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Control power board for Electrical Lights and Fans

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Abstract

The objective of this design project is to build a power control board to switch or dim light bulbs and regulate fan speed. One can use TV remote, serial port interface or a keypad for giving various instructions to the device. A LCD display is also provided to display the levels at which various loads are operating and the current time. The device also has a real time clock with an alarm. The system provides compensation to the extent possible for variation in the mains voltage. Intensity/speed of the load is controlled by changing the RMS voltage across the load using triac circuit that is by changing the corresponding firing angle at the gate of the triac. An ADC circuit monitors unregulated input voltage, followed by software to check for voltage variation and provide regulation.

1. Introduction

The main aim of this project is to design an electric power board which can control intensity of light bulbs and speed of fans with the input control from infrared TV remote, keypad or serial port interface. RMS voltage across a triac is related to the RMS voltage of the mains according to the following relation

$$V_{rms(load)} = V_{rms(mains)}(1- \theta/\pi)^{0.5} \qquad (1)$$

Where, θ is the firing angle of the triac measured from the zero crossing point. Thus by changing the firing angle we can regulate the RMS voltage across the load and vary the intensity of a bulb or speed of a fan. If θ is zero i.e. if triac is fired at the zero crossing, then maximum power is transferred to the load. Similarly if triac is fired at the peak of the cycle (i.e. $\theta = \pi/2$) then only half of the power is transferred to the load. Thus the main task is to generate these pulses according to the desired RMS voltage. The electronic control circuit is to be powered by dc voltage obtained from the mains voltage using a transformer, rectifier-filter and regulator. This arrangement can be used for measuring the RMS voltage of mains supply. The attenuated unregulated DC voltage is monitored using an ADC, so as to provide voltage regulation against variation in mains voltage. For regulation against the mains frequency we are changing the instance of firing of the triac. We have also provided an alarm clock. Alarm can be set and reset by the user. A LCD is used to display the current levels of loads, clock time and time at which alarm is set. A real time clock chip (RTC) is used for time keeping.

2 Design approach

2.1 Block Diagram

The block diagram (Fig. 1) consists of:

- Power supply consisting of 230V/9V step down transformer followed by a bridge rectifier, a low pass filter and a 5V regulator (7805).
- IR receiver for receiving the signals from TV remote.
- RS 232 level shifter for serial port interfacing.
- 4x4 keypad
- RTC for updating time
- Two microcontrollers, one for decoding the signals (40 pin) and other (20 pin) for generating the trigger pulse for triac.
- A zero crossing detector.
- ADC for voltage regulation.
- LCD for displaying the current status of the loads.
- Triac circuitry.

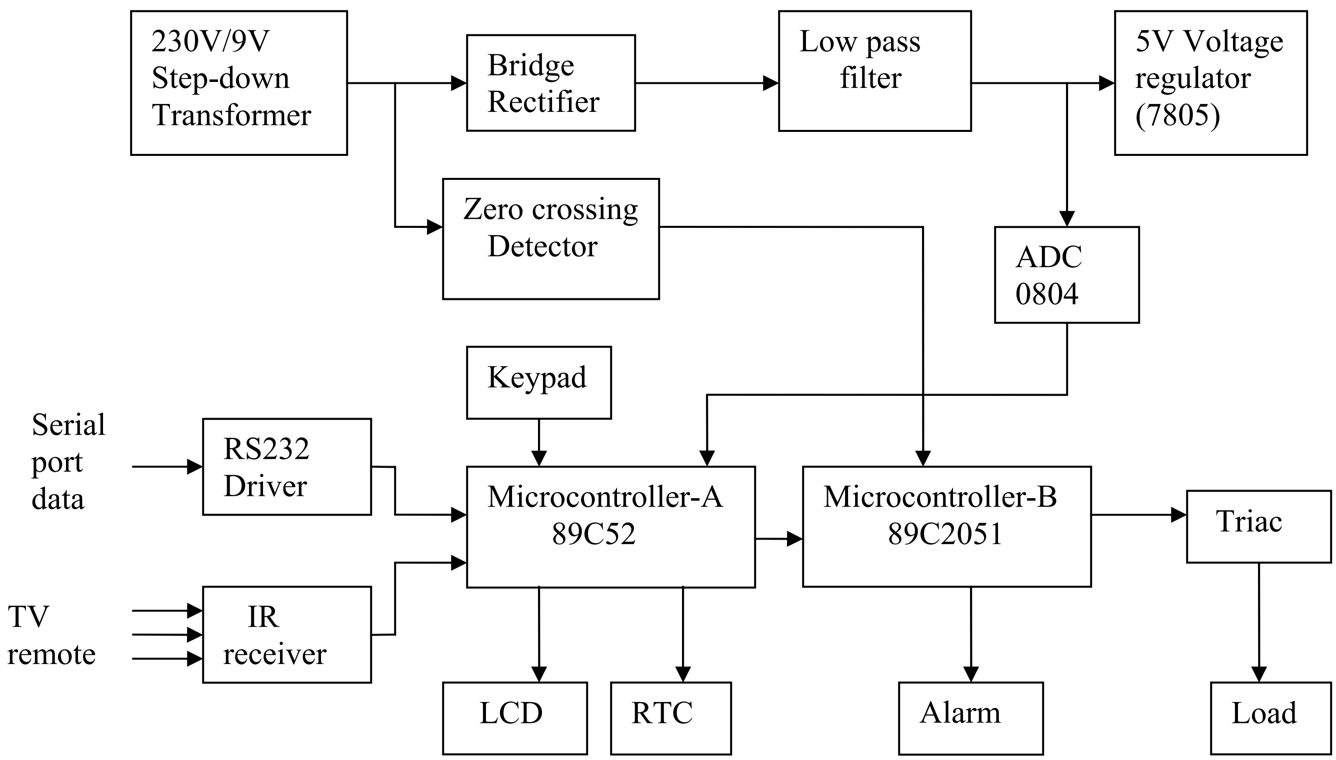

Figure 1: Block Diagram

2.2 Description of the various blocks

a) 5V Power supply

Fig. 2 shows the circuit to generate 5V DC supply [1] from mains supply. For this purpose we used 230V/9V step down transformer followed by a bridge rectifier consisting of IN4001 diodes, low pass filter and 5V voltage regulator LM7805 [2]. Output from transformer is also used to detect zero crossing. Capacitor C1 is used to filter the output from bridge rectifier to generate unregulated DC supply (Vx) which after attenuation serves as input for ADC. C2 and C3 are used for frequency stabilization. This 5V DC supply is used for power supply for various chips in the whole circuit.

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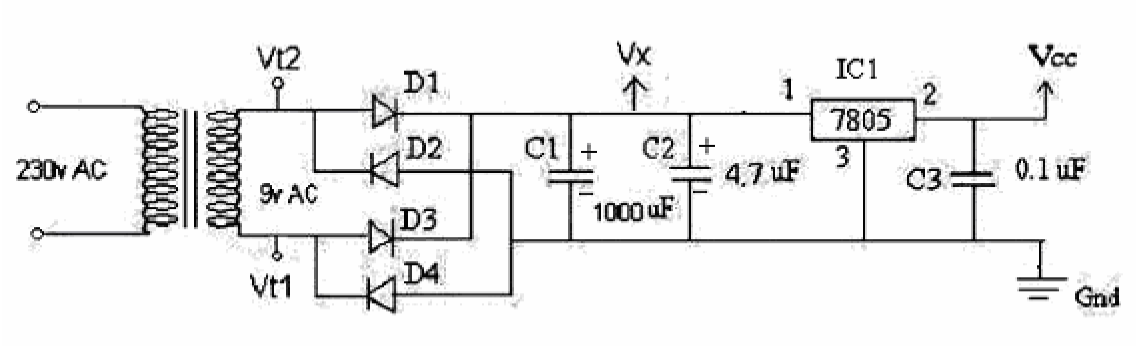

Figure 2: DC Power Supply Circuit

b) IR Receiver

We are using RC5 encoded remote. Every time a button is pressed at the remote control, it sends a pulse train of 14 bits, 1.728 ms per bit. The whole train is repeated every 130 ms if the button is kept pressed. TSOP 1738 [3] is used as an infrared receiver. It's a 3-pin module with active low output. When no key is pressed on remote, it shows high output. Fig. 3 shows the output signal from TSOP. This type of coding is called Manchester coding technically known as return to zero (RZ) format. In this coding each bit is divided into 2 half bits one as left bit and second one right bit. Bit value is determined by the transition at the center of the bit. If there is downward transition i.e. bit is changing from high to low at the center then bit value is one (Logic 1) and if there is upward transition at the center then value of that bit is zero (Logic 0). The first two bits in the bit train, #1 and #2, are called Auto Gain Control (AGC) calibration. They are ON on the left side and make transition from 1 to 0 at the center (Logic 1), and serve to calibrate the IR receiver's AGC. The bit #3 is the CLK bit, every time a key is pressed at the remote (even repeatedly the same key) this bit flips state. The next 5 bits, #4 to #8, are used for SYSTEM ADDRESS, or to identify which kind of device should execute the COMMAND bits. The next 6 bits, #9 to #14, are used for COMMAND information to the device selected by the ADDRESS bits. Bit #14 is the LSB [5].

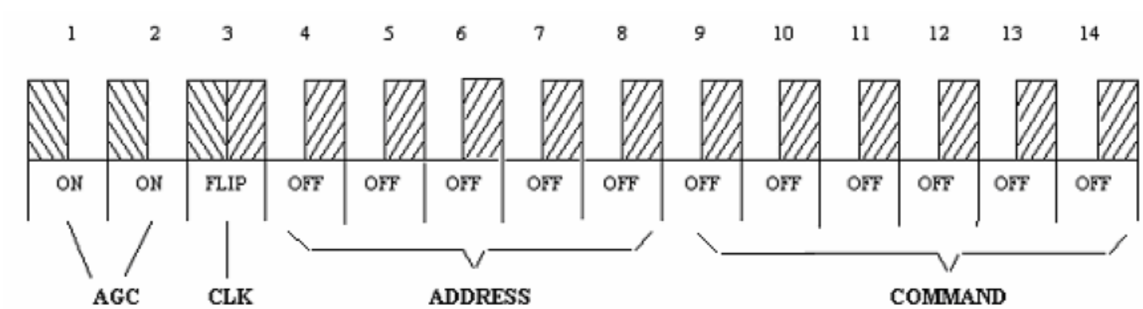

Figure 3: Output from TSOP

c) RS232 Driver

As we have to only receive data, we are using only receiver part of RS232 driver. The level shifting of RS232 input for interfacing to the microcontroller has been carried out using MAX232 [6].

d) Control input handling

A 40-pin microcontroller, AT89C52, is used to decode the IR signal from the TV remote, scan the Keypad and receive control input through RS232. Here we are using a crystal of 11.0562 MHz to get a baud rate of 9600. The output of the TSOP is connected to pin P3.2 (external interrupt 0) and the serial data from Max232 is connected to pin P3.0 (serial interrupt). Keypad is interfaced to port 0 of the microcontroller. Whenever an interrupt comes at pin P3.2 the microcontroller first gives a delay of 0.433 ms so that we can read the mid point of any particular bit. Now as we don't need first 6 bits we skip the first 6 bits and read the next 8 bits by sampling the command bits (14 bit train) received from the TV remote. Flowchart for decoding signal from TV remote is shown in Fig.11. This microcontroller is also being interrupted whenever computer sends a command over the serial port. The command consists of a train of 11 bits including the start bit and the stop bit with baud rate 9600. Microcontroller decodes this data by using the serial receiver (Rx) of the microcontroller. After decoding the signal from the TV remote, keypad or from serial port this microcontroller also sends the instruction to the next microcontroller. This is done by setting the port 2 pins accordingly. First 2 bits, P2.0 and P2.1, denote which load to be executed. In our case we are using 4 loads.

Pin P2.0	Pin P2.1	
0	0	Load 1
0	1	Load 2
1	0	Load 3
1	1	Load 4

Figure 4: Load selection for different port pins

The next 3 bits P2.2, P2.3 and P2.4 are used to send the corresponding level of the load. We are controlling each load in 8 levels from 0 to 7. 0 denotes that load is off and 7 denote that the load is working at highest level.

e) Zero crossing detector

Fig. 5 is circuit for zero crossing. Zero crossing is used as a reference for measuring firing angle of the triac. Output from transformer serves as input for low power quad op amp LM324 [7]. LM 324 has four op amps. One of them was used as comparator with input as output from transformer followed by potential divider while 2nd op amp was used as a buffer which avoids comparator output getting loaded by microcontroller. Because the output of LM741 is bipolar and thus it can damage microcontroller so we used LM324. Output from the buffer (Vz) is connected to microcontroller AT89C2051.

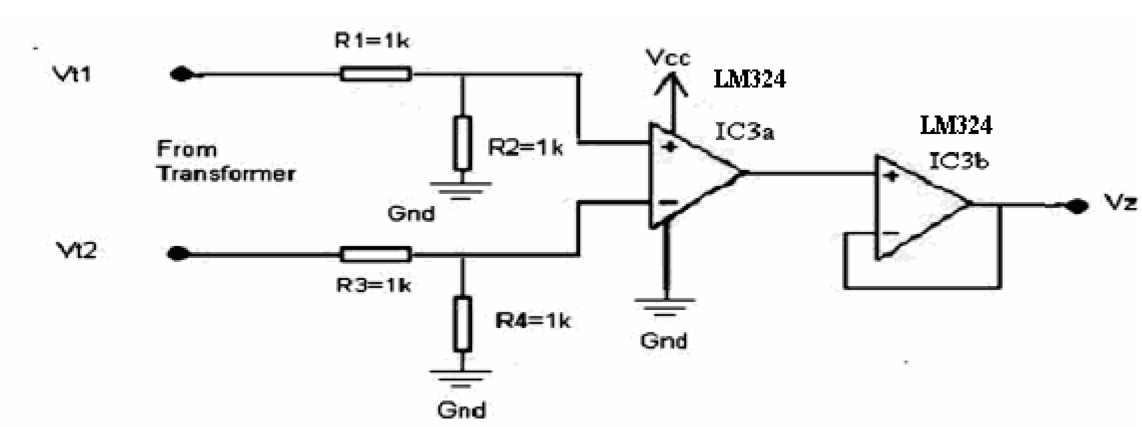

Figure 5: Zero crossing detector

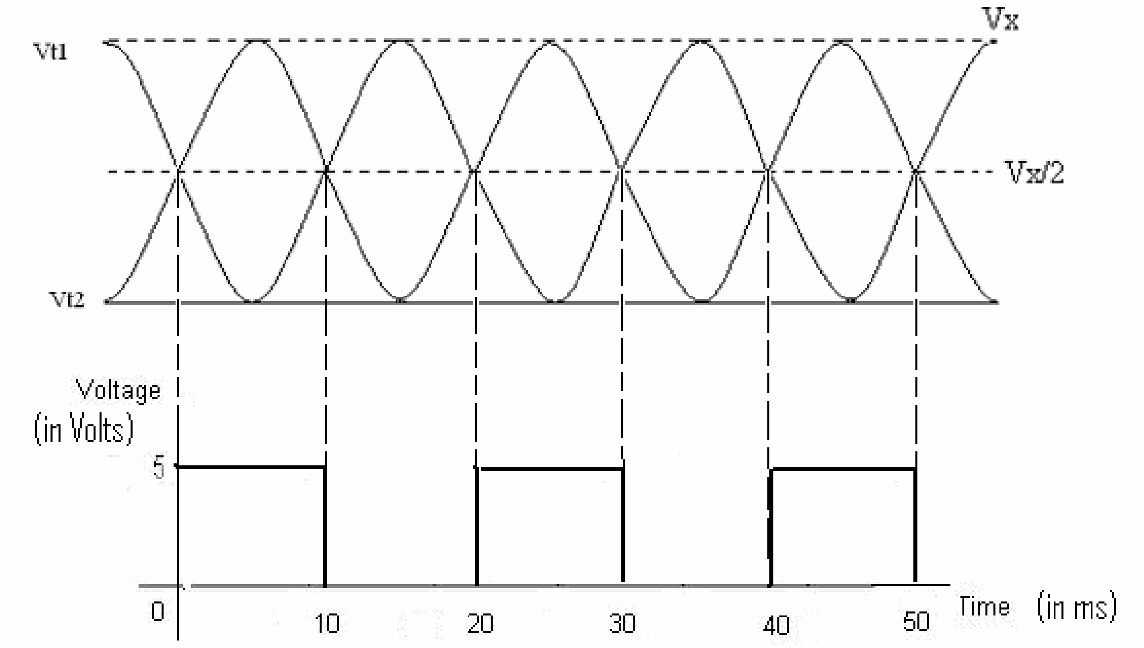

Figure 6: Output waveform across transformer and zero crossing detector respectively

f) Voltage Regulation against mains power supply

For regulation against voltage supply we used ADC0804 [8] which is single channel ADC. Pin diagram of ADC0804 is shown in Fig. 7. It's a 20 pin chip with differential input voltage range 0V-5V. Unregulated DC voltage (Vx) followed by a potential divider is used as input for ADC (pin 6). A resistor R of 10K and capacitor C of 150pf are used to generate a clock frequency of 640 KHz. Because Vx has magnitude about 10V so we used potential divider to make the input for ADC within its input voltage range.

Voltage span of ADC is made 0V to 5V. Here we are assuming voltage variation from 180V to 300V with 230V normal voltage. CS pin of ADC is connected to P3.1, WR to P3.3 and INTR to P3.4 of 89C52. Output from ADC data pins(DB0-DB7) are multiplexed with LCD and connected to pin P1.0 to P1.7 of the microcontroller 89C52. When ADC subroutine is called in the program, P3.1 is made active low. Thus ADC chip is selected. P3.3 is made active low for some time (about 10 us) and then made active high. ADC starts conversion after 1 to 8 clock periods and when conversion is completed it interrupts microcontroller. Interrupt pin is connected to P3.4 of 89C52. We are comparing output of ADC with output corresponding to 230V and changing the firing angle of triac accordingly.

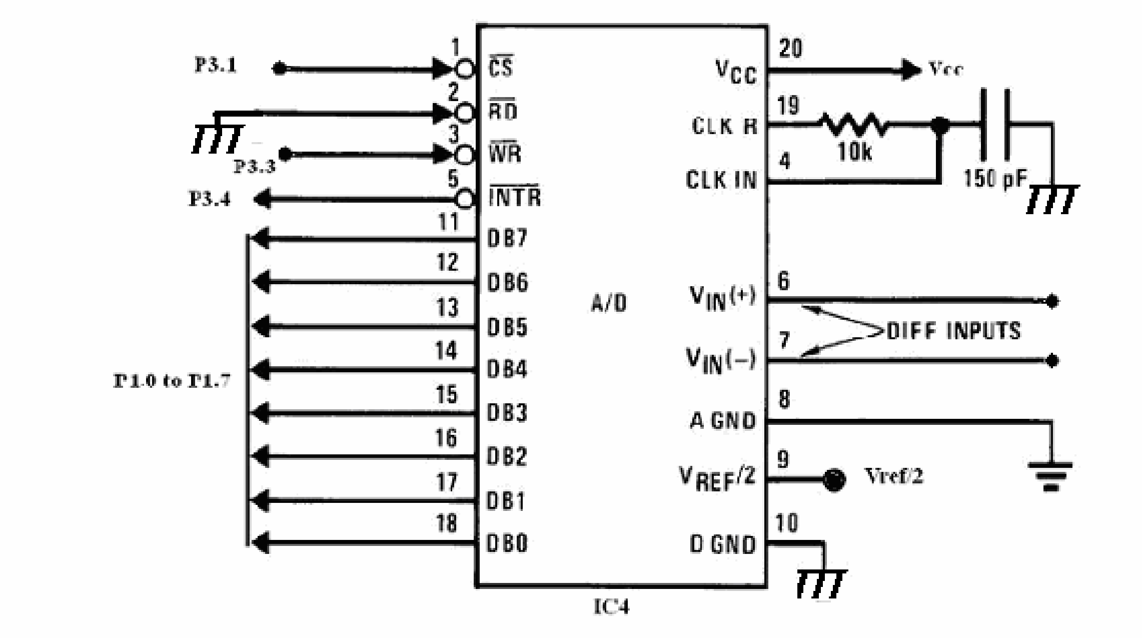

Figure 7: Pin Diagram ADC0804

g) LCD Display

A 16x2 LCD display JHD162A [9] is used for displaying levels at which various loads are operating and the clock time. The LCD display contains two internal byte wide registers, one for commands (RS=0) and the second for characters to be displayed (RS=1). Pins 1 and 3 are connected to the ground, and pins 7 to 14 are connected to Port 1 of the microcontroller AT89C52 to furnish the command or data byte, and pins 4,5 and 6 (register select, read/write and enable high signals respectively) are connected to P3.5,P3.6 and P3.7. Pin 14 of LCD is monitored for logic high (busy) to ensure the display is not overwritten.

h) Real Time Clock

To maintain the accuracy of the time and alarm system, a Real Time Clock chip DS 1302 [10] is used. It has 31 x 8 RAM scratchpad data storage and communicates with microprocessor via a 3-wire serial synchronous interface. The real-time clock provides seconds, minutes, hours, day, date, month, and year information. Only three wires are required to communicate with the clock/RAM: CE, I/O (data line), and SCLK (serial clock). A 3V battery backup is provided to the RTC so that it can run even during power failure. This backup also stores the previous levels at which various loads were operating before the power failure. A typical operating circuit of DS1302 RTC is shown in Fig. 8.

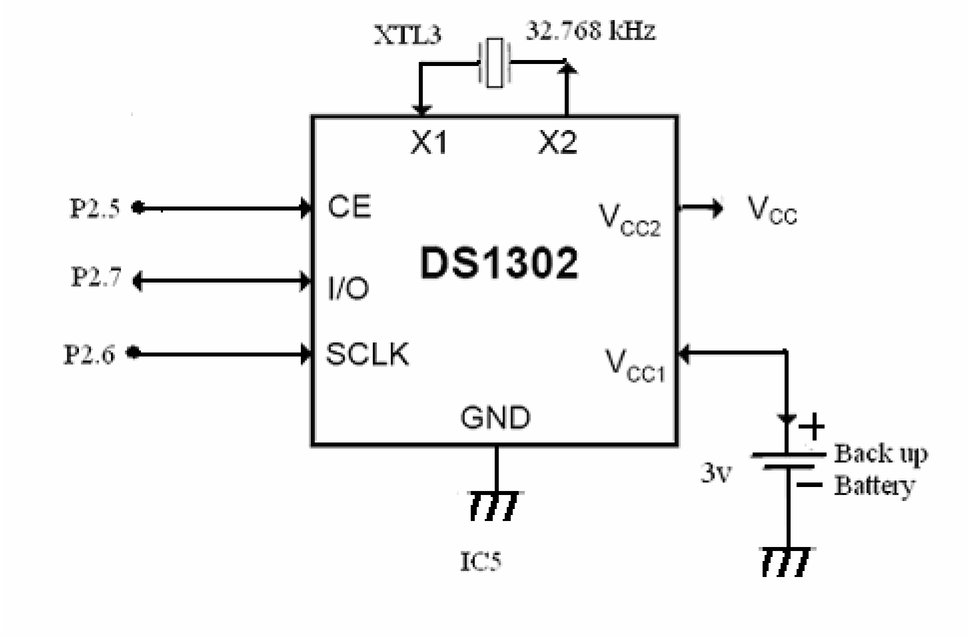

Figure 8: Typical operating circuit of DS1302

i) Keypad

A 4x4 keypad is also provided as a user interface. This keypad takes following inputs from the user: load select, setting of a clock and an alarm. It has 0-9 digits and separate buttons for "UP", "DOWN", "CLOCK SET", "ALARM SET", "LOAD SELECT" and "OK". Microcontroller checks for debouncing to avoid multiple inputs. An external pull-up is required as this is controlled through Port 0 of microcontroller. Keypad interfacing is done by using finite state machine. Complete software is divided into 6 main states. From each state there are 16 possibilities to go to the next state. Corresponding to these 16 possibilities there is a look up table which stores a particular function for each key pressed. Whenever a key is pressed from either keyboard or TV remote or serial interface, the program counter jumps to the new state and the corresponding routine is executed.

j) Firing pulse generation

20 pin microcontroller AT89C2051 [11] processes the instruction from the first microcontroller AT89C52 and generates the triac firing pulses accordingly. Output from the zero crossing detector is connected to pin p1.0 and is used to get the count for the half cycle. This count is then used to generate the firing pulses. Zero crossing detector output is also used to synchronize the triac pulse with the input supply frequency. Fig. 10 shows the flowchart for its working.

k) Triac

A triac [12] is a three terminal semiconductor device that is triggered by a low-energy signal applied to its gate. The supply to the triac is an AC signal and it will always turn off when the applied voltage reaches zero at the end of the current half cycle. If a turn on pulse is applied, the triac goes from a high-impedance state to a conductive state, and it starts passing current through the load. So the position at which this turn on pulse is fired (firing angle) directly controls the power of that half-cycle transmitted to the load.

$$\mathbf{P}_{load} = \mathbf{P}_{main}\,(1\text{-}\theta/\pi) \qquad \textbf{(2)}$$

The pulses from the microcontroller are connected to the pin 2 of the opto-coupler MOC3020 [13] through a resistor and pin 1 is connected to Vcc as shown in Fig. 9. On getting the pulses, the photodiode radiates and drives the triac inside MOC3020. In this part the pulses are in optical form hence providing the optical isolation between the triac load circuit and the electronic circuit. The triac of the opto-coupler further drives the triac with the load connected between a power supply terminal and A2 terminal of the triac(T1) and the other power supply terminal and A1 are shorted.

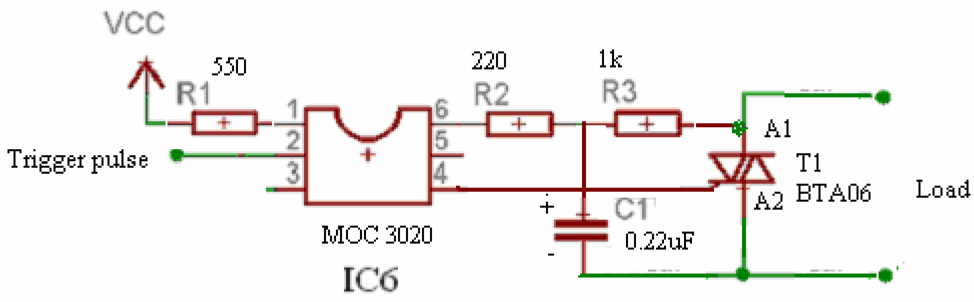

Figure 9: Circuit diagram of the Opto-coupler based Triac drive

3. Implementation

Fig. 12 shows the circuit diagram for generating firing pulses. Fig. 13 and Fig.14 show voltage waveforms for mains supply, pulse at triac and voltage across triac for level 1 (ON), 4 and 7 (maximum speed/intensity).

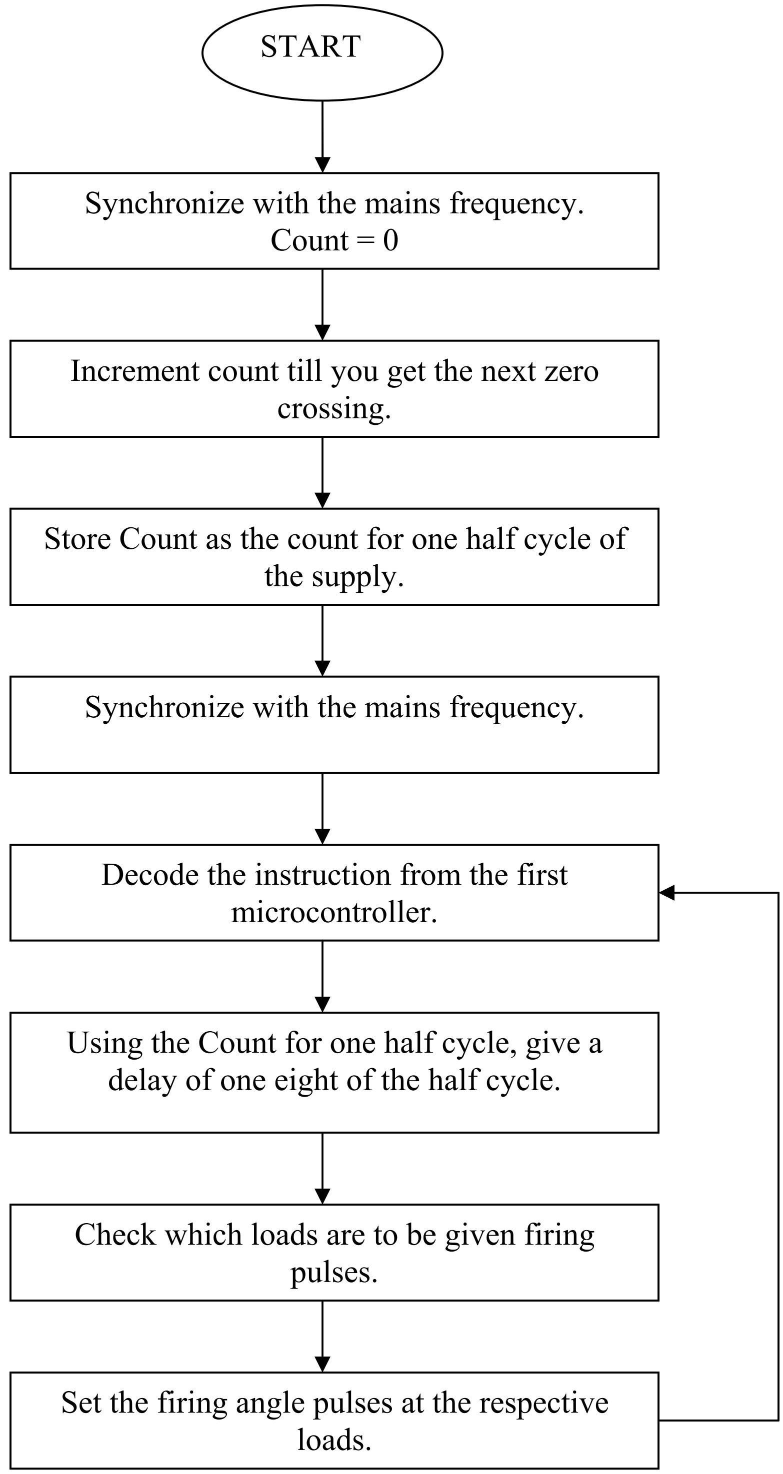

Figure 10: Flowchart for the generation of triac pulses

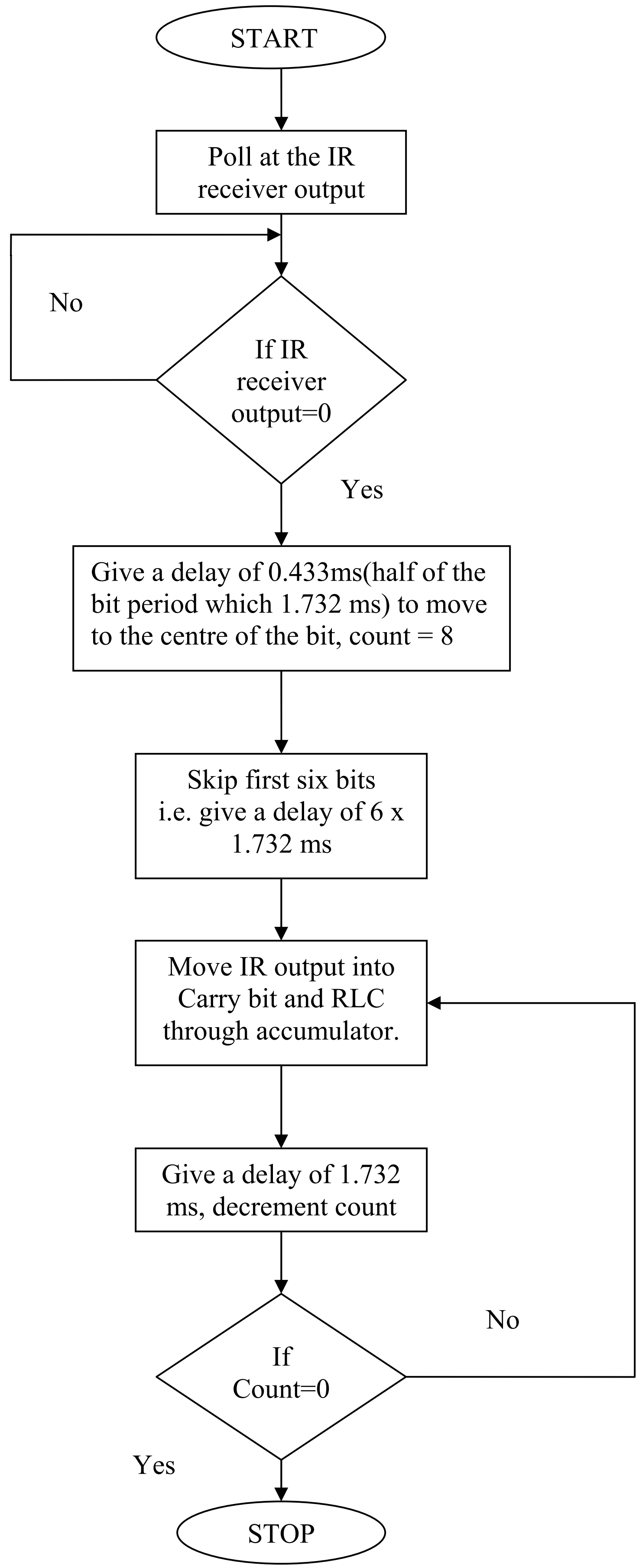

Figure 11: Flowchart for IR decoding

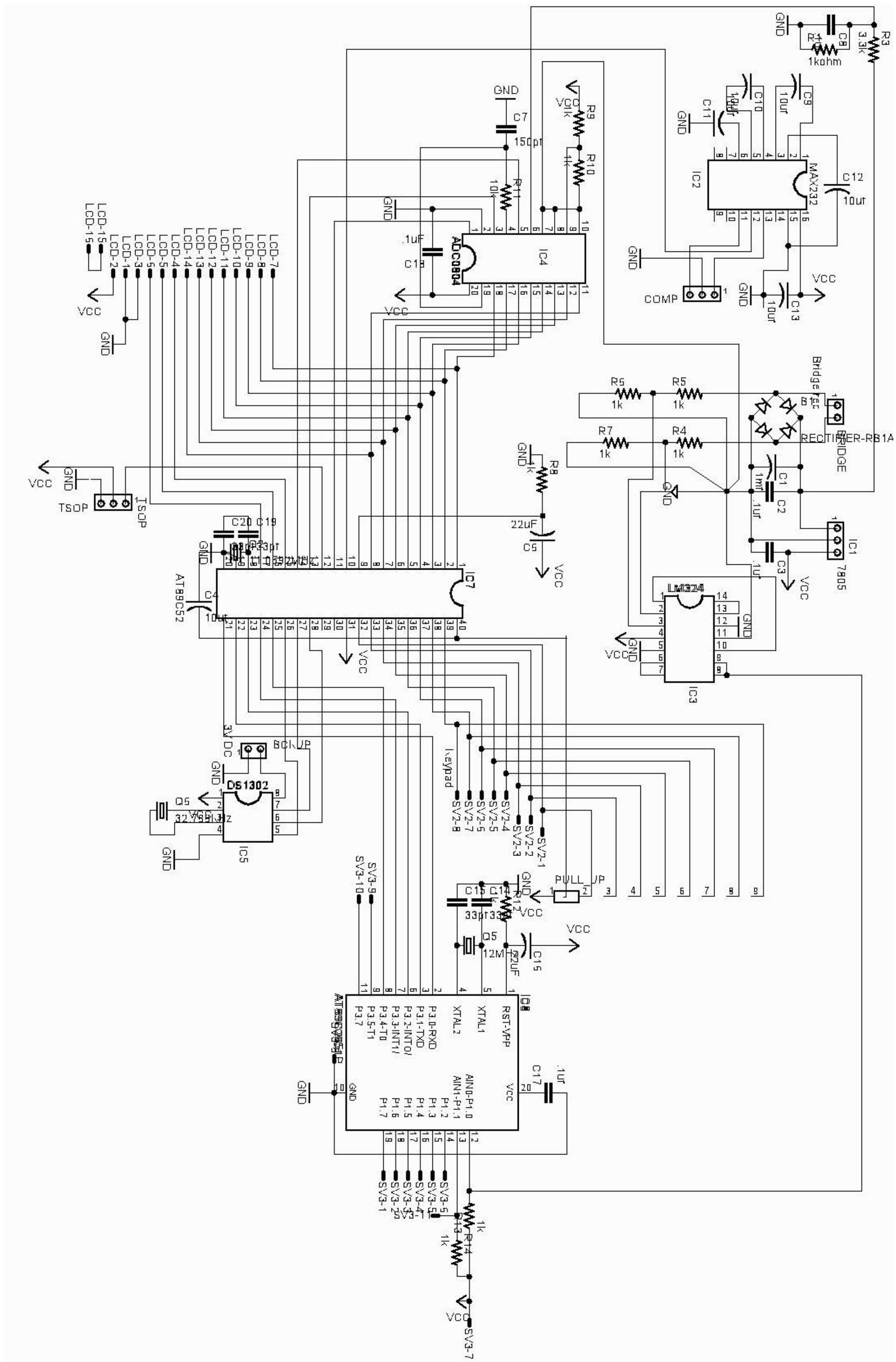

Figure 12: Complete circuit diagram

4. Observations

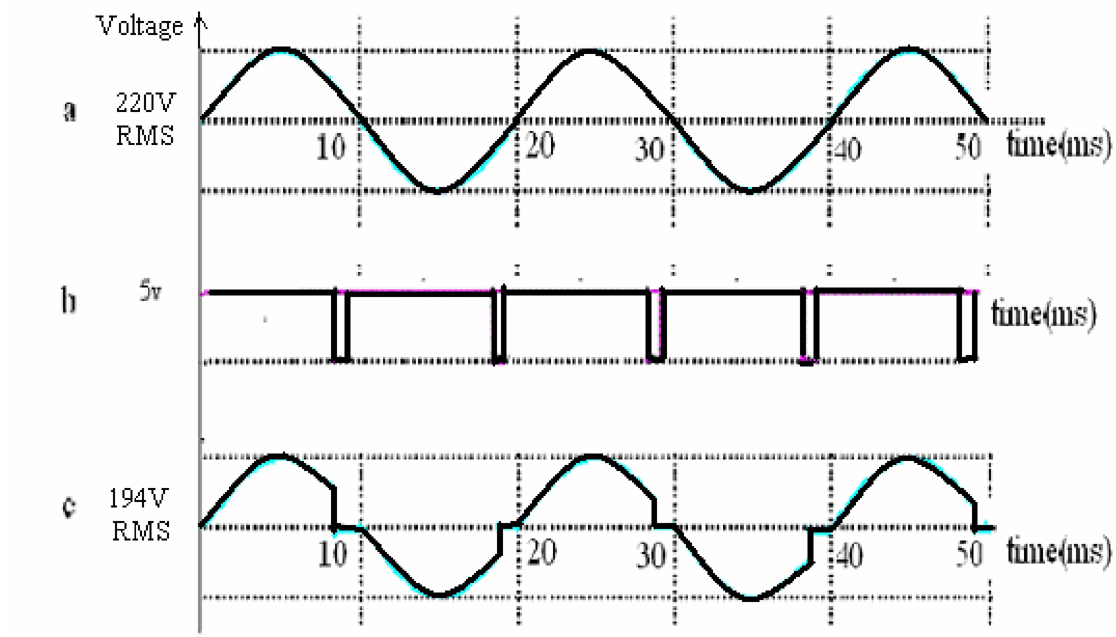

Figure 13: a) Voltage waveform of mains supply
b) Pulse pattern at gate of triac at control level 1
c) Voltage across triac at control level 1

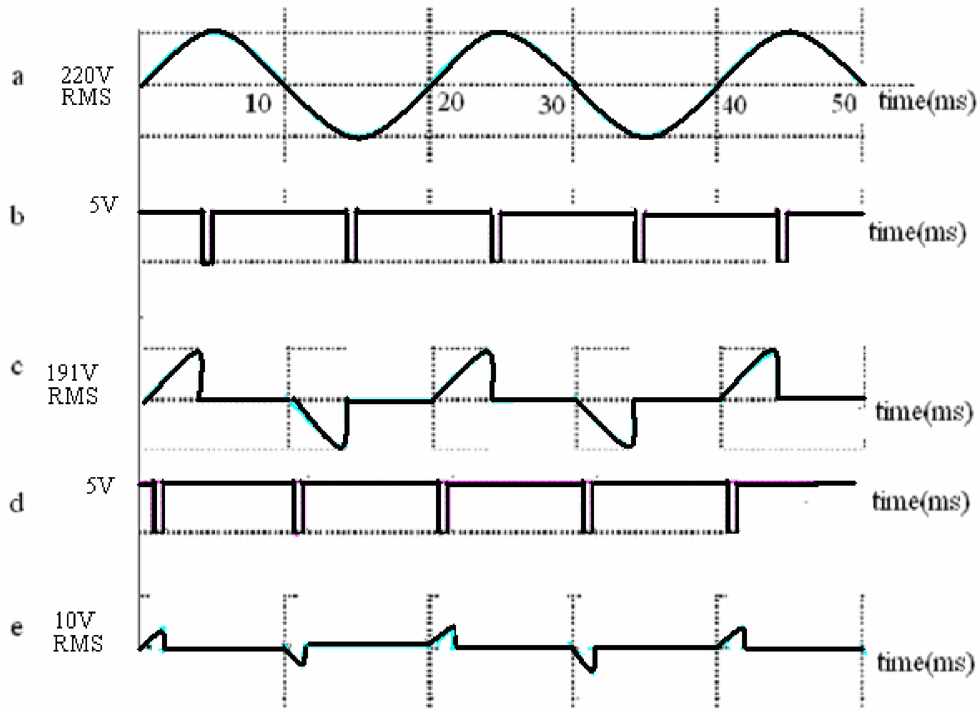

Figure 14: a) Voltage waveform of mains supply
b) Pulse pattern at the gate of triac at control level 4
c) Voltage across triac at control level 4
d) Pulse pattern at the gate of triac at control level 7
e) Voltage across triac at control level 7

5. Conclusion

The above product is able to control the fan speed or light intensity of an electric bulb using fractional cycle power control. It also provides voltage regulation against the mains supply. It can simultaneously control four loads. Add-on features like alarm-clock, serial interface and LCD display make it a commercially viable alternative to existing products.

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APPENDIX

User Manual

a) For remote

(0-9)	Regular numeric keys
Ch up	Increase
Ch down	Decrease
Mute	Clock set
Power	Alarm set
Vol up	Load select
Vol down	OK

b) For serial port

Numpad keys

(0-9)	Regular numeric keys
/	Increase
*	Decrease
-	Clock set
+	Alarm set
Enter	OK
Del	Load select

c) For keypad

Fig. 15 shows the layout of keys for the 4x4 keypad

1	2	3	Clock Set
4	5	6	Alarm Set
7	8	9	Load Select
Up	0	Down	OK

Figure 15: Keypad layout

d) Functions of various keys

0-9: These are the Numeral keys and are used to set the time or to select various loads or to change the levels of loads.

Clock Set: This key is used to set the clock time. The device first asks you to enter hours followed by minutes. When done press OK.

Alarm Set: Using this key you can adjust the time for alarm. If alarm is already set then the device will ask whether you want to adjust the time or disable the alarm.

Load Select: This key is used to select one of the four loads at which you want to operate. After selecting a particular load you can adjust its levels either using the numeral keys (0-7) or using up or down arrow. Once you are done press OK.

OK: This key is used when you have made the changes that you want to do.

UP arrow: This key is used to increase the level of the selected load.

Down arrow: This key is used to decrease the level of the selected load.

e) Instructions for operation

The device always starts with idle state in which the LCD displays the levels at which various loads are operating, and the current time and the time at which alarm is set. For selecting a load on which you want to operate, press Load Select key, then enter the load number between 1 to 4. If you press any other key, system will come back to the idle state. Now after selecting the load you can either use numeral keys 1 to 7 or you can use increase/decrease buttons to move to the desired level.
As you change the level of a particular load you can immediately see the changes on that load. Once you are done press OK key and your instruction would be executed and the display will again come to the idle state.
For setting the clock or alarm use Clock Set or Alarm set key respectively. After this the device will ask for hours and minutes. If you enter hours greater than 23 or minutes greater than 59 then it will again ask you to enter it until you enter a valid time. When you have entered a valid time press ok and the clock/alarm will get updated. If you try to set the alarm when it is already set the device will give you two options one for adjusting the alarm time and other for disabling the alarm. Use up or down arrow key to select one of these option and then press OK key. At any stage of your operation if you waited for more than 10 seconds than the device will automatically go to the idle display state.
An external switch is provided for enabling the alarm. Alarm will function only when this switch is ON. Whenever alarm time is reached alarm will ring up for 30 seconds. You can stop the alarm before this time by disabling the alarm using above mentioned switch.