DESIGN AND CONSTRUCTION OF TEMPERATURE MEASUREMENT AND CONTROL DEVICE UP TO 1200 °C

A MASTER'S THESIS

in

Electrical and Electronics Engineering

Gaziantep Engineering Faculty

Middle East Technical University

By

Nihal Fatma GÜLER

December 1985

Approval of the Graduate School of Natural and Applied Sciences.

Prof.Dr.Bilgin Kaftanoğlu

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Electrical and Electronics Engineering.

Assoc.Prof.Dr.Muhammet Köksal

Chairman of the Department

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Asst.Prof. Dr. Müzeyyen Sarıtaş

Supervisor

Examining Committe in Charge:

Assoc.Prof.Dr.Muhammet KÖKSAL (Chairman)

Assoc.Prof.Dr.Süleyman SARITAŞ

Asst.Prof.Dr.Müzeyyen SARITAŞ

Asst.Prof.Dr.Uğur ÜNVER

Asst.Prof.Dr.Hamdi ATMACA

ABSTRACT

DESIGN AND CONSTRUCTION OF TEMPERATURE MEASUREMENT AND CONTROL DEVICE UP TO 1200 °C

GÜLER, Nihal Fatma

M.S. in Electrical and Electronics Engineering
Supervisor: Asst. Prof.Dr. Müzeyyen Sarıtaş
December 1985, 45 pages

With this thesis, a practical temperature measurement and control device is designed and constructed. Both analog and digital integrated circuit elements are used for construction.

In this work, the signal which is produced by a thermocouple of the furnace is amplified and then compared with a reference signal. After that according to this compared signal value, the furnace's power is controlled with the control stage of the device for the desired temperature value. An A/D converter reads both the temperature of the furnace and the desired temperature.

Keywords: sensor, dc amplifier, comparator, zero voltage switching.

ÖZET

1200 °C'YE KADAR SICAKLIK ÖLÇME
VE KONTROL CİHAZI DİZAYN VE YAPIMI

GÜLER, Nihal Fatma
Yüksek Lisans Tezi, Elektrik ve Elektronik Müh.Bölümü
Tez Yöneticisi: Yrd. Doç.Dr. Müzeyyen Sarıtaş
Aralık 1985, 45 sahife

Bu tezle, pratik bir sıcaklık ölçme ve kontrol cihazı tasarlandı ve yapıldı. Analog ve sayısal entegre devre elemanlarının her ikiside yapım için kullanıldı.

Bu çalışmada, bir fırın termokapılı tarafından üretilen sinyal yükseltilir ve sonra bir referans sinyali ile karşılaştırılır. Sonra, karşılaştırılan bu sinyal değerine göre, arzu edilen sıcaklık değeri için fırının gücü, cihazın kontrol kısmı ile kontrol edilir. Bir A/D çevirici, fırın sıcaklığı ve istenilen sıcaklık derecesinin her ikisinide okur.

Anahtar Sözcükler: Hissedici, dc yükseltici, karşılaştırıcı, sıfır voltaj anahtarlama.

ACKNOWLEDGEMENTS

I would like to express my thanks to my supervisor, Asst. Prof. Dr. M.Sarıtaş for her guidance, encouragement, suggestions, and her great help in the preparation of this work.

I would like to thank to Miss Ayfer Kaya for the typing of the manuscript.

Finally, the author is indebted to Erciyes University for provision of financial grant and to Assoc.Prof.Dr.M. Köksal for providing research facilities in the department of Electrical and Electronics Engineering at METU-Gaziantep Campus.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF SYMBOLS

PTC..... Positive temperature coefficient

NTC...... Negative temperature coefficient

T.........Temperature

S........ Thermoelectric power

Q........ Evolved heat of Thomson effect

μ_T........ Thomson coefficient

J........ Current density

π .... Peltier heat

E........ Electromotive force

V........ Voltage

R........ Resistance

A_v....... Voltage gain

CHAPTER I

INTRODUCTION

The measurement and control of temperature is an important concept in many places. If a constant temperature is needed in anywhere, the measuring and controlling the temperature get an importance. Controlling the room temperature, the heating and cooling, the heating and melting of some materials and many industrial processes often need a constant temperature. To obtain a constant temperature, firstly the temperature must be measured and then controlled according to the desired temperature value. Measuring and controlling the temperature are made preciesly with electronic devices. In this project, the measurement and control of the temperature of an electrical furnace is considered up to 1200°C. For measuring the temperature electrically, the measured ambient temperature must be converted to electrical signals. For this, some thermoelectric devices are used. Sensitivity, accuracy, speed of response, expected useful life, cost, availability of various modes of automatic control and resistance to corrosion, vibration and other conditions of institutional and industrial applications are a few of the factors which require attention in selecting temperature equipment. Numerous types of temperature measuring and controlling instruments are designed and constructed either commercial or not. The commercial devices have many improvements. The same work is made as a B.S. project in the Electrical and Electronics Engineering Department, but it didn't work as desired. It has relay as control element and so has many problems about switching. Taking into account such problems, this work was initiated in the Electrical and Electronics Engineering Department of METU to investigate this subject.

In Chapter II, the theoretical background of thermoelectric devices will be given. The different types of thermocouples and their characteristics will be presented. In Chapter III, the design and realization of practical circuit and its operation principles will be outlined. Finally, results, conclusions, discussions and future proposals will be found in Chapter IV.

CHAPTER II

MEASUREMENT AND CONTROL OF TEMPERATURE

2.1 General

Measurement and control of the temperature have a very wide application area and so, many type of measurement and control techniques were designed for the years. Firstly used techniques are very simple and inaccurate. But with the development of the science, more accurate and reliable techniques and devices have been designed and constructed. According to the construction, many types of thermometers, pyrometers, pellets, paints, color indicators, infrared photography can be employed for measuring temperature. Also, the pressure of a body of confined gas or its volume at a constant pressure can be used to indicate its temperature. These are all only measuring techniques don't have the controlling. For measuring and controlling the temperature at the same time automatically, electrical instruments are more reliable. Nowadays, there are many types of commercial temperature measuring and controlling devices. At these, usually, the temperature is sensed with a sensing element which converts the temperature to electrical signals and then heater is controlled according to the desired temperature. Usually, thermistors and thermocouples are used as sensing elements at these devices. Thermistors are included in semiconductors, the name "thermistors" was derived from thermally sensitive resistors, since the resistance of a thermistor varies rapidly with temperature. They have a controlled temperature coefficient that may be positive (PTC thermistors) or negative

(NTC thermistors). Thermistors are used from -100 to 450°C, but for special applications they can be used up to 500°C and above, and down to -180°C or lower. Thermistors are made from a number of metal oxides and their mixtures. Thermistors range in terminal resistance at room temperature from about 1 ohm to 10^8 ohms, depending on composition, shape and size[1]. Since the thermistors are not sufficient at higher temperatures, the thermoelectric devices are used.

2.2. Thermoelectric Devices

Thermoelectric devices can control the temperature of a given mass or complex of thermally connected masses according to thermoelectricty action. Three experimental observations of the thermoelectricity;the Seeback (1822), Thomson and Peltier (1834) effects are related thermodynamically by the Kelvin (Thomson) relations. The efficiency of a thermoelectric device depends on the Seeback coefficient, thermal and electrical conductivity and the operating temperatures.

2.2.1. Seeback Effect

In 1822, Seeback discovered that there is an electromotive force in a closed circuit of two dissimiliar metals whose junctions are at different temperatures[2].

In the Seeback Effect, the electrons which are at the hot end will be excited to higher energies. The higher energy electrons at the hot end are able to lower their energies by diffusing to the cold end. Thus the cold end becomes negatively charged and a voltage is induced along the rod. The induced voltage causes an electrical current to flow, which is equal to the voltage divided by electrical ressistance of the rod. If we raise the temperature difference T_1-T_2 a small amount, ΔT, the induced voltages will rise a small amount. The rate of change of voltage with temperature is defined as the thermoelectric power, S_{12} of the junction 1-2.

$$S_{12} = \frac{dV_{12}}{dT} = \frac{dV_1}{dT} - \frac{dV_2}{dT} = S_1 - S_2 \qquad \text{......(2.1)}$$

The thermally induced voltage, V_{12} called as the Seeback potential, is often used in measuring temperature. At room temperature and above, thermoelectric potentials are in the millivolt range; at low temperatures, the potentials are in microvolt range.

2.2.2. Thomson Effect

The absorption or evolution of heat is called as the Thomson effect, and the relation,

$$\frac{dQ(\text{Thomson})}{dt} = -\mu_T J_x \frac{dT}{dx} \qquad \text{....................(2.2)}$$

defines the Thomson coefficient μ_T, J_x and dT/dx are current density and thermal gradient along the rod and dQ/dt is heat evolved per unit volume per second[2].

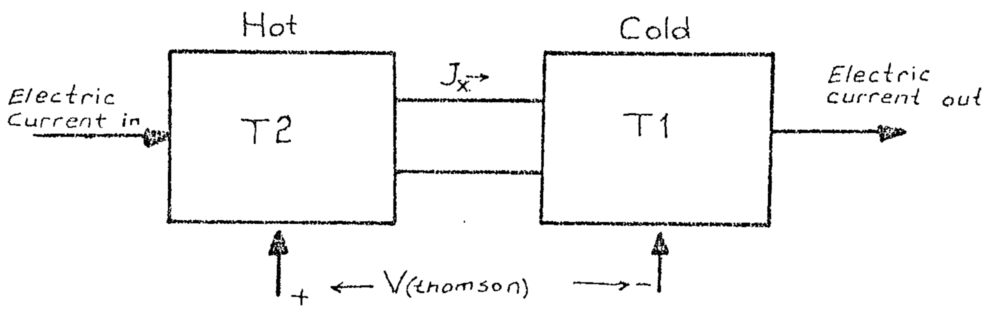

Figure 2.1. Schematic of Thomson Effect

2.2.3. Peltier Effect.

Peltier phenomenon is the generation or absorption of heat at the junction of two different conductors when a current flows through them. The Peltier heat π_{12}, is defined as the reversible heat evolved at the junction per unit time per unit electric current flowing from 1 to 2, or

$$\frac{dQ\ (\text{junction})}{dT} = \pi_{12} \qquad .....(2.3)$$

From this equation

$$\pi_{12} = - \pi_{21}$$

can be written. It is illustrated in Figure 2.2.

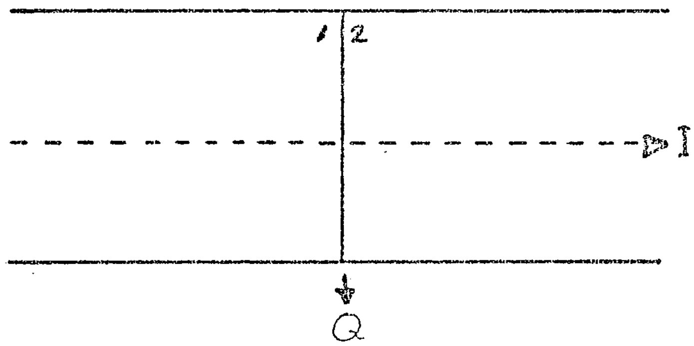

Figure 2.2. Schematic of Peltier effect.

The Peltier effect is proportional to the difference in the heat carried by the conduction of electrons of the two materials. The absolute Peltier heat may be defined as;

$$\pi_{12} = \pi_1 - \pi_2 \qquad ....(2.4)$$

2.2.4. Kelvin (Thomson) Relations

The three parameters which describe thermoelectric behaviour are the thermoelectric power S, the Thomson coefficient μ_T, and the Peltier heat π. These quantities are related with each other[2].

$$\mu_T = T\frac{dS}{dT} \qquad \pi = TS \qquad \text{.....................(2.5)}$$

$$S(T) - S(0) = S(T) = \int_0^T \frac{\mu_T}{T}\, dT \qquad \text{............(2.6)}$$

2.3. Thermoelectricity in Semiconductors

In semiconductors, thermoelectric effects are many times larger than in metals. If electrons are the majority carrier, S is negative and so π and μ_T should also be negative. If holes are the majority carrier, more electrons are excited into the acceptor levels at the hot end and so, more holes are available, and S, π and μ_T are all positive.

The rapid diffusion of the carriers, together with the high electrical resistivities further increases the thermoelectric effects in semiconductors. Since the thermoelectric voltage is determined by the equilibrium between the diffusion of electrons from hot to cold, and the reverse flow of electrons due to the induced voltage, high diffusivity builds up large voltages, and high resistivity reduces the return flow.

2.4. Thermocouples

Thermocouples can be used to measure and control the temperature processing as a sensor. The temperature difference between the junctions of a thermocouple is roughly proportional to the electromotive force (emf) produced in, and the current caused to flow around the thermocouple circuit[3] (see Figure 2.3).

If E is the value of the electromotive force, T_1 is the temperature of the hot junction and T_2 is the temperature of the cold junction, then from the combined Peltier and Thomson effects.

$$E = a\,(T_1 - T_2) + b\,(T_1 - T_2)^2 \qquad \text{................(2.7)}$$

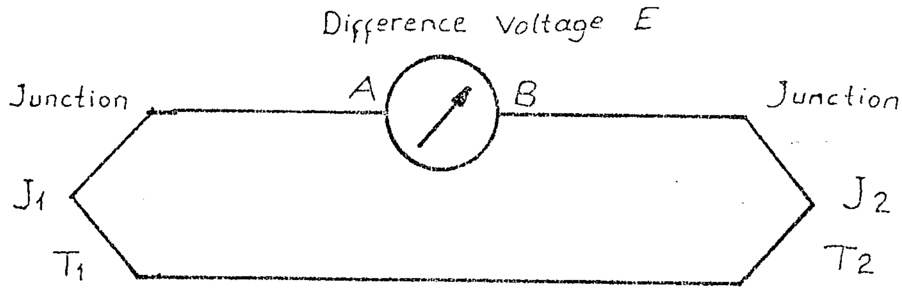

Figure 2.3. Basic principle of thermocouple measurement.

where a and b are constants depending on the materials used. In Eq. 2.7, the second term is negligible since b is very small.

In order to obtain a higher output voltage, it is possible to series connect two or more thermocouples. The total output will then be the sum of the outputs of the individual thermocouples. Standard charts give both the emf generated for a specific temperature difference between the cold junction at $0^{\circ}C$ and the hot junction and temperature difference required to generate a specific electromotive force [3] (see Figure 2.4).

2.4.1. Thermocouple Types

Different types of thermocouples and their characteristics are shown in Figure 2.5.

1- Copper - Constantan (Cu - Con) :

They are used for research work. The sensitivity is approximately 40 $\mu V/{}^{\circ}C$ and the upper limit of temperature measurement is 400 $^{\circ}C$.

2- Iron -Constantan (Fe -Con) :

They are used for measuring temperatures of gases, superheated steam, internal combustion exhaust gases, salt baths and carburising furnaces. The sensitivitiy is 50 $\mu V/{}^{\circ}C$ and

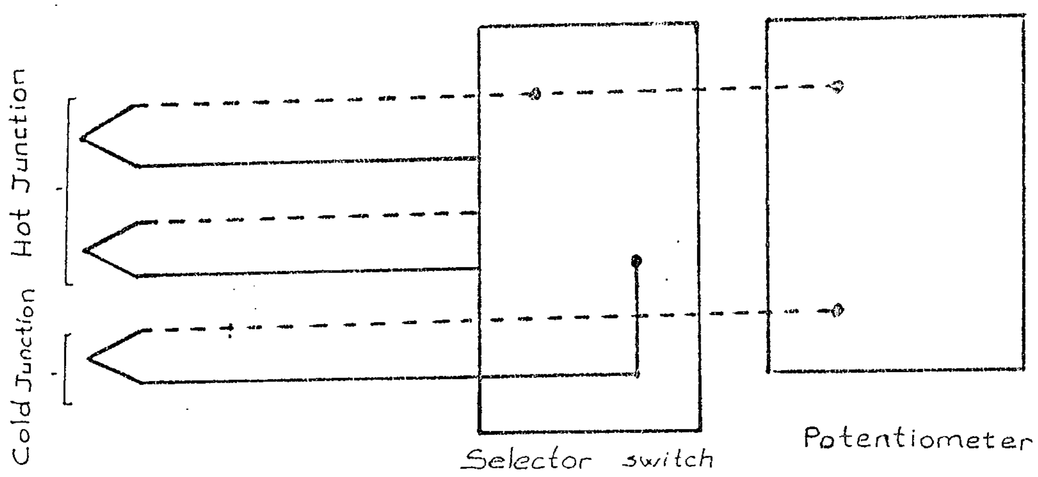

Figure 2.4. Circuit for reading a number of thermocouples with one potentiometer and ice point.

the upper limit of temperature measurement is 900 °C.

3- Chromel - Constantan (NiCr - Con) :

They are used and suited for sub-zero temperature measurement. The sensitivity is 60 μV/ °C and the upper limit of temperature measurement is 850 °C.

4- Chromel - Alumel or Nickel/Chromium -Nickel/Aluminum (Chr-Al or NiCr - NiAl) :

Chromel-Alumel thermocouples are very widely used. The output is linear and they have resistance to oxidising atmospheres. The sensitivity is 40 μV/ °C and the upper limit of the temperature measurement is 1100 °C.

5- Platinum/Rhodium-Platinum (Pt, Rh - Pt) :

They are used for high temperature measurement. The sensitivity is 10 μV/ °C, the upper limit of temperature measurement is 1600 °C.

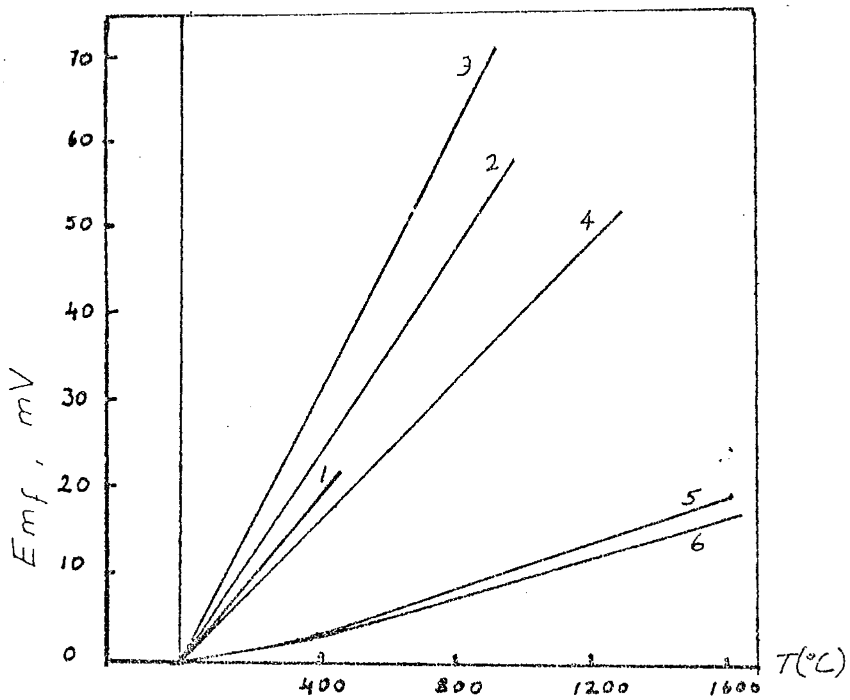

Figure 2.5. Typical Thermocouple Characteristics.

1-Copper-constantan
2-Iron-constantan
3-Chromel-constantan
4-Alumel-constantan
5-87Pt,15Rh-Pt
6-90Pt,10Rh-Pt

2.5. Temperature Measurement and Control Devices

For all analog and digital devices, the thermocouple sensor consists of two wires of dissimiliar metals joined at one end called "hot" or measuring junction, while the other end becomes the reference junction. The reference or "cold" junction is held constant at either 0^{o} C or calibrated to an equivalent emf value. The temperature or difference between the hot and reference junctions develops a dc milivoltage that is linear with temperature. This signal is fed into a bridge balance potentiometer which measures the emf output and, with amplification to a useful level, controls process temperature through the operation of a relay or solid state device. The old devices have anolog circuits and relay at control part. But new devices are almost contain solid state elements and digital circuits.

Temparature controller device is designed and constructed as BS project in Electrical and Electronics Engineering Department. Some integrated circuit elements such as A/D converter could not be found, the relay was used as switching element in control part.

There are many analog type designed temperature controller circuits which involve many problems, to get an accurate control with such a device. In modern devices, nowadays, usually only one integrated circuit element is used. Such a circuit is shown in Figure 2.6, but the PA424 IC cannot be available in Turkey but can be ordered.

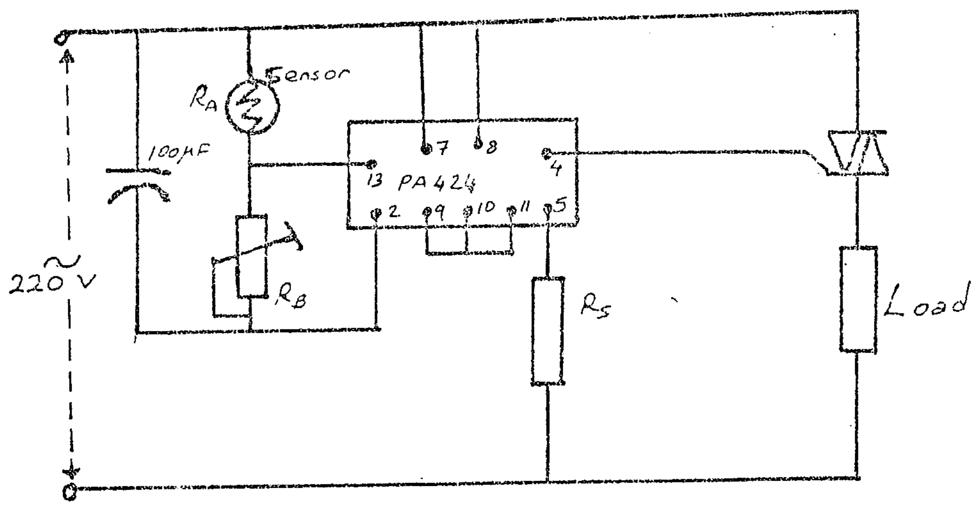

Figure 2.6. IC- Heater Control Circuit

In the Figure 2.6, the PA 424 integrated circuit zero-voltage switch is used as triggering element for triac to give equivalent of thermostat having differential of less than 0.2 ^{o}C, response time only a few seconds and no rfi. Triac turns off at the end of each cycle and removes power from heater, to provide zero-voltage switching of heater.

CHAPTER III

DESIGN AND REALIZATION OF PRACTICAL CIRCUIT

3.1. Introduction

Temperature control, essentially is a subject of mechanical engineering. But in modern technology, many such subjects are easily manipulated by electronic instruments with reduction in cost, increasing precision and easy of mounting and construction. On the other hand,in modern science, an engineer can easily adapt himself from one branch to another. This is especially true for an electronic engineer. Because, human facilities are not able to follow directly the electrical signals. Therefore the engineer should know the theory well in order to succeed in practice. In modern control engineering two main ways of design are present which are analog and digital. By analog devices, precision is limited. Design of an instrument can be most easily realized using analog and digital elements in the circuit design. In the following circuit design all the components are selected among the electronic circuit elements, especially semiconductor elements.

3.2. Design and Operation Principles

The block diagram of the whole system, is shown in Figure 3.1. According to that block diagram, the temperature is sensed by a thermocouple, then it is amplified by a dc amplifier and then it is compared with a voltage V_R corresponding to reference temperature T_R. Comparator output gives necessary command to the corresponding control element. A zero voltage switch is used as power control element with a triac.

and it converts it to electrical signals. These signals are in millivolt levels. In this thesis , a K type Ni-Cr-Ni thermocouple is used when making adjustments of the device. K type thermocouple is more resistant to oxidation and it is widely used at high temperatures. It has wide stability under thermal irradiation , it's output is almost linear. The sensitivity is approximately 40 $\mu V/{}^{o}C$. Thermocouple cold junction must be compensated at $0^{o}C$ for a precision measurement. For this, a bridge circuit is used for cold junction compensation.

3.2.2. DC Amplifier

The integrated operational amplifier is used as dc amplifier. The used operational amplifier is manufactured by National Semiconductor Technology firm and its catalog number is LM308.

In the practical circuit, a dc difference amplifier is designed for amplifying the sensor voltages which are in millivolts. This type of amplifier is often used to amplify inputs from transducers which convert a physical parameter and its variations into an electric signal. It is very versatile, high performance, low-cost dc amplifier system. The following figure is a typical difference amplifier circuit (see Figure 3.2).

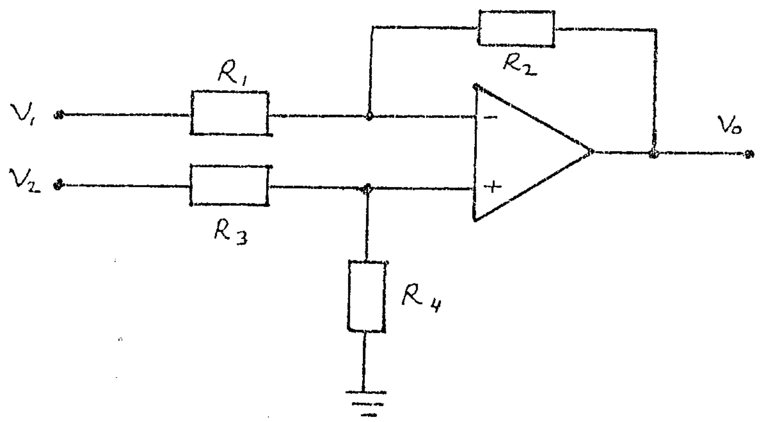

Figure. 3.2. Difference amplifier circuit.

According to figure, if $R_2 = R_4$ and $R_1 = R_3$ then,

$$Vo = \left(\frac{R_1+R_2}{R_3+R_4}\right) \frac{R_4}{R_1} V_2 - \frac{R_2}{R_1} V_1 \quad \text{will be} \quad \ldots\ldots\ldots\ldots(3.1)$$

$$Vo = (V_2-V_1) \frac{R_2}{R_1} \qquad Av = \frac{R_2}{R_1} \quad \ldots\ldots\ldots\ldots(3.2)$$

The temperature change in the furnace will be detected by the thermocouple as a voltage change and then amplified by the practical amplifier which is shown in Figure 3.3.

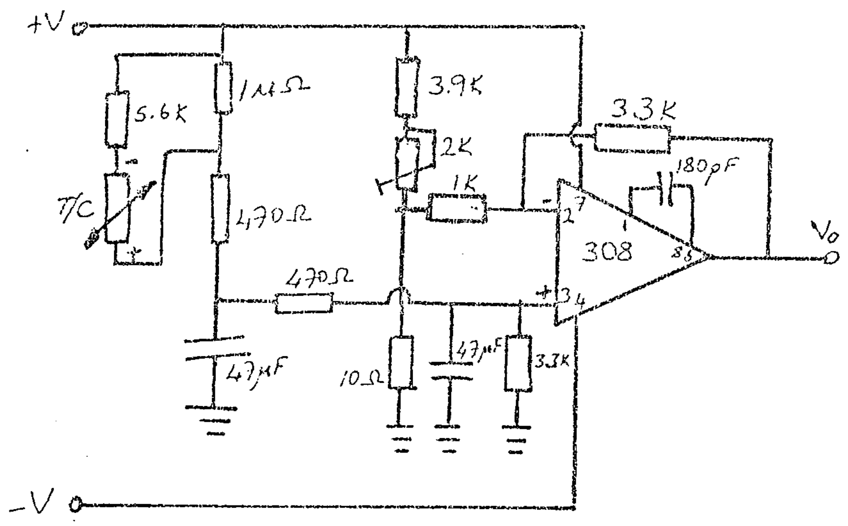

Figure 3.3. Practical dc amplifier circuit.

In the Figure 3.3, the variable resistor is used for offset voltage adjustment of LM308 IC. Detailed information about LM308 is given in Appendix A.

3.2.3. Comparator

The comparator compares two voltages. One is usually a

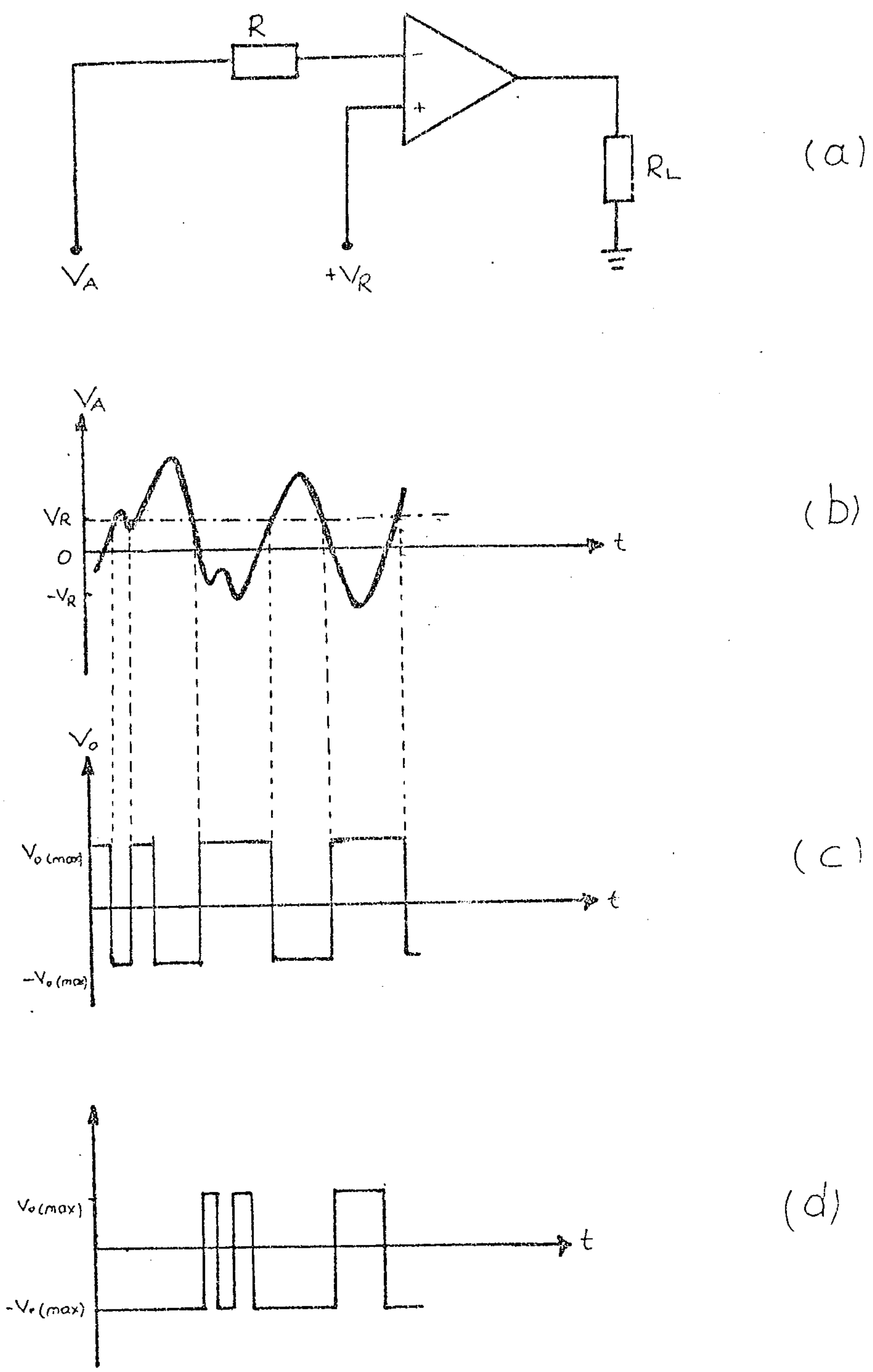

Figure 3.4. a) An op-amp as a comparator
b) Input wave form
c) Output waveform with a positive V_R
d) Output waveform with a negative V_R

fixed reference voltage V_R and the other a time varying signal voltage which is often called an analog voltage V_A. The operational amplifier's output is to swing from Vo (max) to-Vo(max) or vice versa as the analog voltage V_A passes through the reference voltage V_R. This reference voltage V_R can be either positive or negative with respect to ground, and of course, its value and polarity determine the V_A voltage that causes the output switch.

The amplitude of V_A must be large enough to pass through V_R if the switching action is to take place. The switching action of the comparator must be very fast. The general purpose operational amplifiers limited slew-rate may make it unsuitable. High slew-rate operational amplifiers and IC packages are made specifically to work as comparators, and are better suited for high-speed switching [4] (see Figure 3.5) .

In the practical circuit a positive feedback Schmitt trigger circuit is used as comparator. The LM308 operational amplifier is used in comparator stage. The following figure shows the typical positive feedback comparator circuit (see Figure 3.5).

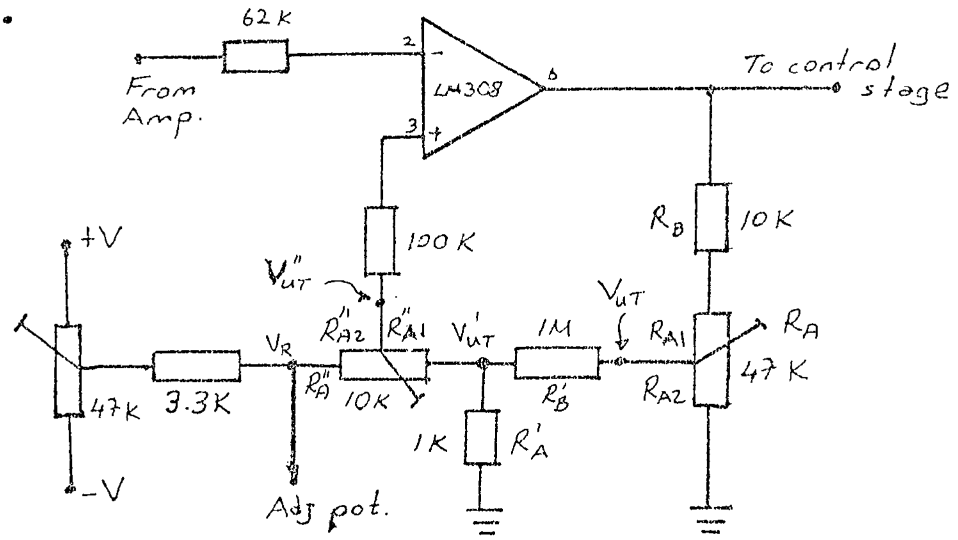

Figure 3.5. Practical circuit of positive feedback comparator circuit.

The upper trigger point and lower trigger point of positive feedback comparator due to $+V_{sat}$ and $-V_{sat}$ are calculated as follows.

If $V_o = +V_{sat}$ value,

$$V_{UTP} = \frac{+V_{sat}}{R_A + R_B} R_{A2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

$$V'_{UTP} = \frac{V_{UT}}{R'_B + R'_A} R'_A \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

$$V''_{UTP} = \frac{V'_{UTP}}{R'_A} R''_{A2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

$$V''_{UTP} = \frac{+V_{sat}}{R_A + R_B} R_{A2} \frac{R'_A}{R'_A + R'_B} \frac{R''_{A2}}{R''_A} \quad \ldots\ldots\ldots(3.6)$$

The lower trigger point (V_{LTP}) can also be calculated as above and found:

$$V_{LTP} = \frac{-V_{sat}}{R_A + R_B} R_{A2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.7)$$

$$V'_{LTP} = \frac{V_{LTP}}{R'_B + R'_A} R'_A \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.8)$$

$$V''_{LTP} = \frac{V'_{LTP}}{R''_A} R''_{A2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

$$V''_{LTP} = \frac{-V_{sat}}{R_A + R_B} R_{A2} \frac{R'_A}{R'_B + R'_A} \frac{R''_{A2}}{R''_A} \quad \ldots\ldots(3.10)$$

The hysteresis range of comparator circuit is the difference between V''_{LTP} and V''_{UTP}.

$$V_H = V''_{UTP} - V''_{LTP} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

$$V_H = \frac{2V_{sat}}{R_A + R_B} R_{A2} \frac{R'_A}{R'_A + R'_B} \qquad \frac{R''_{A2}}{R''_A} \quad \ldots\ldots\ldots (3.12)$$

Let's take $R_{A2} = 1K$, $R''_{A2} = 1K$, V_H will be $50\,\mu V$. If $R_{A2} = 46.9K$, $R''_{A2} = 9.9K$, V_H will be $850\,\mu V$. So the maximum and minimum values of V_H range between $50\,\mu V$ and $850\,\mu V$. Since the voltage gain of amplifier was 33, $50\,\mu V$ and $850\,\mu V$ of V_H values correspond to $1.5\,\mu V$ and $26\,\mu V$ respectively.

The sensitivity of K-type Ni-Cr-Ni thermocouple was given as $40\,\mu V/\,^oC$ in section 3.2.1. The V_H value of the present circuit is adjusted to $800\,\mu V$ which gives :

$$\left(\frac{800\,\mu V}{33}\right) \Big/ 40\,\mu V/\,^oC = 0.6\,^oC$$

So the switching action in the comparator circuit takes place with a sensitivity of 0.6 ^{o}C according to the measured value.

3.2.4 Zero Voltage Switch

Power control can be achieved by switching the triac on and off states for some desired number of complete half or full cycles. This type of control is usually referred to as zero-voltage switching. In zero-voltage switching only two levels of input power are delivered to the load, the load receives the full amount of power for a period of time and zero power for another period of time. This type of switching has being made with analog circuits. But recently, some special operational amplifiers are developed for this usage. In this project, the U106BS monolithic integrated circuit zero voltage switch is used, which is produced by Telefunken firm. It is employed for use in power switching applications of triggering triacs. The U106BS zero voltage switch can be operated either from an ac power supply or a dc supply -Vs= 7-8 V. In the present work, it is operated with the dc power supply. In the resistive heaters, the voltage and current are in phase and the zero voltage switching can be used. The Figure 3.6 shows the full-wave control logic block diagram of the U106BS zero voltage switch, and the Figure 3.7 shows the related pulse diagrams.

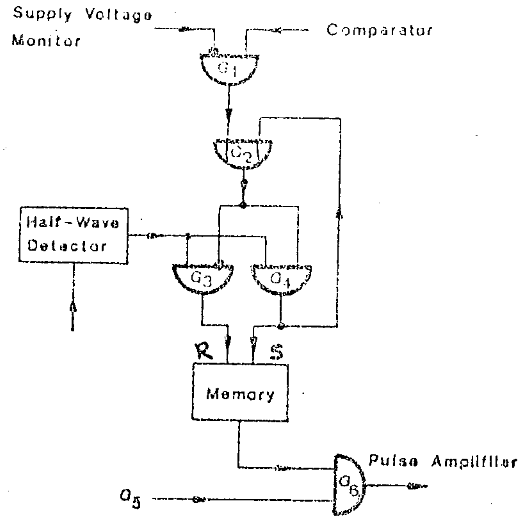

Figure 3.6. Full-wave control logic.

When the supply voltage is in zero-crossover and the comparator receives a "pulse output" command, then G_1 and G_2 will come to high level. If the half-wave detector subsequently changes to high level, then G_4 changes to high level also, and there by sets the memory and enables G_6 to pass pulses received from G_5 to the output. The memory remains in this set condition if G_1 happens to change to low level during a negative half-cycle, since G_4 holds G_2 at high level. When the falling edge of the half-wave signal G_4 goes to low-level, G_2 is blocked, whereby G_3 is ready. The next positive edge of the half-wave signal switches G_3 to high level and the memory is reset. If G_1 and G_2 happen to change from low to high state during a negative half-cycle, then the memory is also set, this is because G_4 is ready and the state of G_2 is directly transferred to the set input, whilst G_3 blocks (off) the reset input of the memory. This means that the memory can change its state only while the half-wave detector produces a high-level signal, i.e. change only during a negative half-cycle. Because there are two zero transitions of the synchronaziotion voltage between successive negative half-cycle peaks, the output pulses are presented in pairs, always begining during the positive zero crossover and ending with a pulse having negative dv/dt. When the output pulses occur, the triac gate is triggered and furnace will be on state. Block diagram and pin connections of U 106 BS is given in Appendix D. Triac specifications are given in Appendix E.

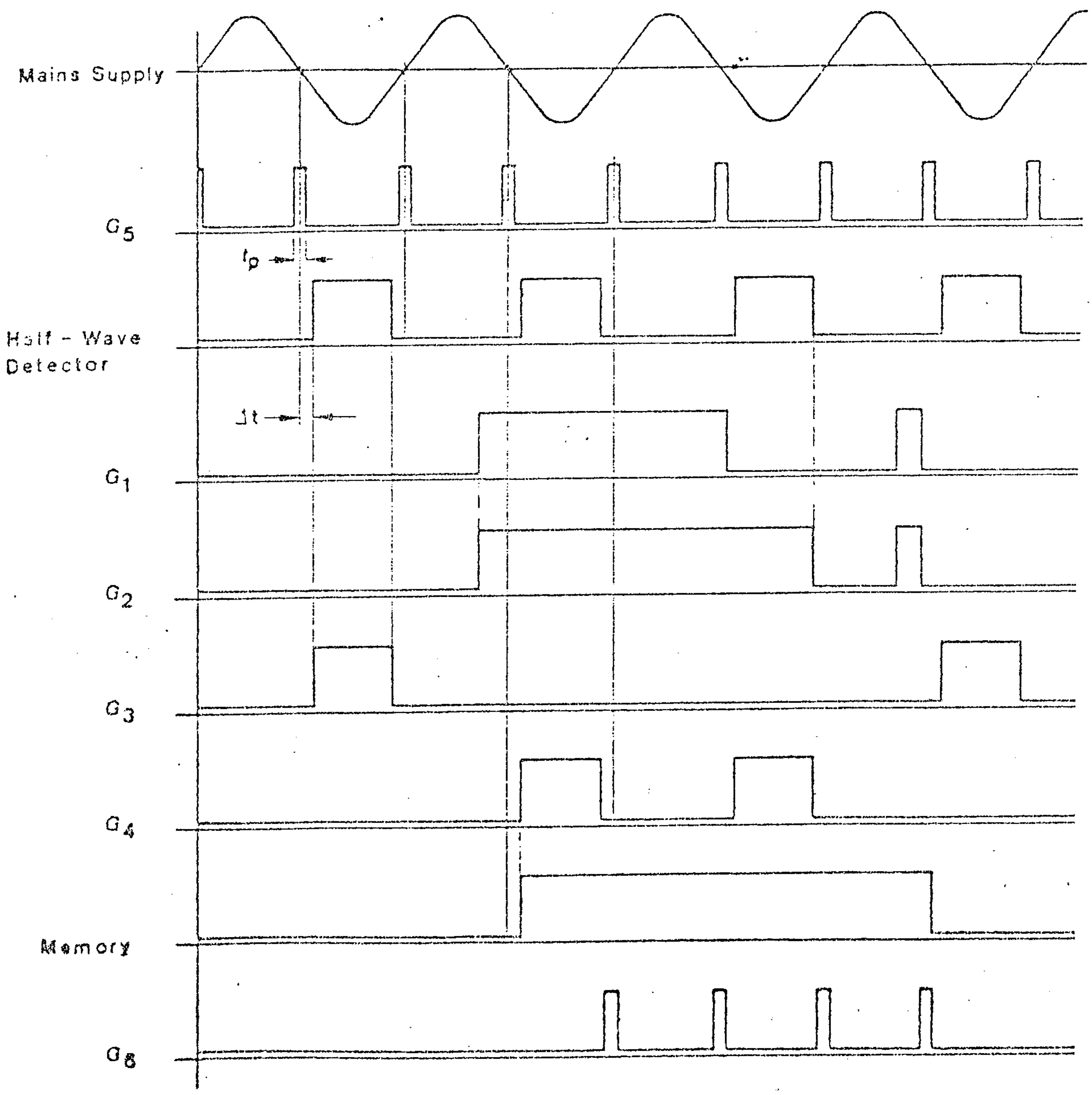

Figure 3.7. Fullwave Control Pulse Diagrams.

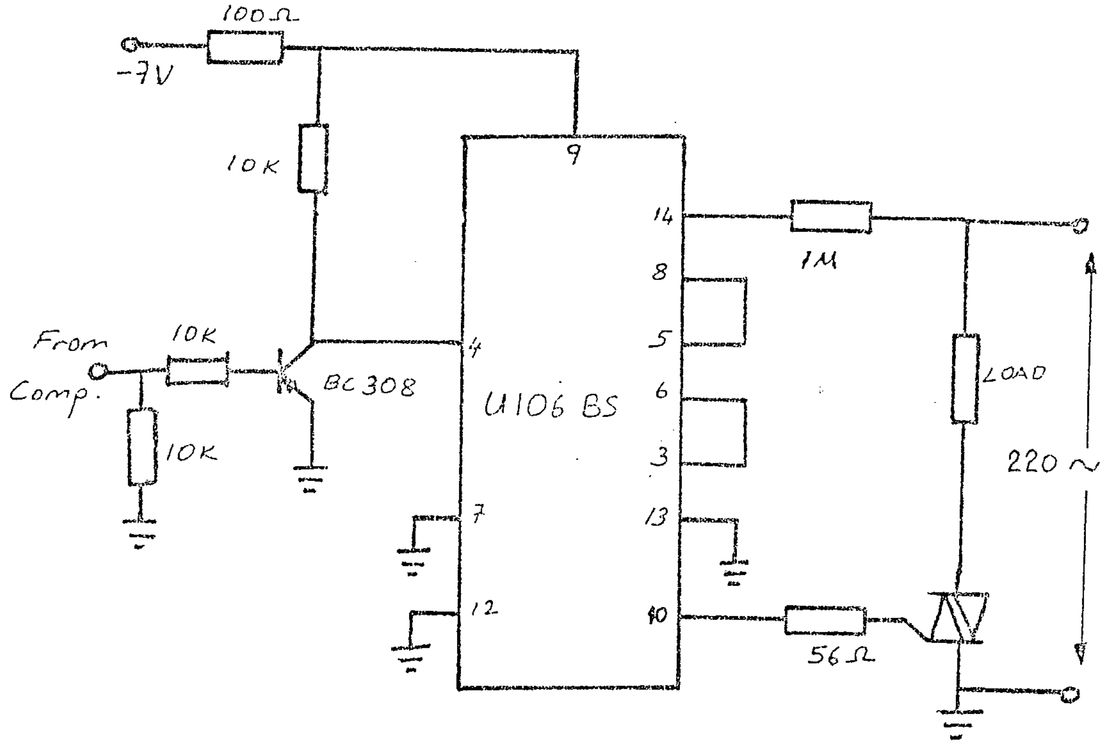

Figure 3.8. Practical control circuit

3.2.5 A/D Converter and Display Unit

A/D converters either convert the analog input signal (either voltage or current) to a frequency or a set of pulses whose time is measured to provide a representative digital output or compare the input signal with a variable reference, using an internal D/A converter to obtain the digital output.

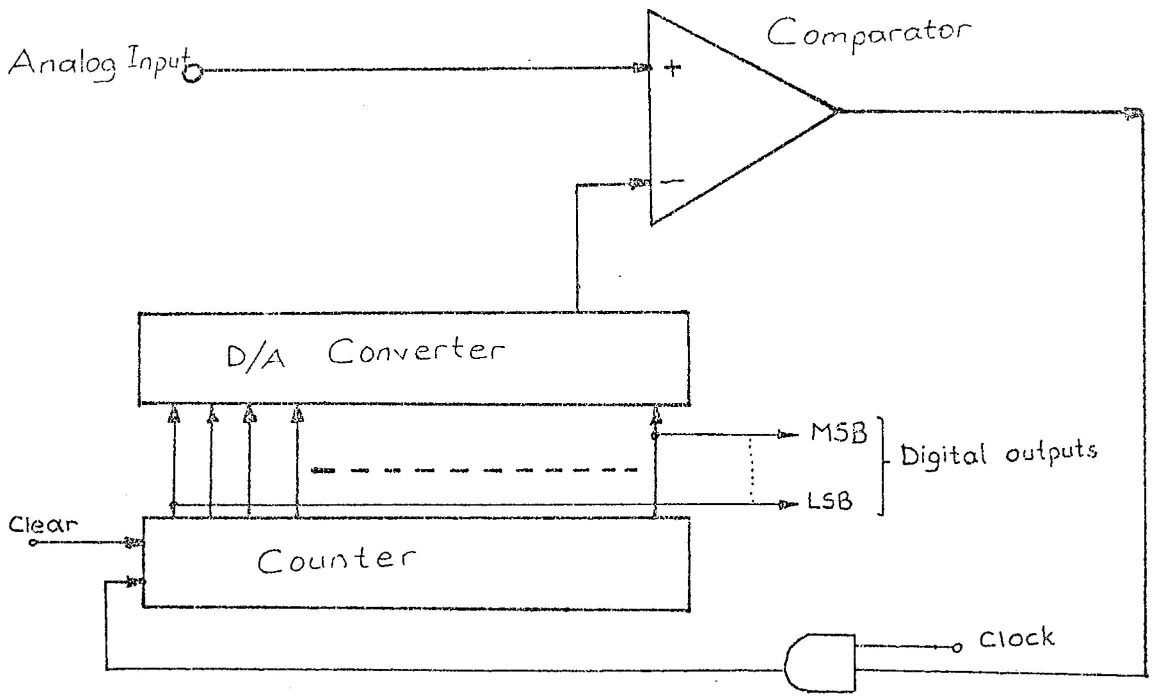

Figure 3.9. Typical A/D converter with a D/A converter in the feedback loop.

The A/D converter is the interface between analog systems and digital systems. The use of integrated circuits has reduced the size, increased the capabilities, and also decreased the cost of A/D converters. The above Figure 3.9. shows an elementary form of A/D conversion with the D/A converter. A clear pulse sets the counter to zero and starts to count. The register counts the clock pulses, driving the D/A converter, which generates a uniformly increasing analog output voltage. When the converter analog output is slightly greater than the analog input signal, the comparator signal becomes negative and stops the clock. The counter output at this point is the digital representation of the analog input. A clear signal wipes out the counter reading to restart the conversion process. There are many types of A/D converters commercially available.

The output of an A/D converter is a series of digital codes. Therefore, accuracy and resolution should be given in digital terms rather than analog. For example, resolution is in bits. When considering the transfer accuracy of converters, one must differentiate between relative accuracy and linearity and absolute accuracy.

Absolute accuracy is the ability of an ADC to yield an output code that define the input voltage in terms of the definition of a standard volt. Relative accuracy and linearity are generally interchangeable [6].

In the practical circuit, the ADD 3501 A/D converter is used, which is a 3 $\frac{1}{2}$ digit converter. It is used in low cost panalmeters, multimeters, digital power supply readouts and in conversion of analog transducers (temperature, pressure, displacement) to digital signals. It operates from single 5V supply and converts 0V to $\pm$ 1.999 V. It drives segments with a medium speed of 200 ms/conversion. It is a monolithic DVM circuit and manufactured using standard CMOS technology, and requires no external precision components. In addition, this technique allows the use of a reference voltage that is the same polarity as the input voltage. ADD 3501 has been designed to drive 7-segment multiplexed LED displays directly with the aid of external digit buffers and segment resistors. 75492 display driver is used as digit buffers in practical circuit.

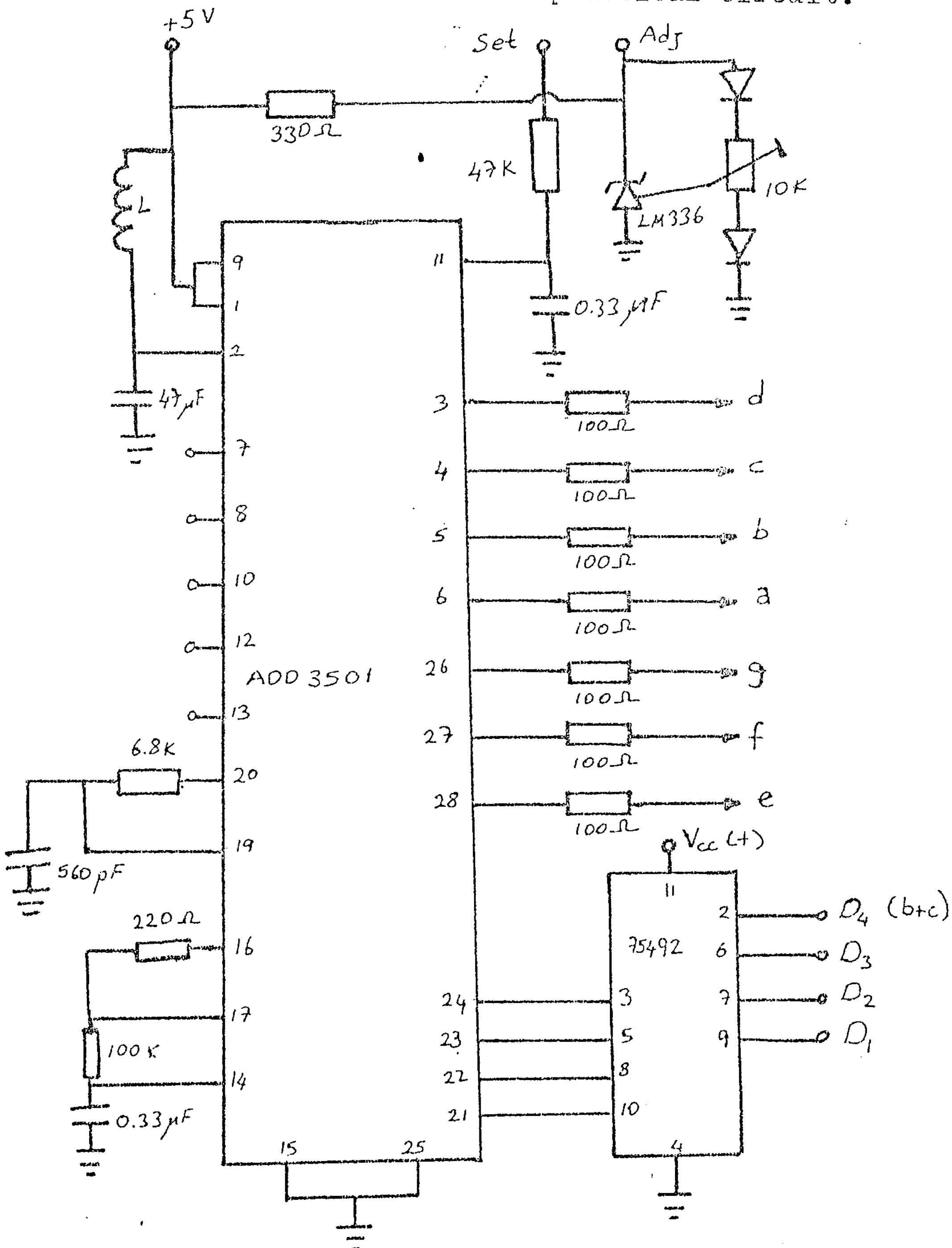

Figure 3.10. Practical A/D converter circuit.

The characteristics and pin connections of ADD 3501 and DM 75492 are given in Appendices B and C respectively.

3.2.6. Power Supply Unit

For supply voltage requirement, the following circuit configuration is used.

For voltage supply, a 4 watt, 220/12 volt transformer is used. The 7805 voltage regulator is used for positive supply voltage.

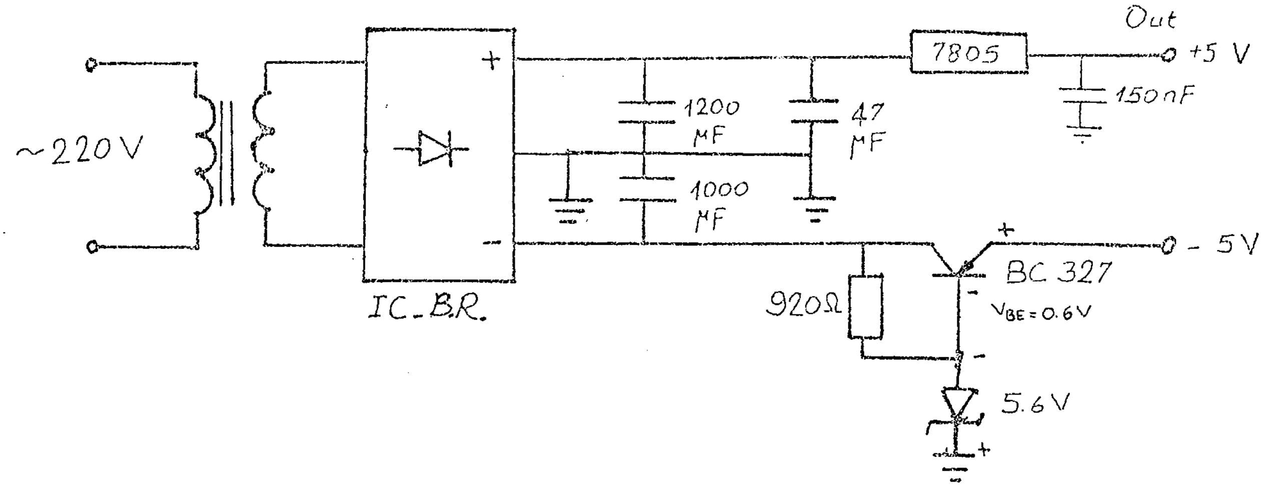

Figure. 3.11. Practical power supply circuit.

Finally the designed circuit diagram is given in Figure 3.12. S1 and S2 positions of button correspond to WORK and SET readings of A/D converter respectively. When the button is set to S2 position, V_R reference value will be adjusted using 10K potentiometer. Then the button is set to S1 position to follow the temparature of the owen.

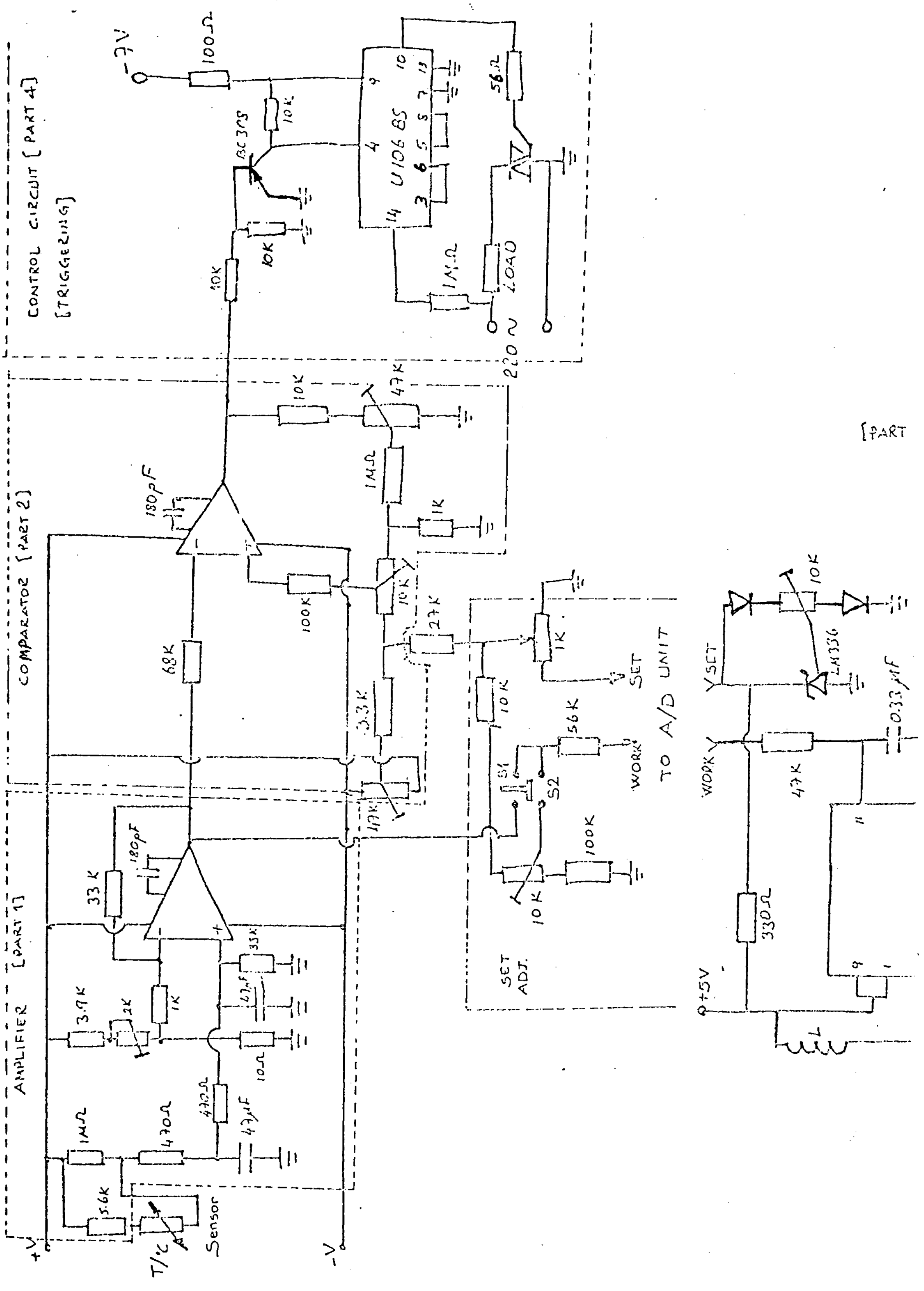

Figure 3.12. Practical Circuit Diagram.

CHAPTER IV

RESULTS, CONCLUSIONS, DISCUSSIONS AND FUTURE PROPOSALS

4.1. Operation of the System

Digital temperature controller device is designed, constructed and tested with available facilities. Temperature controller device is working up to 1200 °C. It has three connections; one of them is between thermocouple to device for receiving the sensed signals, the other one is between device and mains, and the last one is between heater and device which supplies energy to heater and controls the power for on-off states. Device has two buttons externally; one of them makes the desired temperature adjustments, and the other has two states; set and work. At set state, display shows the desired temperature and at work state, display shows the furnace temperature. The photograph of designed system set shown in Figure 4.1.

4.2. Conclusion and Discussion

Temperature control by electronic controllers with high speed, high accuracy, easy to mount, minimum maintenance requirement ability to control simultaneously and low cost really is a good step toward a more comfortable world. In this work an example of this type of control is illustrated by a practical instrument. The practical instrument responds more preciesly to high temperatures. In the present device there is an 8 °C thermal lag at controlling state. It can be a result of heater's characteristics, termocouple characteristics and the switching delay of U 106 BS. It is a problem at low temparatures, but not a big problem at high temperatures. In the control circuit, a zero-voltage switch is used, and on-off control is applied to the load via a triac. Output voltage and current of the U 106 BS equal to 5V and 250 mA respectively. For higher power considerations,these values can be amplified.

Response speed and sensitivity of the temperature controller device with the used solid state materials is much developed according to other analog and having relay devices. With the developing of the solid-state materials, a more accurate and good devices can be designed and constructed, such as using microprocessor. Sensitivity graph of the system is given in Fig. 4.2.

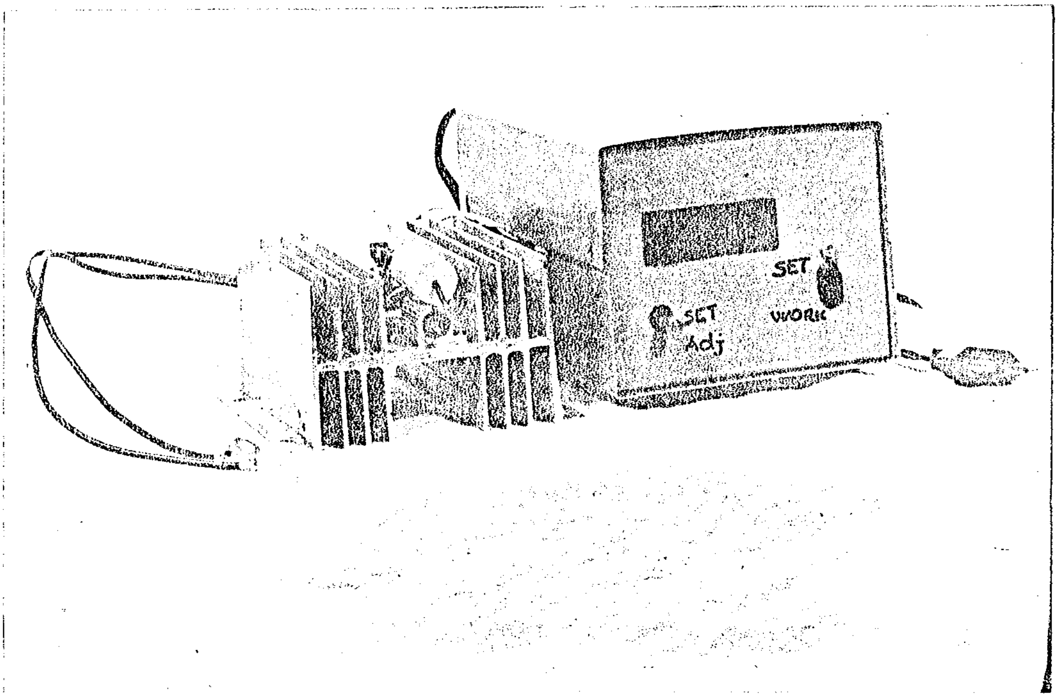

Figure 4.1. Photograph of the System.

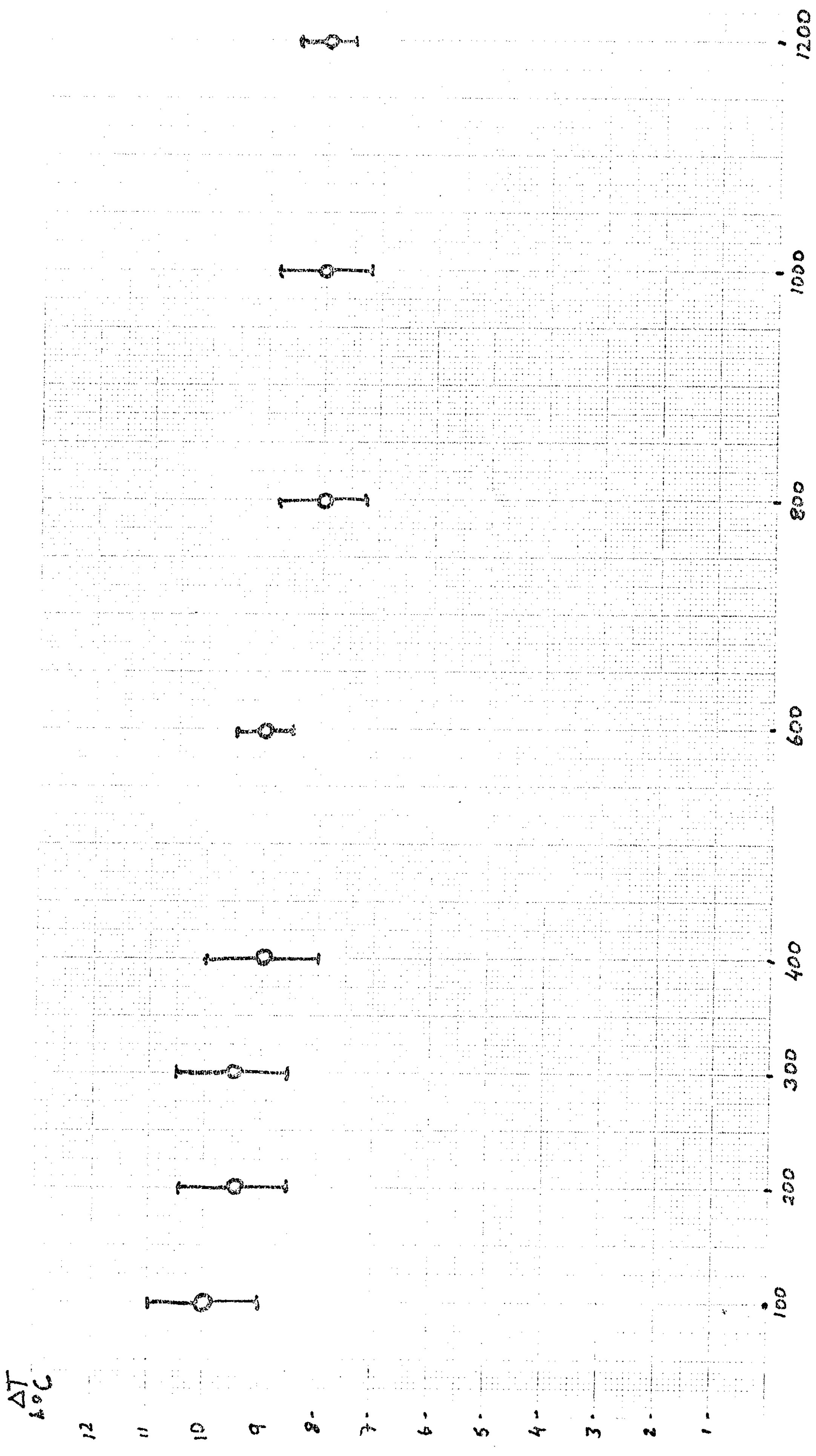

Figure 4.2.Sensitivity graph of the practical system.

4.3. Future Proposals

The constructed instrument shows that such a controller device can be designed and constructed to satisfy the design specifications. However, many improvements in the device can be made. Adjustable timing and alarm circuits will be a good addition and a good help to the technician. Also, some protection circuits for the limited range of instrument can be added. It is well known that, the design of analog electronic circuits get some problems. But in digital circuits error rate is small. For a more reliable result, the same work can be implemented by using microprocessors. It can also be used not only for one furnace but also two or more furnaces at the same time or whenever we want. The Figure 4.2 shows the block diagram of such a system. In that system, the positional temperature signal can be directly taken by microcomputer via an A/D converter. Computer reads the temperature and gives the needed command to the heater for switching the power on-off states. The organization of hardware is presented in Appendix F.

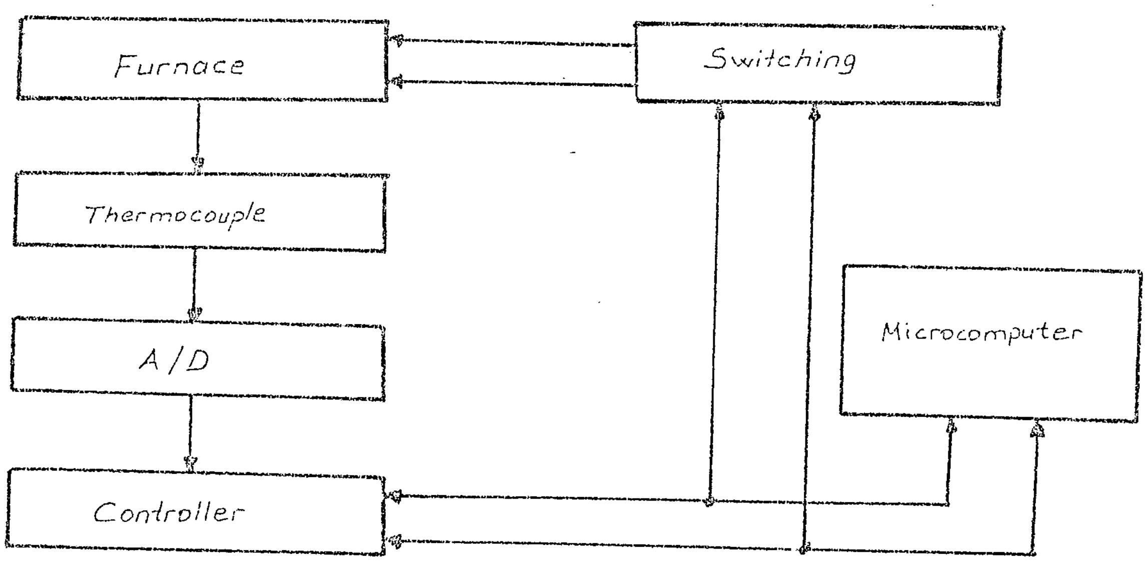

Figure 4.2. Block diagram.

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APPENDICES :

A: LM 308 Operational Amplifier.

B: ADD 3501 3 1/2 Digit A/D Converter.

C: DM 75492 Display Driver.

D: U 106 BS Zero Voltage Switch.

E: Triac Specifications.

F: Hardware Organization of Proposed System.

A

LM 308 OPERATIONAL AMPLIFIER

Ratings :

Supply Voltage	± 18 V
Power Dissipation	500 MW
Differential Input Current	± 10 mA
Input Voltage	± 15 V

Electrical Characteristics :

Input Offset Voltage	0.3-0.5 mV
Input Offset Current	0.2-1 nA
Input Bias Current	1.5-7 nA
Input Resistance	10-40 MΩ
Supply Current	0.3-0.8 mA
Large Signal Voltage gain	80-300 V/mV
Input Offset Current	1.5 nA
Output Voltage Swing	±13 to ±14 V
Input Voltage Range	± 14 V
CMRR	96-110 dB
Supply Voltage Rejection Ratio	96-110 dB

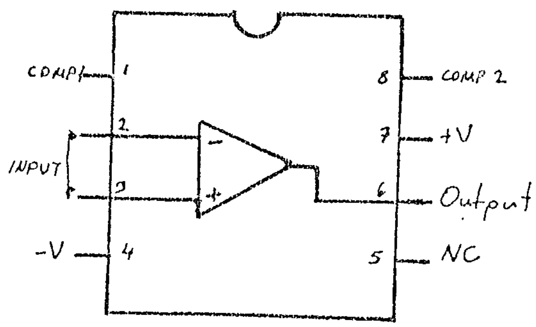


Figure A-1. Pin Connections of LM 308.

ADD 3501 3 1/2 Digit A/D Converter

Features :

- Operates from single 5V supply
- Converts 0V to $\pm$ 1.999 V
- Multiplexed 7-segment
- Drives segments directly
- No external precision componet necessary
- Accuracy specified over temperature
- Medium speed 200 ms/conversion
- Internal clock set with RC network or driven externally
- Overrange indicated by +OFL or -OFL display reading and OFLO output.

Applications :

- Low cost digital power supply readouts.
- Low cost digital multimeters
- Low cost digital panelmeters
- Convert analog transducers(temperature, pressure, displacement, etc) to digital transducers.

ADD 3501 monolitihic DVM circuit is manufactured using standard CMOS technology. A pulse modulation A/D conversion technique is used and requires no external precision components. In addition, this technique allows the use of a reference voltage that is the same polarity as the input voltage.
One 5 V power supply is required.

ADD 3501 has been designed to drive 7-segment multiplexed LED displays directly with the aid of external digit buffers and segment resistors.

Internally, the ADD 3501 is always continuously converting the analog voltage present at its inputs. The Start Conversion input is used to control the transfer of information from the internal counter to the display latch.

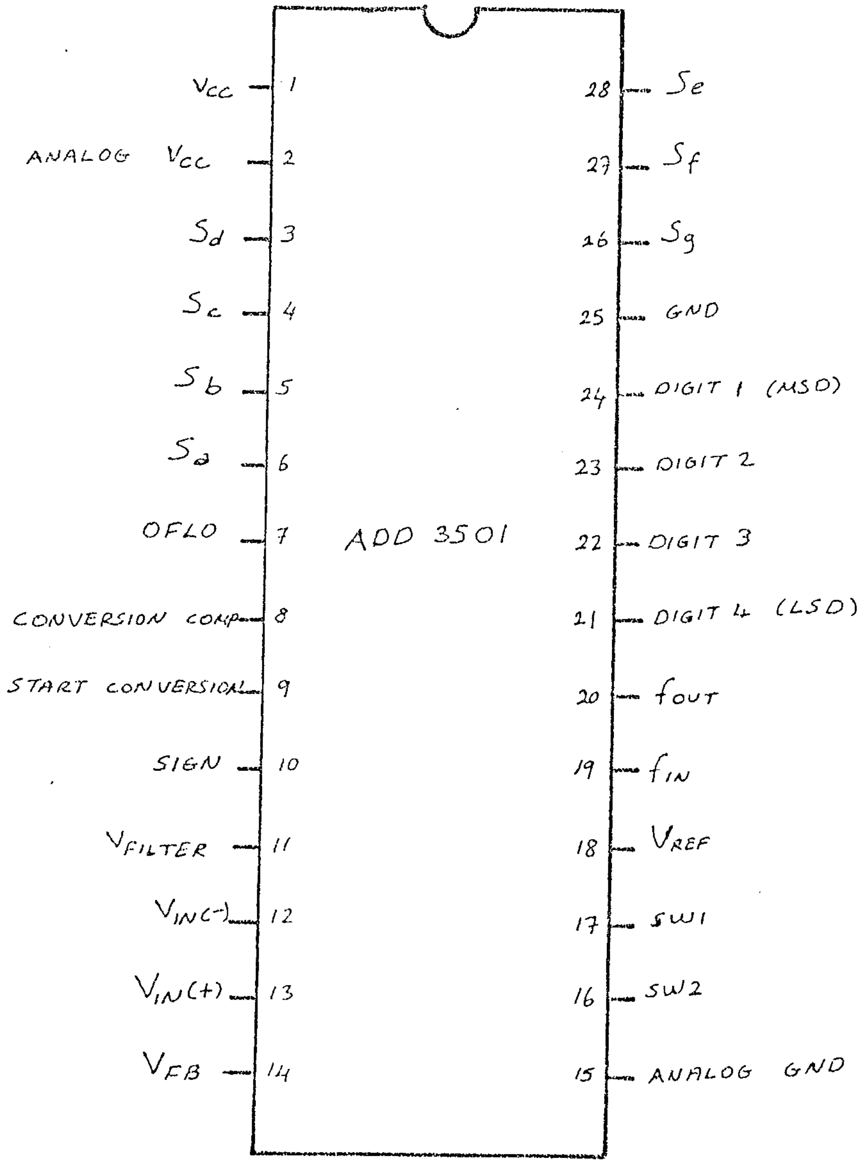


Figure B-1. Pin connections of ADD3501.

Ratings :

Voltage at any Pin	− 0.3 V to Vcc + 0.3 V
Package Dissipation	800 mV
Operating Vcc Range	4.5 to 6.0 V
Absolute Maximum Vcc	6.5 V

Electrical Characteristics :

$V_{IN(1)}$	Logical "1" Input Voltage	Vcc −1.5 V
$V_{IN(o)}$	Logical "0" Input Voltage	1.5 V
$V_{ouT(o)}$		0.4 V
$V_{ouT(1)}$		Vcc−1.6 V
I_{source}		2 mA
f_{IN}	Clock frequency	100−640 kHz
fc	Conversion rate	f_{IN}/64,512 count/sec
f_{MUX}	Digit Mux Rate	f_{IN}/256 Hz
Non-linearity		−0.05 to +0.05 %
Quantization Error		−1 to +0 counts
Offset Error, V_{IN}=0V		−0.5 to +3 mV
Analog Input Current		−5 to +5 nA

-C-

DM 75492

Features :

- Source or sink capability per driver 250 mA
- MOS compatibility (low input current)
- High-gain Darlington circuits

DM 75492 are interface circuits designed to be used in conjunction with MOS integrated circuits and common-cathode LED's in serially adressed multi-digit displays.
The number of drivers required for this time-multiplexed system is minimized as a result of the segment address and digit-scan method of LED DRIVE.

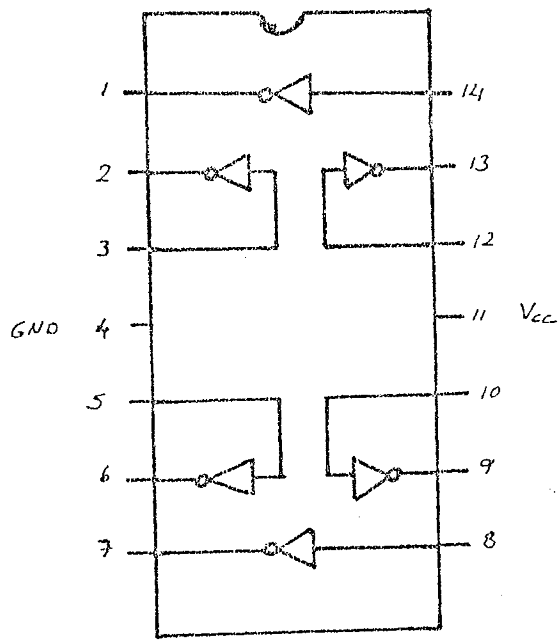


Figure C-1. Pin connections of DM 75492

U 106 ZERO VOLTAGE SWITCH

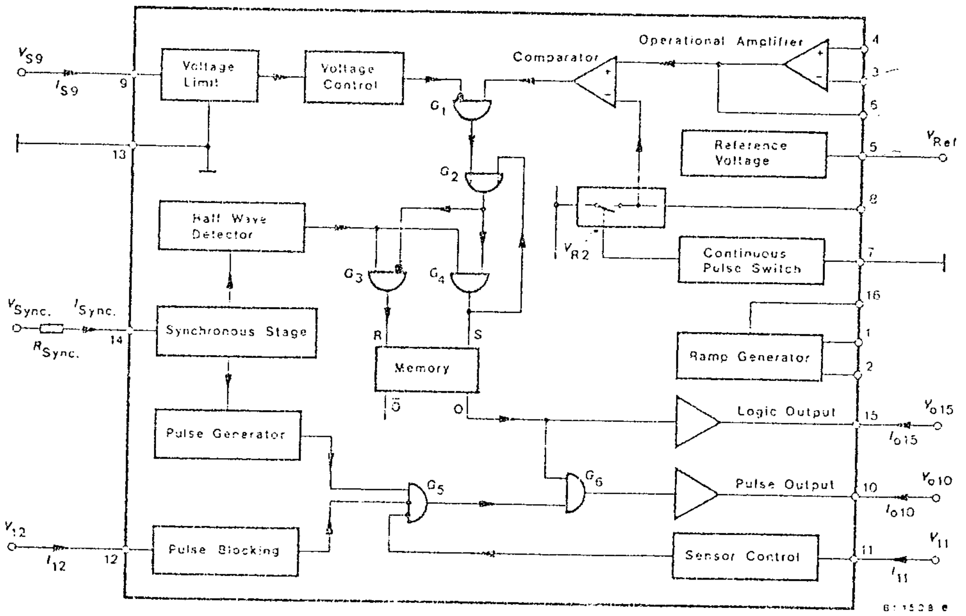


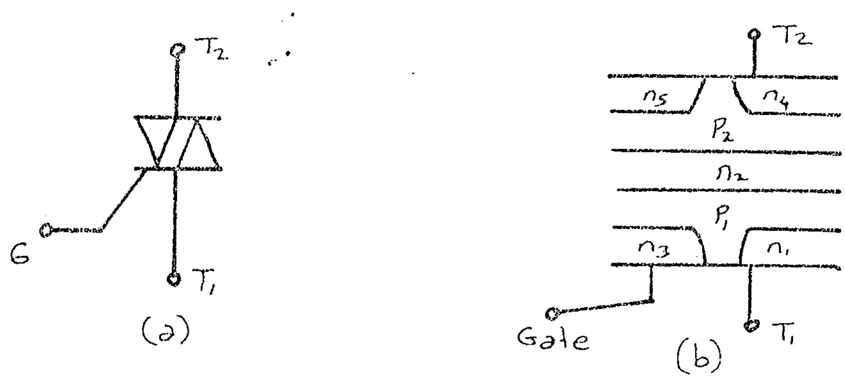
Figure D-1. Block diagram and pin connections.

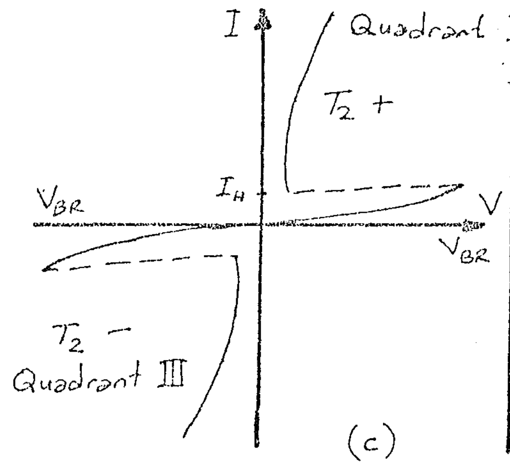
The U106 BS can be operated either from an ac supply or a dc supply -Vs= 7.....8V.
Gate G_5 in the output logic produces a pulse of variable width every time the alternating voltage applied to pin 14 via a synchronizing resistor goes through zero. The full-wave control unit, comprising gates G_1 to G_4, a half-wave detector an RS flip-flop, processes the output inpormation derived from synchronizing, voltage monitor and comparator stages so that only pulse comprising an even number of pulses are produced. The pulse amplifier can supply output current and incorprates a current limiter which fully protects the pulse output (pin 10) against short circuits to ground (pin 13). An internal frequency compensated op-amp

and high impedance comparator enable relatively insensitive sensors to be employed in the control circuit using only a few additional components. A safety feature is the pulse blocking circuit which causes gate G_5 and hence the pulse output to be immediately blocked whenever Pin 12 is grounded (also Pin 13). The dc supply voltage can be applied directly to Pin 9.

TRIAC

The triac has a gate terminal for controlling the turn-on conditions of the bilateral device in either direction.





Triac Triggering Modes		
Polarity T_1	Gate	Quadrant Mode
+	+	I +
+	−	II −
−	+	III +
−	−	III −

Figure E-1. TRIAC a) symbol,
b) basic construction,
c) characteristics.

The graphic symbol for the device and the distribution of the semiconductor layers are provided in the above figure. In the triac, the power terminals are not named anode and cathode since the device is bidirectional, and so the terms anode and cathode lose their meaning. Instead, the main terminals are labeled as 1 & 2. The remaining terminal, of course, is the gate. All voltages and currents are referenced to main terminal 1; thus T_2 would mean that main terminal 2 is positive wrt main terminal 1. The gate signal of the triac is applied between the gate and T_1. Triacs may trigger into conduction either by positive or by negative gate signals with either polarity of main terminal voltage. For example, triac can be turned "on" when T_2 is positive wrt T_1 and the gate is negative wrt T_1. Gate losses control when device is triggered on. Conduction ceases when current drops below minimum holding current (I_H). Transistors, optocouplers, zero voltage switches and some other devices are using as triggering the triac gates.

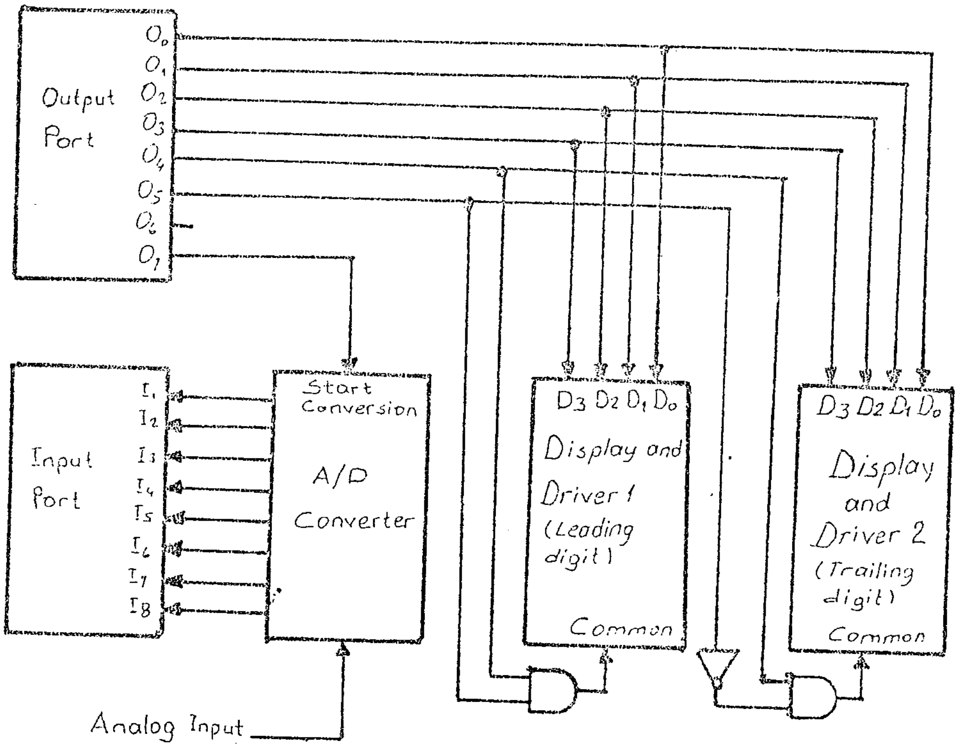


Figure F. 1. I/O configuration.

Figure F. 1 shows the organization of the hardware. The project uses one input and one output port, 7-segment display, a 7404 inverter, a 7400 nand gate or a 7408 and gate depending on the polarity of the displays, an Analog Devices AD7570J 8-bit monolithic A/D converter, an LM311 comparator and various peripheral drivers, resistors and capacitors are required by the displays and the converter.

Output line-7 is used to send a START CONVERSION signal to the A/D converter. Input lines 0 through 7 are attached directly to the eight digital data lines from the converter. Output lines 0 through 3 are used to send BCD digits to the 7-segment decoder/drivers. Output line 4 activates the displays and output line 5 selects the leading or trailing display.