DESIGN AND CONSTRUCTION OF A SOFTWARE CONTROLLED TRIAC LIGHT DRIVER

BY

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MATRICULATION NO. 2000/9928EE

DEPARTMENT OF ELECTRICAL
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A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA NIGER STATE.

OCTOBER, 2006.

DECLARATION

I Ubendu Ikechukwu David declare that this work was done by me and has never been presented else where for the award of degree. I hereby also relinquish the copyright to the Federal University of Technology, Minna.

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DEDICATION

This project work is dedicated to my dear parents, Mr. Obisike David Ubendu and Mrs. Onyemaechi Ubendu.

ACKNOWLEDGEMENT

I am most grateful to the Almighty God for the sustenance, wisdom, guidance, unmerited love and protection he granted me through out my undergraduate years.

I am indebted to my supervisor, Mr. David Michael who took the pain to scrutinize all my manuscripts and was a source of encouragement and inspiration. Indeed I am so grateful to my parents Mr. Obisike Ubendu and Mrs. Onyemaechi Ubendu for their love, advice, encouragements, financial and moral support. I am also thankful to my H.O.D Engr. M.D Abdullahi and level Adviser Mr. J.G. Kolo and all my lecturers for their advice and fruitful directives through the years.

My warm appreciation goes out to my ever caring siblings, Davison Ugochukwu, Mrs. Rose Umezurike, Mrs. Esther Achi Kalu, Uchechukwu, Chukwuma, Chidinma and Chidiebere for their love, encouragement and sincere wish for the success of this project. I wish to express my deep and sincere gratitude to my dearest friends Reuben Audu and Dr. Ayo Adene for their support and expression of true friendship. I also want to say a very big thank you to all my friends and colleagues for their support directly and indirectly to the successful completion of this project work. Special thanks to the Lawals, Seun Olayemi, Abraham, Ronke, Remi, Tunde Togun, Patience, Mrs. Christy Osifoye, Felix Udanyi, Elijah, Cecilia, Amadi, Adelu,Ugo and finally to my special friend Patience Oshuare Ilalokwen.

ABSTRACT

This work is carried out for the purposes of controlling and monitoring electrical appliances connected to a hardware circuitry from software installed on a computer through the parallel port which is the commonly used port in interfacing home made appliances.

This is achieved by constructing a hardware circuitry with an Opto-Triac slaving a Triac and a DB25 Male connector as the major components. This is connected to a software interface (discolitez/WinAmp) on the system which does the switching through a Male-Female connector scanner cable. Rigs (control sequence) are configured on the software interface which determines the control sequence.

This project design is unique in its purpose and cost effectiveness as it cuts down on expended manual human time and energy. It is therefore highly recommended for automated security lighting, entertainment halls and in intelligent systems for conveying information.

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CHAPTER ONE

1. O INTRODUCTION

This project is conducted out of the dare need to control the lighting in my room using the personal computer. [1]. It shows how to build a simple electronic board that will allow you to use software installed on computer to flick a number of switches which are connected to your parallel port. [4].This circuit controls the intensity of one or more lights in response to an audio input [6]. This is achievable with the use of Triacs which handles mains lights using an opto-coupled TRIAC switching circuit [5]. This circuit contains an opto-coupler which actually makes no electrical connection between the high voltage and low voltage sections of the driver circuit to avoid shock at the instance of any problems at the high voltage section. An audio input controls an LED. The light from the LED drives a photo triggered form of a silicon controlled rectifier (SCR) or Triac which are mounted within a single package. This opto triac is used as a driver to control a separate, slave triac capable of handling larger currents [6]. The control software used in the switching from the computer is called the Discolitez. This is a Win Amp plug-in that allows you to control lighting equipment from your computer [3]. Win Amp is music software that provides the required audio signal to be controlled by the discolitez which does the actual switching. The switching is done in such a way that the lighting to be controlled switches on and off with respect to the amplitude of the audio signal. This is done using the parallel port of the computer. The parallel is the most commonly used port for interfacing home made projects. This port will allow the input of up to 9 bits or the output of 12 bits at any one given time, thus requiring minimal external circuitry to implement many simpler tasks. The port is composed of 4 control lines, 5 status lines and 8 data lines. It's found commonly on the back of your PC as a D-Type 25 pin female connector. There may also be a D-Type 25 pin male connector. This will be a serial RS-232 port and thus, is a totally incompatible port. Newer parallel ports are standardized under the IEEE 1284 standard first released in 1994.

This standard defines 5 modes of operation which are as follows,

- Compatibility Mode
- Nibble Mode
- Byte Mode
- EPP Mode (Enhanced Parallel Port)
- ECP Mode (External Parallel Port)

The aim was to design new drivers and devices which were compatible with each other and also backwards compatible with the Standard Parallel Port (SPP). Compatibility, Nibble & Byte modes use just the hardware available on the original Parallel Port cards while EPP & ECP modes require additional hardware which can run at faster speeds, while still being backwards compatible with the Standard Parallel Port.

Compatibility mode or "Centronics Mode" as it is commonly known can only send data in the forward direction at a typical speed of 50Kbytes per second but can be as high as 150+ Kbytes a second. In order to receive data, you must change the mode to either Nibble or Byte mode. Nibble mode can input a nibble (4 bits) in the reverse direction. E.g. from device to computer. Byte mode uses the Parallel's bi-directional feature (found only on some cards) to input a byte (8 bits) of data in the reverse direction.

Extended and Enhanced Parallel Ports use additional hardware to generate and manage handshaking. To output a byte to a printer (or anything in the matter) using compatibility mode, the software must,

- Write the byte to the Data port.

- Check to see if the printer is busy. If the printer is busy, it will not accept any data, thus any data which is written will be lost
- Take the Strobe (pin 1) low. This tells the printer that there is the correct data on the data lines. (pin 2-9).
- Put the Strobe high again after waiting approximately 5 microseconds after putting the strobe low. (Step 3).

This limits the speed at which the port can run at. The EPP & ECP ports get around this by letting the hardware check to see if the printer is busy and generate a strobe and/or appropriate handshaking. This means only one I/O instruction need to be performed, thus increasing the speed. These ports can output at around 1-2 megabytes per second. This in turn increases the switching speed of the external circuitry [7].

1.1 OBJECTIVES

This work is carried out for the following primary objectives:

- Automation
- Control
- Interfacing
- Switching speed of solid state relay

1.2 SCOPE OF WORK

This work will contain the following sourced information as relevant to the subject of discussion:

- Historical background of switching in general
- Theoretical background of external circuitry (hardware)
- Detailed analysis/mode of operation of circuit components.

- Analysis of the mode of operation of the control software (Discolitez/WinAmp).
- Relevant issues arising from design modification and FAQ's.
- Recommendations.

The sources of materials used were basically in Minna, Abuja and Lagos.

The constraint to achievable performance is basically problems posed by the non availability of very new components as well as the scarcity of some of the major components.

The involvement of Mr. Michael David who screened this project topic weighing its vantage and ill vantage points before approval as my Supervisor and Mr. Chris who helped out in the modification and design of the circuit can not be overemphasized.

CHAPTER TWO

2.1 LITERATURE REVIEW

2.2 INTRODUCTION

This chapter talks about the basics of electrical switches and switching in general. It puts into a very co incise discussion the functionality of switches ranging from manual to automatic with special reference to the subject matter; solid state relay switching (Triac switching).

2.3 WHAT ARE SWITCHES

Switches are devices for changing the course (or flow) of a circuit. The prototypical model is a mechanical device (for example a railroad switch) which can be disconnected from one course and connected to another. The term "switch" typically refers to electrical power or electronic telecommunication circuits. In applications where multiple switching options are required (e.g., a telephone service), mechanical switches have long been replaced by electronic variants which can be intelligently controlled and automated.

The switch is referred to as a "gate" when abstracted to mathematical form. In the philosophy of logic, operational arguments are represented as logic gates. The use of electronic *gates* to function as a system of logical gates is the fundamental basis for the computer—i.e. a computer is a system of electronic switches which function as logical gates [8]

Here is what switches look like:

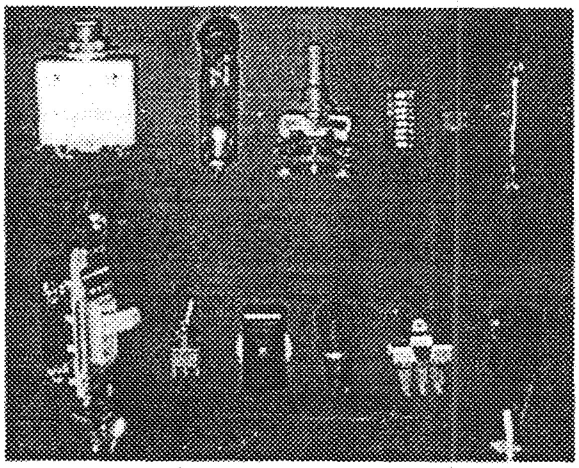


FIG 2.1 Electrical switches

Top, left to right: circuit breaker, mercury switch, wafer switch, DIP switch, surface mount switch, reed switch. Bottom, left to right: wall switch (U.S. style), miniature toggle switch, in-line switch, push-button switch, rocker switch, micro switch. [8]

A **light switch** is a switch, commonly used to operate electric lights, hardwired equipment, or electrical outlets.

In modern homes most lights are operated using switches set in walls, usually 6-10 inches (15-25 cm) away from a door, to operate overhead ceiling lights. In torches (flash light) the switch is far nearer the bulb.

Home light switches, being in reality a metal or plastic box with a switch in it, commonly have switch plate covers called wall plates. These are usually plastic, or ceramic, and are there to prevent accidental electrocution. It also allows the switch to more properly blend in with the style of a room.

A **dimmer switch** is a kind of light switch that allows a light to be dimmed or brightened continuously. An inefficient and more dangerous method of doing this would involve placing a variable resistor in series with the circuit. More sophisticated methods use a form of pulse width modulation, stopping current flow completely for a fraction of a second and allowing it to flow freely for other periods. Dimmers should be used only with light fixtures and then only with incandescent lamps. [9]

Now the above explanaition of switches/switching makes it all manual. In this present age where almost all sectors`are experiencing automation in almost every form of it, there is actually a need for switches/switching to automate. In this vain I have decided to biuld software controlled switching device which will be discussed in the next chapter of the work.

In data communications, an **automatic switching system** is a switching system in which all the operations required to execute the three phases of information-transfer transactions are automatically executed in response to signals from a user end-instrument.

In an automatic switching system, the information-transfer transaction is performed without human intervention, except for initiation of the access phase and the disengagement phase by a user.

In telephony, it refers to a system in which all the operations required to set up, supervise, and release connections required for calls are automatically performed in response to signals from a calling device.[16] while in electrical switching it refers to a system in which all the operations required to set up, supervise, and release connections required for the switching of several lighting points and other electrical devices are automatically performed in response to signals from a software-hardware computer interface without wasting human energy and time.

In automatic switching, there two basic electronics components that need be talked about: the Relay and the Triac. These are different components that perform the same task but at different rates.

2.4 THE RELAY

A **relay** is an electrical switch that opens and closes under control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. It was invented by Joseph Henry in 1835. Because a relay is able to control an output circuit of higher power than the input circuit, it can be considered, in a broad sense, to be a form of electrical amplifier.

These contacts can be either **Normally Open (NO)**, **Normally Closed (NC)**, or **change-over** contacts.

- Normally-open contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called **Form A** contact or "make" contact. Form A contact is ideal for applications that require to switch a high-current power source from a remote device.
- Normally-closed contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called **Form B** contact or

"break" contact. Form B contact is ideal for applications that require the circuit to remain closed until the relay is activated.

- Change-over contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called **Form C** contact.[17]

Here is what a relay looks like:

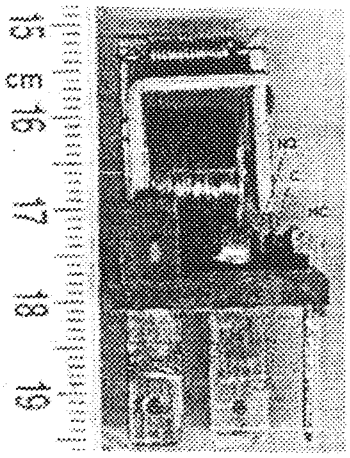


Fig 2.2 Automotive style miniatures relay

2.5 THE TRIAC

The triac is a three terminal semiconductor for controlling current in either direction. Below is the schematic symbol for the triac. Notice the symbol looks like two SCRs in parallel(opposite direction) with one trigger or gate terminal. The main or power terminals are designated as MT1 and MT2. (See the schematic representation below) When the voltage on the MT2 is positive with regard to MT1 and a positive gate voltage is applied, the left SCR conducts. When the voltage is reversed and a negative voltage is applied to the gate, the right SCR conducts. Minimum holding current, Ih, must be maintained in order to keep a triac conducting.

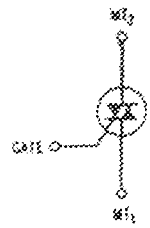
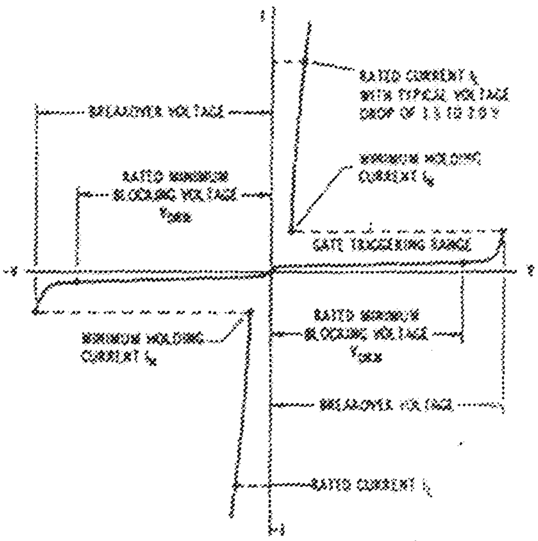


Fig 2.3 Symbol of a triac

A triac operates in the same way as the SCR however it operates in both a forward and reverse direction. To get a quick understanding of its operation refer to its characteristic curve below and compare this to the SCR characteristic curve. It can be triggered into conduction by either a PLUS (+) or MINUS (-) gate signal.



Typical triac VI characteristic curves.

Fig 2.4 Typical triac VI characteristic curves

Obviously a triac can also be triggered by exceeding the break over voltage. This is not normally employed in triac operation. The break over voltage is usually considered a design limitation. One other major limitation, as with the SCR, is dV/dt, which is the rate of rise of voltage with respect to time. A triac can be switched into conduction by a large dV/dt. Typical applications are in phase control, inverter design, AC switching, relay replacement, etc.

Major considerations when specifying a triac are.

(a) Forward and reverse break over voltage.

(b) Maximum current

(c) Minimum holding current

(d) Gate voltage and gate current trigger requirements.

(e) Switching speed

(f) Maximum dV/dt [18]

2.6 WHY TRIAC

The most traditional way to control these lights is through mechanical relays but there are a lot of disadvantages which can make them ineffective.

This work shows how triacs can substitute for mechanical relays in controlling lights with a higher level of quality and reliability. The triac is a three-terminal ac semiconductor switch that is triggered into conduction when a low energy signal is applied to its gate. Unlike the silicon controlled rectifier, or SCR, the triac will conduct current in either direction when turned on: and the triac also differs in that either a positive or negative gate signal will trigger the triac into conduction: The triac may be thought of as two complementary SCRs in parallel.

The triac offers the circuit designer an economical and versatile means of accurately controlling ac power with several advantages over conventional mechanical switches: The triac has a positive 'on' and a zero current 'off' characteristic; it does not suffer from the contact bounce or arcing inherent in mechanical switches: the switching action of the triac is very fast compared to conventional relays, giving more accurate control; a triac can be triggered by dc, ac, rectified ac or pulses; and because of the low trigger energy required the control circuit can use any of many low-cost solid-state devices such as transistors, sensitive gate SCRs and triacs, optically coupled drivers, and integrated circuits. [18]

CHAPTER THREE

3.0 SYSTEMS DESIGN

3.1 INTRODUCTION

This chapter basically talks about the design and construction of the Triac light driver which discusses how the various units sum up to produce and influence the computerized interface. The block diagram below shows the different units and its relationship to the digital system.

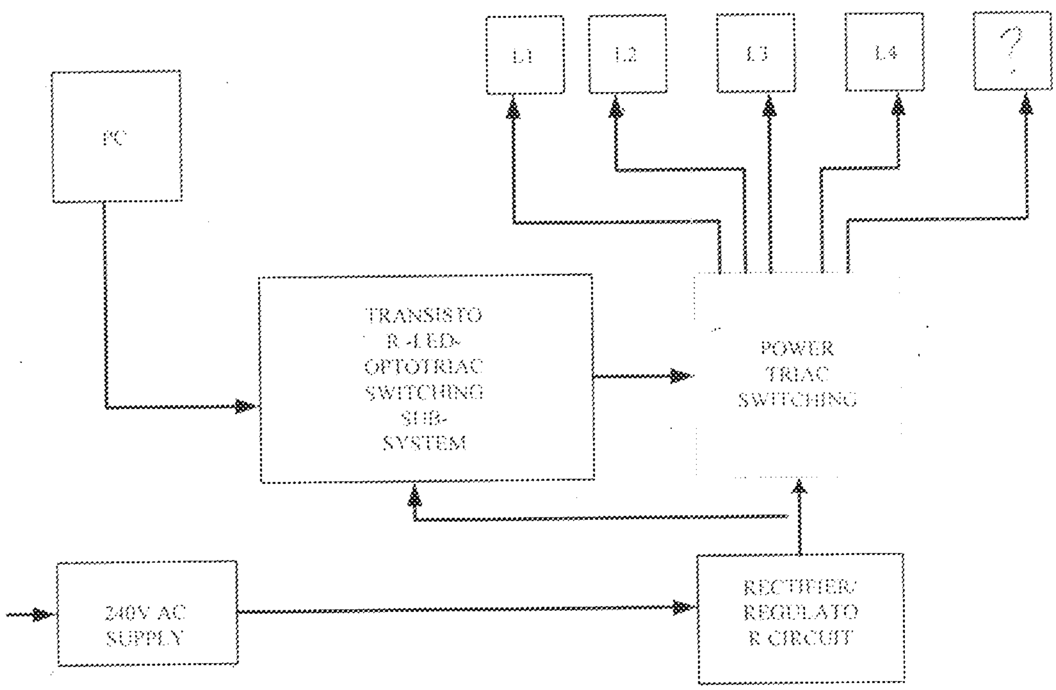


FIG 3.1 The block diagram of the various units and its relationship to the digital system

The PC based disco lighting system is composed of the under listed subsystems:

1 Power supply: rectifier plus regulator

2 Power triac switching

3 Transistor – LED – Opto- triac switching sub subsystem.

3.2 POWER SUPPLY

The power supply comprises a 12V1A transformer, a 7805 regulator, a packaged full wave bridge rectifier, and two electrolytic capacitors connected as shown below:

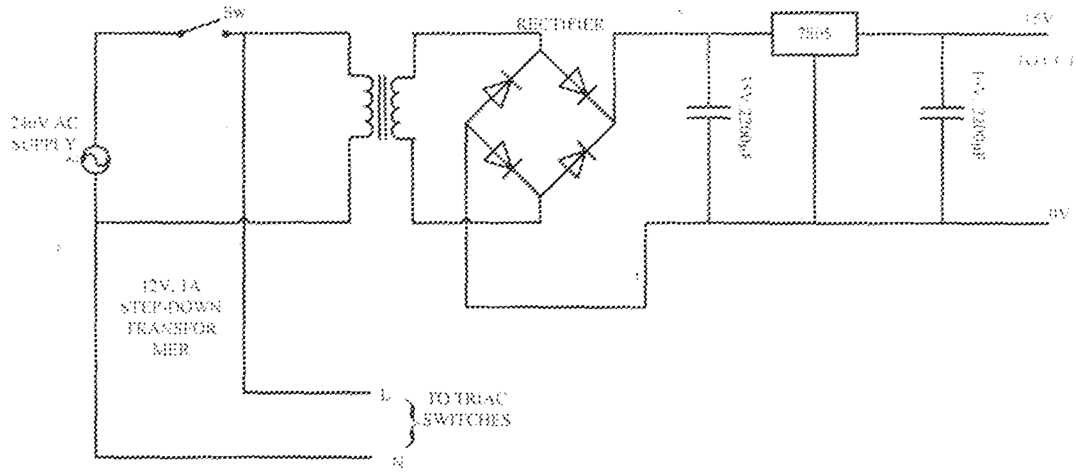


FIG 3.2 Power supply unit

The output voltage of the rectifier is given by the expression:

$$V_{out} = V_{rms}\sqrt{2}\,(1-1/4FR_LC)$$

Where Vrms = secondary voltage of the transformer

F = Frequency of rectified DC = 2 * line frequency = 2* 50 = 100Hz

R_L = Total circuit resistance

C = Capacitance on the power line.

Discounting $1/4FR_LC$, the output voltage is approximately given by

$$V_{out} = V_{rms}\sqrt{2}.$$

Thus, for a 12Vrms transformer, $V_{rectified} = 12\sqrt{2}. \approx 16.97V$.

This voltage is present at the input of the 7805 regulator. The regulated output is held stabilized against fluctuations by a 16V 2200μF capacitor.[12]

3.3 TRANSISTOR – OPTOTRIAC SWITCH

The 5-bit digital outputs from a computer's parallel port are interfaced to the 240V mains AC lines through a network of transistors and opto-triacs. For complete isolation between the 5V computer logic and the high tension AC mains, five MOC3023 opto-triacs with integral Gallium Arsenide Infra Red emitting diode and a light activated silicon bilateral switch are used. The MOC3023 device is shown below

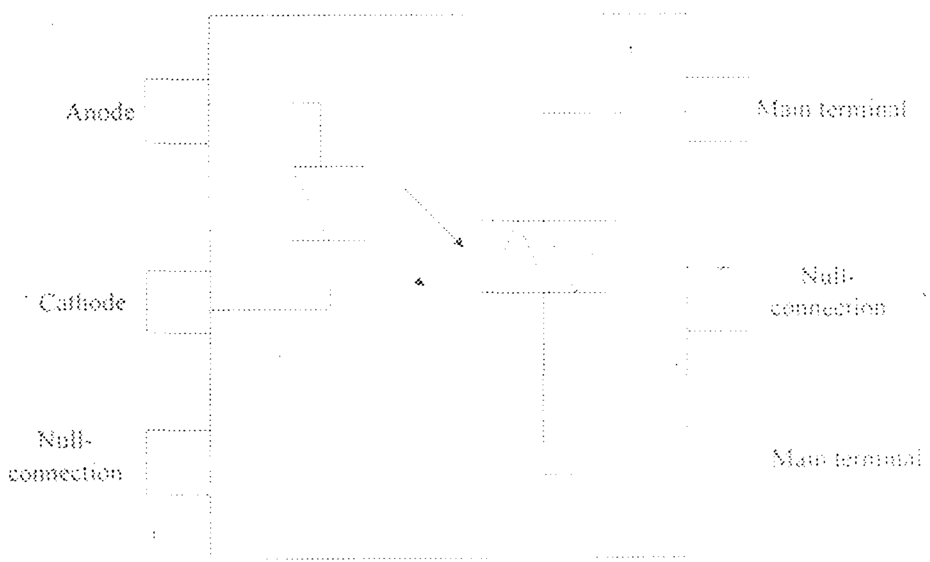


Fig 3.3 MOC3023

The MOC3023 is a 6-pin DIP (dual in-line package) random turn-on opto-isolator triac driver capable of standing off 400V peak without breakdown.

3.4 C9014 SWITCHING TRANSISTORS

The parallel port is buffered by five NPN silicon transistors whose collector loads are the integral LEDs in each opto-triac.

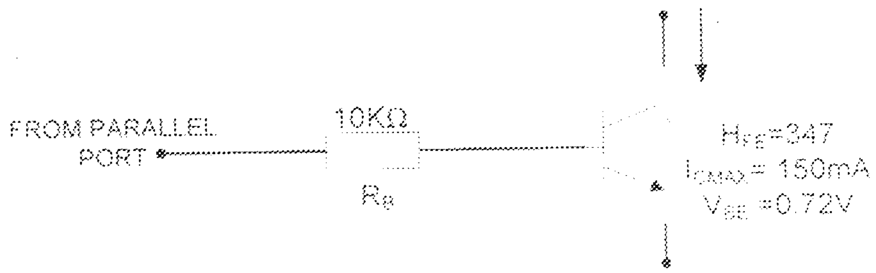


Fig 3.4 C9014 switching transistor

The infra red LEDs in the opto-triacs can handle a continuous forward current of up to 60mA, at a forward voltage drop of 1.17V. Choosing a forward current of 35mA and operated off +5V, a series limiting resistance of: $(5 - 1.17 / 0.035) = 109\Omega$ was calculated. The rarest preferred value of 100 Ω was used.

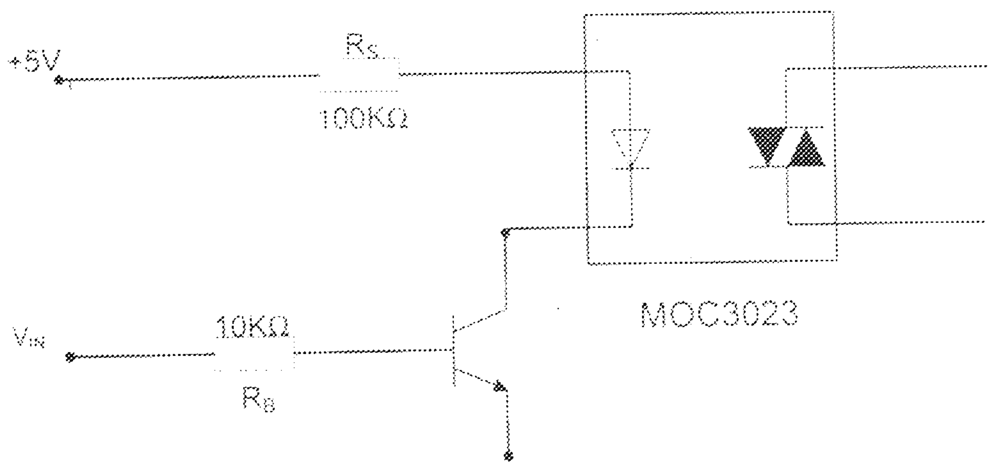


Fig 3.5 TRANSISTOR-OPTO-TRIAC SWITCH

With $I_C = 35mA$, $h_{fe} = 347$. $I_B = I_C / h_{fe} = 100mA$:

$R_B = V_{in} - V_{be} / I_B = 3.4 - 0.72 / 10^{-4} \approx 270\ K\Omega$

This value of R_B gives the maximum value of R_B above which the transistor can no longer sink the I_F needed to keep the LED on. Since the parallel port can sink/source up to 24mA at 3.4V (TTL) a minimum value of R_B would be 142Ω. To ensure complete saturation without loading the parallel port printer card, a 100kΩ resistance was used. By calculation this translates to an I_C of 9mA which still fits within the MOC3023 LED current demand of between 5mA – 60mA [10]

3.5 POWER TRIAC

Five BT 139 power triacs were used in the design work. The BT 139 is a TO220AB packaging as shown below:

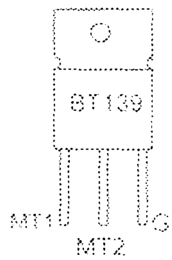


Fig 3.6 Power triac

The triacs are operated in quadrant I, i.e. +ve I, +ve MT2, +ve G with respect to MT1.

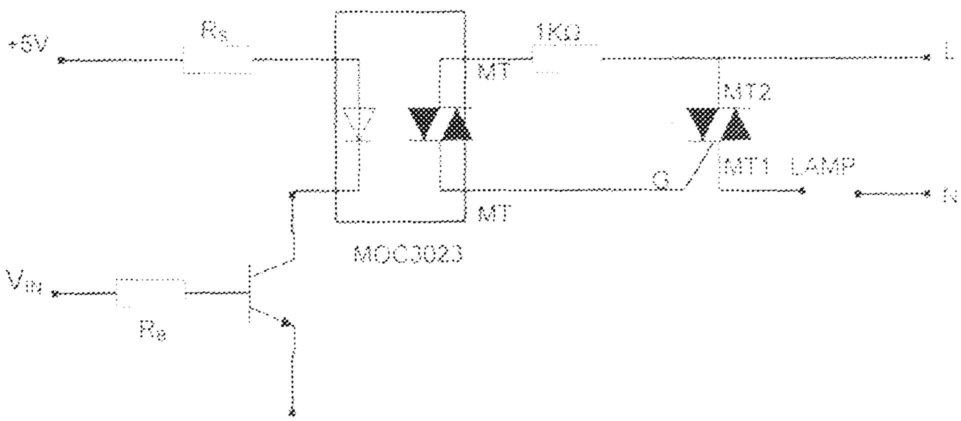


Fig 3.7 Transistor-Optotriac-Triac switching unit

The transistor – optotriac – triac combination is illustrated above. The opto-triac is connected to the live input of the 240V 50Hz AC mains such that the gate is made positive relative to MT1 when the C9014 transistor is switched on by the logic level from the DB25 port. The integral LED comes on and switches on the silicon bilateral switch which causes current to flow into the gate terminal on the triac, and consequently information is transferred in parallel: each bit in a particular value is sent simultaneously as an electrical pulse across a separate wire, in contrast to the slower mechanism of a serial port, which requires each bit to be sent in series over a single wire. The number of wires and the type of connector on a parallel port can vary.

3.7 USES

Parallel ports are most often used by microprocessors to communicate with peripheral devices. The most common kind of parallel port is a printer port, such as a Centronics connector based port which transfers eight bits at a time. Disk drives are also connected via special parallel ports, such as those used by the SCSI and ATA technologies. However, when people refer to a parallel port, they are usually referring to a printer port, either on a printer or a PC.

Before USB connections became widespread on mass-market computers, many external devices, such as portable disk drives for Microsoft windows and MS-DOS systems, used a pass-through connector so the device could share a parallel port with a printer. This was done because mass-market Windows boxes of the era lacked any equivalent of the SCSI connections then common on some other platforms; the only convenient connection was usually the single printer port. The parallel port of an IBM PC-compatible computer is, by far, the most common standard computer port that brings standard computer logic voltages directly out to a set of pins. It is much beloved by experimenters and engineers who often use it for inexpensive computer controlled projects. The standard logic voltage, 5 volts DC, is virtually harmless. On the other hand, the parallel port's circuitry is in general quite fragile; appropriate care must be taken to avoid damaging it.

3.8 CONNECTORS

Parallel port connectors usually have at least 25 pins, most of which are used, resulting in thick cables. These cables are also limited in length to a maximum of 3-8 meters, depending on the specific port and cable characteristics. Although several standards for parallel ports exist today, they are not always followed (especially on older devices), which sometimes makes finding the proper cable and software driver difficult.

Parallel ports have four types of pins:

- Data pins, usually 8, sometimes 16, and sometimes with an extra pin for a parity bit. They can be either unidirectional (e.g., from a computer to a printer) or bidirectional.
- Control pins, used to send control signals such as STROBE to indicate that the data on the data pins is ready and R/W to specify whether bidirectional ports are reading or writing data.
- Status pins, used to send status signals such as BUSY to indicate the device is not ready to receive data and ACK to acknowledge successful receipt of the symbol.
- Ground pins, to complete the circuits from the other pins.

Lately, the Universal Serial Bus (USB) port has grown in popularity and started displacing parallel ports because USB makes it simple to add more than one device (such as printers) to a computer.

Some examples of parallel ports:

- IEEE 1284 is the IEEE standard for the common PC printer port.
- 8255 for intel microprocessors
- Z80PIO for Zilog microprocessors

3.9 PORT ADDRESSES

Traditionally IBM PC systems have allocated their first two parallel ports according to the configuration in the table below.[13]

Table 3.1 Port addresses

PORT NAME	Interrupt #	Starting I/O	Ending I/O
LPT1	IRQ 7	0x378	0x37f
LPT2	IRQ 5	0x278	0x27f

The Parallel Port has three commonly used base addresses. These are listed in table 2, below. The 3BCh base address was originally introduced used for Parallel Ports on early Video Cards. This address then disappeared for a while, when Parallel Ports were later removed from Video Cards. They have now reappeared as an option for Parallel Ports integrated onto motherboards, upon which their configuration can be changed using BIOS.

LPT1 is normally assigned base address 378h, while LPT2 is assigned 278h. However this may not always be the case as explained later. 378h & 278h have always been commonly used for Parallel Ports. The lower case "h" denotes that it is in hexadecimal. These addresses may change from machine to machine.

Table 3.2 Port Addresses

Address	Notes:
3BCh - 3BFh	Used for Parallel Ports which were incorporated on to Video Cards - Doesn't support ECP addresses
378h - 37Fh	Usual Address For LPT 1
278h - 27Fh	Usual Address For LPT 2

When the computer is first turned on, BIOS (Basic Input/Output System) will determine the number of ports you have and assign device labels LPT1, LPT2 & LPT3 to them. BIOS first look at address 3BCh. If a Parallel Port is found here, it is assigned as LPT1, and then it searches at location 378h. If a Parallel card is found there, it is assigned the next free device label. This would be LPT1 if a card wasn't found at 3BCh or LPT2 if a card was found at 3BCh. The last port of call is 278h and follows the same procedure than the other two ports. Therefore it is possible to have a LPT2 which is at 378h and not at the expected address 278h.

What can make this even confusing is that some manufacturers of Parallel Port Cards have jumpers which allow you to set your Port to LPT1, LPT2, and LPT3. Now what address is LPT1? - On the majority of cards LPT1 is 378h, and LPT2, 278h, but some will use 3BCh as LPT1, 378h as LPT1 and 278h as LPT2.

The assigned devices LPT1, LPT2 & LPT3 should not be a worry to people wishing to interface devices to their PC's. Most of the time the base address is used to interface the port rather than LPT1 etc. However should you want to find the address of LPT1 or any of the Line Printer Devices, you can use a lookup table provided by BIOS. When BIOS assigns addresses to your printer devices, it stores the address at specific locations in memory, so we can find them.

Table 3.3 LPT Addresses in the BIOS Data Area

Start Address	Function
0000:0408	LPT1's Base Address
0000:040A	LPT2's Base Address
0000:040C	LPT3's Base Address
0000:040E	LPT4's Base Address (Note 1)

Note 1: Address 0000:040E in the BIOS Data Area may be used as the Extended Bios Data Area in PS/2 and newer BIOS's.

The above table, table 3, shows the address at which we can find the Printer Port's addresses in the BIOS Data Area. Each address will take up 2 bytes.

3.9.1 HARDWARE PROPERTIES

Below is a table of the "Pin Outs" of the D-Type 25 Pin connector and the Centronics 34 Pin connector. The D-Type 25 pin connector is the most common connector found on the Parallel Port of the computer, while the Centronics Connector is commonly found on printers. The IEEE 1284 standard however specifies 3 different connectors for use with the Parallel Port. The first one, 1284 Type A is the D-Type 25 connector found on the back of most computers. The 2nd is the 1284 Type B which is the 36 pin Centronics Connector found on most printers.

Table 3.4 Pin Assignments of the D-Type 25 pin Parallel Port Connector

Pin No (D-Type 25)	Pin No (Centronics)	SPP Signal	Direction In/out	Register	Hardware Inverted
1	1	nStrobe	In/Out	Control	Yes
2	2	Data 0	Out	Data	
3	3	Data 1	Out	Data	
4	4	Data 2	Out	Data	
5	5	Data 3	Out	Data	
6	6	Data 4	Out	Data	
7	7	Data 5	Out	Data	
8	8	Data 6	Out	Data	
9	9	Data 7	Out	Data	
10	10	nAck	In	Status	
11	11	Busy	In	Status	Yes
12	12	Paper-Out / Paper-End	In	Status	
13	13	Select	In	Status	
14	14	nAuto-Linefeed	In/Out	Control	Yes
15	32	nError / nFault	In	Status	
16	31	nInitialize	In/Out	Control	
17	36	nSelect-Printer / nSelect-In	In/Out	Control	Yes
18 - 25	19-30	Ground	Gnd		

The above table uses "n" in front of the signal name to denote that the signal is active low. E.g. nerror. If the printer has occurred an error then this line is low. This line normally is high, should the printer be functioning correctly. The "Hardware Inverted" means the signal is inverted by the Parallel card's hardware. Such an example is the busy line. If +5v (Logic 1) was applied to this pin and the status register read, it would return back a 0 in Bit 7 of the Status Register.

The output of the Parallel Port is normally TTL logic levels. The voltage levels are the easy part. The current you can sink and source varies from port to port. Most Parallel Ports implemented in ASIC, can sink and source around 12mA. However these are just some of the figures taken from Data sheets. Sink/Source 6mA, Source 12mA/Sink 20mA, Sink 16mA/Source 4mA, Sink/Source 12mA. As you can see they vary quite a bit. The best bet is to use a buffer, so the least current is drawn from the Parallel Port. [7]

3.10 THE SOFTWARE PROGRAM

The software was programmed in using java language. It is basically a plug-in to a music software called Win Amp. The interface was built to be compatible with other programming languages that could be used to access windows printer parallel port under windows 98 operating system. Due to the design of the Windows NT not to allow direct software access to any of their hardware resources, Discolitez does not work on it. But it works with the newer versions which are backward compatible e.g. Windows XP.

3.11 HOW THE SOFTWARE WORKS WITH THE PARALLEL PORT

Parallel port is assigned a unique I/O address, which is generally among the following:

- 378h (mostly the case)
- 278h (normally found when there is more than one parallel port)
- 3BCh (rare case)

3.12 TO CONFIRM THE PORT ADDRESS ON THE COMPUTER

Restart the computer, go into BIOS. Then see the address of the port, if it is set auto then there are two options:

1 Explicitly assigns an address in the BIOS

2 Check the address in windows by going through the following procedure:

CONTOL PANEL → SYSTEM → DEVICE MANGER

↓

PROPERTIES ← PRINTER PORT ← PORTS

RESOURCES → INPUT/OUTPUT RANGE

3.13 DIFFERENCE BETWEEN MEMORY ADDRESS SPACE AND I/O ADDRESS

In Intel family of x86 processors the memory addresses and I/O addresses are different.

Memory addresses

They depend upon the RAM/ROM present in your PC and Address lines

3.14 I/O

This address space is dependent upon the number of address lines available for accessing I/O.devices.

3.15 RELATION BETWEEN BITS PRESENT AT THE PORT ADDRESS AND VOLTAGE LEVELS ON PORT PINS

- Each bit present at base address of the port has direct link with the voltage level on corresponding port pin. i.e. a '1' in register at I/O address corresponds to logic high at port pin.

3.16 OVERVIEW OF LOGIC HIGH AND LOGIC LOW LEVELS OF PARALLEL PORT

- Logic high means a voltage of +5V with respect to ground.
- Logic low means a voltage of 0V with respect to ground.

Deviation from above 'bit-logic level' relation in case of hardware –inverted pins the above described relation of bit and logic level is reversed i.e. '1' corresponds to 0V on port pin. Examples are busy and strobe. [7]

3.17 THE INTERFACING CIRCUIT

The circuit components are described below:

Component listing

- DB25 male connector
- C9014 NPN Transistors
- MOC3023 Opto-triacs
- BT139 Triacs
- 12V 1A Transformer
- 7805 Voltage regulator
- Packaged Full wave bridge rectifier
- Capacitors
- Resistors
- Power switch
- Screw Lamp holders
- Scanner cable (male – female)
- 25W 240V Colored bulbs

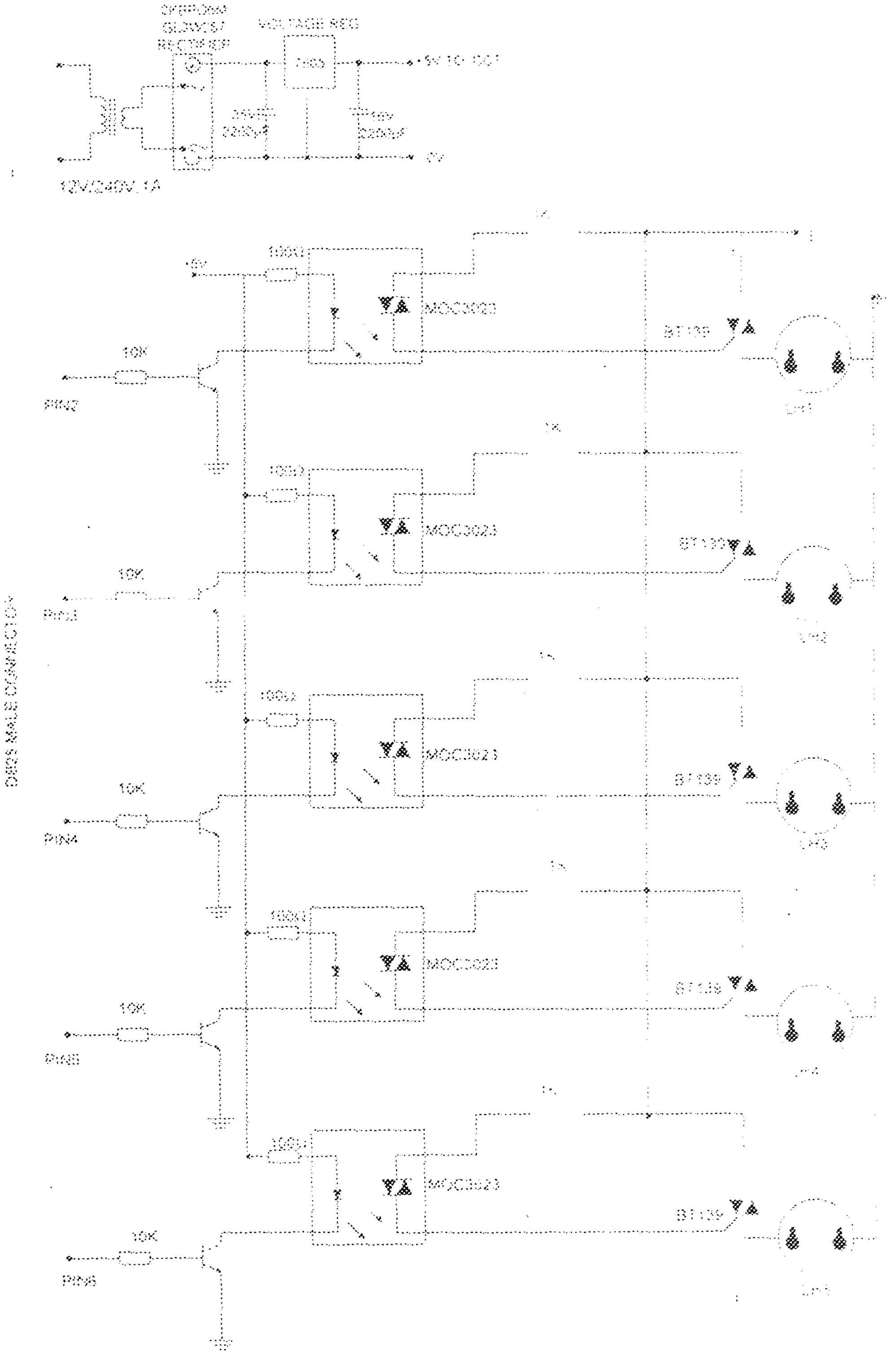


FIG. 3.8 CIRCUIT DIAGRAM OF SOFTWARE CONTROLLED TRIAC LIGHT DRIVER

TABLE 3.5 BILL OF ENGINEERING MEASUREMENT AND EVALUATION

S/NO.	COMPONENTS	DESCRIPTION	UNIT COST(₦)	QUANTITY	AMOUNT (₦)
1	Connector	DB 25 pins(M)	200	1	200
2	Transistor	C9014 NPN	10	5	50
3	Opto-triac	MOC3023	150	5	750
4	Triac	BT139	150	5	750
5	Transformer	Step down 12V,1A	350	1	350
6	Voltage Reg.	7805	100	1	100
7	Rectifier	Full wave bridge	100	1	100
8	Capacitor	Electrolytic 35V,2200µF/, 16V/2200µF	100	2	200
9	Resistors	Colour code	5	15	75
10	Power Switch		20	1	20
11	Lamp holder	Screw type	50	5	250
12	Scanner cable	Male - Female	400	1	400
13	Coloured Bulbs	Screw type 25W, 240V	50	5	250
14	Casing	Brown Ceramic	3000	1	3000
	TOTAL			49	6495

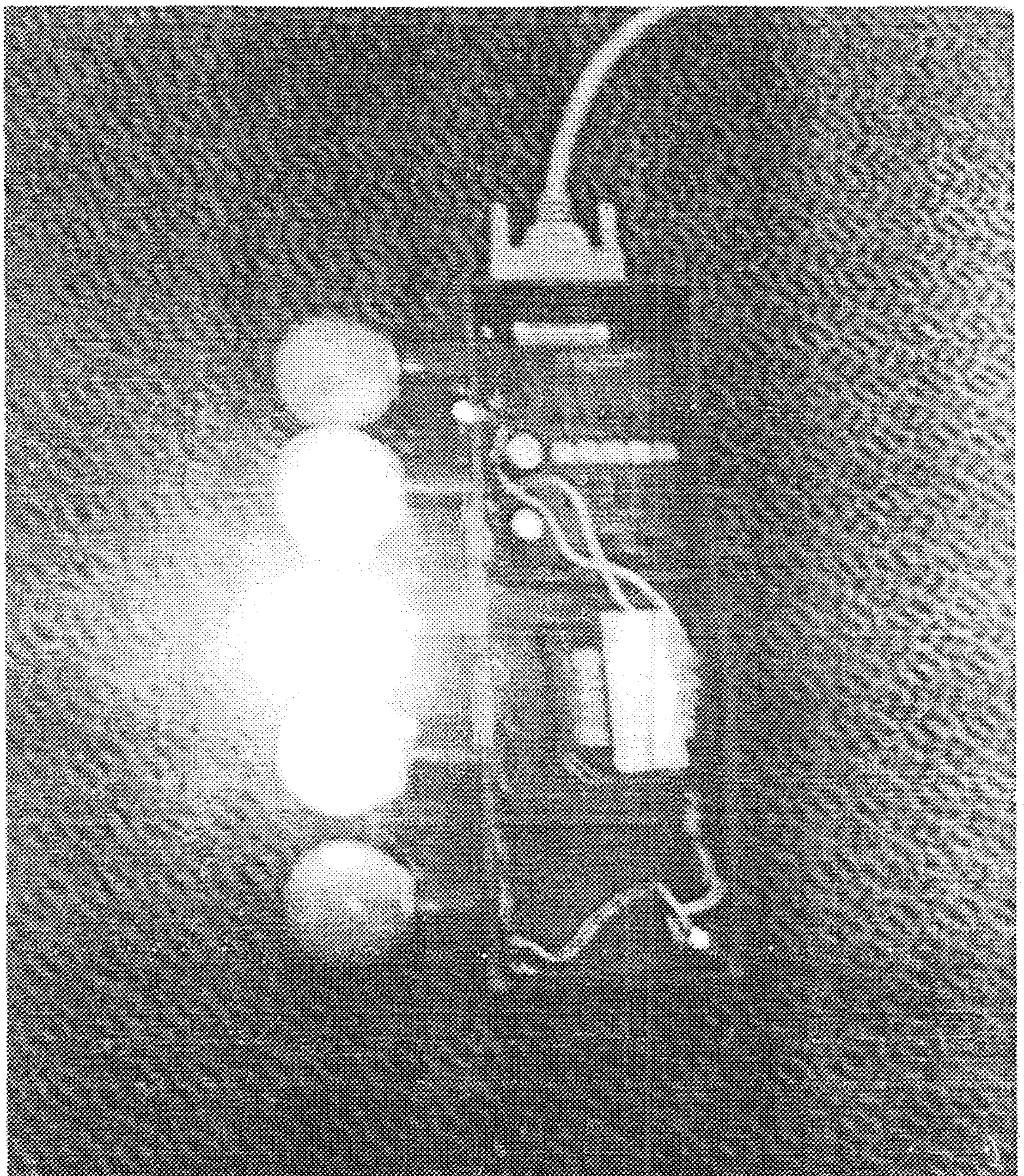


FIG. 3.9 ARIAL PHOTOGRAPH OF TRIAC LIGHT DRIVER WHEN LIT

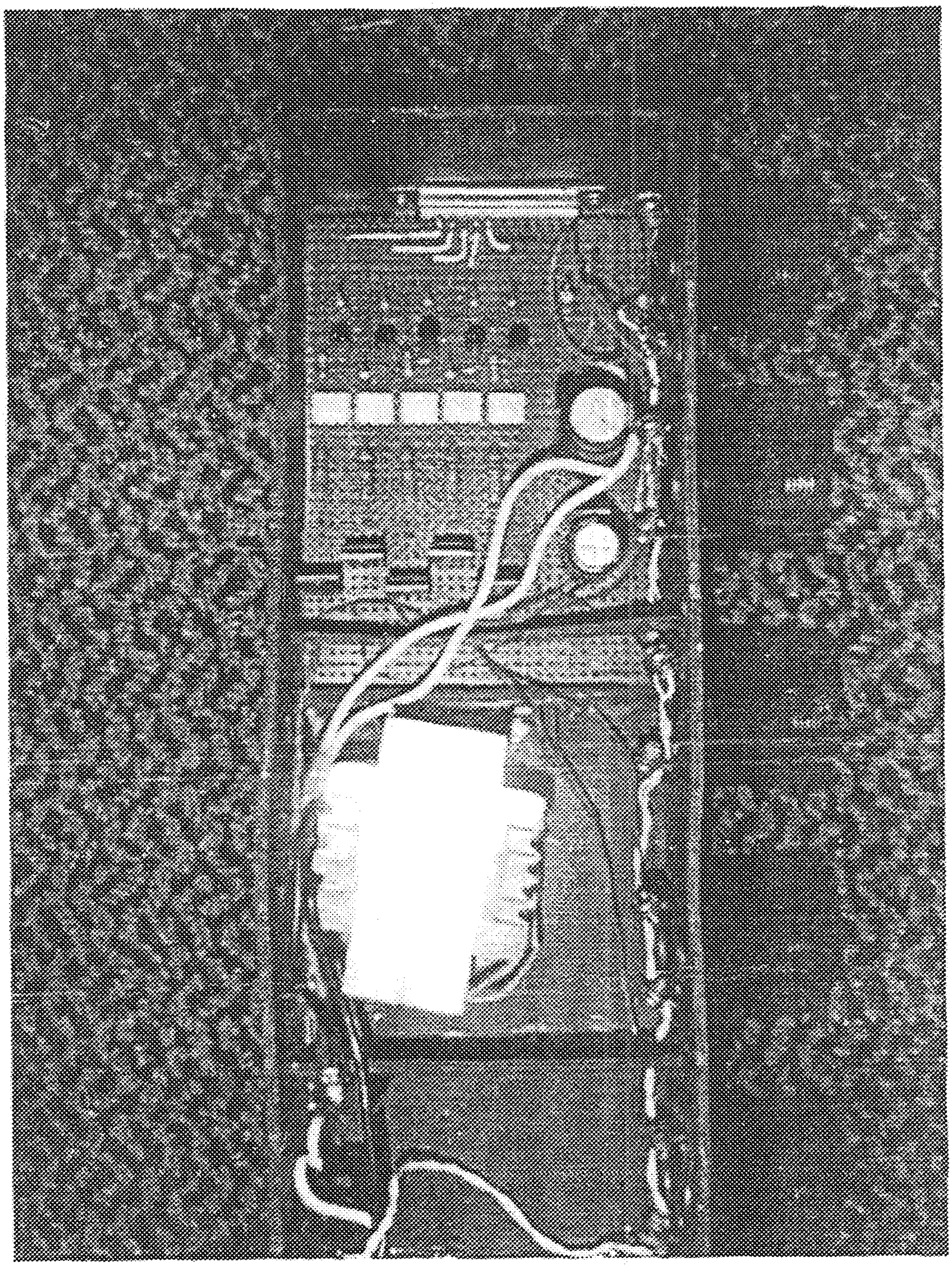


FIG.3.10 ARIAL PHOTOGRAPH OF TRIAC LIGHT DRIVER CIRCUITRY

CHAPTER FOUR

4.1 INTRODUCTION

This chapter talks about the testing of the prototype copy of the project design with properly documented testing and measurement method, the tabulation and the discussion of these test results.

4.2 TESTING AND METHOD OF TESTING

This project was designed to serve as a control center to several lighting points and appliances through an automated software controlled interface at a speed faster than that of a relay with the help of a triac. In order to demonstrate the aim of this software controlled hardware circuitry, the following major steps are taken:

- Power on the personal computer with a Microsoft windows operating system other than Windows NT.
- Install the control software (Win Amp and Discolitez)
- Connect the DB25 female end of the scanner cable to DB25 male connector on the hardware circuitry and the DB25 male end of the scanner cable to the DB25 female connector of the computer's parallel port.
- Screw in the 4 25W 240V and 1 40W 240V colored bulbs to the screw type lamp holders on the hardware circuitry.
- Plug the circuit to a 240V mains power source.
- Power on the circuit by a switch on the rear side of the circuit casing.

The above procedure is confirmed by an LED power indicator coming on, as well as all the colored bulbs coming on.

Now in testing the switching ability and speed of the triac in the circuitry through the automated software controlled interface, the following steps are taken:

- Double click on the Win Amp music software on the desktop.
- Play some music
- Click the START button
- Locate ALL PROGRAMS on the pop up menu
- Locate the Discolitez icon on the next pop up menu and click
- On the Discolitez software interface configure a control sequence as you desire to switch the various bulbs.

4.2.1 CONFIGURING A CONTROL SEQUENCE (A RIG)

The Discolitez environment provides you with several input/ output and visualization options on it. This is shown on fig.4.1. In configuring a simple control sequence, the following steps are taken:

- Click on **OUTPUT** and three options will be displayed.
- Click on the Icon with the Win Amp logo which is the Win Amp Control
- Click on the work space below and the component will be drawn.
- Repeat steps 2 and 3 for the **DLOP** icon
- Click on **INPUT** and several options are displayed.
- Repeat steps 2 and 3 for the **MOUSE INPUT**, **DL TIMER**, **SWITCH**, **SLIDER**, **LINE INPUT** and **Win Amp AUDIO**.
- Click on **VISUAL** and repeat steps 2 and 3 on the icon **GRAPH**.
- Click on **NETWORK** and repeat steps 2 and 3 on the icon **NETWORK PIPE**
- Drag input signals from any of the **INPUT** icons through the **NETWORK PIPE** to the **DLOP** and the **GRAPH**.
- Save the **RIG**.
- Repeat steps 1-10 for several **RIGS**.[3]

4.3 TABULATION OF TEST RESULTS

TABLE 4.1 TEST RESULTS

OUTPUT STATES

INPUT RIGS	LIGHT OUTPUT
RIG ONE	All five light outputs flicker in response to input pulses from the DL TIMER at rate of one pulse at every 300milliseconds with each pulse lasting for 20milliseconds.
RIG TWO	The DL TIMER sends impulse signals to the yellow, white and blue bulbs at 300ms/20ms while the green and red bulbs are switched ON and OFF using the SWITCH input push button.
RIG THREE	The SLIDER input controls the ON/OFF states of the green and blue bulbs while the SWITCH input push button controls the ON/OFF states of the yellow, red and white bulbs.
RIG FOUR	The SLIDER input controls the ON/OFF states of all the bulbs as it slides across with the help of the mouse.
RIG FIVE	All five light outputs flicker in response to input pulses from the DL TIMER at the rate 100ms/30ms.
RIG SIX	All five light outputs flicker in response to input pulses from the DL TIMER at the rate 100ms/2ms.

4.4 DISCUSSION OF RESULTS

When the hardware circuitry is connected to the computer through the scanner cable to the parallel port, the parallel port supplies 5V to the base resistances of the C9014 transistors through pins 2-6 with pin 1 serving as the strobe (control pin) This turns on all the five colored bulbs. The strobe is hardware inverted: writing a 1gives a 0 on the output and a 0 gives a 1. Since the discolitez is built originally for Windows 98 but with the Discolitez professional II it is now backward compatible for use in Windows XP. On the network pipe component, both the receive and destination port addresses are set to the beginning address of the systems parallel port (0378HEX). While on the DLOIP component, when the icon like a folded arm is clicked several operating options come up. Clicking on the DLO-Advance parallel378-dll icon all the bulbs go off while clicking on the DLO-invertparallel378-dll icon brings them on again. When input signals are dragged from the input components to the DLO component, they function in the following ways:

MOUSE INPUT – this reads the location of the mouse as an input

SLIDER – it controls an output value depending on where slider is dragged to

DL TIMER – outputs pulses at regular intervals in this format 250ms/25ms i.e. there is an output of a pulse at every 250 milliseconds with each pulse lasting for 25 milliseconds

SWITCH – displays a push button which may be clicked. The output is high as long as the button is held down.

NETWORK PIPE – links two discolitez pro instances together through a TCP/IP compatible network. Each instance can send value to the other.

Win Amp AUDIO – this is the win amp audio input module. it reads audio data from Win Amp.

LINE INPUT – takes sound input from the sound card line input.

DLOP LOADER – loads discolitez output plug-in compatible to the discolitez 2.xx. provided for backward compatibility.

Win Amp CONTROL – sends commands to running instance of Win Amp. [3]

4.5 TROUBLE SHOOTING

This project is not 100% reliable, as a result their might be hitches in executing the aim of this work. Some of the hitches might be from personal mistakes or malfunctioning of the system in use.

NB: all the light outputs must come on when the hardware circuitry is connected to the parallel port and its power switch is activated. If this is not so, check the connection to the male or female connectors on the PC and the hardware circuitry. Or click on the options provided by the DLOP loader to confirm it is not on the Advance parallel378-dll mode. if so change it to the invertparallel-dll icon and click ok.

CHAPTER FIVE

5.1 CONCLUSION

The software controlled hardware circuitry was built to perform the following major operations:

- To switch on electronic devices connected to an AC power source.
- To monitor the status of various loads from my personal computer.
- To automatically control devices for the period of usage
- To show the fast switching speed of the Triac.

The above objective of the Triac light driver has been achieved from the results of the testing. It virtually achieved these almost at the same time on a control center without waste of time and energy. This project can be improved on by using more powerful triacs to switch components or devices with higher power rating as well as writing more programs that can control the switching without much configurations and as well being able to function on its own and not as a plug-in to software.

5.2 RECOMMENDATION

The testing of this project gives more assurance of its necessity in future on a larger scale. So I strongly recommend that this work should be encouraged and supported for use in homes, offices, art galleries, cinema halls and as a means of communication for high intelligent systems.

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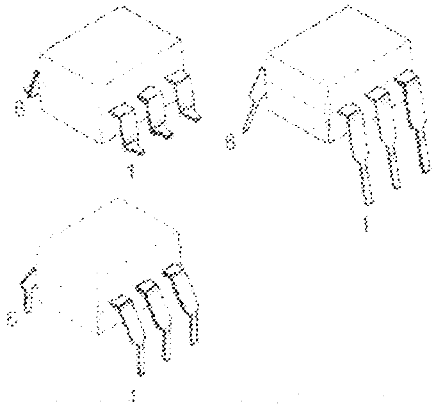
APPENDIX

FAIRCHILD
SEMICONDUCTOR®

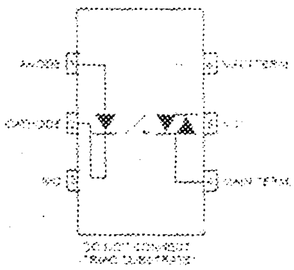
6-PIN DIP RANDOM-PHASE OPTOISOLATORS TRIAC DRIVER OUTPUT (250/400 VOLT PEAK)

MOC3010M MOC3011M MOC3012M MOC3020M MOC3021M MOC3022M MOC3023M

PACKAGE



SCHEMATIC



DESCRIPTION

The MOC301XM and MOC302XM series are optically isolated triac driver devices. These devices contain a GaAs infrared emitting diode and a light activated silicon bilateral switch, which functions like a triac. They are designed for interfacing between electronic controls and power triacs to control resistive and inductive loads for 115 VAC operations.

FEATURES

- Excellent I_{FT} stability—IR emitting diode has low degradation
- High isolation voltage—minimum 5300 VAC RMS
- Underwriters Laboratory (UL) recognized—File #E90700
- Peak blocking voltage
  - 250V-MOC301XM
  - 400V-MOC302XM
- VDE recognized (File #94766)
  - Ordering option V (e.g. MOC3023VM)

APPLICATIONS

- Industrial controls
- Traffic lights
- Vending machines
- Solid state relay
- Lamp ballasts
- Solenoid/valve controls
- Static AC power switch
- Incandescent lamp dimmers
- Motor control

FAIRCHILD
SEMICONDUCTOR®

6-PIN DIP RANDOM-PHASE OPTOISOLATORS TRIAC DRIVER OUTPUT (250/400 VOLT PEAK)

MOC3010M MOC3011M MOC3012M MOC3020M MOC3021M MOC3022M MOC3023M

ABSOLUTE MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Parameters	Symbol	Device	Value	Units
TOTAL DEVICE				
Storage Temperature	T_{STG}	All	-40 to +150	°C
Operating Temperature	T_{OPR}	All	-40 to +85	°C
Lead Solder Temperature	T_{SOL}	All	260 for 10 sec	°C
Junction Temperature Range	T_J	All	-40 to +100	°C
Isolation Surge Voltage[1] (peak AC voltage, 60Hz, 1 sec duration)	V_{ISO}	All	7500	Vac(pk)
Total Device Power Dissipation @ 25°C	P_D	All	330	mW
Derate above 25°C			4.4	mW/°C
EMITTER				
Continuous Forward Current	I_F	All	60	mA
Reverse Voltage	V_R	All	3	V
Total Power Dissipation 25°C Ambient	P_D	All	100	mW
Derate above 25°C			1.33	mW/°C
DETECTOR				
Off-State Output Terminal Voltage	V_{DRM}	MOC3010M/1M/2M MOC3020M/1M/2M/3M	250 400	V
Peak Repetitive Surge Current (PW = 1 ms, 120 pps)	I_{TSM}	All	1	A
Total Power Dissipation @ 25°C Ambient	P_D	All	300	mW
Derate above 25°C			4	mW/°C

Note

1. Isolation surge voltage, V_{ISO}, is an internal device dielectric breakdown rating. For this test, Pins 1 and 2 are common, and Pins 4, 5 and 6 are common.

FAIRCHILD
SEMICONDUCTOR®

6-PIN DIP RANDOM-PHASE OPTOISOLATORS TRIAC DRIVER OUTPUT (250/400 VOLT PEAK)

MOC3010M MOC3011M MOC3012M MOC3020M MOC3021M MOC3022M MOC3023M

ELECTRICAL CHARACTERISTICS (T_A = 25°C Unless otherwise specified)

INDIVIDUAL COMPONENT CHARACTERISTICS

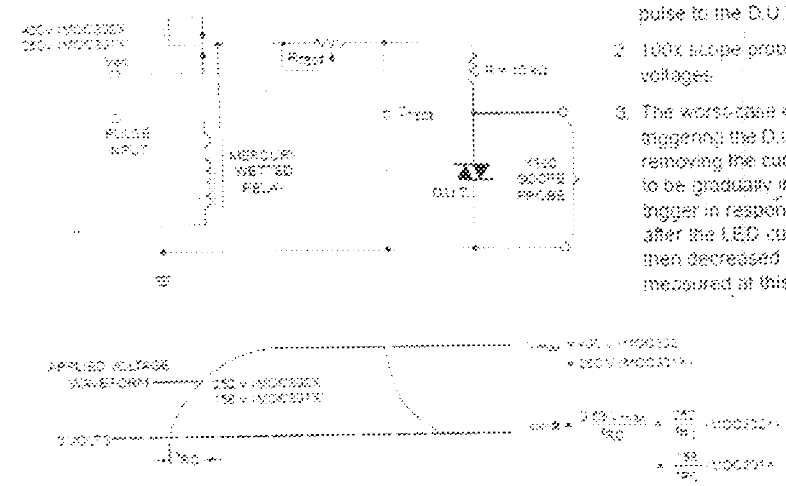
Parameters	Test Conditions	Symbol	Device	Min	Typ	Max	Units
EMITTER							
Input Forward Voltage	I_F = 10 mA	V_F	All		1.15	1.5	V
Reverse Leakage Current	V_R = 3 V, T_A = 25°C	I_R	All		0.01	100	µA
DETECTOR							
Peak Blocking Current,Either Direction	Rated V_{DRM}, I_F = 0 (note 1)	I_{DRM}	All		10	100	nA
Peak On-State Voltage,Either Direction	I_{TM} = 100 mA peak, I_F = 0	V_{TM}	All		1.8	3	V

TRANSFER CHARACTERISTICS (T_A = 25°C Unless otherwise specified)

DC Characteristics	Test Conditions	Symbol	Device	Min	Typ	Max	Units
LED Trigger Current	Voltage = 3V (note 3)	I_{FT}	MOC3020M			30	mA
			MOC3010M			15	
			MOC3021M				
			MOC3011M			10	
			MOC3022M				
			MOC3012M			5	
			MOC3023M				
Holding Current, Either Direction		I_H	All		100		µA

Note

1. Test voltage must be applied within dv/dt rating.
2. This is static dv/dt. See Figure 5 for test circuit. Commutating dv/dt is a function of the load-driving thyristor(s) only.
3. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}. Therefore, recommended operating I_F lies between max I_{FT} (30 mA for MOC3020M, 15 mA for MOC3010M and MOC3021M, 10 mA for MOC3011M and MOC3022M, 5 mA for MOC3012M and MOC3023M) and absolute max I_F (60 mA).



1. The mercury wetted relay provides a high speed repeated pulse to the D.U.T.
2. 100x scope probes are used, to allow high speeds and voltages.
3. The worst-case condition for static dv/dt is established by triggering the D.U.T. with a normal LED input current, then removing the current. The variable R_{TEST} allows the dv/dt to be gradually increased until the D.U.T. continues to trigger in response to the applied voltage pulse, even after the LED current has been removed. The dv/dt is then decreased until the D.U.T. stops triggering. τ_{RC} is measured at this point and recorded.

Figure 5. Static dv/dt Test Circuit

Note: This optoisolator should not be used to drive a load directly. It is intended to be a trigger device only.

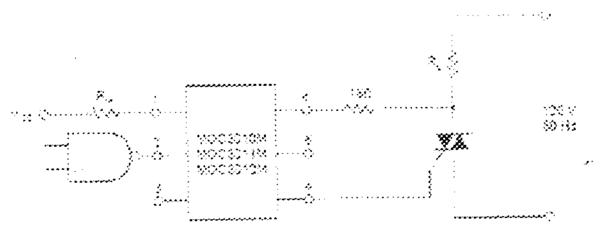


Figure 6. Resistive Load

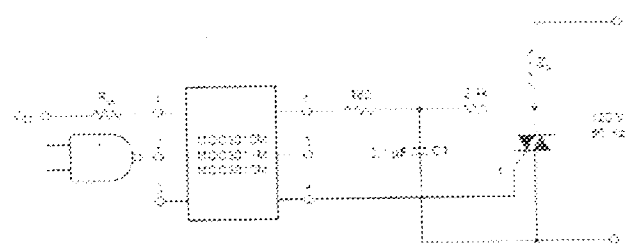


Figure 7. Inductive Load with Sensitive Gate Triac (I_{GT} ≤ 15 mA)

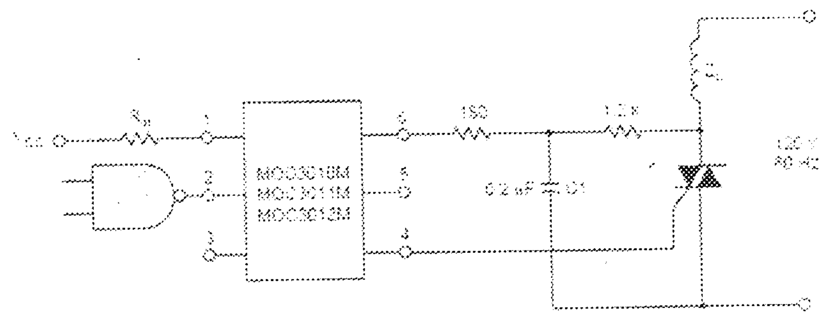
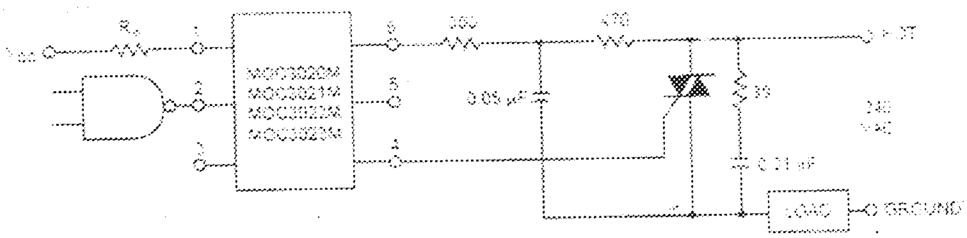


Figure 8. Inductive Load with Sensitive Gate Triac ($I_{GT} \leq 15$ mA)



In this circuit the "hot" side of the line is switched and the load connected to the cold or ground side.

The 39 ohm resistor and 0.01µF capacitor are for snubbing of the triac, and the 470 ohm resistor and 0.05 µF capacitor are for snubbing the coupler. These components may or may not be necessary depending upon the particular and load used.

Figure 9. Typical Application Circuit

Fig. 1 LED Forward Voltage vs. Forward Current

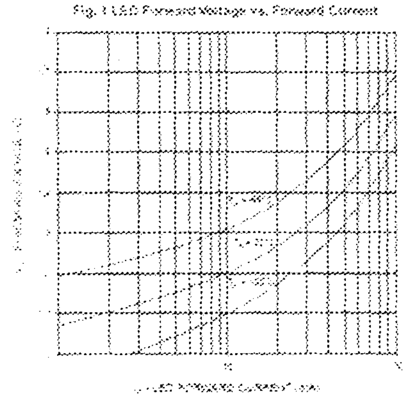


Fig. 2 On-State Characteristics

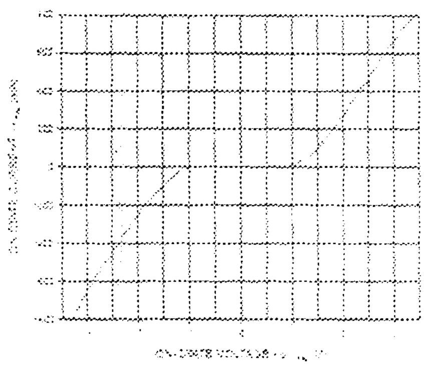


Fig. 3 Trigger Current vs. Ambient Temperature

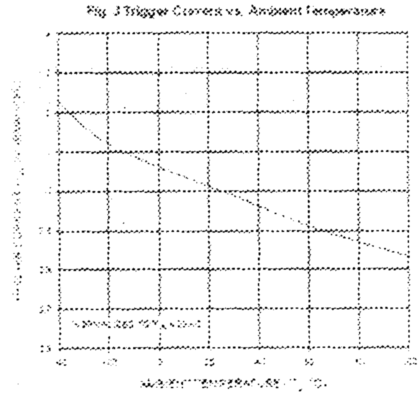


Fig. 4 LED Current Required to Trigger vs. LED Pulse Width

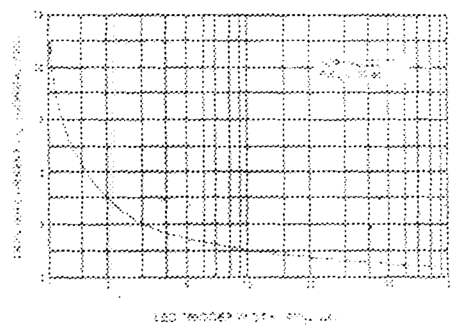


Fig. 6 dv/dt vs. Temperature

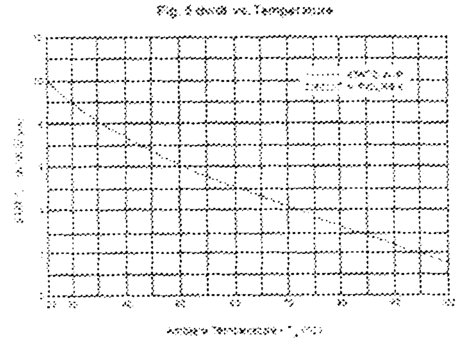
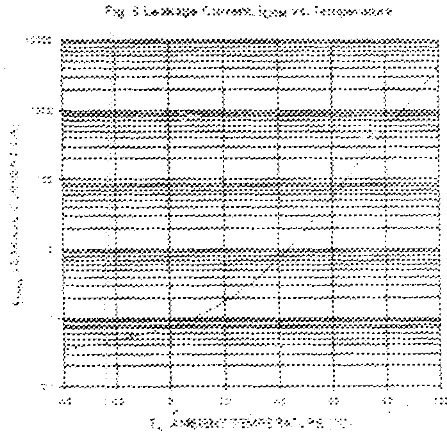


Fig. 5 Leakage Current, I_{DRM} vs. Temperature



GENERAL DESCRIPTION

Glass passivated triacs in a plastic envelope, intended for use in applications requiring high bidirectional transient and blocking voltage capability and high thermal cycling performance. Typical applications include motor control, industrial and domestic lighting, heating and static switching.

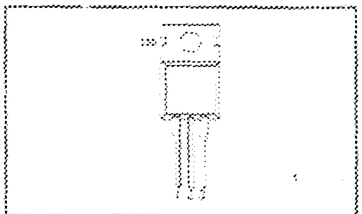
QUICK REFERENCE DATA

SYMBOL	PARAMETER	MAX.	MAX.	MAX.	UNIT
	BT139-	500	600	800	
	BT139-	500F	600F	800F	
	BT139-	500G	600G	800G	
V_{DRM}	Repetitive peak off-state voltages	500	600	800	V
$I_{T(RMS)}$	RMS on-state current	16	16	16	A
I_{TSM}	Non-repetitive peak on-state current	140	140	140	A

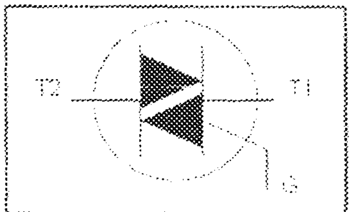
PINNING - TO220AB

PIN	DESCRIPTION
1	main terminal 1
2	main terminal 2
3	gate
tab	main terminal 2

PIN CONFIGURATION



SYMBOL



LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.			UNIT
				-500	-600	-800	
V_{DRM}	Repetitive peak off-state voltages		-	500[1]	600[1]	800	V
$I_{T(RMS)}$	RMS on-state current	full sine wave; $T_{mb} \leq 99$ °C	-	16			A
I_{TSM}	Non-repetitive peak on-state current	full sine wave; T_j = 25 °C prior to surge					
		t = 20 ms	-	140			A
		t = 16.7 ms	-	150			A
I^2t	I^2t for fusing	t = 10 ms	-	98			A^2s
dI_T/dt	Repetitive rate of rise of on-state current after triggering	I_{TM} = 20 A; I_G = 0.2 A; dI_G/dt = 0.2 A/µs					
		T2+ G+	-	50			A/µs
		T2+ G-	-	50			A/µs
		T2- G-	-	50			A/µs
		T2- G+	-	10			A/µs
I_{GM}	Peak gate current		-	2			A
V_{GM}	Peak gate voltage		-	5			V
P_{GM}	Peak gate power		-	5			W
$P_{G(AV)}$	Average gate power	over any 20 ms period	-	0.5			W
T_{stg}	Storage temperature		-40	150			°C
T_j	Operating junction temperature		-	125			°C

1 Although not recommended, off-state voltages up to 800V may be applied without damage, but the triac may switch to the on-state. The rate of rise of current should not exceed 15 A/µs.

THERMAL RESISTANCES

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$R_{th\,j-mb}$	Thermal resistance junction to mounting base	full cycle	-	-	1.2	K/W
		half cycle	-	-	1.7	K/W
$R_{th\,j-a}$	Thermal resistance junction to ambient	in free air	-	60	-	K/W

STATIC CHARACTERISTICS

T_j = 25 °C unless otherwise stated

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.			UNIT
		BT139-			...	...F	...G	
I_{GT}	Gate trigger current	V_D = 12 V; I_T = 0.1 A						
		T2+ G+	-	5	35	25	50	mA
		T2+ G-	-	8	35	25	50	mA
		T2- G-	-	10	35	25	50	mA
		T2- G+	-	22	70	70	100	mA
I_L	Latching current	V_D = 12 V; I_{GT} = 0.1 A						
		T2+ G+	-	7	40	40	60	mA
		T2+ G-	-	20	60	60	90	mA
		T2- G-	-	8	40	40	60	mA
		T2- G+	-	10	60	60	90	mA
I_H	Holding current	V_D = 12 V; I_{GT} = 0.1 A	-	6	30	20	60	mA
V_T	On-state voltage	I_T = 20 A	-	1.2	1.6			V
V_{GT}	Gate trigger voltage	V_D = 12 V; I_T = 0.1 A	-	0.7	1.5			V
		V_D = 400 V; I_T = 0.1 A; T_j = 125 °C	0.25	0.4	-			V
I_D	Off-state leakage current	$V_D = V_{DRM(max)}$; T_j = 125 °C	-	0.1	0.5			mA

DYNAMIC CHARACTERISTICS

T_j = 25 °C unless otherwise stated

SYMBOL	PARAMETER	CONDITIONS	MIN.			TYP.	MAX.	UNIT
		BT139-	...	...F	...G			
dV_D/dt	Critical rate of rise of off-state voltage	V_{DM} = 67% $V_{DRM(max)}$; T_j = 125 °C; exponential waveform; gate open circuit	100	50	200	250	-	V/μs
dV_{com}/dt	Critical rate of change of commutating voltage	V_{DM} = 400 V; T_j = 95 °C; $I_{T(RMS)}$ = 16 A; dI_{com}/dt = 7.2 A/ms; gate open circuit	-	-	10	20	-	V/μs
t_{gt}	Gate controlled turn-on time	I_{TM} = 20 A; $V_D = V_{DRM(max)}$; I_G = 0.1 A; dI_G/dt = 5 A/μs	-	-	-	2	-	μs

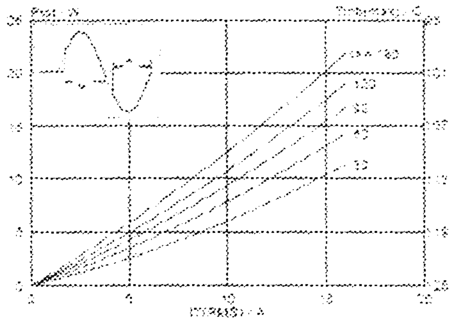


Fig.1. Maximum on-state dissipation, P_{tot}, versus rms on-state current, $I_{T(RMS)}$, where α = conduction angle.

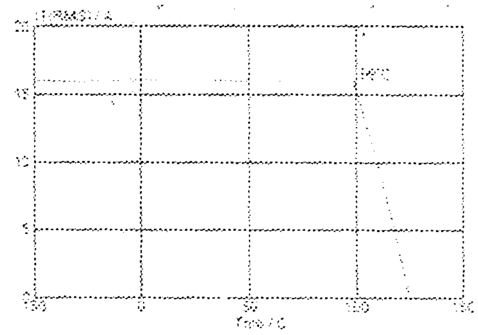


Fig.4. Maximum permissible rms current $I_{T(RMS)}$, versus mounting base temperature T_{mb}.

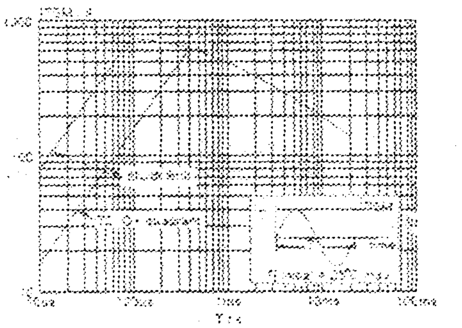


Fig.2. Maximum permissible non-repetitive peak on-state current I_{TSM}, versus pulse width t_p, for sinusoidal currents, $t_p \leq 20$ms.

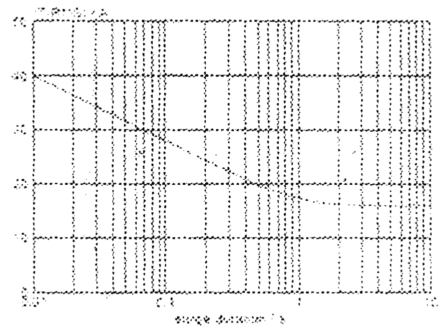


Fig.5. Maximum permissible repetitive rms on-state current $I_{T(RMS)}$, versus surge duration, for sinusoidal currents, f = 50 Hz; $T_{mb} \leq 90$˚C.

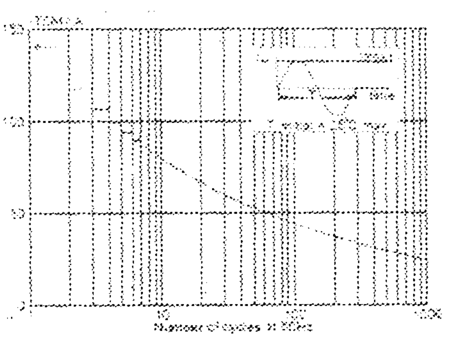


Fig.3. Maximum permissible non-repetitive peak on-state current I_{TSM}, versus number of cycles, for sinusoidal currents, f = 50 Hz.

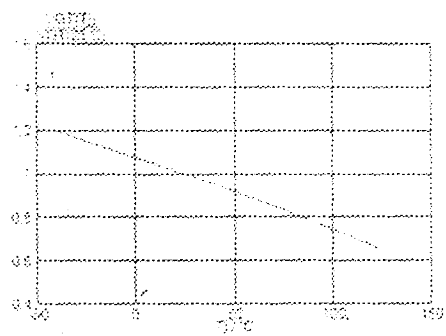


Fig.6. Normalised gate trigger voltage $V_{GT}(T_j)/V_{GT}(25˚C)$, versus junction temperature T_j.

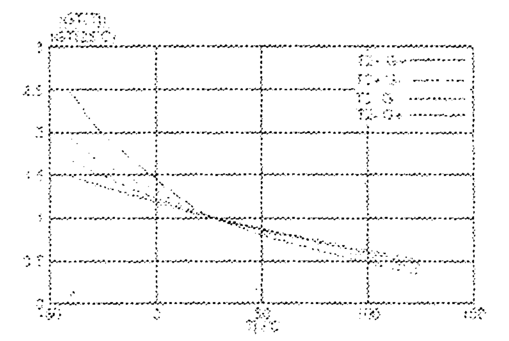


Fig.7. Normalised gate trigger current $I_{GT}(T_j)/I_{GT}(25°C)$, versus junction temperature T_j.

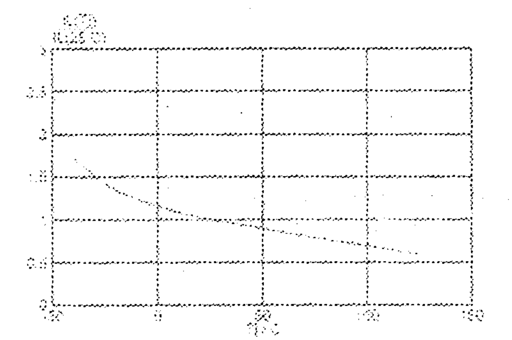


Fig.8. Normalised latching current $I_L(T_j)/I_L(25°C)$, versus junction temperature T_j.

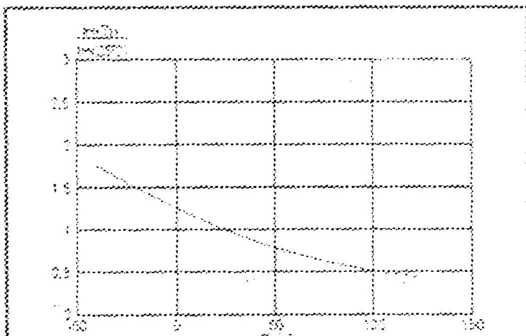


Fig.9. Normalised holding current $I_H(T_j)/I_H(25°C)$, versus junction temperature T_j.

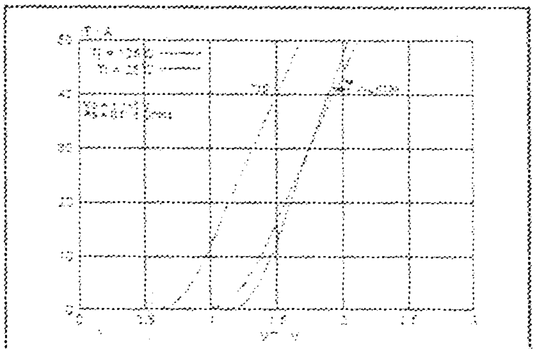


Fig.10. Typical and maximum on-state characteristic.

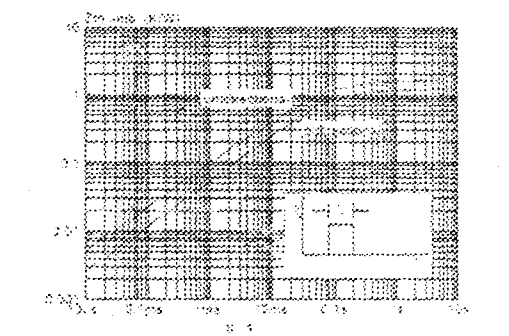


Fig.11. Transient thermal impedance $Z_{th\,j\text{-}mb}$, versus pulse width t_p.

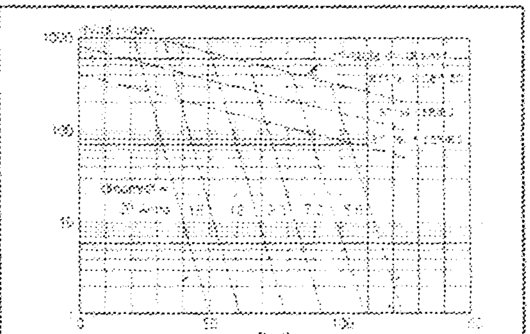


Fig.12. Typical commutation dV/dt versus junction temperature, parameter commutation dI_T/dt. The triac should commutate when the dV/dt is below the value on the appropriate curve for pre-commutation dI_T/dt.