beam is detected, the ceiling fan regulator would cycle from the ‘off’ state to the ‘on’ state at speed one, then to speed two, speed three, speed four, speed five and eventually off again. This cycle would only terminate when the control beam is withdrawn from the detector LDR, consequently the controlled output will remain in the state it was when the beam was withdrawn. For example if the beam is withdrawn when the fan regulator is set at speed three, the fan remains at speed three unless it detects the beam again whereby it continues the cycle and goes to speed four and so on.

To achieve this, a common circuit is used. The output from the light beam detector is used to turn a clock pulse generator circuit ON. This circuit consists of the NE555 Timer IC which is used in its astable multivibrator mode to generate clock pulses. The clock pulses from the astable multivibrator are used to trigger a CD4017BC Decade Counter/Divider IC. The output from the CD4017BC IC is decoded which implies that with every count only one of its ten different outputs is activated (HIGH) while all the rest are inactive (LOW). This fact allows the use of its different outputs to control the different states of the ceiling fan regulator.

3.2 THE 555 TIMER IC BASED CLOCK PULSE GENERATOR

All IC timers rely upon an external capacitor to determine the off-on time intervals of the output pulses. It takes a finite period of time for a capacitor (C) to charge or discharge through a resistor (R). Those times are clearly defined and can be calculated given the values of resistance and capacitance.

The 555 timer integrated circuit is a user friendly IC for both monostable and astable applications. Fig. 3.1 shows the block diagram of the 555 Timer. [13]

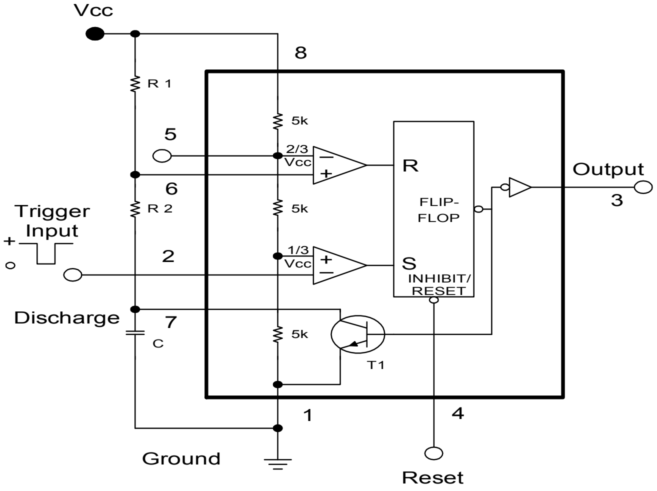


Fig. 3.1 Block Diagram of the 555 Timer

The 555 timer has two basic operational modes: monostable multivibrator (one-shot) and free-running multivibrator (astable). A monostable is said to have a single stable state – that is the off state. Whenever an input pulse triggers it the monostable switches to its temporary state. It remains in that state for a period of time determined by an RC network. It then returns to its stable state. In other words, the monostable circuit generates a single pulse of fixed time duration each time it receives an input trigger pulse. This explains the name ‘one-shot’.

The other basic operational mode of the 555 is as an astable multivibrator. An astable multivibrator is simply an oscillator. It is this mode that is used in this work to generate clock pulses. The astable multivibrator generates a continuous stream of rectangular off-on pulses that switch between two voltage levels. The frequency of the pulses and their duty cycle are dependent on the external RC network values.

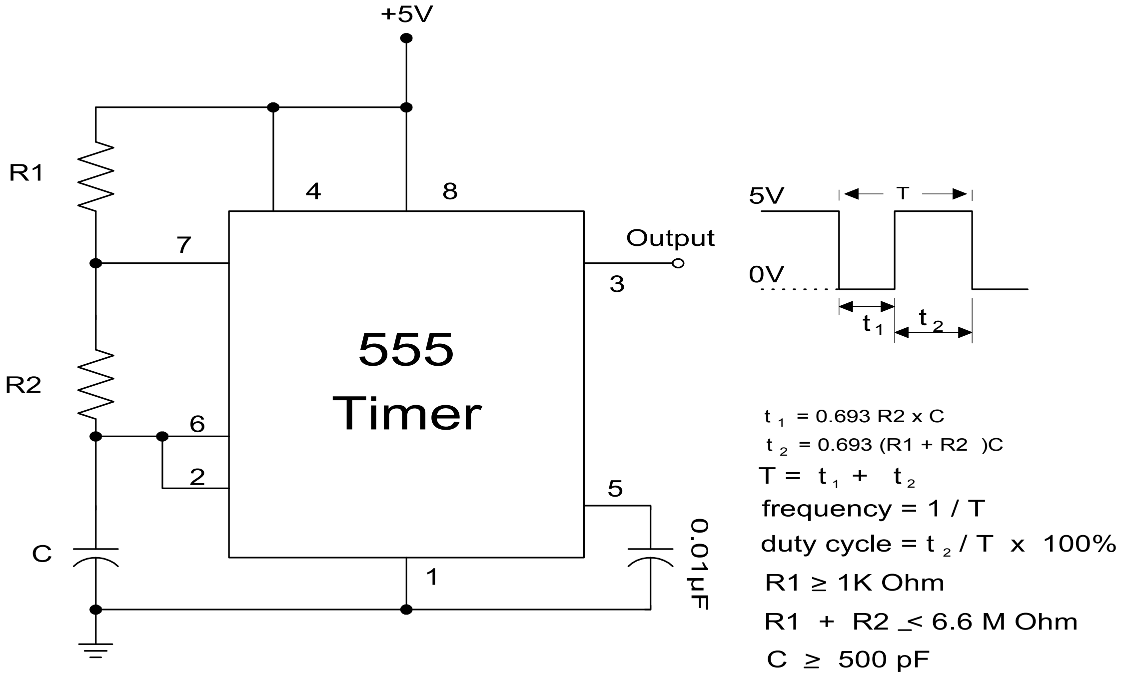


Fig. 3.2 The 555 Timer as an Astable Multivibrator [11]

Fig. 3.2 shows the 555 connected as an astable multivibrator. Both the trigger and the threshold inputs (pins 2 and 6) to the two comparators are connected together and to the external capacitor. The capacitor charges towards the supply voltage through the two resistors, R1 and R2. The discharge (pin 7) connected to the internal transistor is connected to the junction of those two resistors. When power is first applied to the circuit, the capacitor will be uncharged; therefore, both the trigger and threshold will be near zero volts (see Fig. 3.1). The lower comparator sets the control flip-flop causing the output to switch HIGH. That also turns off transistor T1. That allows the capacitor to begin charging through R1 and R2. As soon as the charge on the capacitor reaches 2/3 of the supply voltage, the upper comparator will trigger causing the flip-flop to reset. That causes the output to switch LOW. Transistor T1 also conducts. The effect of T1 conducting causes resistor R2 to be connected across the external capacitor. Resistor R2 is effectively connected to ground through internal transistor T1. The result of that is the capacitor now begins to discharge through R2.

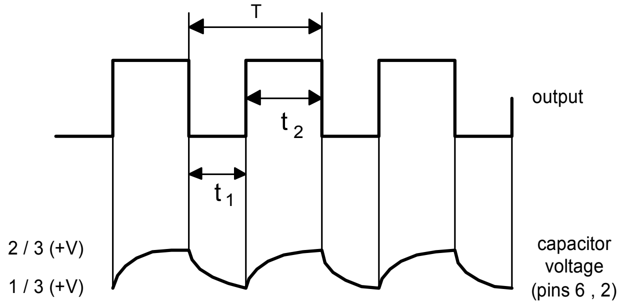


Fig. 3.3 Output Voltage versus Threshold & Trigger Input Voltage

As soon as the voltage across the capacitor reaches 1/3 of the supply voltage, the lower comparator is triggered. That again causes the control flip-flop to set and the output to go HIGH. Transistor T1 cuts off and again the capacitor begins to charge. That cycle continues to repeat with the capacitor alternately charging and discharging, as the comparators cause the flip-flop to be repeatedly set and reset. The resulting output is a continuous stream of rectangular pulses.

The frequency of operation of the astable circuit is dependent upon the values or R1, R2, and C. The frequency can be calculated with the formula:

$$f = \frac{1}{0.693 \times C \times (R1 + (2 \times R2))} \qquad \text{3.1}$$

The frequency f is in Hz, R1 and R2 are in ohms, and C is in farads. The time duration between pulses is known as the period, and usually designated with a 'T'. The pulse is on for t_2 seconds, then off for t_1 seconds. The total period, T, is equal to $t_1 + t_2$ (see Fig. 3.3). That time interval is related to the frequency by the relationship:

$$f = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{f} \qquad \text{3.2}$$

The time intervals for the 'on' and 'off' portions of the output depend upon the values of R1 and R2. The ratio of the time duration when the output pulse is HIGH to the total period is known as the duty-cycle. The duty-cycle can be calculated with the formula:

$$D = \frac{t_2}{T} = \frac{R1 + R2}{R1 + (2 \times R2)} \qquad \text{3.3}$$

t_1 and t_2 times can be calculated with the formulas below: [13]

$$t_1 = 0.693 \times R2 \times C \qquad \text{3.4}$$

$$t_2 = 0.693 \times (R1 + R2) \times C \qquad \text{3.5}$$

As Equations (3.4) and (3.5) indicate, the t_1 and t_2 intervals cannot be equal unless R1 is made equal to zero. This cannot be done without producing excess current through the device. This means that it is impossible to produce a perfect 50 percent duty-cycle square wave output. It is possible, however to get very close to a 50 percent duty cycle by making R2>>R1 (while keeping R1 greater than 1 kΩ), so that $t_1 \approx t_2$. [11]

In the design of the oscillator used in this system, the NE555 IC by SGS-Thomson® Microelectronics was used. The general description and detailed datasheet information about the NE555 Timer IC are contained in Appendix II. The 555 Timer based clock pulse generator used in this work is shown in Fig. 3.4.

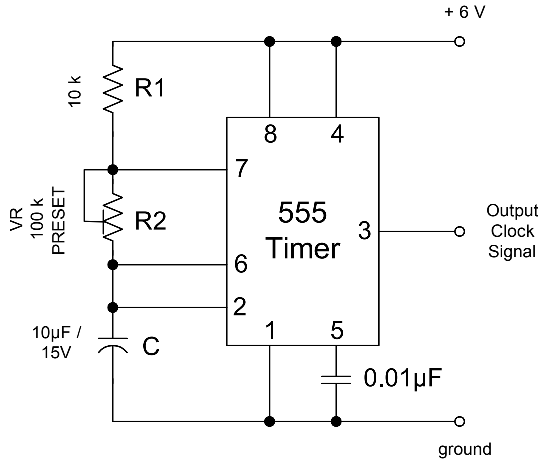


Fig. 3.4 The NE555 Timer Based Oscillator

With R1 = 10kΩ and C = 10µF, R2 can be varied between 0 and 100kΩ to produce a frequency of 14.43Hz to 0.69Hz. This range is calculated as shown using Equation (3.1). For this design, the variable resistor R2 is varied to give a period of approximately one second (frequency of 1Hz). This period was chosen to allow the human operator to conveniently respond to observe the changing states of the output from the regulator and withdraw the beam of light when the desired state is reached.

When R2 = 0kΩ,

$$f = \frac{1}{0.693 \times 0.00001 \times (10000 + (2 \times 0))} = 14.43 \text{ Hz}$$

When R2 = 100kΩ,

$$f = \frac{1}{0.693 \times 0.00001 \times (10000 + (2 \times 100000))} = 0.69 \text{ Hz}$$

3.3 THE CD4017BC IC BASED OUTPUT SWITCH CONTROL CIRCUIT

The CD4017BC Integrated Circuit is used to control the state of the output switches of the ceiling fan regulator. The output switches in turn determines when the ceiling fan is off or on at any of the five possible speed settings. The CD4017BC is a Decade Counter/Divider with ten decoded outputs. The general description and detailed datasheet information about the CD4017BC IC are contained in Appendix IV.

The CD4017BC IC was used in this work in the circuit configuration showed in Fig. 3.5.

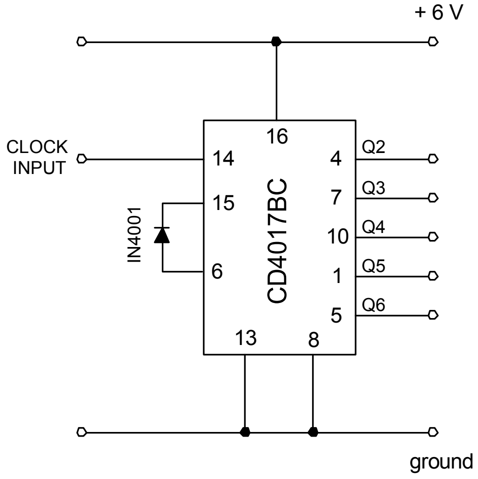


Fig.3.5 The CD4017BC IC Based Output Switch Control Circuit

Pin 16 of the counter, the positive power supply, V_{DD}, is connected to the same positive power rail as the preceding 555 Timer stage, the +6V Vcc line. The negative power supply line Vss at pin 8 is connected to the GROUND line of the Timer circuit. Pin 13 the CLOCK ENABLE pin is active low and so is also connected to the ground line. When active, connected to ground, it allows the IC to respond to clock inputs at pin 14.

When activated by the detector, the output from the 555 timer based clock circuit (pin 3) is used to clock the counter IC at pin 14. This causes the ten decoded outputs at pins 3,2,4,7,10,1,5,6,9, and 11 to become high and then low in sequence and never any two concurrently. In other words, with each positive transition of the clock signal only one of the ten decoded outputs from the counter is in the HIGH state. This fact is used in the subsequent stage to select one of the five outputs of the inductive coil of the ceiling fan regulator to connect to the regulators output.

In order to allow the human controller adequate time to respond to the first output from the regulator, the first and second decoded outputs Q0 and Q1 at pins 3 and 2 respectively are not used and serve as delay before ceiling fan activation. The fan regulator used for this work has only five speeds hence only five of the decoded outputs Q2, Q3, Q4, Q5, and Q6 at pins 4, 7, 10, 1, and 5 respectively are used for the subsequent switching stages. Pin 6, the Q7 decoded output is used to reset the counter by connecting it to the counter's active-high RESET input at pin 15 through an IN4001 diode.

This is done in order to prevent a waste of time in the count cycle since delays have already been incorporated by not using the Q0 and Q1 decoded outputs. In this arrangement eight counts have been assigned functions, Q0 and Q1 for delay, Q2, Q3, Q4, Q5, and Q6 for fan speeds and Q7 for resetting the counter. The last two counts Q8 and Q9 at pins 9 and 11 respectively are not used.

3.4 THE RELAY BASED CEILING FAN REGULATOR OUTPUT SWITCHES

The preceding circuits are used in this work to convert a conventional five speed manual ceiling fan regulator to a remotely controlled one. The actual speed control in the manual controller is achieved by inserting an inductive coil with four outputs of fixed inductances in series with the fan motor as shown in Fig. 3.6. The slowest speed, speed 1, is achieved when the whole coil is in series with the fan. Subsequent speeds, speeds 2, 3, and 4, are attained by selecting subsequent outputs from the inductive coil with progressively less inductance. It is interesting to note that the fastest speed, speed 5, is attained when the entire coil is bypassed. At this speed, the fan is directly connected across the 220-240V 50Hz AC supply. To put the fan off, the output is open circuited.

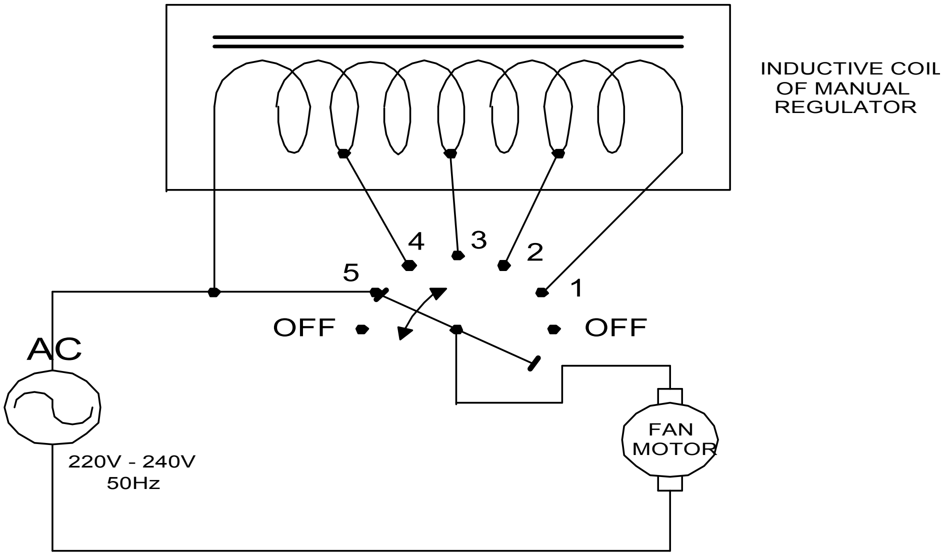


Fig. 3.6 Schematic of the Manual Ceiling Fan Regulator

In this work, relays were used to take over the function of the manual rotary switch. Five of the outputs from the CD4017BC Decade Counter/Divider are used to control the power to five relays RL1 through RL5. The relays are the JZC - 20F (4088) 10A model. They are Single Pole Single Throw (SPST) relays with normally open contacts. They are powered by 6V and use a 100Ω coil. The switching circuit is shown in Fig. 3.7.

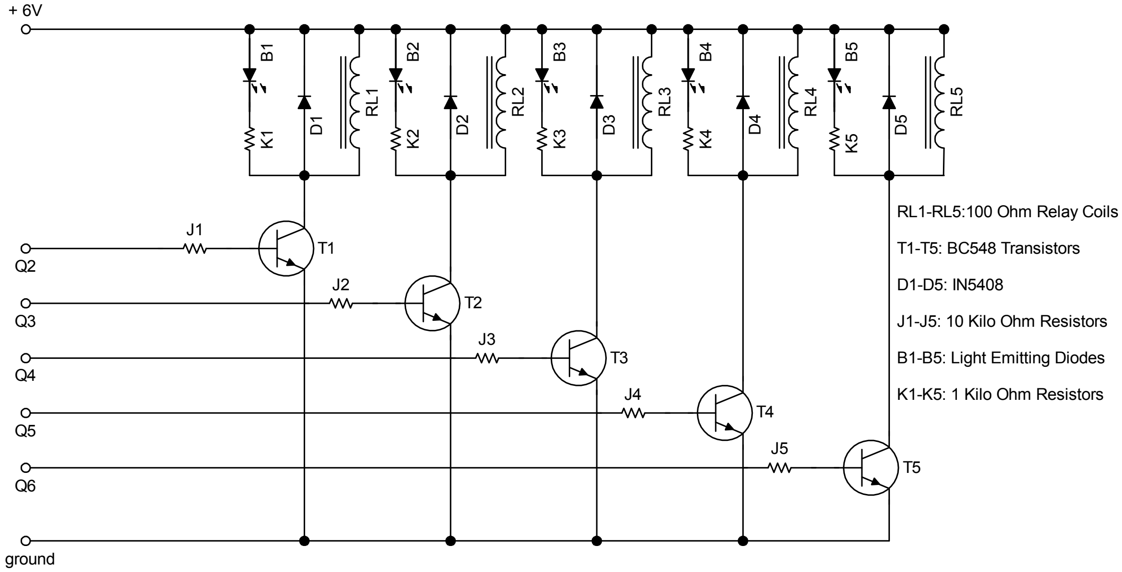


Fig. 3.7 The Relay Based Ceiling Fan Regulator Output Switching Circuit

Resistors J1, J2, J3, J4 and J5 are 10kΩ current limiting resistors used to protect the outputs from the CD4017BC IC and the base of the NPN transistors from excessive current.

Transistors T1, T2, T3, T4 and T5 are the BC548 type. They are used here for switching the relays on and off. The BC548 transistor is a silicon NPN general purpose transistor, with V_{CE} (max.) = 30V, hfe = 200, I_C (max.) = 100mA and P_D (max.) = 0.5W. [12]

To indicate the speed at which the fan is set, one of five green LEDs B1, B2, B3, B4 and B5 lights up to identify the relay that is powered on and hence the speed setting of the regulator. K1, K2, K3, K4 and K5 are 1kΩ resistors used to regulate the current through the LEDs to control their brightness and prevent them from damage when the transistors are turned on. Diodes D1, D2, D3, D4 and D5 are used here as free-wheeling diodes, they are the IN5408 type. They protect the switching transistors from the high current that is created when the electromagnetic energy stored in the relay coil is returned to the circuit whenever any of the switching transistors is turned off. They are connected in reverse bias and the transistors, when on, carry a negligible current as a result of the reverse biased diodes. However, when the transistors turn off, the free-wheeling diodes drain the current created by the electromotive force created by the relay coil.

When powered, each LED drops approximately 1V. With Vcc = 6V and using 1kΩ LED current limiting resistors the current through each LED is approximately equal to:

$$\frac{(6 - 1)\text{ V}}{1000\text{ Ohms}} = 5\text{ mA}$$

At Vcc = 6V and with a coil resistance of 100Ω, the current required by each relay coil is:

$$\frac{6\text{ V}}{100\text{ Ohms}} = 60\text{ mA}$$

The current each transistor needs to carry is the sum of the currents required by the relay coil and the LED.

From the forgoing this is equal to:

$$60\text{ mA} + 5\text{ mA} = 65\text{ mA}$$

Hence the BC548 transistor with a rated maximum collector current, I_C (max.), of 100mA is well suited to carry the switched loads.

When 'on' the BC548 is saturated, with hfe (β) = 200, $V_{CE} = 0V$ and $I_C = 65mA$ the required minimum base current, I_B, is calculated as follows:-

$$I_B = \frac{I_C}{ß} \qquad I_B = \frac{65mA}{200} = 0.325mA \quad \cdots\cdots\cdots\cdots \quad 3.6$$

To turn on any of the transistors, the decoded outputs from the preceding CD4017BC Decade Counter/Divider, when in the HIGH state, must be able to sink or source the required bias current. From Appendix IV the HIGH Level Output Current, I_{OH}, for the CD4017BC is quoted as:-

At 25^OC and $V_{DD} = 5V$, $V_O = 4.6V$ and typical value of I_{OH} is -0.36mA.

At 25^OC and $V_{DD} = 10V$, $V_O = 9.5V$ and typical value of I_{OH} is -0.90mA.

Interpolating for $V_{DD} = 6V$ at 25^OC gives:-

$V_O = 5.58V$ and typical value of I_{OH} is $\approx$ -0.47mA.

The negative values for I_{OH} indicate that the IC sinks the required current.

From Fig. 3.7 it can be deduced that: -

$$V_O = I_B J + V_{BE} \quad \cdots\cdots\cdots\cdots \quad 3.7$$

Where J = current limiting resistance and V_{BE} = base-emitter voltage, typically 0.4V.

Therefore with I_B estimated as –0.47mA, the value of current limiting resistors, J1 – J5, is calculated from Equation 3.7 as follows: -

$$J = \frac{V_O - V_{BE}}{I_B} = \frac{5.58 - 0.40}{0.47mA} = 11.02kOhms \sim 10kOhms \quad \cdots\cdots \quad 3.8$$

The closest standard value resistor that is just less than 11.02kΩ is 10kΩ. 10kΩ resistors were therefore used as the current limiting resistors in order to ensure saturation.

A similar calculation can be used to show that the decoded outputs from the IC are also able to source the required LOW Level Output Current I_{OL} through the selected 10kΩ current limiting resistors.

Since only one of the inputs, Q2, Q3, Q4, Q5 and Q6 are expected to be high at any instant, only one of the speed control relays can come on at a time.

The switched contacts S_{RL1}, S_{RL2}, S_{RL3}, S_{RL4} and S_{RL5} belonging to relays RL1, RL2, RL3, RL4, and RL5 respectively are connected in the A.C. section of the regulator to control the ceiling fans as shown in Fig. 3.8.

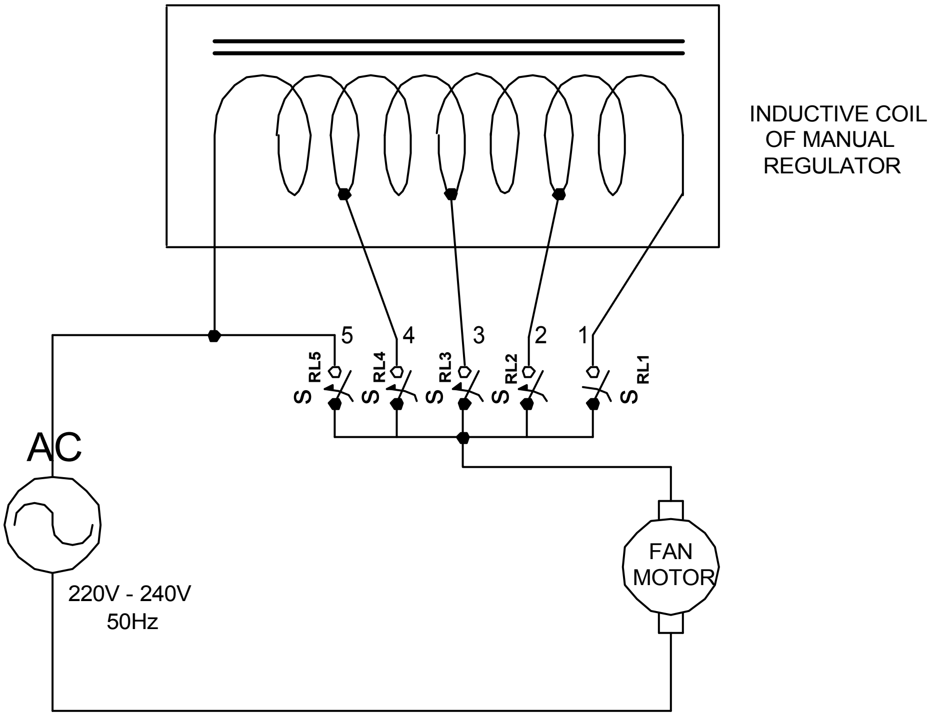


Fig. 3.8 Schematic showing how the Relay Switches Connect the Inductive Coil to the Ceiling Fan.

CHAPTER FOUR

THE COMPLETE LIGHT ACTIVATED REMOTE CONTROLLED FAN REGULATOR SYSTEM

4.1 INTRODUCTION

The three main parts of the electronic ceiling fan regulator system, namely the light beam detector, the clock pulse generator, and the timer IC based speed switching circuit are assembled as shown in Fig. 4.1. The system is powered using the Power Supply Unit described at the end of Chapter Two.

The sensitivity of the light beam detector is set indoors under normal lighting conditions. Initially, the two encased Light Dependent Resistors R_D and R_R are placed in complete darkness. The voltage across the ground terminal and the non-inverting input is measured and compared to that across the positive power supply rail and ground.

If the voltage at the non-inverting input is less than half the value of the positive power supply voltage, variable resistor R_{V1} is set at its maximum value of 1kΩ and variable resistor R_{V2} will be used for sensitivity adjustment. Alternatively, if the voltage at the non-inverting input is more than half the value of the positive power supply voltage, R_{V2} is set at its maximum value of 1kΩ and R_{V1}will be used for sensitivity adjustment. This is done to ensure that when the light beam detector's sensitivity is finally set, the series arrangement of R_{V1} and R_{V2} will drain as little current as possible from the power supply. This is so because one of them is always set at its maximum value. It is possible to adjust the two variable resistors to provide the inverting input with the required voltage for optimum sensitivity at an infinite range of values as long as their resistances are at the same proportion with respect to each other. However, to set the current drain to the least possible value the procedure of always setting one to the maximum value is mandatory.

With the two LDRs placed in complete darkness, the variable resistor designated for sensitivity adjustment is slowly varied to the position where the output of the comparator just switches from the HIGH state to the LOW state. This can be observed from relay RLD's switching action, or during construction by inserting a 1kΩ resistor in series with an LED between the comparator's output and the ground terminal. After the state where the output just goes LOW when the two LDRs are in complete darkness, the detector LDR, R_D, should be exposed to the ambient lighting conditions; this should cause the output to go HIGH since the other is in complete darkness. The detector LDR should now be replaced in complete darkness, if the comparator's output doesn't immediately return to the LOW state, as is usually the case; the variable resistor designated for sensitivity adjustment should be further adjusted in the direction that turns the output back LOW.

This process of exposing the detector LDR, R_D, to ambient light, replacing it in complete darkness, and tweaking the value of the sensitivity adjustment resistor should be repeated until such the state when the output from the comparator immediately returns to LOW whenever the detector LDR is exposed to ambient light and is replaced in complete darkness.

At this point the light beam detector circuit is at its most reliable sensitivity setting. It may be more sensitive at the previous settings, but the fact that the output doesn't immediately return to the LOW state immediately the detector LDR is replaced in darkness makes it unreliable for control purposes.

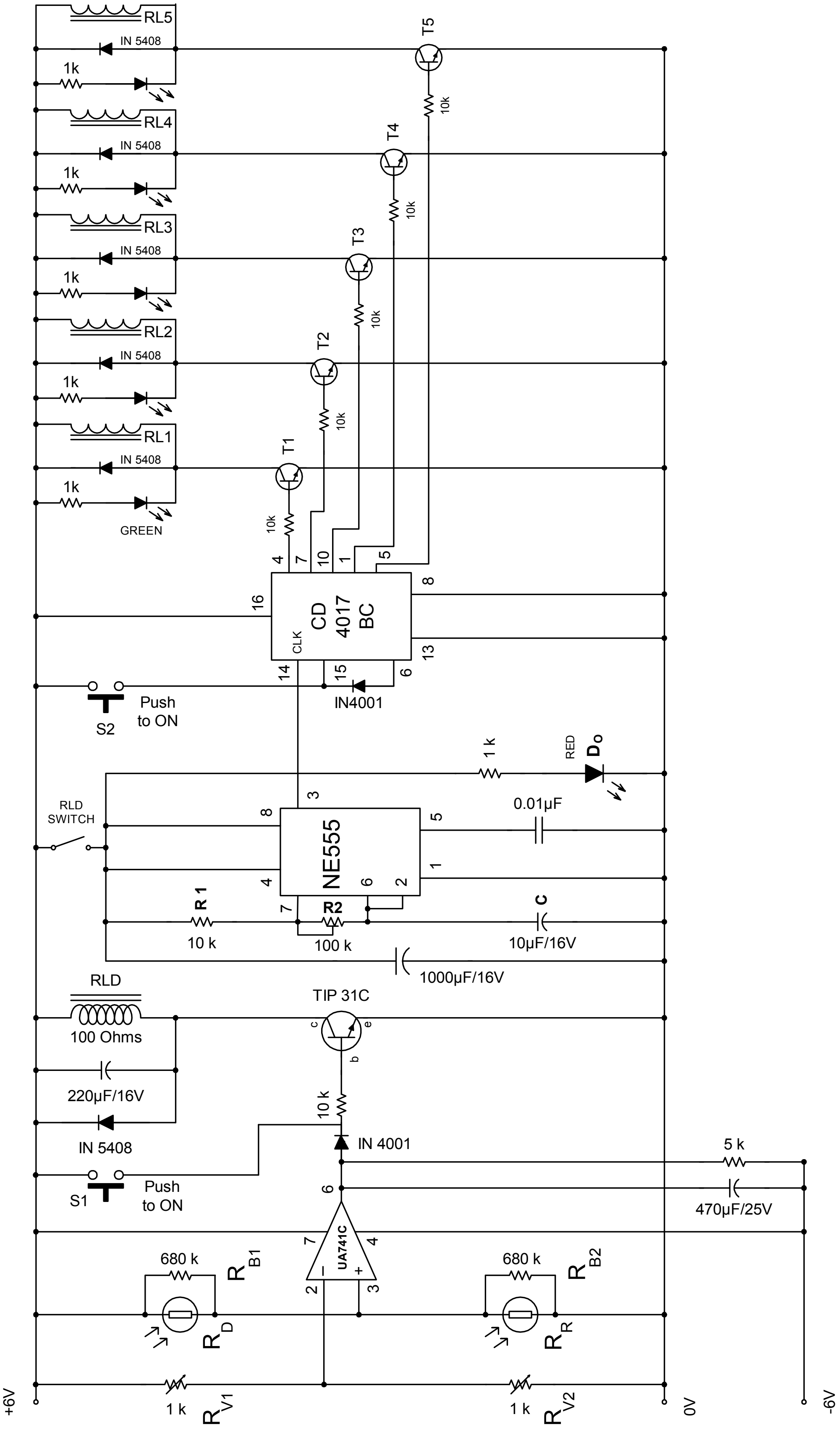


Fig. 4.1 The Complete Circuit Diagram of the Light Activated Remote Controlled Fan Regulator

The output from the comparator assumes one of two states HIGH or LOW. Recall that a comparator acts like a single bit analog-digital-converter. The HIGH state refers to an output voltage equal to or slightly less than the positive power supply voltage, in this circuit that is +6V. At the LOW state the output voltage is equal to or slightly higher (more positive) than the negative power supply voltage, -6V.

In the LOW state, the 470µF/25V capacitor and 5kΩ resistor connected across the comparator's output and the negative power supply line have virtually zero volts across them and serve no purpose. The IN4001 diode is reverse biased and no current flows through. Switch S1 may be used to manually activate the subsequent circuitry to change the speed of the fan or switch it off. When the manual control switch S1 is pushed down, the base of the TIP31C power transistor is connected to the positive power rail, +Vcc through a 10kΩ resistor. This activates the subsequent stages. With S1 pushed down, the IN4001 diode protects the output of the Op-Amp which is in the LOW state from being forced to the high state and potentially creating a short across the positive and negative supply rails.

When the control light beam is detected, to transit to the HIGH state the output of the detector's comparator must first charge the 470µF/25V capacitor this creates a very short delay, and when charged the capacitor helps filter out any transient state changes that may occur to cause instability in the switching of the next stage. The 5kΩ resistor serves as a pull-down resistor to enable the output return to the LOW state quickly whenever the control beam is withdrawn. It provides a path for the capacitor in parallel with it to discharge. When in the output is HIGH the IN4001 diode conducts and turns the TIP31C switching transistor on through a 10kΩ resistor.

The TIP31C, when on, is operating in the saturated region of its operational characteristics and consequently its V_{CE} is approximately equal to zero. The collector terminal is virtually grounded and relay's (RLD) coil is supplied with the right voltage +6V to turn on. It however only comes on after a very short delay as the 220µF/16V capacitor charges across it. The IN5408 diode, in parallel with the relay coil and the 220µF/16V capacitor, is connected in reverse bias as a free-wheeling diode to drain the high current that is created when the energy stored in the magnetic field of the relay coil returns to the circuit whenever the transistor switches off.

The combination of the 470µF/25V capacitor at the output of the comparator and the 220µF/16V across the relay RLD coil help to filter out detection transients and cause a delay to ensure reliability of detection in the light beam detector system.

Whenever the control light beam is detected the TIP31C transistor switches on and Relay RLD is powered, this causes its contacts RLD Switch to close. The closing of switch RLD causes the NE555 Timer IC based clock pulse generator circuit to be powered.

When RLD switch is closed, power is suddenly applied to the NE555 Timer clock pulse generator; this causes undesirable transients in its output before its steady state operation is attained. The undesirable transients on the CLK input to the 4017 Counter/Divider IC clocks the IC a random number of times causing an unpredictable state of its outputs. To avoid this initial random state of the controllers output whenever the control beam is detected, a high value capacitor 1000µF/16V is used to force the power to the clock pulse generator to rise slowly to the positive power supply voltage, +6V. The inclusion of this capacitor completely eliminates the transients in the output of the NE555 Timer based clock pulse generator and allows a smooth clocking of the CD4017BC Decade

Counter/Divider in order to have a predictable transition of the output of the ceiling fan regulator from one state to another.

As explained in Chapter Three, when the 555 Timer is used in the astable multivibrator circuit configuration, the values of three components R1, R2, and C determine the frequency of the clock pulses generated. In this work R1 is 10kΩ, R2 is a pre-settable 100kΩ resistor and C is 10μF/16V. The pre-settable 100kΩ is adjusted near its maximum value to give an output frequency of approximately 1Hz. As long as the circuit is powered it continues to generate square wave clock pulses indefinitely.

A red LED D_O in series with a 1kΩ resistor is used to indicate whenever the control beam is detected and the clock pulse generator circuit turns on. The LED however, doesn't accurately indicate when the control light beam is retracted because when RLD switch opens, the clock pulse generator circuit goes off much slower than the beam detector as a result of the need for the 1000μF/16V to discharge which it does mainly through the series arrangement of the 1kΩ resistor and the red LED, D_O.

The CD4017BC Decade Counter/Divider IC is used to set the output of the ceiling fan regulator at the desired states. The IC is powered by connecting pin 16 to the positive power supply rail and pin 8 to the ground terminal. Pin 13, the Clock Enable input is active-low and is also connected to the ground rail. The Clock Enable input is tied to the ground rail to permit the CLK input at pin 14 to trigger the IC whenever a positive transition is detected. The clock input to the IC at pin 14 is triggered on the rising edge of the clock pulse which is why the power to the 555 Timer stage is controlled at the positive terminal and not the ground. If the clock signal is at the HIGH state when the power to the 555 Timer is disconnected, it goes LOW and falling edge of the clock pulse doesn’t further trigger the Counter/Divider IC. If the clock signal is at the LOW state when the power to the 555 Timer is disconnected, it remains LOW and doesn’t trigger the Counter/Divider either.

Whenever the 555 Timer based clock pulse generator IC is powered on the detection of the continued presence of the control beam, the 4017 Decade Counter/Divider continues to respond to the positive transition of the clock input at pin 14. At any point in time, unless when reset at pin 15, one of its ten decoded outputs Q0, Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9 at pins 3,2,4,7,10,1,5,6,9, and 11 respectively is in the HIGH state. Q0 and Q1 at pins 3 and 2 respectively are not used and serve as delay before an output from the regulator is observed. Outputs Q2, Q3, Q4, Q5, and Q6 at pins 4, 7, 10, 1, and 5 respectively are used to set the regulator at a particular speed setting. Output Q7 at pin 6 is used to reset the count of the IC by connecting it to the RESET input at pin 15. Whenever the Q7 output goes HIGH, all the Q outputs are set LOW and on the next positive transition of the clock pulse the count restarts at Q0 at pin 3. This cycle continues and only terminates when the control light beam is withdrawn. When the control beam is withdrawn the detector output goes LOW, transistor TIP31C and Relay RLD both turn off, disconnecting the power to the clock pulse generator. When the clock pulse generator turns off the input to the 4017 IC becomes a steady LOW signal, and its outputs remain at the state they were before the withdrawal of the control signal. A means by which the electronic ceiling fan regulator’s output can be reset to the off state without turning off the regulator’s power supply is provided via switch S2. Whenever S2 is pressed the RESET input at pin 15 of the 4017 Decade Counter/Divider IC, which is an active-high input is temporarily connected to the positive power rail. To prevent harm to the IC through pin 6, which is also used to reset the count, pin 6 is connected to pin 15 through and IN4001 diode. This diode ensures that during manual resetting of the IC the pin 6 output is protected from damage by a direct connection to the positive power rail which can cause excessive current flow due to short-circuiting of the power line when the output is LOW.

For each speed output of the regulator, the HIGH state either of the Q2, Q3, Q4, Q5, or Q6 decoded outputs at pins 4, 7, 10, 1, or 5 respectively of the 4017 Decade Counter/Divider IC is used to turn on the corresponding switching transistor T1, T2, T3, T4, or T5 respectively through 10kΩ current limiting resistors. Whenever either of these transistors is on, the corresponding relay coil RL1, RL2, RL3, RL4, or RL5 is powered across the +6V and ground power supply terminals. A freewheeling diode is used across each of the five relay coils to protect the switching transistors from damage as a result of the high current created by the collapse of the magnetic fields of the relay coils whenever the transistors turn off. To indicate the particular speed at which the output from the electronic ceiling fan regulator has been set, a green LED in series with a 1kΩ resistor is also connected across each relay coil to indicate when the coil, which controls a particular output speed, is powered.

Recall that only one of the 4017 IC's decoded outputs should be in the HIGH state at any point in time; this implies that the regulator can not be set at more than one speed at a time.

The schematic showing how the relays switches control the speed of the fan, by selecting the particular output from the manual regulator's inductive coil to connect to the ceiling fan or opening the circuit by connecting to none has been illustrated in Fig 3.8.

CHAPTER FIVE

POWER REQUIREMENTS, CONSTRUCTION, TESTING AND INSTALLATION

5.1 INTRODUCTION

In this chapter, the Light Activated Remote Controlled Fan Regulator's power consumption will be estimated. A description of the construction and testing of the prototype will be given. Finally, recommendations for the features of the location for placement/installation of the system will be provided.

5.2 POWER REQUIREMENTS

In this section an estimate of the power consumption of the Electronic Ceiling Fan Regulator will be made. To do this, the complete circuit diagram in Fig 4.1 will be divided into five parts;

a) Op-Amp IC based detector circuit: - This comprises of the two potential divider variable resistors that bias the inverting input of the IC, the two Light Dependent Resistor each in parallel with one fixed 680kΩ resistor that bias the non-inverting input of the IC, the Op-Amp IC itself, and the three components, the IN4001 diode, the 5kΩ resistor and the 470μF/25V capacitor, at the output of the comparator.

b) The Oscillator Switch: - This comprises of the 10kΩ current limiting resistor at the base of the TIP31C transistor, the TIP31C transistor, and the three components at the collector circuit, the freewheeling diode, the 220μF/16V capacitor and the 100Ω relay coil.

c) The NE555 Timer based Oscillator: - This comprises of the NE555 Timer IC, the three frequency determining components 10kΩ resistor, 100kΩ pre-settable resistor and the 10μF/16V capacitor, and the 1kΩ resistor in series with LED D_O.
d) The Decade Counter based output-switching controller: - This comprises primarily of only the CD4017BC Integrated Circuit. and
e) The Output Switch: - Like the oscillator switch, this comprises of the 10kΩ current limiting resistor at the base of the BC548 transistor, the BC548 transistor, and the three circuit branches at the collector circuit, the freewheeling diode, the 1kΩ resistor in series with the speed indication LED, and the 100Ω relay coil.

An estimate of the power consumption of each of these parts will be made for all their possible different states. These are evaluated for each of the five different parts as shown below. These are not very accurate evaluations and are only rough estimates that will allow an estimate of the system's steady state power consumption. In these calculations only components that continuously drain current will be considered. Capacitors that take current only when charging will be excluded from the estimates.

ESTIMATE OF POWER CONSUMPTION OF THE FIVE DIFFERENT PARTITIONS

A) THE OP-AMP BASED DETECTOR CIRCUIT

At the final sensitivity setting, R_{V1} was set at the maximum, 1kΩ and R_{V2} was set at approximately 850Ω. Their total resistance is 1.85kΩ, this is connected across a 6V supply hence the power consumed by them is calculated as: -

Current through the branch is: - 6V / 1850Ω = 3.24mA

Power = VI, Power = 6V x 3.24mA

Power = 19.5mW

Power consumed by series arrangement of R_{V1} and R_{V2} is: - 19.5mW

In very bright lighting conditions taken to be Ambient Illumination Level 1 the resistance of the LDRs is 25.3kΩ these values in parallel with the fixed 680kΩ resistors give: -

Effective Resistance is: - (25.3 x 680) / (680 + 25.3) = 24.39kΩ

Effective Resistance of two of these in series is: - 24.39 x 2 = 48.78kΩ

Current through the branch is: - 6V / 48.78kΩ = 123μA

Power = VI, Power = 6V x 123μA = 738μW

Power consumed by LDRs in parallel with 680kΩ resistors is: - 738μW

In very bright lighting conditions taken to be Ambient Illumination Level 1 when the control light beam is present the resistance of one of the LDRs is 3.5kΩ and the other is 25.3kΩ these values in parallel with the fixed 680kΩ resistors give: -

Effective Resistance of first pair is: - (3.5 x 680) / (680 + 3.5) = 3.48kΩ

Effective Resistance of second pair is: - (25.3 x 680) / (680 + 25.3) = 24.39kΩ

Effective Resistance of both pairs in series is: - 3.48 + 24.39 = 27.87kΩ

Current through the branch is: - 6V / 27.87kΩ = 215µA

Power = VI, Power = 6V x 215µA = 1.29mW

Power consumed by LDRs in parallel with 680KΩ resistors is: - 1.29mW

This represents the highest power these four components may consume.

In dark conditions, taken to be less than Ambient Illumination Level 4, the resistance of the LDRs is virtually infinite these values in parallel with the fixed 680kΩ resistors give and effective resistance approximately equal to 680kΩ

Effective Resistance of two of these in series is: - 1.36MΩ

Current through the branch is: - 6V / 1.36MΩ = 4.4µA

Power = VI, Power = 6V x 4.4µA = 26.5µW

Power consumed by LDRs in parallel with 680kΩ resistors is: -26.5µW

From page 5 of Appendix II The datasheet for the UA741C, the Op-Amp IC is estimated to have an average power consumption of 20mW at ±6V.

Average power consumed by UA741C Op-Amp at ± 6V is: - 20mW

The 5kΩ Resistor

When the output of the comparator is LOW, the 5kΩ resistor consumes no power. However, when the output is HIGH, power consumed in the resistor is: -

When the output is HIGH the output voltage is 6V, hence this resistor is connected across the entire bi-polar supply of 12V.

The current drain will be: - 12V / 5kΩ = 2.4mA

Power consumption, P = VI, P = 12V x 2.4mA

Power consumed by 5kΩ resistor is: - 28.8mW

In the absence of a detected beam, the total power consumed by the Op-Amp based detector circuit in very bright ambient lighting conditions is:-

(19.5 + 0.738 + 20) mW = 40.24mW

The highest power consumption of the detector circuit occurs in very bright ambient conditions when the control beam is detected, the total power consumed by the Op-Amp based detector circuit in these conditions is:-

(19.5 + 1.29 + 20 + 28.8) mW = 69.59mW

The lowest power consumption by the detector circuit occurs in dark ambient lighting conditions when the control beam is absent, the total power consumed by the Op-Amp based detector circuit in these conditions is:-

(19.5 + 0.0265 + 20) mW = 39.53mW

B) THE OSCILLATOR SWITCH

When the output from the preceding Op-Amp comparator stage is LOW the TIP31C is off and virtually no power is consumed in this circuit as there is no current flow.

When the preceding stage has a HIGH output however power consumption is significant and is calculated thus: -

The 10KΩ current limiting resistor,

Current through this resistor is: - (6 – 0.4 – 0.4) V / 10kΩ = 0.52mA

The two 0.4V values represent the voltage drop in both the discrete IN4001 diode and the base-emitter junction of the transistor. The voltage drop across the resistor is: -

(6 – 0.4 – 0.4) V = 5.2V

Power = VI, Power = 5.2 x 0.52mA = 2.7mW

Power consumed by 10kΩ resistor is: - 2.7mW

Power consumed in both diodes,

P = V x I here V = 0.4v + 0.4v = 0.8v and I = 0.52mA

P = 0.8v x 0.52mA = 0.416mW

Power consumed by diodes is: - 0.42mW

Power consumed by relay coil,

When the transistor is on, the whole positive power supply voltage is connected across the 100Ω relay coil. The current is given as,

6V / 100Ω = 60mA, hence the power consumed is: -

P = VI, P = 6 x 60mA = 360mW

Power consumed by relay coil is: - 360mW

The freewheeling diode,

The freewheeling diode is connected in reverse bias, hence virtually no current flows through it and its power consumption is negligible. It only conducts when the magnetic fields of the relay coil collapses and hence doesn't drain current directly from the source.

The Switching Transistor,

When the transistor is off, virtually no current flows and its power consumption is negligible. When it is on, however, its collector emitter voltage is about 0.2V and its power consumption is: - 0.2 x 60mA = 12mW.

Total steady state power consumed by the oscillator switch when on is: -

(2.7 + 0.42 + 360 + 12) mW = 375.12mW

C) THE NE555 TIMER BASED OSCILLATOR

Power consumed by R1 and R2

Given that the frequency of the output from the oscillator is one Hz, the capacitor C charges through R1 + R2 and discharges through R2 each second. It can be assumed that the power dissipated in these resistors is equal to half the maximum instantaneous value that occurs when the capacitor is fully discharged.

The initial charging current when C is discharged by one-thirds is:-

4V / 110kΩ = 36.4µA

Hence power dissipated while charging initially is 4V x 36.4µA = 145.6µW

At the instant when the capacitor stops charging the charging current is:-

2V / 110kΩ = 18.2µA

Hence power dissipated while charging initially is: - 2V x 18.2µA = 36.4µW

Average charging power is: - (145.6 + 36.4) µW / 2 = 91µW

When discharging, the initial discharging voltage is 4V (it charges to two-thirds Vcc only) and it discharges only through R2. Hence initial charging current is:-

4V / 100kΩ = 40μA

and the initial discharging power is 4V x 40μA = 160μW

At the instant when the capacitor stops discharging the charging current is:-

2V / 100kΩ = 20μA

Hence power dissipated at final state of discharge is: - 2V x 20μA = 40μW

Average discharging power is: - (160 + 40) μW / 2 = 100 μW

Total power consumed by R1 and R2 is the average of the charging and discharging power, this is so because it charges and discharges within each second.

Power consumed by R1 and R2 is: - (91 + 100) μW / 2 = 95.5 μW

NE555 Timer IC

For the rest of the oscillator circuit, the only significant power consumption will be in the NE555 Timer IC itself.

From Figure 2 of page 4 of Appendix III, at 6V and 25^{O}C the Supply current, Iss, to the NE555 Timer IC is 5mA. NE555 Timer IC is evaluated to have an average power consumption of 30mW at 6V.

Average power consumed by 555 Timer IC at + 6V is: - 30mW

Total steady state power consumed by the 555 Timer based oscillator when on is: -

(0.095 + 30) mW = 30.095mW

D) THE DECADE COUNTER BASED OUTPUT SWITCHING CONTROLLER

CD4017BC Decade Counter/Divider IC

The only significant power-consuming device in this part of the system is the CD4017BC IC itself.

From Appendix IV (The datasheet for CD4017BC), the power consumption of this device is estimated. At a DC Supply of 5V, ambient temperature of 25^{O}C, the device has a typical quiescent current, I_{DD} of 5μA and maximum of 20μA. Estimating the current as 10μA at 6V, the CD4017BC Decade Counter/Divider IC is evaluated to have a power consumption of, 6V x 10μA, 60μW.

Average power consumed by CD4017BC IC at 6V is: - 60μW.

E) THE OUTPUT SWITCH

Whenever either of the outputs, Q2, Q3, Q4, Q5 or Q6, from the CD4017BC IC is HIGH, the fan is set at one of the five speeds. Power is consumed in one of the five output switches and its value is calculated thus: -

The 10kΩ current limiting resistor,

Current through this resistor is (6 – 0.4) V / 10kΩ = 0.56mA

The two 0.4V values represent the voltage drop in the base-emitter junction of the transistor. The voltage drop across the resistor is, (6 – 0.4) V, 5.6V

Power = VI, Power = 5.6 x 0.56mA = 3.1mW

Power consumed by 10kΩ resistor is: - 3.1mW

Power consumed in transistors base – emitter junction,

P = V x I   here V = 0.4V and I = 0.56mA

P = 0.4V x 0.56mA = 0.224mW

Power consumed in transistors base-emitter junction is: - 0.22mW

Power consumed by relay coil,

When either of transistors, T1 through T5, is on, the whole positive power supply voltage is connected across the 100Ω relay coil. The current is given as,

6V / 100Ω = 60mA, hence the power consumed is: -

P = VI,   P = 6 x 60mA = 360mW

Power consumed by relay coil is: - 360mW

The freewheeling diode,

The freewheeling diode is connected in reverse bias, hence virtually no current flows through it and its power consumption is negligible. It only conducts when the magnetic fields of the relay coil collapses and hence doesn't drain current directly from the source.

The Switching Transistor,

When the transistor is off, virtually no current flows and its power consumption is negligible. When it is on, however, its collector emitter voltage is about 0.2V and its power consumption is: -   0.2 x 60mA = 12mW.

Total steady state power consumed by the output switch when on is: -

(3.1 + 0.22 + 360 + 12) mW = 375.32mW

Given the preceding evaluation of the power consumption of the partitioned system, the power consumption of the entire system in three situations will be given below.

1) Maximum power consumption: - In this state, which shall be referred to 'Speed Changing State', the ambient lighting is high, the control beam is detected, the oscillator switch & oscillator are on, and the output switch is on at any of the five speeds.

   Power consumed = (69.59 + 375.12 + 30.095 + .060 + 375.32) mW

   System Maximum Power Consumption is: - 850.185mW

   850mW

2) Working power consumption: - In this state, which we shall refer to as 'Regulator Working State', dark ambient lighting conditions will be assumed, no control beam is detected, the oscillator switch & oscillator are off, and one of the output switches is on at any of the five speeds.

   Power consumption = (39.53 + 0.060 + 375.32) mW

   System Working Power Consumption is: - 414.91mW

   415mW

   If a bright ambient lighting condition is assumed: -

   Power consumption = (40.24 + 0.060 + 375.32) mW

   System Working Power Consumption is: - 415.62mW

   416mW

3) Minimum power consumption:- In this state, which we shall refer to as 'Standby State", both bright and dark ambient lighting conditions will be assumed, no control beam is detected, the oscillator switch & oscillator are off, and all five output switches are off.

   Assuming bright ambient lighting conditions: -

   Power consumption = (39.53 + 0.060) mW

   System Standby Power Consumption in bright light is: - 39.59mW

   Assuming dark ambient lighting conditions: -

   Power consumption = (40.24 + 0.060) mW

   System Standby Power Consumption in the dark is: - 40.30mW

From the power requirement analysis carried out, it can be seen that the power supply unit which uses a 6V-0-6V 300mA secondary transformer is well rated to handle the systems power requirement as it can supply a total of 12V x 300mA = 3.6VA power across the entire secondary coil or 6V x 300mA = 1.8VA across each end of the secondary coil and the center-tap terminal. It can be observed that in this system most of the load is connected across one end of the secondary coil and the center-tap.

5.3 CONSTRUCTION

The prototype light activated remote controlled fan regulator was built around a conventional manual ceiling fan regulator the SMT "Original" ceiling fan regulator, which is commonly available as a replacement part. The manual rotary switch part of the regulator was removed and the output switching part of the electronic system was built into the vacant space. The LED speed indicators were projected onto the surface of the regulator to indicate the set speed using number markers already provided on the case of the manual system. The switches control the connections of the output of the inductive coil, which is already enclosed in the manual system, to the fan. Two manual switches were provided on the casing of manual regulator, one to manually activate the oscillator which changes the state of the output to the ceiling fan and the other to reset the output of the regulator and immediately turn it ‘off’ from any of the ‘on’ states.

Three other parts of the system, The Power Supply Unit, The Beam Detector Circuit and the combined 555 Timer Based Oscillator and CD4017BC Decade Counter/Divider based output switching controller were each separately built in plastic surface wiring socket/switch boxes.

All circuits were built on Vero boards, with all ICs placed in IC Sockets for easy change. The Light Dependent Resistors were placed in specially designed cylindrical containers described in section 2.8. The conventional use of the containers is as Junction Boxes also used in surface wiring of buildings. All the containers encasing the various parts of the system were firmly placed on a piece of plywood, which measures 10 inches in width and 17.5 inches in height.

The entire system can be built in an infinite range of configurations and in a more compact arrangement. In whatever physical arrangement this system is to be realized, effort must be made to properly avoid the negative effects of electromagnetic induction from either the regulators AC speed control coil or DC relay coils from causing improper operation of the Integrated Circuits by exceeding their noise immunity specifications.

For demonstration purposes, the AC power to the prototype system is provided through a 13Amp plug connected to the mains supply and the output to the load (the ceiling fan) is provided through a commercially available power outlet extension box meant for three 2-pin AC plugs rated at 1.5 Amps.

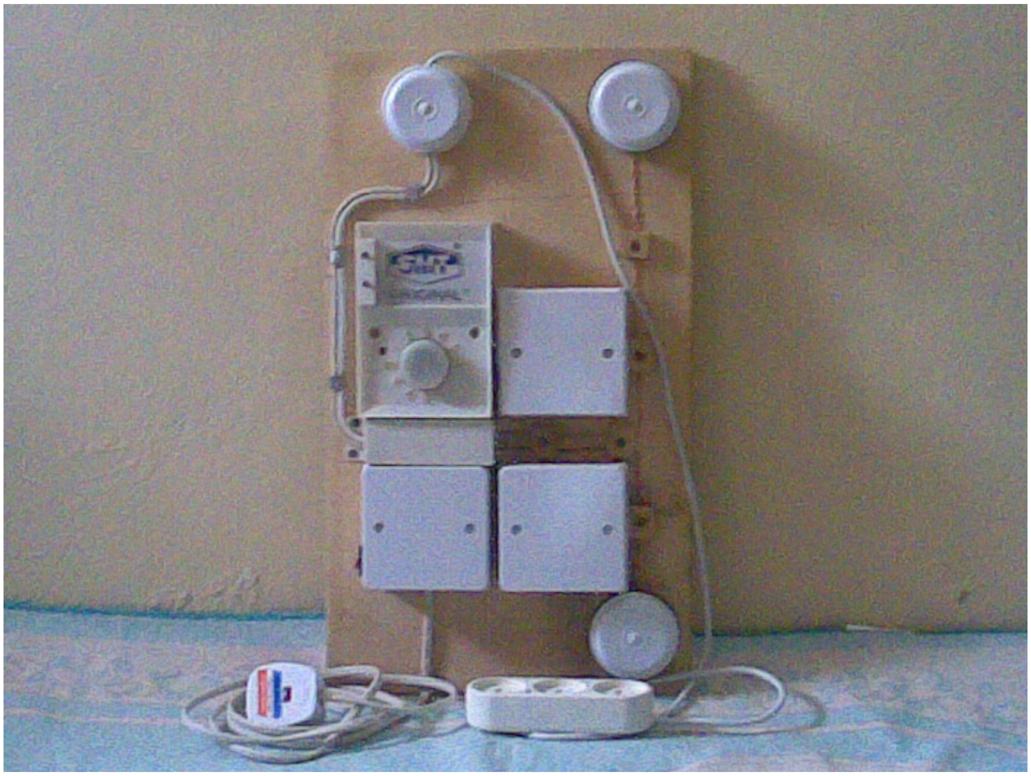


Fig. 5.1 The Prototype Light Activated Remote Controlled Fan Regulator

5.4 TESTING

The system was constructed in the logical sequence of its signal flow. First, and most importantly, the light beam detector circuit was designed through the iterative process of design, construction, testing, observation, design modification, re-testing, etc until the final detector circuit was arrived at.

The remaining parts, in operational sequence, were constructed and tested piecewise. This was done to eliminate all malfunctions along the path to the eventual output. This sequence of testing was implemented until the final part of the system; the output switch was integrated with the rest of the circuitry. With the circuit complete, the whole system was tested to ensure that it operated properly and according to design.

Finally, the light activated remote controlled fan regulator was tested with the target load, a ceiling fan, connected. It responded correctly when manually or remotely controlled.

5.5 INSTALLATION

The electronic ceiling fan regulator uses Light Dependent Resistors in a comparative arrangement to differentiate between ambient lighting conditions and a relatively higher level of illumination as a result of the control beam. Consequently, it is strongly recommended that the encased Light Dependent Resistors used for the detection of this difference should be fixed on the wall in a location as far away from other light sources, natural or man-made, as possible. It should be placed in such a manner that the amount of ambient light reaching the two encased Light Dependent Resistors would be as equal as possible. These, in addition to all precautions made in the design to ensure sensitivity, will ensure that the electronic ceiling fan regulator can be remotely controlled from the furthest possible distances.

CHAPTER SIX

CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

6.1 INTRODUCTION

The Light Activated Remote Controlled Fan Regulator presented in this work was a product of a practical investigation into arriving at a suitable design for a workable and potentially marketable range of derivative systems that explore the niche which exist for the remote control of power to electrical fittings using visible light. The specific types of electrical fittings for this type of remote control are light switches, power outlets (sockets), dimmer switches and ceiling fan regulators.

The luminous intensity difference detector realized, the main focus of the design work carried out in this thesis, was very effective in detecting a difference in the luminous intensity on two light dependent resistors. Consequently, subsequent circuitry could be activated and used to carry out the actual power control for the electrical fitting.

The detected beam was used in this work to control a ceiling fan because a ceiling fan regulator represents one of the most challenging cases of power control for a domestic electrical fitting.

For simple power on and power off operations required by most other electrical fittings, only one of the decoded outputs from the CD4017BC IC will be required to power on the controlled device and any other of the decoded outputs in sequence can be used to reset the output of the IC and hence turn the controlled device off. Alternatively, the CD4017BC IC can be replaced by a JK flip-flop IC and either of its outputs, which toggle whenever the IC is clocked, can be used to turn the controlled device on and off.

The ability of the system to detect the control beam depends on the intensity of the beam incident on the detector LDR. The distance from which the focused light beam can be detected depends on its intensity at the detector. For a further control distance, the detector may be made more sensitive or the control light beam may be made more intense. However, for this type of application, a limit has to be to set for the sensitivity of the detector beyond which the system will become unreliable.

6.2 CONCLUSIONS

The Luminous Intensity Difference Detector designed and constructed in this work has the following features:-

i) Successfully detects the difference between the ambient illumination and the illumination as a result of a focused beam of light, from the controller, on the detector LDR in a very wide range of ambient illumination.

ii) Responds only to a sustained beam of light that is focused on the detector LDR which has an intensity which is higher than the ambient to a preset extent. Such a beam is not normally obtainable by random light sources or phenomena.

iii) Does not respond to luminous intensity differences caused by shadows (steady or passing) or light beams of a short duration.

iv) Maintains the state of its output in the presence of all ambient lighting conditions.

v) Simple in design and cheap to implement, making it an attractive solution for the remote control of electrical fittings.

vi) Reliability. Always detects the luminous intensity difference, provided the luminous intensity at the beam detector LDR is sufficiently higher than that on the reference LDR.

vii) Free from output state changes due to power fluctuations or LDR resistance change transients.

Undesirable transients in the output of the light beam detector as a result of the factors explained in section 2.9 were successfully prevented from affecting the proper switching of power to the Oscillator Switch by the joint filtering action of the 470µF/25V output filter capacitor and the 220µF/16V capacitor connected in parallel with the oscillator power switching relay, RLD, coil. The effect of the inclusion of 470µF/25V output filter capacitor alone is shown in a comparison of Fig. 2.13 with Fig. 2.15 and Fig. 2.14 with Fig.2.16.

With the light beam detector set at its most sensitive and reliable state the results in Tables 6.1 and 6.2 were obtained.

Table 6.1 The Maximum Distance for the Detection of the Light Beam from a Flashlight with 3.0V battery & 2.5V/0.4W Incandescent Bulb.

Ambient Lighting Conditions	Maximum Distance for Light Beam Detection (m)
Ambient Illumination Level 1	6.60
Complete Darkness	10.20

To obtain the results in the Table 6.1, the system's detector LDR was illuminated using the originally intended controller a flashlight powered by 3V (two 1.5V cells in series) and using a 2.5V/ 0.4W bulb.

Ambient Illumination Level 1, as defined previously in this thesis, indicates the brightest ambient lighting condition which the LDR, exposed or encased, was exposed to. It refers to the luminous intensity obtained when a 220V/60Watt incandescent light bulb is placed exactly 1.0m away from the LDR with no other light sources present.

Before this work was completed, a new type of flash light was introduced to the local Nigerian market and is rapidly replacing the incandescent bulb type. The new flashlights use ultra-bright Light Emitting Diodes (LED) in combinations of three, five, seven etc. They are much brighter, energy efficient and have at least a three fold extended battery life than the incandescent bulb type. Using one of these Ultra Bright LED flashlights which has seven LEDs focused into a reasonably narrow beam and powered by three 1.5V cells in series (for a total of 4.5V), the results in Table 6.2 were obtained.

Table 6.2 The Maximum Distance for the Detection of the Light Beam from a Flashlight with a 4.5V battery & Seven Ultra Bright LEDs.

Ambient Lighting Conditions	Maximum Distance for Light Beam Detection (m)
Ambient Illumination Level 1	4.35
Complete Darkness	8.25

From the results in Table 6.1 and Table 6.2, it can be seen that, the system design objective of detecting the control beam from a distance of 4.0m was achieved. The use of the new Ultra Bright LED flashlight specified above did not improve the range of distances from which the regulator could be controlled, but it has the advantage of a design which incorporates a pre-focused beam, unlike with the incandescent bulb flashlight which has to be adjusted to focus. Some types of incandescent bulb flashlights have widely dispersed beams and do not have adjustable focus.

6.3 LIMITATIONS

The system was designed as a low cost, cheap solution for detecting luminous intensity differences for the remote control of electrical fittings. Accurate measurements of the extent of luminous intensities differences were not made. Photometers could not be obtained locally.

The choice of components used in this work was strongly influenced by availability. The electronics components market in Nigeria is strongly driven by the components that sell very quickly. This excludes many components from retail outlets as what sell quickly are usually replacement parts for contemporary household electronics or common general purpose ICs. Hence, to build a system that can be easily maintained, local designers must design systems with components that are easily available. To ease the task of component procurement, the design was built around general purpose Integrated Circuits. The use of specialized components, for example specialized comparator ICs like the LM324 would probably have a quicker and more definite response to voltage level changes at its inputs.

Relays were used to effect the switching of the fan between the off state and the five different speeds; they also served to isolate the DC circuit from the AC circuit. The use of relays resulted in a larger energy and space requirement for the implementation of the system. The system would have been more energy efficient if an Opto-coupler, for example the MCT2E wired as a zero-crossing detector and an Opto-isolator, for example the MOC3021 used to drive a triac, were used to control the output power to the ceiling fan using voltage phase control. The system would have also been more compact, spatially. The optical devices could not be obtained in the course of the systems development.

6.4 RECOMMENDATIONS

i) Investigations could be carried out to find out if other light sensing devices, photodiodes or phototransistors, and specialized voltage comparators, for example those in the LM300 family of ICs, could be used to derive a more sensitive light beam detector.

ii) Photometer readings would aid in the scientific evaluation of designs like that undertaken in this thesis which involves luminous intensity difference detection.

iii) To have a more compact and energy efficient ceiling fan controller of this kind, investigations into how optical coupling and isolating devices could be used for the control of the power output from the regulator should be carried out.

iv) A study into the possible short-term and long-term disadvantages, if any, of using the output of a voltage phase control system to regulate the speed of a ceiling fan should be carried out.

v) The use of relays should be maintained if the voltage waveform as a result of phase control is found to cause excessive radio interference, undesirable harmonics, audible noise output or any other harmful effect in the controlled device.

REFERENCES

[1] Layton J., 'How Remote Controls Work'
http://electronics.howstuffworks.com/remote-control.htm, 2007

[2] Brain M., 'Inside a TV Remote Control'
http://electronics.howstuffworks.com/inside-rc.htm, 2007

[3] Phillips W.D., '3P: Investigating LDRs'
http://www.doctronics.co.uk/ldr_sensor.htm, 1999

[4] Collinson A., 'Dark Activated Switch'
http://www.zen22142.zen.co.uk/circuits/switching/darksw.htm, 2007

[5] Van Roon T., 'Dark/Light Activated Relay'
http://www.uoguelph.ca/~antoon/circ/actrelay.htm, 2007

[6] WhatIs.com, 'Photon', 'Luminous Intensity', 'Candela', 'Lumen', and 'Lux'
http://whatis.techtarget.com/definition, 2007

[7] Wikipedia.org., 'Illuminance'
http://en.wikipedia.org/wiki/illuminance, 2007

[8] 'Optoelectronic Devices'
http://tpub.com/neets/book7/26f.htm, http://tpub.com/neets/book7/26g.htm, 2007

[9] Farnell Electronic Components Limited, Farnell Electronic Components 2000 - 01, pp. 245, 2000.

[10] Theraja B.L. and Theraja A.K., A Text-book of Electrical Technology, S. Chand & Company LTD, New Delhi, India, pp. 1753-1761, 1995.

[11] Tocci R.J. and Widmer N.S., Digital Systems: Principles and Applications, Prentice Hall International (UK) Limited, United Kingdom, pp. 240, 490, 1998.

[12] TECH/ECA Asia Pacific Edition 2005, Up-To-Date World's Transistor. Thyristor. SMD Code. Diode. IC. Linear. Digital. Analog Comparison Tables A–Z, Tech Publications PTE. LTD, Singapore, 2005

[13] Van Roon, T., '555 Timer-Oscillator Tutorials' www.uoguelph.ca/~antoon/gadgets/555/555.html, 2007

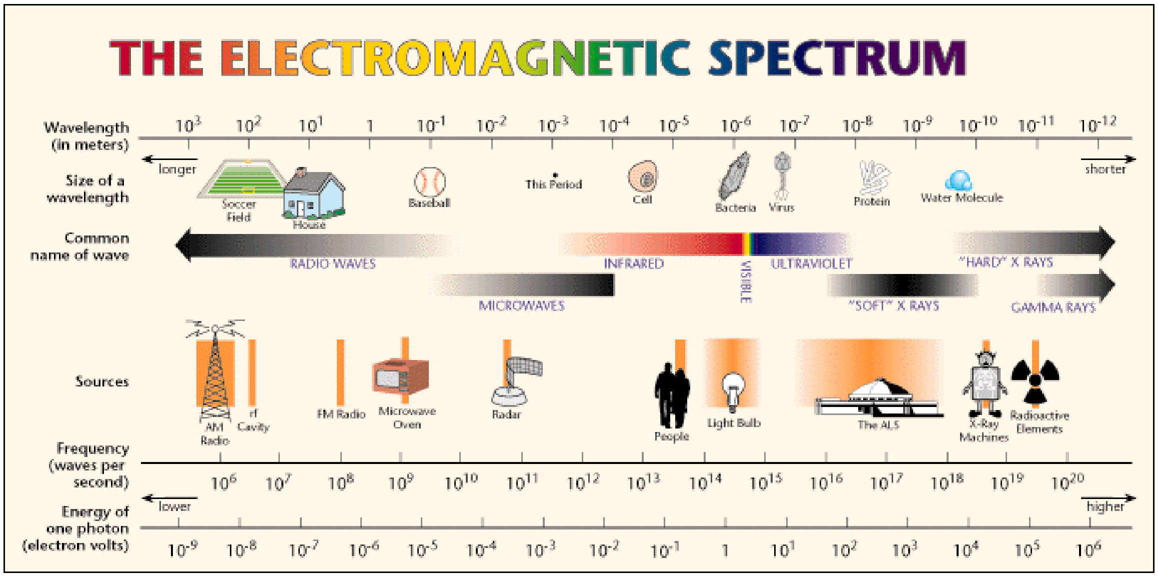
[14] Appendix I, 'The Electromagnetic Spectrum' www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.htm, 2007

[15] Appendix I, 'The Electromagnetic Spectrum' http://en.wikipedia.org/wiki/Electromagnetic_Spectrum, 2007

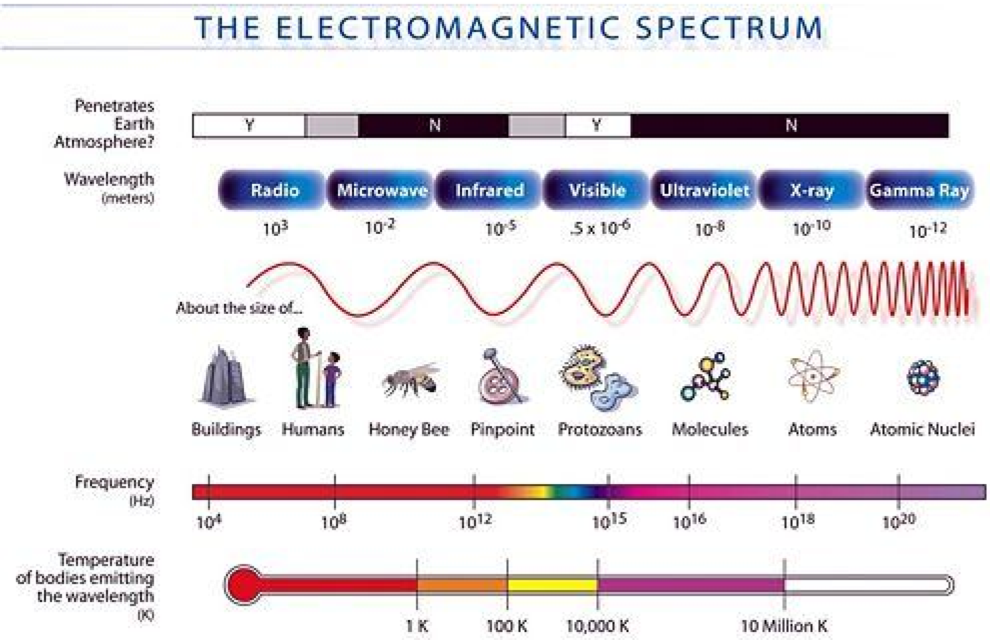
[16] Appendix II, Appendix III and Appendix IV www.alldatasheet.com, 2007

APPENDIX I

THE ELECTROMAGNETIC SPECTRUM



[14]



[15]

APPENDIX II

DATASHEET FOR THE SGS-THOMSON® MICROELECTRONICS UA741 GENERAL PURPOSE SINGLE OPERATIONAL AMPLIFIER ICs

APPENDIX III

DATASHEET FOR THE SGS-THOMSON® MICROELECTRONICS NE555, SA555 & SE555 GENERAL PURPOSE SINGLE BIPOLAR TIMER ICs

APPENDIX IV

DATASHEET FOR THE FAIRCHILD ELECTRONICS™ CD4017BC, CD4022BC COUNTER/DIVIDER ICs