DESIGN AND CONSTRUCTION OF AN ELECTRONIC THERMOSTAT

BY

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2000/9773EE

A THESIS SUBMITTED TO THE DEPARTMENT OF
ELECTRICAL AND COMPUTER ENGINEERING IN PARTIAL
FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE
DEGREE OF BACHELOR OF ENGINEERING (B.ENG) IN ELECTRICAL
AND COMPUTER ENGINEERING OF THE FEDERAL UNIVERSITY OF
TECHNOLOGY, MINNA.

OCTOBER 2006

DEDICATION

I dedicate this work to the one who has not dealt with me according to my wrong doings but has decided to be merciful and kind to me. To God who loves me with a boundless love.

DECLARATION

I hereby declare that this work titled "Electronic Thermostat" was done by me in partial fulfillment of the requirement for the award of the degree of B. Eng in Electrical and Computer Engineering Department of the Federal University of Technology Minna.

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ACKNOWLEDGEMENT

To Him who is immeasurably more than all I could ever imagine, God Almighty, for His unconditional love and great mercy towards me every time and everyday, i remain forever indebted to you.

I am also grateful to my supervisor, Engr. (Dr) Y. A. Adediran. It is a great privilege and honor to be under your supervision sir. I admire your diligence, commitment and your great wealth of knowledge. Thanks for making out time despite your busy schedules. I am also grateful to my very humble and intellectual H.O.D, Engr. Abdullahi, and the very distinguished lecturers of Electrical and Computer Engineering Department.

To my dad and mum, I say a very big thank you for your unending love towards me, both in kind and in cash. To my three lovely siblings; Yety, Bolito, and Folawemimo, words alone can't express how much I love you. I wish to acknowledge my very special and amiable brothers; Oluseun, Bodunde, Toyen, Oladipupo, Akinsolo, Gboyegs, Sesan, Guze, Ay, Tolu, Brospar. Also to my Godsend sisters; Anike, Omolola, Veronica, Olubunmi, shade. You are too numerous to be mentioned. My heart goes out to you all. I want you all to know that you are of priceless worth, you guys are real gifts. Thanks for making my stay in F.U.T worthwhile.

My profound gratitude also goes to Prof and Mrs. Oladimeji, Pastor Toba, brother kayode, Tobology, aunty Funmi, aunty Favor and my big mummy. Your prayers and financial supports have been of great help. A big Thank You. Press family, my acknowledgement is incomplete without you. You are indeed a great family and I will always love “this family of God”. Thanks for letting God use you to bless me. I love you press unit and FCS. Cheerio!!

ABSTRACT

For temperature monitoring instruments, accuracy and precision are important factors because they are factors that determine how efficient, accurate and reliable the instrument is. Most temperature sensors that use bimetallic strip and thermal sensors have certain limitations; low sensitivity, large differential and low level of accuracy. In order to obtain a good temperature monitoring and regulating device, there is the need to design a device with a better level of accuracy, sensitivity, and effectiveness. Hence the design and construction of Electronic Thermostat.

Electronic Thermostat is a device that directly or indirectly controls sources of heating and cooling in order to maintain a desired temperature. The design uses an electronic control circuit involving an integrated circuit chip (LM35), an NPN transistor, a comparator IC, and electromechanical devices. The LM35 senses temperature changes, compares it with an already preset temperature and switches the relay accordingly via a transistor switching unit. The temperature sensor (LM35) provides the device with the better accuracy, higher precision, greater sensitivity that is needed for a good temperature monitoring device.

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Chapter One

1.1 GENERAL INTRODUCTION

Measurement and control of the temperature of a machine or conditioned area (room) has become very important over the years. Development and uses of measuring devices with high precision such as silicon sensors have added to the beauty of modern day technology, especially in the electrical and computer engineering aspects.

Early temperature measuring devices such as mercury in glass thermometer have certain limitations; small thermal inertia, low sensitivity, inaccuracy and error of parallax. Due to these and many more, there is a great need to design a project that can help to a great extent in measuring, monitoring and regulating temperature.

This project is aimed at the design and construction of an electronic thermostat. Electronic thermostats offer a degree of flexibility and precision that simply cannot be matched by mechanical thermostats.

The heart of this device is a National semiconductor's linear/precision temperature sensor, LM35. A sensor is usually accompanied by a set of specifications that indicate its overall effectiveness in measuring the desired variable. The sensor is a transducer that is capable of measuring and converting physical quantities such as force, temperature, pressure e.t.c into a more readily manipulated electrical quantity. It provides reasonable temperature monitoring technique and has a voltage output terminal that is linearly proportional to the Celsius temperature. The relationship is that every one degree centigrade is corresponding to "10mV" at the output. The relationship is quite precise because the sensor is already calibrated to standard Celsius temperature during its manufacturing procedures. [1] Therefore temperature is easily related to electric energy through the sensor.

Electronic thermostats are used to control a relay and to supply power to a small space heater through the relay contacts. The relay contacts should be rated above the current requirements for the heater. This design embodies a comparator circuit that compares the output from the temperature sensor with a referenced voltage. Temperature changes are detected by the sensor.

The referenced voltage is adjustable for different temperature responses and ranges. This is done through a variable resistor (with an assumed value of 10kΩ) which allows the device to adjust its hysteresis range (temperature range when relay engages and disengages). In operation, the resistor is adjusted so that the relay just toggles OFF at a desired temperature. A 3 centigrade degree drop in temperature should cause the relay to toggle back ON and remain ON until temperature again rises to preset level.

Basically, the circuit converts change in temperature, sensed by the sensor from an outside system, into change of voltage. It compares that voltage with the voltage of the preset temperature using the comparator and then drives a relay. This is the thermostat operation of the device. This device is suitable for application in incubators, domestic heaters, high temperature fans, and some temperature controlled practices(laboratory experiments) such as enzyme reactions and food drying processes to obtain components like vitamin, protein etc. .

1.2 MOTIVATION AND OBJECTIVE

Electrical and computer engineering is so vast that it finds application in almost all areas of our everyday life. This has motivated me to design a simple project whose application is not restricted and limited but provides an opportunity for any device within its current rating to be operated. It also allows any device connected through it to function, not exceeding any desired temperature according to its use.

The project is aimed at the design and construction of a thermostat that involves a precision integrated-circuit temperature sensor. This provides a more precise reading than the ordinary thermostat that uses thermistor. It also maintains superior accuracy longer compared to their mechanical counterpart. This project is also aimed at designing a device that provides more accurate control and have small differential i.e. will shut OFF only a degree above the set point.

1.3 SCOPE AND LIMITATION OF THE PROJECT

The thermostat measures temperature in the range 0°C-100°C. Therefore it is not suitable for high temperature applications. Also, the heating control is done through relay switching; frequent turning ON and OFF when it gets to the set point may damage the motor

Chapter Two

LITERATURE REVIEW

One of the earliest inventors of a thermometer was probably Galileo. Galileo is said to have used a device called a "thermoscope" around 1600. These first thermometers were not really convectional; and while several inventors invented a version of the thermoscope at the same time, Italian inventor Santorio was the first inventor to put a numerical scale on the instrument. Galileo Galilei invented a rudimentary water thermometer in 1593 which, for the first time, allowed temperature variations to be measured. In 1714, Gabriel Fahrenheit invented the first mercury thermometer (the modern thermometer) and its scale.

In the early 60's, with the development of silicon fabrication, integrated temperature sensors were invented as a unique temperature sensing device. Silicon Temperature Sensors differ significantly from the other types in a couple of important ways.

The first is the operating temperature range. A typical temperature sensor IC can operate over the nominal IC temperature range of -55°C to +150°C. Some devices go beyond this range, while others, because of package or cost constraints, operate over a narrower range. The second major difference is functionality. A silicon temperature sensor is an integrated circuit, and can therefore include extensive signal processing circuitry within the same package as the sensor. A design does not require a cold-junction compensation or linearization circuits for temperature sensor ICs. Unless for extremely specialized system requirements, there is no need to design comparator or analogue-to-digital converter (ADC) circuits to convert their analog outputs to logic levels or digital codes. Those functions are already built into the ICs.

For further development, a biodynamist and flight surgeon with the Luftwaffe during World War II, Theodore Hannes Benzinger invented the ear thermometer. David Phillips invented the infra-red ear thermometer in 1984. Dr. Jacob Fraden, CEO of Advanced Monitors Corporation, invented the world's best-selling ear thermometer, the Thermoscan Human Ear Thermometer.

Other related temperature devices are thermistors, thermocouple, and resistive sensors. These devices have limited application due their inaccurate calibration. In a classical mechanical thermostat, the thermometer is a coiled bimetallic strip. A bimetallic strip is made by uniting several layers, made up of two different types of metal, together. The metals that make up the strip get bigger or smaller when they are heated or cooled. Each type of metal expands at its own specific rate, and the two metals (usually iron and copper) that make up the strip are selected so that the rates at which the strip gets bigger and smaller aren't the same. When the strip cools off, one side of the metal on the inside of the coil gets smaller and the strip will wind more tightly. When the coil tightens, the circuit is completed by a switch attached to the coil, and the furnace turns on. The switch in the circuit is typically a mercury switch (a bead of liquid mercury metal inside a glass bulb with two leads at one end). As the temperature of the room rises, the opposite occurs, and the coil unwinds, opening the circuit and turning the furnace off. Like this project, most modern thermostats are digital, with a solid-state temperature sensor rather than a bimetallic strip, and a transistor switch instead of a mercury switch. [1] [2] [3] [11]

A thermostat is used in automobiles using an internal combustion engine to regulate the flow of coolant. When the thermostat is open, coolant passes through the cylinder head where it gets hot. It is then led from the engine into the radiator where it looses the heat to the air flowing through it. A "water pump" driven from the engine propels the coolant around the system. When the thermostat is closed the flow is prevented and so the engine is allowed to heat up to its optimum operating temperature. This type of thermostat operates mechanically. It makes use of a wax pellet inside a sealed chamber. The wax is solid at low temperatures but as the engine heats up the wax melts and expands. The sealed chamber has an expansion provision that operates a rod which opens a valve when the operating temperature is exceeded. The operating temperature is fixed, but is determined by the specific composition of the wax. Thermostats of this type are available to maintain different temperatures, typically in the range of 70 to 90°C (160 to 200°F).

Electronic thermostat is an instrument which directly or indirectly controls one or more sources of heating and cooling to maintain a desired temperature. It is a device that monitors and automatically responds to changes in temperature and activates switches controlling devices such as furnaces or air conditioners. To perform this function a thermostat must have a sensing element and a transducer. The sensing element measures changes in the temperature and produces a desired effect on the transducer. The transducer converts the effect produced by the sensing element into a suitable control of the device or devices which affect the temperature. [2]

They are devices that detect temperature changes for the purpose of maintaining the temperature of an enclosed area essentially constant. The thermostat generates signals, usually electrical, to activate relays, valves, switches, and so on when the temperature rises above or falls below the desired value.

The most commonly used principles for sensing changes in temperature are (1) unequal rate of expansion of two dissimilar metals bonded together (bimetals), (2) unequal expansion of two dissimilar metals (rod and tube), (3) liquid expansion (sealed diaphragm and remote bulb or sealed bellows with or without a remote bulb), (4) saturation pressure of a liquid-vapor system (bellows), and (5) temperature-sensitive resistance element.

The most commonly used transducers are (1) switches that make or break an electric circuit, (2) potentiometer with a wiper that is moved by the sensing element, (3) electronic amplifier, and (4) pneumatic actuator. Thermostats are used mostly for room temperature control. Thermostats are also used extensively in safety and limit application. They are generally of the following types: insertion types that are mounted on ducts with the sensing element extending into a duct; immersion types that control a liquid in a pipe or tank with the sensing element extending into the liquid; and surface types in which the sensing element is mounted on a pipe or similar surface. [1] [2] [4]

Chapter Three

DESIGN ANALYSIS

In electrical, electronics and computer engineering, systems are usually described with the aid of block diagrams that are either functional or logical. Hence the block diagram of the system under construction is shown in figure 3.0

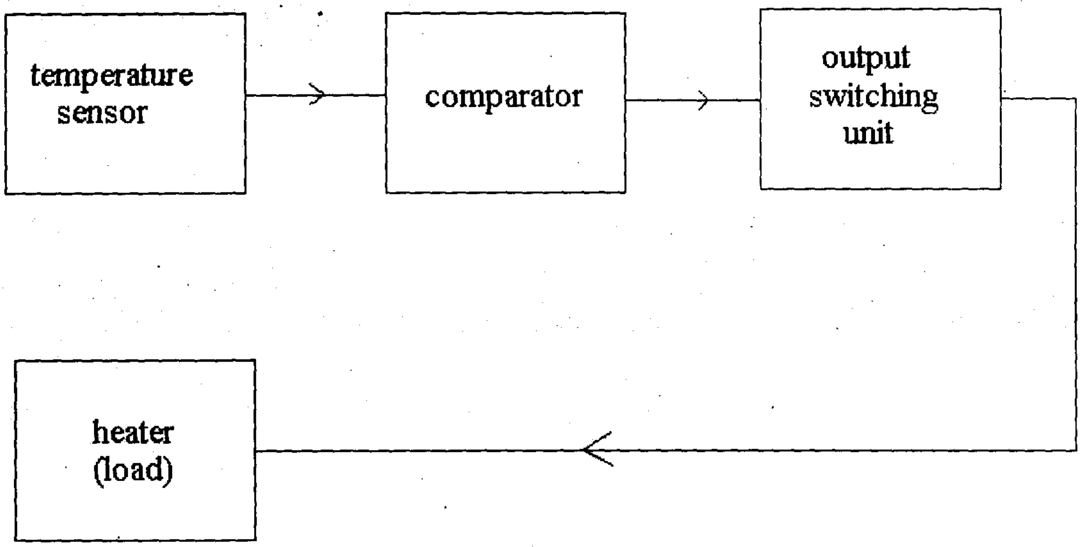


Figure 3.1 Block diagram of the electronic thermostat

The circuit's block diagram consists of four units; input (sensor) unit, comparator unit, output switching unit, and power unit. They are described below

3.1 INPUT/SENSOR UNIT

The input/sensor unit comprises LM35 temperature sensor. It is used for temperature monitoring and heat signal feedback for the device. As earlier stated in chapter one, the temperature sensor has a temperature-voltage relationship of 1°C – 10mV. The sensor operates within a temperature range of 0 - 100°C. It is a three terminal component, two of the terminal are the power supply while the third is the output. The output provides the stated relationship.

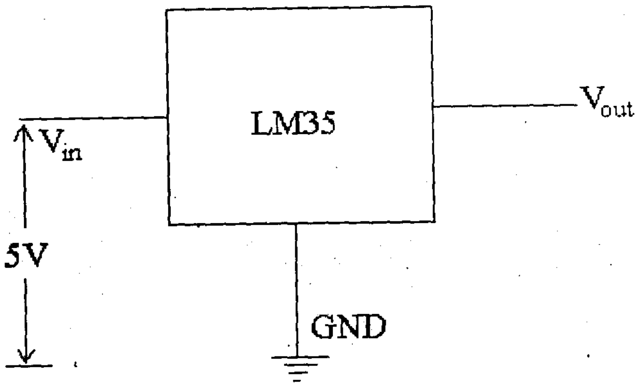


Figure 3.2 The functional diagram of the LM35

The device is supplied with +5V and the output cover a range of 0-1000mV in accordance with the 1°C – 10mV relationship. The device is connected to a comparator circuit. The temperature sensor allows the comparator to respond to the involved temperature.

3.2 COMPARATOR UNIT

For this project, there is the need to establish desired reference output voltages; therefore this particular comparator is used. The comparator unit incorporates a LM339, a quad comparator circuit. It is designed for adjusted switching application. A normal comparator possesses two main inputs and a single output; also two power supply terminals. The supply voltage is 5V. The two inputs are the inverting V_{in} (-) and non-inverting V_{in} (+) inputs.

The comparator can typically accept relatively large inputs and have provision for selecting the desired reference voltage levels. Outputs of comparators digitally work in response to the states of the input conditions. Whenever the non-inverting input, Vin (+), is greater than the inverting input, V_{in} (-), side, the output is a logic state 1 but when the inverting input, V_{in} (-), is greater or equals to the non-inverting, V_{in} (+), the output is always in a logic state of 0.

V_{in} (+) > V_{in} (-) output is in logic state 1.

V_{in} (-) ≥ V_{in} (+) output is in logic state 0.

LM339 comparator is incorporated into the circuit to monitor and respond to the output state of the input (LM35). The device functions like a switching tool by adjusting one of its input with a particular stable voltage. Since the 5V regulator supplies voltage to the comparator circuit, extra voltage stabilization circuit such as the one involving zener diode is not involved in the comparator's circuit. The stability of the power supply is sufficient for the aimed operation.

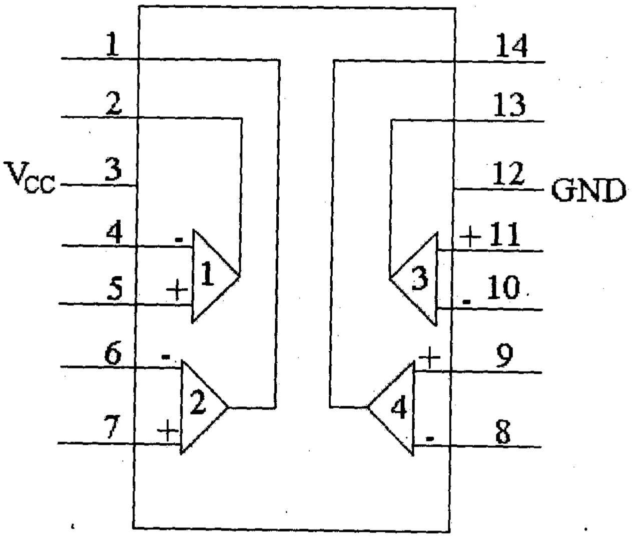


Figure 3.3 The Pin Layout of the LM339

A single LM339 integrated circuit possesses four unit comparators. Only one of the four in-built comparator is in use. The others are not connected in the circuit.

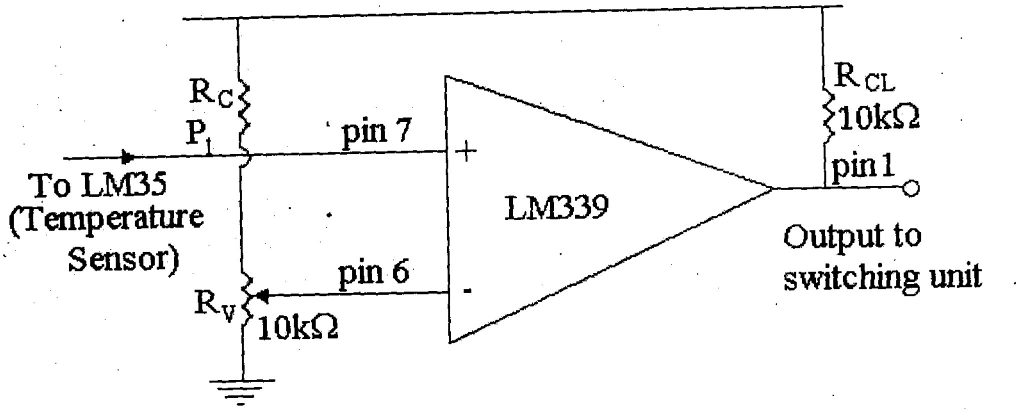


Figure 3.4 The Comparator Circuit

The comparator circuit involves four main components; three resistors and a single comparator unit. A 10kΩ (variable resistor, R_V) is used for adjusting or varying the voltage at the inverting input (V_{in} (-)) of the comparator. The 10kΩ resistor allows the connection of the output transistor to any choice supply voltage. The actual value of the resistor is not critical, since the transistor is operated in saturation mode; values between few hundreds and few thousand ohms are typical. [9]

The main purpose of the referencing technique is to allow different responses for certain inputs. These inputs (output of the temperature sensor) are applied at the non-inverting side of the comparator (V_{in} (+)). Initial conditions often involves that the voltage at the non-inverting input (V_{in} (+)) be lower than the inverting input side. As a result of this, the output is in logic state 0. As earlier stated in this chapter, the temperature sensor involves a temperature-voltage relationship of 1°C – 10mV. With this relationship, the voltage at the input of the comparator corresponds linearly to sensor's temperature. For example, a temperature of 35°C corresponds to 350mV with respect to the comparator.

Assuming the non-inverting input (V_{in} (+)) of the comparator is adjusted to say 500mV (corresponds to 50°C) and the temperature of the temperature sensor is say around 30°C (corresponding to 300mV). The comparator will give an output of logic state 0 but as the temperature surrounding the temperature sensor increases, its corresponding output voltage also increases. When it gets to a point whereby the temperature of this sensor produces a voltage which is about going beyond 500mV (corresponding to 50°C). At this point, the output of the comparator changes from state 0 to 1. Therefore, the comparator electronically detects a particular temperature change at the temperature sensor through the set voltage of the non-inverting input (V_{in} (+)). In fact, the voltage at the inverting input (V_{in} (-)) of the comparator is corresponding to the cut-off temperature for regulation.

However, in figure 3.5, R_V is quite significant for R_C voltage/temperature referencing. R_C is connected in series with R_V. The range which is either 0 – 1000mV or 0 - 100°C due to the response range of the temperature sensor is adjusted through the R_V. In other words, the voltage across R_V (10kΩ) must be 1000mV or 1V so that when the variable resistor is adjusted, a particular voltage can be selected within the 0 – 1V range. The adjusted voltage corresponds to a temperature value.

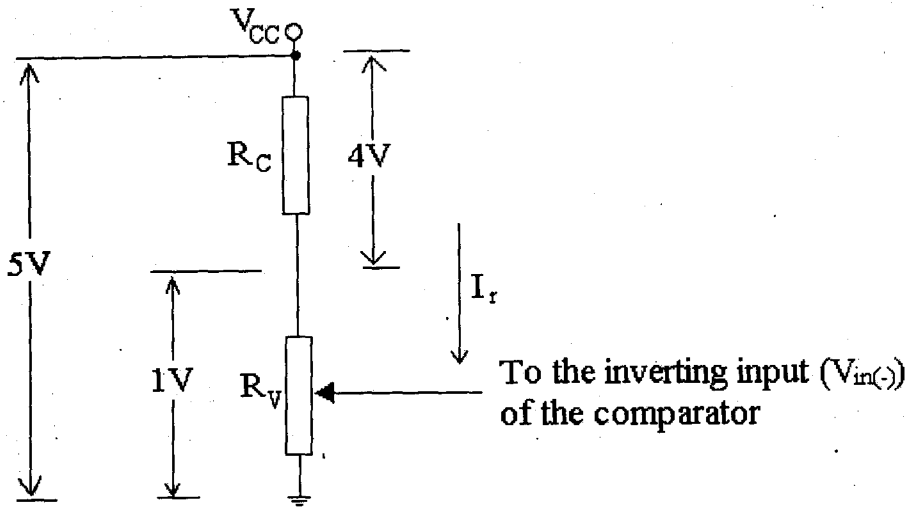


Figure 3.5 The Comparator's Voltage Referencing Circuit

The voltage across the series connected resistor is 5V. R_C holds 4V and 1V is across R_V.

Therefore, the current flowing through the circuit is given below:-

$$I_r = \frac{V_{CC}}{R_C + R_V}$$

$$I_r = \frac{5}{10 + R_C}$$

Therefore,

$$1V = R_V \times \frac{5}{10 + R_C}$$

$$1 = \frac{50}{10 + R_C}$$

$10 + R_C = 50$

$R_C = 40$

The resistance value is in kΩ. Therefore, R_C is 40kΩ.

$R_C = 40\text{k}\Omega$

$$I_r = \frac{5}{10 + R_C}$$

$$I_r = \frac{5}{40 + 10} = \frac{5}{50} = 0.1mA$$

$I_r = 0.1$mA

R_{CL} is specified by the manufacturer's data sheet from National semiconductor. The resistance is the load to the open collector output of the comparator.

The device does not possess a temperature display feature. Therefore, R_V is calibrated on a dial scale to show the referenced voltage. The scale is based on the linearity of R_V and the temperature sensor's temperature-voltage relationship. This makes the adjustment of the reference voltage accurate for practical importance.

3.3 The Output Switching Unit

The digital output of the comparator is used for switching application. A high logic state output from the comparator is for switching off power supply to a heating element which directly determines the temperature of the sensor (LM35). A low logic state output from the comparator allows power supply to the heater which results into increase in temperature of the sensor (LM35). A base resistor is required to ensure perfect switching of the transistor in saturation.

The temperature sensor feeds back the state of the heater into the comparator. Through the reference temperature, switching operation is denied at cutting off electric power supply to the heater or allowing it to run. The heater's ON/OFF switching is performed through a relay's switch. The relay responds to the control signal from the comparator through the transistor.

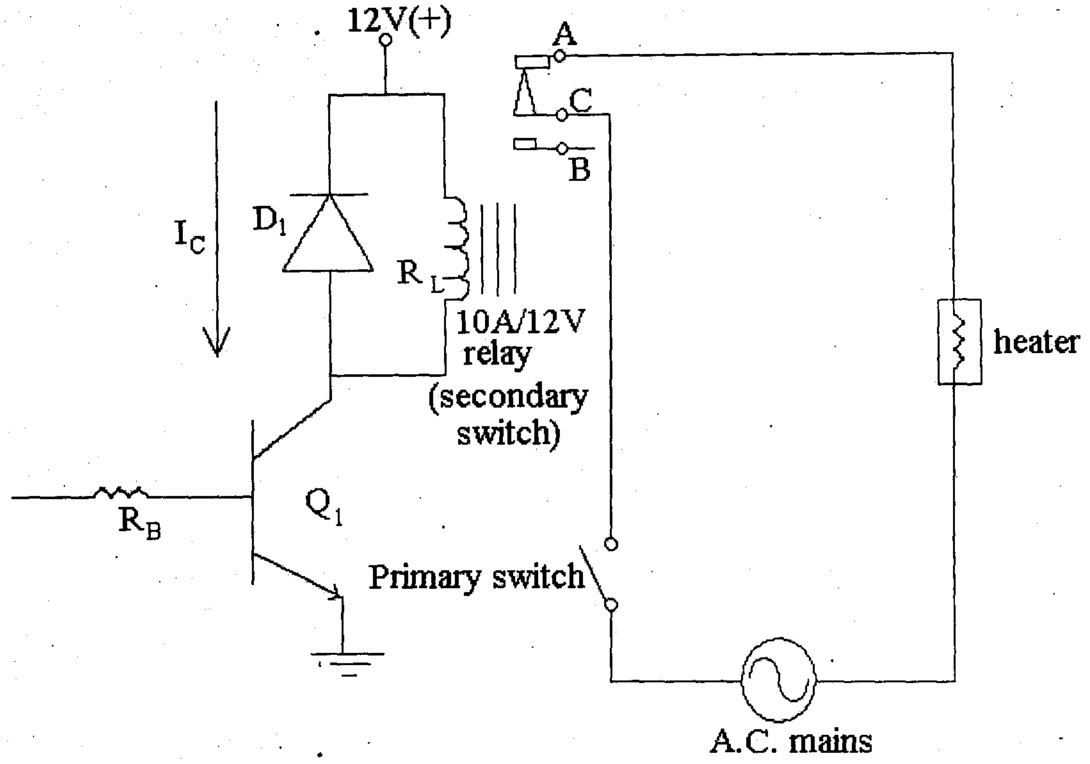


Figure 3.6 The Output Switching Unit

An NPN transistor operating in the common-emitter configuration is involved in the switching of the 10A/12V relay. The power supply (12V) is from a 12V regulator (7812). The collector of the transistor is loaded with both D_1 and R_L. R_L is the resistance in the relay's coil. The relay possesses three switching terminals A, B and C. Normally, terminal C is connected to A, that is, when the relay is not operated, it is normally in contact. Whenever a 12V power supply is set across the inductive part of the relay, contact C leaves A for B. The initial output state of the relay is restored back when power is cut from the inductive part.

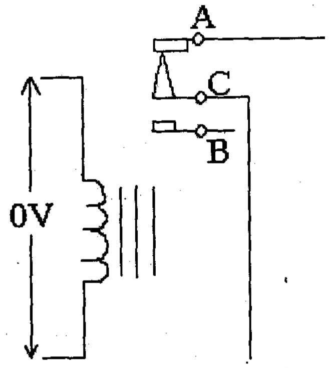


Figure 3.7a No Voltage Across the Inductive Part of a Relay

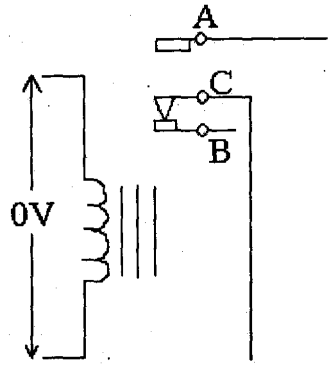


Figure 3.7b Voltage Across the Inductive Part of a Relay

The switching is done through the magnetic effect of the coil, when electricity is supplied to it, a magnetic field is created around the coil. This field is always proportional to the amount of electricity applied. The action of the inductor or coil is attributed to back emf. It is based on Lenz's law of electromagnetism/induction. It states that "there is always a force in the opposite direction of a particular change in a coil". The switching on and off change in the relay's coil sets this back emf which is potentially strong enough to damage a related switching transistor. To prevent this damage, a reverse biased diode is usually placed across the collector of the transistor involved and the V_{CC}. This diode protects the transistor from back e.m.f that might be generated since the relay coil presents an inductive load. In this case, R_C which is the collector resistance is the resistance of the relay coil, which is 400Ω for the relay type used in this project. [6] [7]

R_L is 400 Ω, in the saturation mode of the transistor a voltage of 12V is expected across it.Therefore, collector current

$$I_C = \frac{12}{400} = 0.03A$$

Ic = 0.03A

The transistor has a typical current gain of 100. [7]

Therefore, base current

$$I_B = \frac{I_C}{100}$$

$$I_B = \frac{0.03}{100} = 0.0003A$$

I_B = 0.3mA

5V is expected to switch the transistor through the base.

Therefore,

$$R_B = \frac{5-0.7}{0.3mA} = 14333.3\Omega$$

$$R_B \approx 14k\Omega$$

A value of 10kΩ is used in the circuit owing to the expected voltage drop at the base of the transistor. This value is more practical.

The output state initially involves the contact of terminal A with C. This results into the flow of AC mains through the heating load whenever the primary switch is close. The comparator's output is logical 0 for this particular condition. That is, the transistor is cut-off.

But in a situation whereby the comparator produces a logical 1 output or relatively high voltage, the transistor is saturated and the relay is energized resulting to the movement of contact C from A to B. The heater's circuit is opened, no more current flows for heating purpose. Heating starts when the base of the transistor is returned back to logical 0 through the comparator.

In summary, the temperature at the LM35 sensor, indirectly switches on and off the heater through the comparator and relay circuit. [2]

When a regulating voltage or temperature is preset at the comparator, heater is on and off in order to keep the temperature around the preset. Therefore, the heater and temperature sensor are closely put together.

The involved relay switch is rated 10A. Therefore, when the ac mains is 220V, maximum power rating or heating load of the set up is roughly 220 x 10 = 2200W or 2.2kW. Any load beyond the stated might cause severe damage to the relay, that is, a serious short circuit condition.

3.4 The Power Supply Unit

12 volts and 5 volts d.c voltages are required for this project from the mains electricity supply of 240 volts ac. To achieve this, the following steps are undergone.

- Stepping down the A C supply with a transformer
- Full wave rectification
- Removal of ripple from the rectified waveform
- Voltage regulation to desired value
- Power display LED

The power unit involves the transformer-bridge rectifier circuit. A 24V transformer is used to provide power to both 7812 and 7805 voltage regulators which produces regulated 12V and 5V respectively. [4] [5]

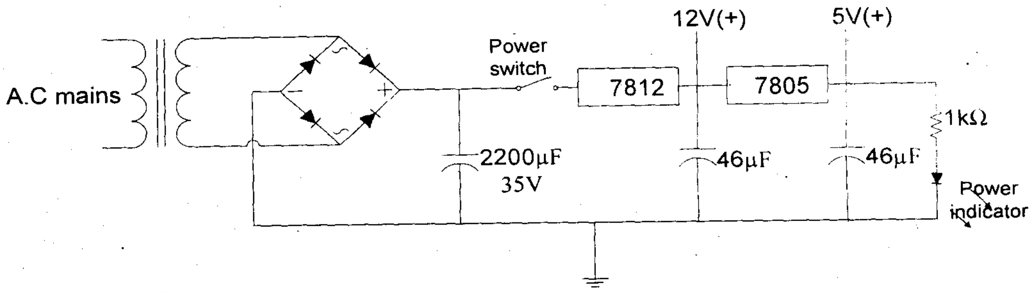


Figure 3.8 The Power Supply Unit

The common bridge rectifier, comprising four rectifying diodes, is used for converting the 24V ac power supply into corresponding roughly 24V dc voltage. The involved ripple at the output of the bridge rectifier is filtered through a 2200µF, 35V capacitor. The voltage rating of the capacitor is about twice the expected output voltage of the rectifier, to protect the device from the effect of high voltage supply.

A power switch opens and closes the complete circuit. Both 7812 and 7805 voltage regulators are connected in parallel across the rectified voltage output. The two devices are aimed for stability of the complete circuit. The 12V power supply from the 7812 is connected to just the output switching circuit owing to the involved 12V relay. The 7805 supplies the other parts of the circuit with 5V.

A power indicator circuit comprising of a resistor and Light Emitting Diode (LED) shows the presence of power in the circuit.

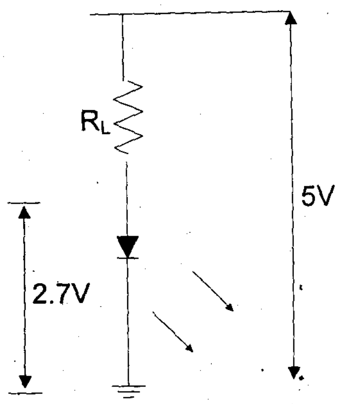


Figure 3.9 The Power Indicator Circuit

A voltage of around 2.7V is expected across the diode with a current of roughly 2mA.

$$\text{Therefore, } R_L = \frac{5-2.7}{2\times10^{-3}} = 1150\Omega$$

A resistor of 1kΩ is used instead for more practical importance and availability. It was also chosen to limit the power on the light emitting diode, LED. Power dissipated by the resistor is given by

$P = V^2/R$

$= 12^2/1000 = 0.144W$ [12]

Chapter Four

This chapter deals with the construction and testing of electronic thermostat using components specified in the previous chapter. This project was designed with an effective circuit that would be able to detect or sense temperature and also control/regulate a heating element.

4.1 CONSTRUCTION

Relevant components were purchased and tested using a digital multimeter to see if they were in good working condition for the purpose of this project. The surface of a veroboard of suitable size was scraped using a razor blade to enhance easy and firm soldering of components on it. According to the circuit layout, each component was set on the copper-tracked veroboard one after the other. I started with the construction of the power supply unit involving transformer, the bridge rectifier, filtering capacitor, the regulators (7805 and 7812), and the indicator circuit, in that order. This section was plugged to the AC mains and the light emitting diode (LED) emitted light. This indicates proper and accurate connection, that is, there is power in the circuit. Next was the connection of the input/sensor unit followed by the connection of the comparator unit and the relay switching unit.

Plastic material was used for the casing of the project because of its durability and resistance to corrosion. A flat 13A socket was also mounted on the casing. Load is connected to the thermostat through this flat socket.

4.2 CONSTRUCTION TOOLS AND EQUIPMENTS

A brief discussion of the construction tools is given below:

Soldering iron: a modular soldering iron with 60 watts heating element was used for the project. .

Soldering stand: this was used for keeping the soldering iron in a safe position. The stand was constructed in such a way that it does not touch any metallic or plastic part.

Lead: flux-core type of lead was used for the soldering of the various components.

Lead sucker: this was used for sucking up molten solder

Digital multimeter: this was used for quite a number of functions; to test continuity of circuit current, to measure resistance, capacitance and voltage in various sections of the circuit

Wire cutters and wired

4.3 TESTING

The testing pin of the digital multimeter was placed on pin 6 of the comparator IC and the temperature equivalent, as related to voltage, was set to 35°C (350mV) by adjusting the variable resistor. The testing pin was later placed on pin 7 of the same comparator IC and the multimeter's reading was observed. A hot soldering iron was brought close to the temperature sensor (Lm35) and the temperature reading was observed, as it increased, on the digital multimeter. Immediately the LM35 sensed a 36°C temperature, the switching unit of the device was triggered. This switching unit is expected to trigger OFF any heater (load) connected to the device immediately the temperature of the load exceeds that of the device's referenced temperature.

4.4 RESULTS

The triggering OFF of the load (heater) connected to the electronic thermostat at exactly 36°C, a centigrade degree higher than the referenced temperature input, helps in the monitoring and regulation of the heater's (load) temperature. It also shows that the device's high precision, accuracy, and high sensitivity. This is the needed advantage that makes electronic thermostat better than its mechanical counterparts that use bimetallic strip and thermal sensors.

Chapter Five

5.1 CONCLUSION

The main objective of this project was to design a simple electronic thermostat that can measure temperature in the range of 0 degree centigrade to100 degree centigrade. The various units of the design were constructed in stages and each unit was confirmed to be working perfectly after being tested. The practical implementation of the design made me to be more familiar with electronic components. It also enhanced my skills and techniques in handling construction tools and equipments.

This project can be adapted for use in other circuitry by devices that require temperature regulation. It can also be used in biological laboratories; in incubators and oven, in reactions such as enzyme reactions that requires heating experiment to be carried out at a particular temperature in order to prevent the denaturing of enzymes when they are subjected to heat.

Due to the applications of this project, it shows that Electrical and Computer Engineering finds application in all areas of our life. Therefore it can be concluded that the aims and objectives of the project were achieved.

5.2 PRECAUTIONS

1. Integrated circuit socket was used to protect the integrated circuit comparator. This also serves to facilitate easy removal and replacement in case of damage.
2. All components were properly laid out and firmly soldered on the copper- tracked veroboard to ensure proper connection and current flow.

3. Care was taken to ensure that components were not exposed to excessive heat while soldering

4. Rip of the soldering iron was cleared after each soldering

5. Special care was taken to orientate polarized components e.g. electrolytic capacitors, transistors and diodes with respect to their potentials.

5.3 RECOMMENDATIONS

In a more sensitive conditioned areas it is advised that IC sensors that have wider temperature range such as LM 35A and LM 35CZ version of the LM series can be utilized. In order for the device to regulate the temperature of equipments/devices of higher current rating, a relay of higher current rating can be used. A digital display of temperature and a remote sensing that allows sensor to be placed up to several hundred feet away can also be used for a more effective operation.

APPENDIX

COMPONENTS USED

The following components were chosen and used based on their availability, effectiveness and precision.

LM 35 TEMPERATURE SENSOR

CAPACITOR (2200μF)

VARIABLE RESISTOR (10kΩ)

LM 339

10A/12V SOLID STATE RELAY

RESISTORS (1kΩ)

NPN Transistor 2SC945 .

SPECIFICATIONS OF COMPONENT

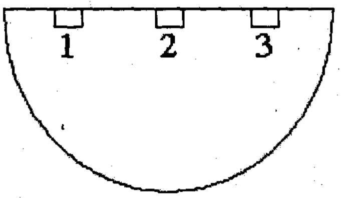
This section shows a brief description of the components used. Most of the information used was acquired from the internet. The data sheets for each component was obtained from the manufacturer's sites.

THE LM35 TEMPERATURE SENSOR

The Lm35 temperature sensor is a natural semiconductor precision integrated circuit, whose output voltage is linearly proportional to the Celsius (centigrade) temperature. The Lm35 has an advantage over linear temperature sensors calibrated in Kelvin as the user is not required to subtract a large constant (273) voltage from its output to obtain the convenient centigrade scaling. The Lm35 does not require any external calibration or trimming to provide typical accuracies of ± $^{1}/_{4}$% at room temperature and ± 3% over a full 0 - 100°C range. The Lm35 produces an output voltage of 10mV for every 1°C temperature increment. Therefore a temperature of 60^{0}C is recognized as 600mV by the device The output voltage range for the device is 0 – 1V.[4]

THE 2SC945 TRANSISTOR

The 2SC945 is an NPN transistor designed for audio and low speed applications. Its maximum Collector to Base voltage (V_{CBO}), Collector to emitter voltage (V_{CEO}), Emitter to Base voltage (V_{EBO}), Collector current (I_C) and Base current (I_B) are 60V, 50V, 5.0V, 100mA and 20mA. Its actual power dissipation is 250mW.[2]



1. **Emitter**
2. **Collector**
3. **Base**

Casing SEDEC: T092

Fig 3.10 Pin Layout Of A 2SC945 Transistor.

THE 1N4001 DIODE

1N4001 is a typical rectifying P-N diode. Its maximum voltage current ratings are 50V and 1A.It also has a high reliability, low leakage, low forward voltage drop and high current capability.[10]

Fig 3.11 Pin Layout Of In4001 PN Diode.

THE LM339 COMPARATOR

The Lm339 is a single supply quad comparator integrated circuit. It is designed for use in level detection, low level sensory and memory applications in consumer, automotive and industrial electronic applications. It is both TTL and CMOS compatible[5]

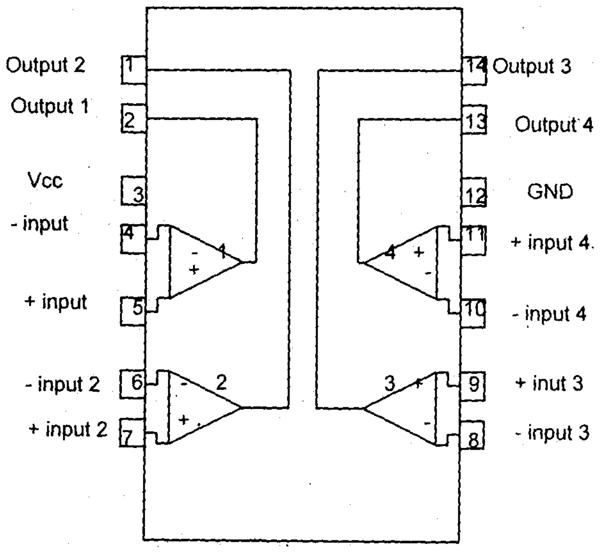


Fig 3.12 Pin Layout Of Lm339 Comparator.

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CIRCUIT OF AN ELECTRONIC THERMOSTAT