DESIGN AND CONSTRUCTION OF A DIGITAL TEMPERATURE MEASURING INSTRUMENT USING A THERMISTOR

BY

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Minna,

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CERTIFICATION

This is to certify that the work titled ***"Design and Construction of Digital Temperature Measuring Instrument (DTMI)"***, was carried by ***Folaranmi Matthew Adebayo*** with registration number ***(98/6829EE)***, under the supervision of **Engr. M.D. Abdullahi**, for the award of B. Eng in the department of **Electrical and computer Engineering** of the **Federal University of Technology**, Minna.

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DECLARATION

I hereby declare that the work titled "Design and Construction of Digital Temperature Measuring Instrument" was an original concept of mine, and was so designed, constructed, tested and presented by me in partial fulfillment of the requirements for the award of B. Eng in Electrical and Computer Engineering Department of the Federal University of Technology, Minna.

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DEDICATION

This work is dedicated to the strength of my heart – the *I AM that I AM*, and everyone who one way or the other had contributed to the successful completion of my study.

ACKNOWLEDGEMNT

All praise to God who through the Lord Jesus Christ has helped me so far in life, especially for seeing me through the rigorous academic battle up to this level and making the execution of this project work a success, I give Him all the glory!

My sincere appreciation goes to my parents, Mr. & Mrs. S. A. Folaranmi, my siblings - Engr. & Mrs. Olusegun Folaranmi, Mr. & Mrs. Sunday Folaranmi, Mrs. Deborah Abioye, Tope, Tunde, Bukky, for their support morally, financially and physically during the course of my studies. May the good Lord bless and reward you all. Amen.

I'm most grateful and appreciate the efforts of my supervisor, Engr. M.D. Abdullahi, the H.O.D, and all the lecturers in the department for their words of encouragement and knowledge imparted in the course of their lectures

Finally, I wish to thank all my friends and colleagues; Moses, James, Adex K, A. B. S., Afolayan, Joshua, Hannah, Lola, Sunday, Bukky, Yahaya, Solomon, and others too numerous to mention, who had one way or the other contributed to the successful completion of this project work. I love you all.

God Bless!

M. A. FOLARANMI

TABLE OF CONTENT

ABSTRACT

In industries and homes, one of the most important ways of operating machines/equipment and certain processes is by monitoring and possibly regulating its temperature. A review of literature disclosed a number of facts concerning temperature and its measurement. In view of the above, the focus of this project work, design and construction of Digital Temperature Measuring Instrument has been deemed necessary and fit for harmonizing human, machines, and its environment.

The instrument mentioned above consists of three fundamental units: power supply unit (PSU), which supply multi-direct dc voltages to the system; processing unit (PU), which senses temperature, convert it to electrical signal(voltage) and then amplifies the voltage; display unit (DU), which present the value of the measured temperature in digits.

The Digital Temperature Measuring Instrument can be used to measure temperature from 0°C - 100°C.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 INTRODUCTION

Measurement and instrumentation of physical quantities is one of the most vital disciplines in harmonizing man, machines, and the environment to real time world of elemental changes.

The purpose of an instrumentation system is to extract the desired information regarding some physical quantities. The development and uses of precision measuring instruments have indeed contributed to the beauty of the modern day technology, e.g. Forecasting.

Temperature is a measure of the average kinetic energy of molecules. The concept of temperature stems from the idea of measuring relative hotness and coldness. There are conditions at homes, hospitals, offices, industries, and laboratories when the knowledge of these quantities becomes so important than can be over looked. Temperature plays an important part in determining the condition in which living things can survive. For example, an incubator must be within a very narrow range of temperatures to keep prematurely born or usually weak baby warm. Therefore there exist a great need to design instruments that can help to a great extent in measuring and monitoring the temperature.

Digital Temperature Measuring Instrument (DTMI) is one of the devices that can be used in doing these effectively. The advantages of DTMI are too numerous than what can be exhausted in this report.

In an analogue circuit, the electrical signal (voltage and current) waveforms are similar to the signal variations. A digital signal however is a group of pulses with the same level but either ON or OFF.

Though the quantity of interest for this project work is analogue (continuous) in nature, digital instrumentation often provides the most convenient and accurate means of processing and display; hence Digital Electronics circuit techniques is employed.

Ambient temperature is the principal concern of measurement and variation in the magnitude of this fundamental quantity may be monitored in an optimized manner for any measurement situation.

The tremendous advancement in electronic engineering has brought about 'modern technology' which offers real time exploits of the advantages of digital electronic components (including integrated circuit chips) in implementing the construction of digital temperature measuring instrument for application in atmospheric temperature measurement, egg incubator, storage silos, amongst others.

In earliest temperature measurement, mercury in glass thermometer and other similar indicating instrument were used. The limitations of the afore-mentioned instruments often include: small thermal inertia, low sensitivity, inaccuracy, and parallax while taking readings.

Progressive development in technology led to the development of analogue temperature measuring instrument using thermal sensors such as thermocouple, and thermistor. The advent of integrated circuit chip sensors (LM35 series) with higher sensitivity and greater accuracy and better resolution has since redefined the technology of temperature measurement.

The temperature sensor used for this design work is a negative temperature coefficient thermistor. The sensor is a temperature dependent resistor whose resistance decreases with an increase in temperature. The variation of the resistance with temperature of the NTC thermistor is shown in appendix A. The Digital Temperature Measuring Instrument offers greater accuracy and low power consumption.

1.2 OBJECTIVE AND MOTIVATION

Temperature measurements have been carried out by the use of thermometer. Various forms of thermometric substances have led to the design of different types of thermometers for temperature measurement. Amongst these are the liquid-in-glass thermometer, minimum and maximum thermometer for recording minimum temperature at night and maximum temperature at day time, clinical thermometer for measuring the temperature of human body, resistance thermometer and thermoelectric thermometer which measures very high temperatures.

The aforementioned thermometers used scale, which are analog in nature. Interpreting the exact value of temperature indicated by the thermometer usually poses problem to most users. Also some with pointers are prone to error due to parallax, bended pointers, and pointer vibrations. However having taken courses in, measurement and instrumentation, analogue and digital electronics in the department, I have been keenly motivated to designing and constructing a very reliable instrument (digital) to harmonize man, machines and its environment. The design and construction of the Digital Temperature Measuring Instrument encompasses the application of all the fundamental ideas and principles that have been acquired in the course of study.

The aim and objective of this project work, amongst others, is to design and construct a functional and reliable digital temperature and measuring instrument that:

- Measures temperature in the range of 0°C - 100°C suitable for atmospheric temperature, temperature of complex engineering processes, equipment room, and equipment that must be operated or kept at a fixed or temperature range while in service, e.g. egg incubator.
- Facilitate easy and accurate temperature read-out in digits, thereby eliminating errors due to parallax, scale calibrations, bended pointers, and vibration of the pointer associated with analog meters.

1.3 PROJECT LAYOUT

This project is outlined into five chapters. The general introduction to the topic is presented in chapter one.

Chapter two examines the background knowledge of the work. Here, succinctly discussed, is the importance of thermometers in industries and/or the society, with the need for digital thermometers, various techniques employed by other people in designing temperature measuring circuits as well as analog to digital conversion methods.

Chapter three explicitly deals with the system analysis and design. Here, for easy understanding and design, the system was divided into subsystems or units with their principles of operation explained in brevity. This comprises of the power supply unit, the processing unit, and the display unit.

Basically, chapter four has to do with the construction and testing of the system designed, the result obtained, discussion of result, precautions as well as the tools used.

In chapter five, the conclusion and recommendation for future modification of the system are clearly stated.

CHAPTER TWO

2.0 LITERATURE REVIEW

The phenomenon of temperature is natural to human beings as it affects one of the fundamental senses. But it was realized as early as the time of *Galileo* (1610) that for scientific purposes the human skin is not sufficiently accurate as a thermometer. The draw-backs of this crude thermometer are that certain amount of heat must be transferred to the skin before the sensation is felt and only a limited range of temperature between those that numb and those that burn the skin, can be measured (*The New Illustrated science and invention Encyclopedia Vol.21 1987*).

The earliest temperature indicators were made just before 1600 by *Galileo* and others, the important step of attaching scale to make a thermometer was taken by *Santorio* ten years later. These early instruments were essentially barometers using water in the tube, and so they respond to changes in pressure as well as temperature. *By 654 AD the Grand Duke of Tuskany, Ferdinand II*, had invented the familiar sealed glass tube thermometer with the fluid contained in a bulb. In the basic pattern of all liquid-in - glass thermometers, the fluid being used was contained in a glass tube with a narrow tube or capillary. The principle on which they work was that the volume of the liquid increases with its temperature. Temperature can be measured on any of the following scales, Kelvin or Absolute scale, Fahrenheit scale, Celsius or Centigrade scale and Ranking scale. (*The New Illustrated Science on Invention Encyclopedia Vol.21 1987*).

Several temperature-monitoring devices that exist today employ different transducers and display methods. There are those designed based on the principle of thermocouple, which measures temperature difference using voltage developed by the junction of two dissimilar metals. One junction called the sensing junction is placed at the point of interest, while the other called the reference junction, is maintained at a reference (colder) temperature. The voltage developed across the junction is proportional to the difference between the two temperatures.

The circuit problems with thermocouple stem from their low output voltage (50μV/°C or there-about), combine with large common mode ac and radio frequency interference. The amplifier therefore must have good common mode rejection at 60Hz and stable differential gain.

Another temperature sensor/transducer employed in earlier electronic thermometer is the thermistor. This could either be negative temperature coefficient (NTC) or positive temperature coefficient (PTC) temperature sensors. The resistance of the NTC decreases as the temperature increases, while for the PTC, the resistance increases with increase in temperature. Thermistors are fabricated in discs, rods, beads, and washers covering resistances up to $10^6\Omega$ and with a wide variety of temperature coefficients. The method of temperature displays also varies. Some utilize direct temperature readout on a scale calibrated in degree Celsius (°C), others convert the output voltage from the temperature measuring circuit (which is analog) to digital signal. This is then displayed on *LED* or *LCD* seven segment displays.

Methods of converting analog signal to digital signal, includes:

i. Flash analog to digital conversion

ii. Successive approximation method

iii. The ramp or counter method

iv. Integration method of analog to digital conversion.

CHAPTER THREE

SYSTEM ANALYSIS AND DESIGN

3.1 INTRODUCTION

In electrical, electronics and computer engineering, systems are usually described with the aid of block diagrams. Hence the block diagram of the system under construction is presented in fig. 3.0 below. The block diagram basically consists of three units, briefly described below:

The power supply unit provides electrical energy or power to the system and its in-dispensability can be appreciated from the fact that, the system will not perform any function or work in its absence. The unit provides four different voltage levels with a common ground to every other units of the system.

The processing unit has to do with the sensing of the physical quantity (temperature) to be measured, convert it to an equivalent electrical signal and then process the latter to an appropriate level.

The display unit constitutes electronic circuits and components for converting the analogue signal output of the previous unit into its digital equivalent, and for presenting the latter into a form comprehensible to human being.

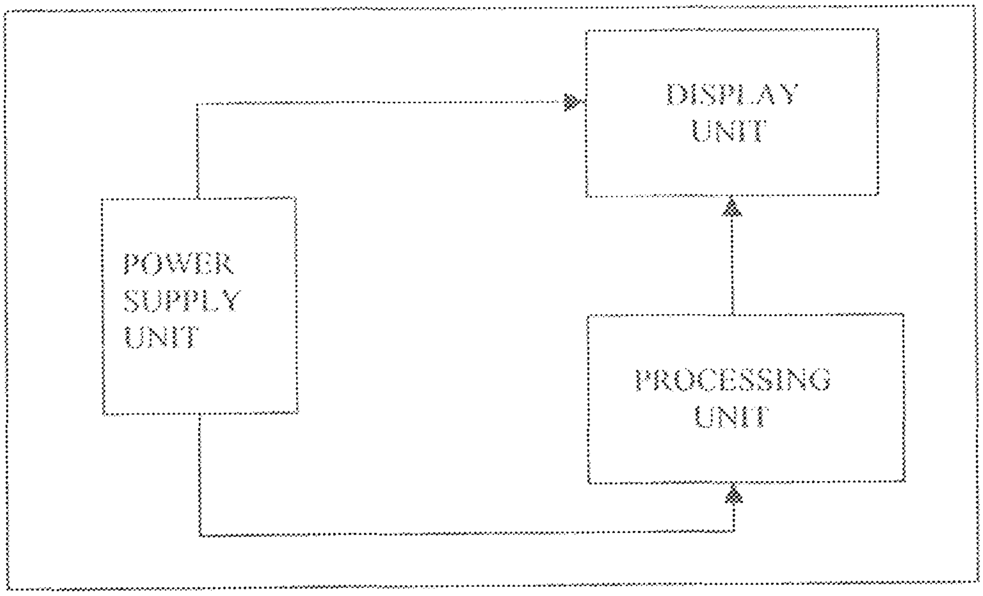

FIG. 3.0: Block Diagram of the Digital Temperature Measuring Instrument

3.2 POWER SUPPLY UNIT (PSU)

The electronic circuit being designed requires dc voltages +9 V, -9 V, +5 V, and -5 V with their common grounded. The power supply unit converts the domestically supplied 240 V ac voltages from the supply authority (National Electric Power Authority – NEPA) into the required dc voltages. These voltages are expected to be constant even when variations occur in the ac supply voltage or the load.

In order to achieve constant dc supply to the system, the power supply unit incorporates series of stages, which include:

- Transformation stage
- Rectification stage
- Filtering stage
- Regulation stage

The block diagram of the power supply unit showing various stages involved and their output waveforms are shown below in fig. 3.1.

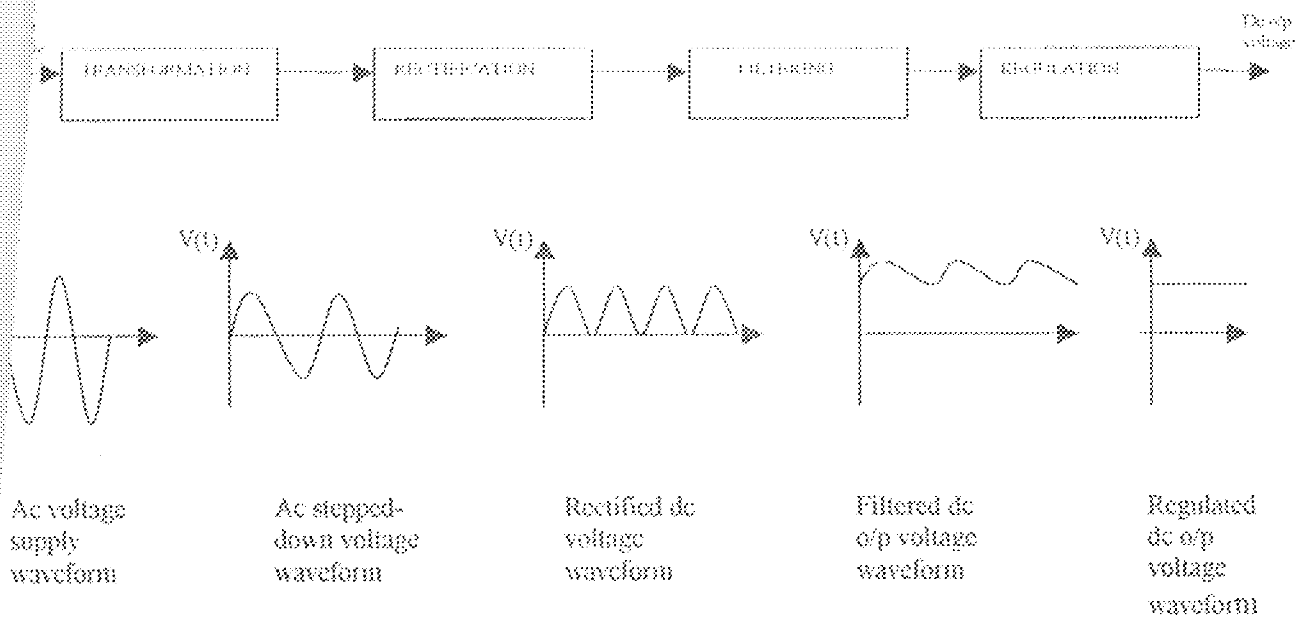

Fig. 3.1: Block Schematic of the Power Supply Unit (with corresponding output waveform of each block)

3.2.1 TRANSFORMATION STAGE

This stage involves transforming the domestic ac supply from level of 240 V into a lower level of 12 V – 0 – 12 V. To this end, a step-down transformer with center tapping is required and thus was utilized. The output current of the transformer by design from the manufacturer is 500mA. The circuit diagram of the transformer is shown in figure 3.2 below.

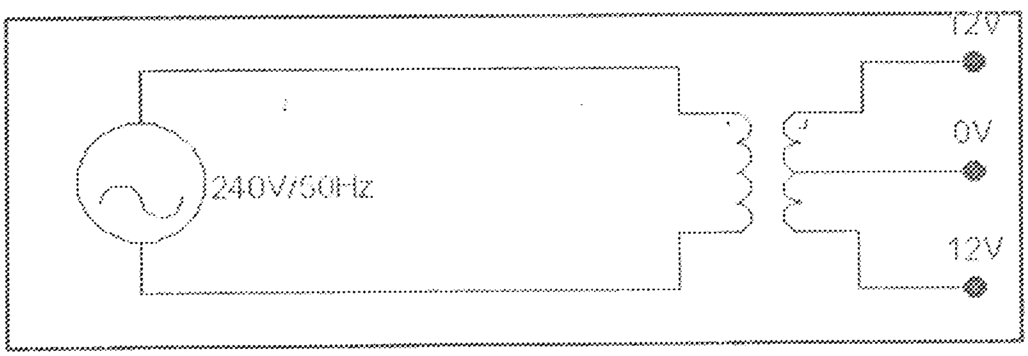

Fig. 3.2: Circuit diagram of a center-tapped transformer

3.2.2 RECTIFICATION STAGE

The essence of this stage is to rectify the stepped-down 12 V – 0 – 12 V ac voltage by converting it into a dc voltage of approximately the same value. An IC (B380/C1500) is used for this purpose. It integrate a full wave bridge rectifier diodes and has four pins as shown in fig. 3.3

The use of this integrated circuit minimizes the space occupied on the Vero board (on which the circuit is constructed) and of course saves on cost. The internal circuit diagram of the bridge rectifier is presented in fig 3.4.

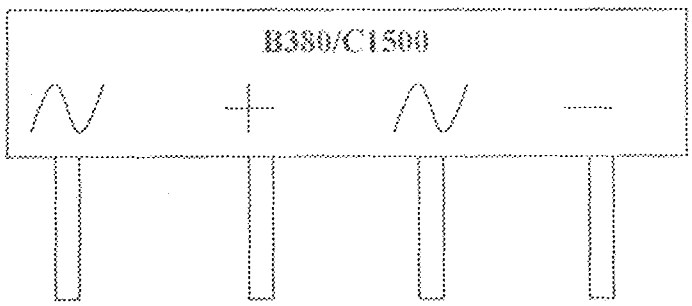

Fig. 3.3: Circuit Symbol of an integrated full-wave bridge Rectifier

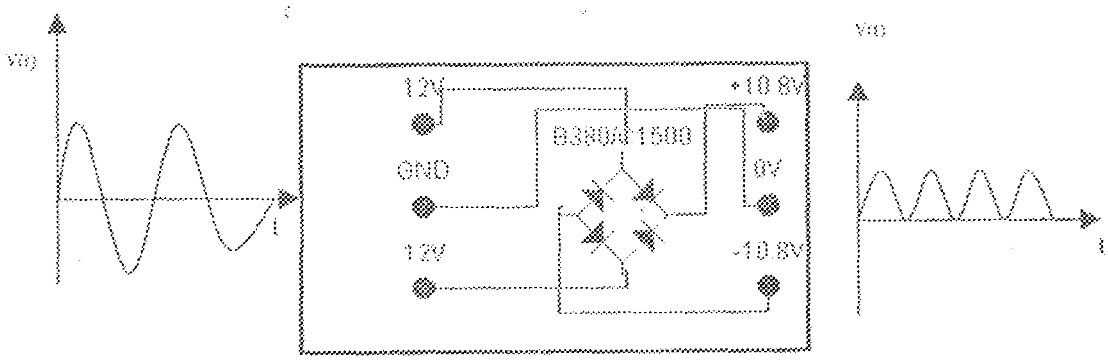

Fig 3.4 Circuit diagram of a full-wave bridge rectifier with its waveforms

The principle behind the rectification is that only two diodes (non-linear unidirectional devices), which are forward biased, conduct for both positive and negative half cycles of the ac voltage. The peak to peak value of the output dc voltage from the rectifier is given by;

$$V_{pp} = \frac{2V_m}{\pi}$$

Where V_m is the peak value of the ac voltage and is related to the root means square values of the ac voltage by

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

Where, $V_{rms} = 24$ V.

Hence; $V_m = 24\sqrt{2}$

Therefore

$$V_{pp} = \frac{2 \times 24\sqrt{2}}{\pi} = 21.6 \text{ V}$$

The full wave bridge rectifier was chosen because of the following reasons:

- It has low ripple factor compared to half wave rectifier
- It has maximum forward current and the peak inverse voltage (PIV) rating of each diode is less.
- Smaller transformers are used

It can be seen from figure 3.4 that the output of this stage is pulsating, hence smoothening is necessary which leads to the next stage - filtering.

3.2.3 FILTERING STAGE

The rectification stage produces an output, which is made up of two components only viz:

- dc component and
- a number of ac components also known as ripples.

The purpose of the filtering stage is to eliminate the ripple or at least reduce it to such a value that its influence becomes negligible in the circuit. With the availability of various types of filters, the choice for this project is shunt capacitor filter shown in figure 3.5

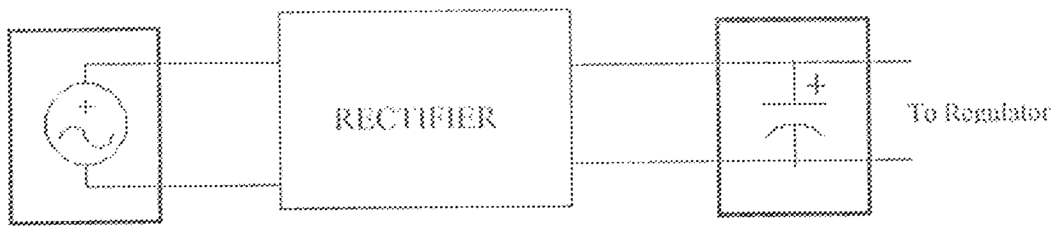

Fig. 3.5 Circuit showing a shunt capacitor

Filter Design

If a load R_L is connected across the capacitor, the ripple voltage which occurs can be approximated by a triangular wave-form shown in figure 3.6.

The ripple voltage has a peak to peak value of $V_{r(p-p)}$ and a time period of T_r centered around the dc level, where T_r is the discharging time. Since the charging time is negligibly small compared to T_r, then T approximately equal to T_r. $V_{r(p-p)}$ is the amount by which the capacitor voltage drop during discharging period, Tr. The charge ΔQ lost in this interval is,

$$\Delta Q = I_{dc} \cdot T_r ;$$

Where, I_{dc} is the current flowing through the load.

Therefore,

$$V_{r(p-p)} = \frac{\Delta Q}{C} = \frac{I_{dc} \cdot T_r}{C}$$

$$= \frac{I_{dc}}{F_r \cdot C} = \frac{V_{dc}}{C \cdot F_r R_L}$$

Where, F_r is the frequency of the ripple component.

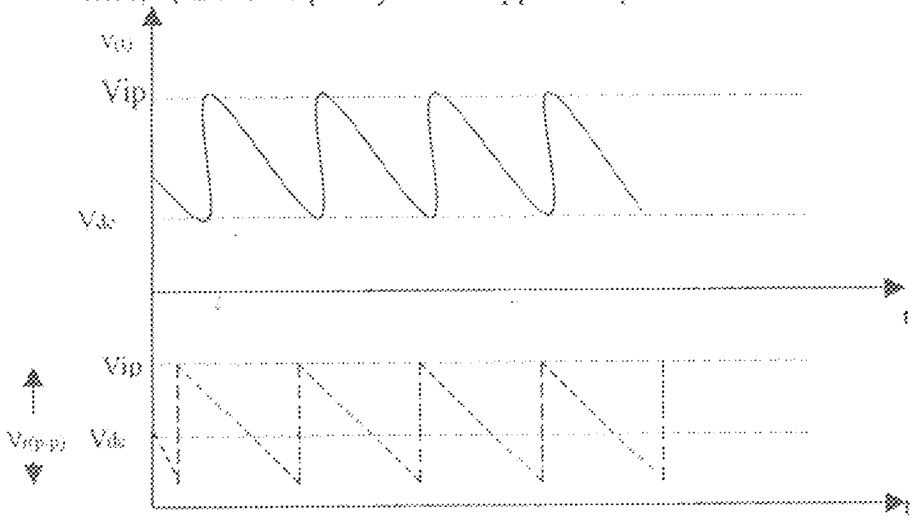

Fig. 3.6 Triangular approximation of the ripple component of the rectifier's

The root means square value of the triangular ripple is

$$V_{r(rms)} = \frac{V_{dc}}{2 \times \sqrt{3} \times F \times C \times R_L}$$

The ripple factor 'r' is defined as

$$r = \frac{V_{r(rms)}}{V_{dc}}$$

$$= \frac{I_{dc}}{4\sqrt{3} \times F \times C \times V_{ip}}$$

$$I_{dc} = \frac{2I_m}{\pi}$$

For the design in progress, a ripple factor r = 1.5% is desired for optimum performance.

I_m = 500 mA

F = 50 Hz

V_{ip} = 24 V

Hence,

$$C = \frac{2 \times I_m}{4\sqrt{3} \times F \times r \times V_{ip} \times \pi}$$

$$= \frac{500 \times 10^{-3} \times 2}{4\sqrt{3} \times 50 \times .015 \times 24 \times \pi}$$

$$= 2500\ \mu F$$

Consequent to the design above; figure 3.7 below present the circuit diagram of the filter for both +10.8 V and -10.8 V

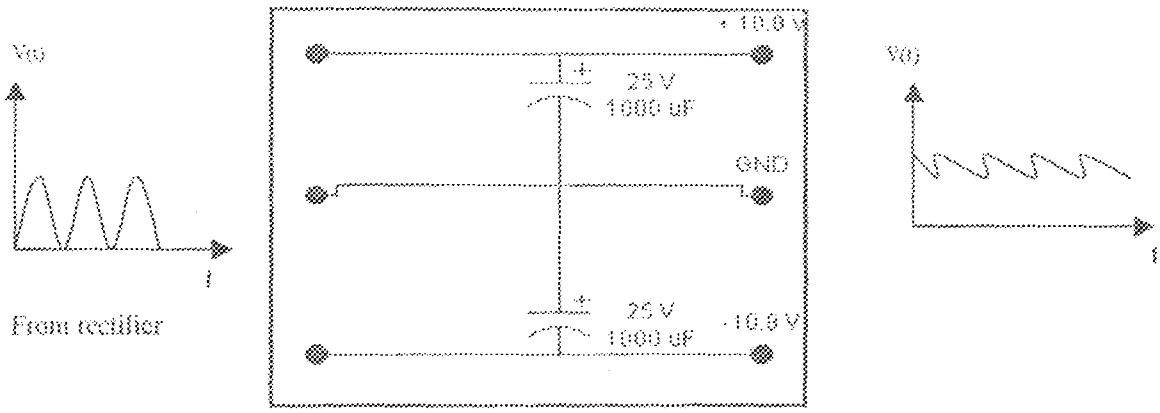

Fig 3.7: Filter Circuit

The shunt capacitor filter was chosen because it provides very good smoothening of the ac ripple from the rectifier output. The shunt capacitor is an electrolytic type.

3.2.4 REGULATION STAGE

The regulation stage ensures that the outputs of the power supply unit are constant dc voltages. It makes use of IC regulators, which constitute components like zener diodes for stabilization and transistors for amplifications and are supplied with external capacitors for further smoothening of the output of the filter.

The integrated circuits regulators utilized in this design are 7809, 7909, 7805, and 7905 for +9 V, -9 V, +5 V, and -5 V respectively. They have the advantage of on-chip circuitry each, to prevent damage in the event of overheating or excessive load current. The circuitry simply shut down rather than blowing out.

In addition, the on-chip circuitry prevent operation outside the transistor save operating area by reducing the available output current or large input –output voltage differential. The circuit diagrams and circuit symbols of the regulators are shown with pin descriptions in figure 3.8(a-h) below. The input voltage range for the four regulators are (+7 V to +35 V), (+7 V to +35 V), (-10.5 V to -5 V), (-12.5 V to -35 V).

3.2.5 POWER INDICATION

Four light emitting diodes (LEDs each of maximum current rating of 20 mA and forward drop of 2 V are used for the purpose of power indication. To make this LEDs usable in the power supply unit for power indication, a series resistor whose value is calculated as shown below is connected with each of them as shown in figure 3.9 below. The resistor limits the current that flows through each of the light emitting diodes.

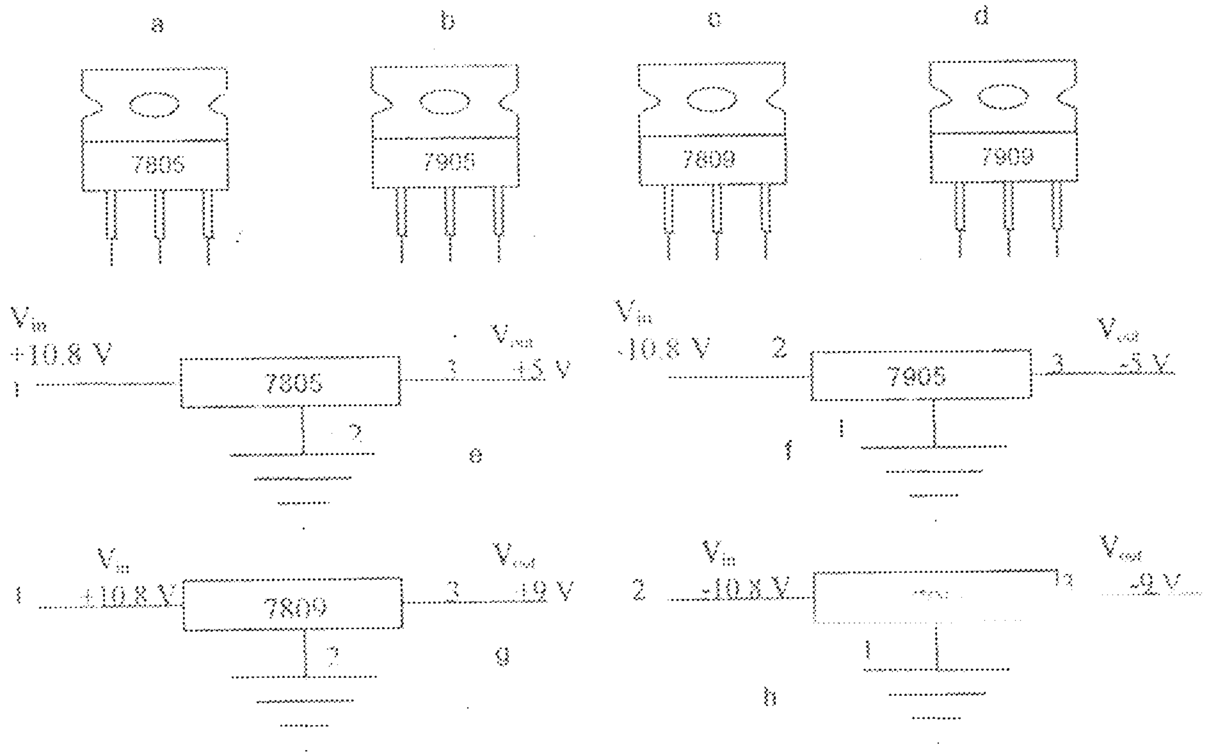

Fig. 3.8 Circuit symbols and diagram of 7805, 7905, 7809, and 7909 regulator ICs.

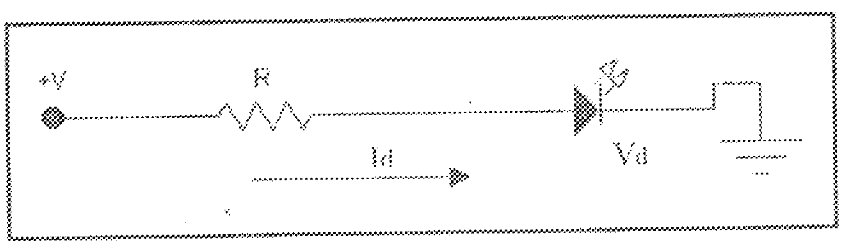

Fig 3.9: LED indicator circuit for power indication

Determination of the value of R

Applying kirchoffs' voltage law (KVL) to the circuit diagram of figure 3.9, "the algebraic sum of e.m.f in closed loop is equal to the algebraic sum of voltage drop across the elements in the loop".

$$V = I_a . R + V_a$$

Therefore;

$$R = \frac{V - V_a}{I_a}$$

For 5 V and -5 V;

$$R = \frac{5 - 2}{20 \times 10^{-3}} = 150\ \Omega$$

Also for +9 V and -9 V,

$$R = \frac{9 - 2}{20 \times 10^{-3}} = 350\ \Omega$$

Thus, the complete circuit diagram of the power supply unit (PSU), is shown in figure 3.10

3.3 PROCESSING UNIT

This unit is concerned with the sensing of the temperature (of the object or space) to be measured, converting it into an electrical signal, and the de-amplification of the latter to suit the requirement of the display unit Therefore it consists of a transducer and de-amplifier circuit.

Principle of operation:

The DTMI makes use of a temperature sensor (transducer) to convert the quantities of interest, temperature to electrical signal. The electrical signal (voltage) is supplied to the input of an ADC upon shifting and scaling. The ADC converts the analog signal to a digital display.

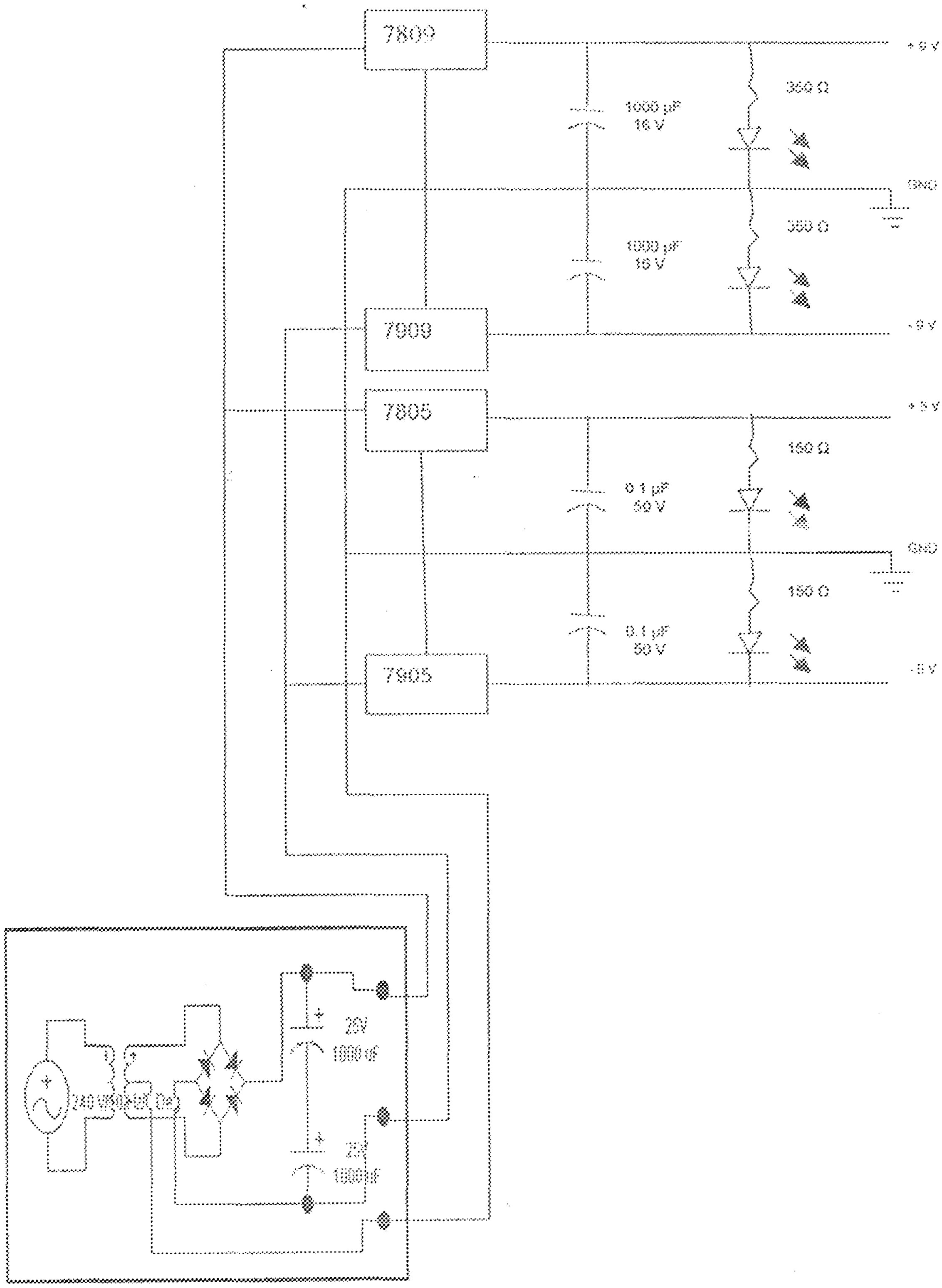

Figure 3.10: Circuit diagram of the power supply unit.

3.3.1 THE CONCEPT OF TRANSDUCER

Measurement by direct comparison with reference standard having the same characteristic as those of the quantity measured are called direct measurement, but most measurements yield result in more indirect way. They are based on the knowledge of the relationship between the quantity to be measured and the response of the measuring instrument of system influenced by it. The Instrument society of America (ISA) defines a transducer as a device, which provides a usable output in response to a specific measurand. The measurand is a physical quantity, or condition, which is measured. The output is electrical quantity produced by the transducer, which is a function of the applied measurand.

A transducer can also be defines as a device that is able to convert one form of energy into another. Since what is required is electrical signal, the transducers of specific interest are those that can convert temperatures, which are physical quantities into their equivalent electrical signal. Various forms of transducers for the measurement of temperature include thermocouple, thermistor, integrated circuit etc. For this project work, a negative temperature coefficient (NTC) thermistor is used.

3.3.2 THEORY OF THERMISTOR

Thermistors are basically made of oxides of nickel and manganese and undergo a very large change in resistance with temperature rise. They could either be NTC or PTC types. For the NTC type, the resistance falls with an increase in temperature while a rise in temperature causes the resistance of the PTC type to increase. The general characteristics of thermistor is given below.

$$R_T = RoC^{\beta(1/T - 1/To)}$$

Where

R_T = Thermistor resistance (Ω)

Ro = Thermistor resistance at a base temperature To

β = thermistor constant (which is dependent on the materials used).

Effective temperature coefficient is given by

$$\$ = -\beta/T$$

The resistance of the thermistor with voltage drop across R1 as temperature varies is given in appendix A. The circuit of the processing unit is presented in figure 3.11

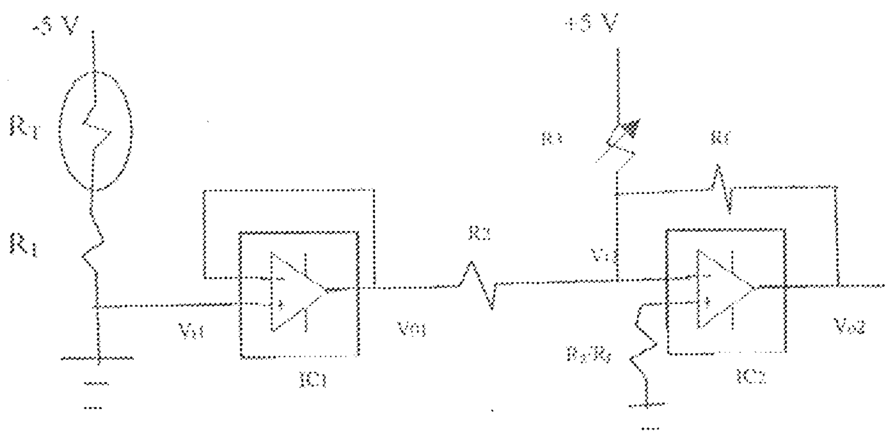

Fig.3.11 Circuit diagram of the processing unit

The sole aim of the processing unit is to generate analog voltage representing temperatures from 0°C to 100°C. That is, at 0°C, the output voltage Vo2 is 0 V and 0.5 V at 100°C. The thermistor R_T and resistor R_1 forms a voltage divider network. The output voltage drop across R_1 is given by,

$$V_{i1} = R_1 / (R_1 + R_T) \times Vs$$

The output of the voltage divider network ranges from;

$V_{i1} = 100/(100+1500) \times -5 = -0.312$ V,

To, $V_{i1} = 100/(100+233) \times -5 = -1.5$ V

IC1 is a unity gain buffer that prevent the later part of the circuit from loading the voltage divider network, thus $V_{01} = V_{i1}$. The voltage range -0.31 V to -1.5 V is to be converted to 0 V to 0.5 V range required by the display unit for digital read out 0 °C to 100 °C to achieve this, V_{02} is shifted by +0.31 V to obtain a 0 V signal for 0 °C and -1.2 V and 100 °C and scaled to a 0.5 V range. In figure 3 11 above, IC_2 and resistors R_2, R_3 and R_f which form an inverting summing amplifier performs the operation.

A 10 KΩ is assumed for R_2. At 0 °C, Vo1 = -0.31 V thereby feeding a current Vo1/ R_2 = -0.31/10kΩ = -0.031 mA into the summing junction. To compute R_3, a positive current equals 0.031 mA has to flow through it to balance that in R_2 thereby causing the current through R_f to be zero. Since the inverting input voltage is also zero, i.e. $V_{01}/R_2 = 5/R_3 = -0.031$ mA.

Therefore, $R_3 = (5/0.031 \text{ mA}) = 161.3$ KΩ

In order to make V02 = 0.5V when Vo1 = -1.5 which corresponds to -1.2 after shifting, it is necessary to determine the gain of IC2. Thus, $A = -R_f/R_2$. The negative sign indicate negative feedback is employed. Hence,

$$Vo_2 = -R_f/R_2 \times Vo_1$$

$$0.5 = -R_f/10K \times 1.2$$

$$\Rightarrow \quad R_f = 5000/1.2 = 4.17 \text{ K}\Omega$$

Therefore A = 0.42.

Based on the above design, the value 0.42 is desirable for an ideal op-amp. However, since a practical op-amp (741) is used and all of its non-ideal features affect the performance in the circuit, A is made to be 0.45 to compensate for deviations from an ideal situation. The op-amps come in numerous kinds from different manufacturers. The one used for this design is analog μA741CN op-amps. The circuit diagram of the op-amp is shown in figure 3.12 while the manufacturer's characteristic is presented in appendix A.

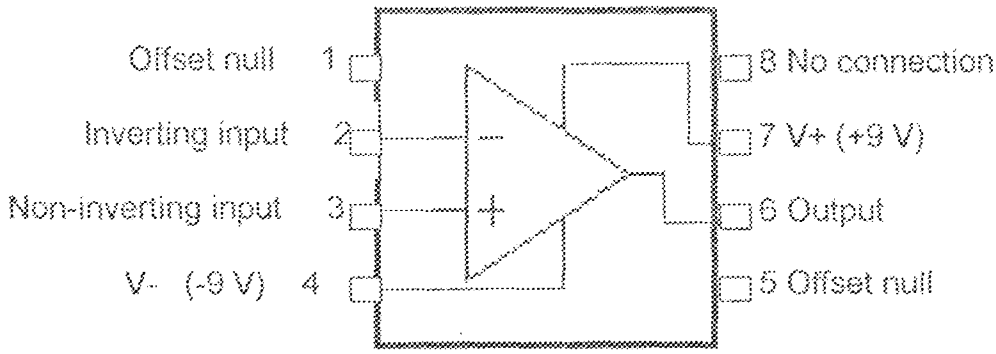

Fig. 3.12: Circuit diagram and symbol of 741 Op-Amp

These values were tested in the circuit on Electronic Work Bench (EWB) and the results obtained are quite within the limit of accuracy. The results obtained on simulating the amplifier circuit on the EWB are presented in table 3.1 for ideal op-amp, while those obtained on testing the circuit with 741 on bread- board are presented in table 3.2.

Table 3.1: Results obtained for an ideal op-amp on simulating the amplifier circuit on computer.

T°C	V_{i1} (mV)	A_{f1}	V_{o1} (mV)	V_{i2} (mV)	A_{f2}	V_{o2} (mV)
0	-310	1.0	-310	0	0.42	0
30	-415	1.0	-415	-103	0.42	42.1
50	-740	1.0	-740	-430	0.42	176.6
70	-1000	1.0	-1000	-690	0.42	285.8
90	-1300	1.0	-1300	-990	0.42	410.8

Table 3.2: Results obtained for 741 op-amp on testing the amplifier circuit on bread-board

T°C	V_{i1} (mV)	A_{f1}	V_{o1} (mV)	V_{i2} (mV)	A_{f2}	V_{o2} (mV)
0	-310	1.0	-308	0	0.45	0
30	-415	1.0	-416	-103	0.45	47.5
50	-740	1.0	-740	-430	0.45	193.0
70	-1000	1.0	-1000	-690	0.45	307.0
90	-1300	1.0	-1298	-990	0.45	440.0

The output of this unit is analog in nature and needed to be converted to its digital equivalence and a readable format, which necessitate the next stage.

3.4 DISPLAY UNIT

The display unit happens to be most interesting part of the system because; it enhances the readability as well as offering improved accuracy of the measured temperature values. It is composed of analog to digital stage and digital readout stage.

3.4.1 Analog to Digital Conversion Stage

This stage utilizes a 3½ digit analog to digital converter IC, ICL7107CPL, for converting the output analog voltage of the processing unit into its digital equivalent.

The 7107CPL is employed simply because it does the conversion directly from analog signal into seven-segment display equivalent without requiring any interface such as a BCD/seven-segment decoder.

In addition, it also exploits the advantages of Dual Slope integration technique in its operation.

Furthermore, it includes an automatic zeroing circuit in its operation and finally, it requires minimum number of external passive components for normal operation.

The circuit symbol diagram of the ICL7107 with pins description is presented in figure 3.13.

The IC generates a periodic pulse (clock signal) whose frequency is determined by the values of the resistance and capacitors connected between 39 and 38 respectively. For three readings per second, the frequency is given as:

$$F = \frac{0.45}{RC}$$

Where R = 100 K, and C = 100 pF

$$\Longrightarrow \quad f = \frac{0.45}{100 \times 10^3 \times 100 \times 10^{-12}}$$

$$\approx 48 \text{ KHz}$$

The period of the pulse, $T = 1/f = \frac{1}{48 \times 10^3} = 0.021\text{ms}$

The output of the IC is either a pulse ('1' or 'high' for 3 V to 5 V), or a no pulse ('0' or 'low' for 1 V to 2.9 V). it actually count from 000 to 999 making a total of 1000 counts. However the desirable counting range is from 000 to 100 for 0 °C to 100 °C, which is equivalent to 0 V to 0.5 V output voltage range of the processing unit.

$$\text{No of counts} = \frac{1000 \times V_i}{V_{ref}}$$

Where,

$V_{ref.}$ = the reference voltage of the ADC:

V_i = analog input to the ADC from the processing unit.

At T = 100 °C, i.e. No. of counts = 100: V_i = 0.5 V

Then,

$$V_{ref} = \frac{1000 \times 0.5}{100} = 5\ V$$

It is worth mentioning here, some of the advantages of the dual slope integrating technique:

~ It provides immunity to temperature caused variations in R and C

~ It cost less to implement

~ Conversion accuracy is independent of both the capacitor value and the clock frequency, because they affect both the up-slope and the down-slope in the same ratio.

The circuit diagram of the 7107CPL IC is shown in appendix B, while the photograph of the unit is shown in appendix D.

3.4.2 Digital Readout Stage

The numeric indicator used is a 3-digit 7-segment LED display. These ICs are green LED display. Its circuit symbol is shown in figure 3.14.

The ICL7107CPL generates a seven bit codes (a, b, c, d, e, f, g,) to control the display. It output logic 0 (low) to turn ON any of the seven segments (a-g) and output a logic 1 (high) to turn it OFF. The anodes of all the 3-digit display are connected to +5V. Each of the seven segment inputs forms the cathode for that segment. The circuit diagram of the display unit is shown in figure 3.15.

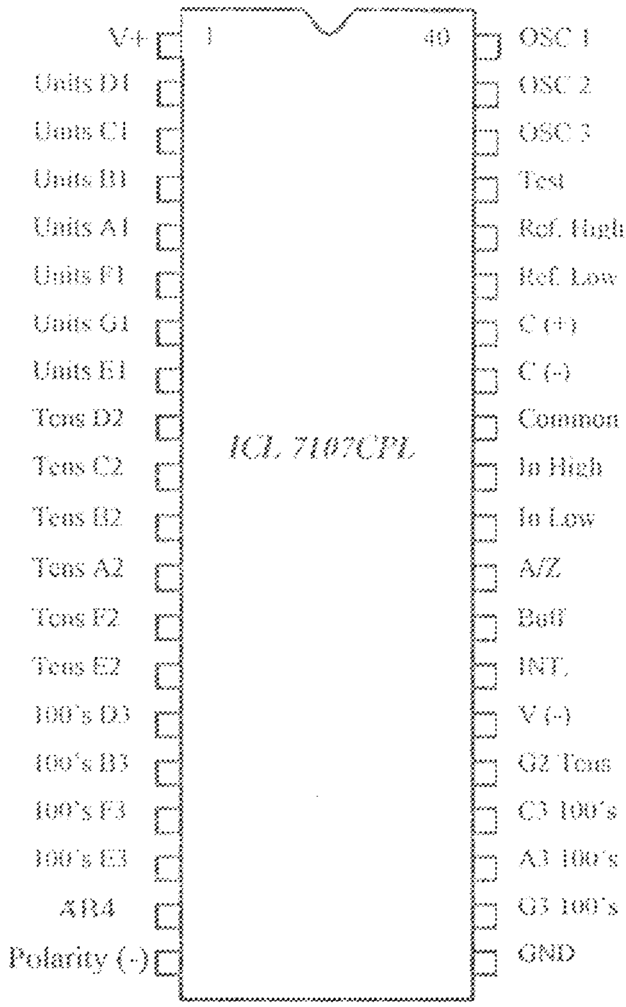

Fig. 3.13 Circuit symbol (with pins description) for ICL7107CPL 3½ digits ADC to seven-segment display driver.

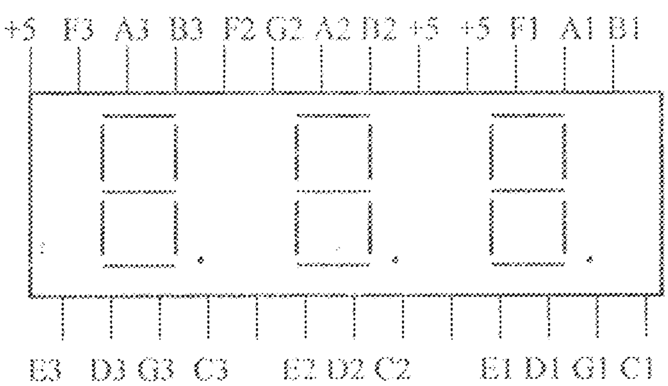

Fig. 3.14 circuit symbol of the seven-segment display

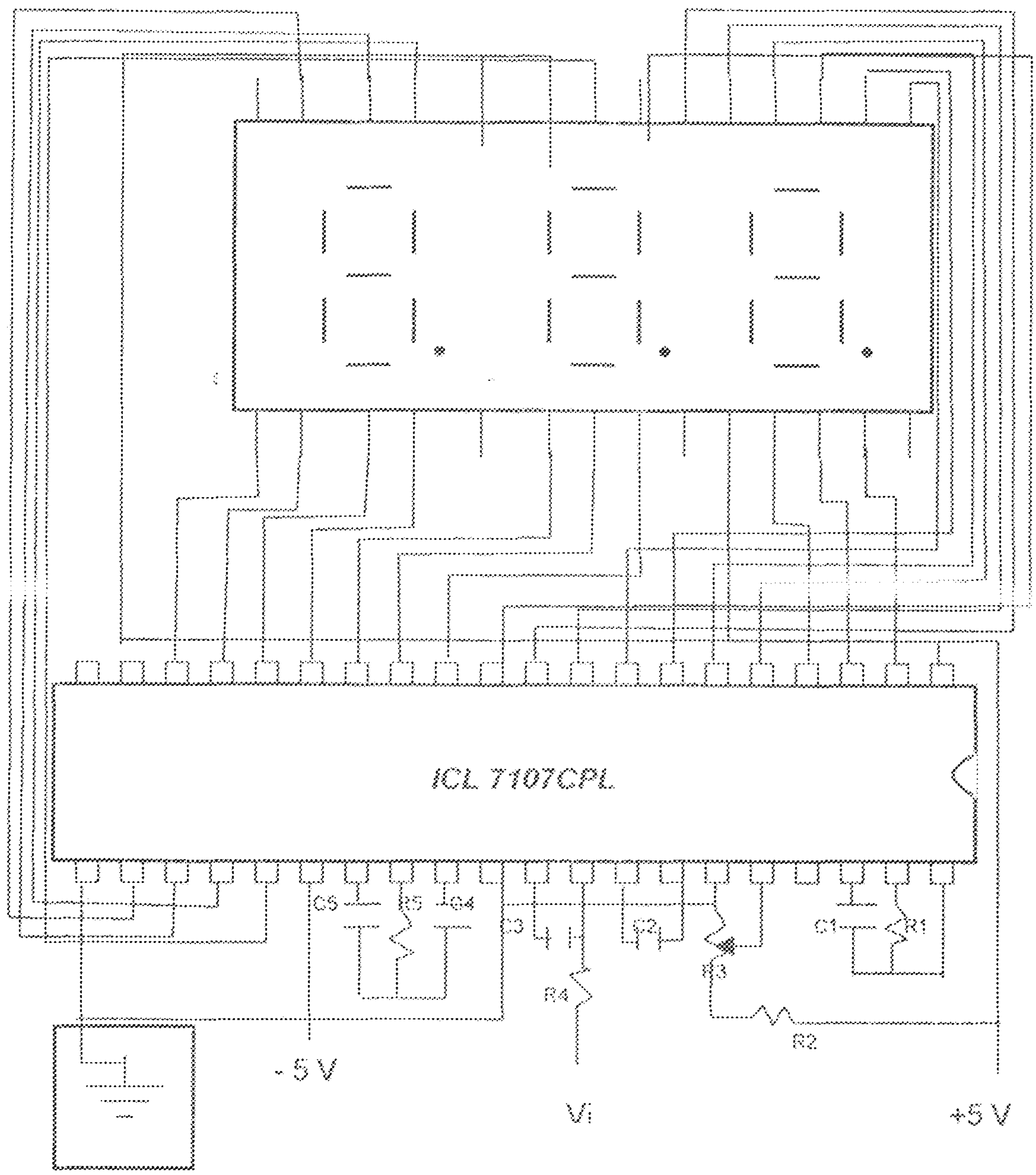

Fig. 3.15: Circuit diagram of the display unit

List of components:

Processing unit,

R_T = 1.5 kΩ

R_1 = 100 Ω

R_2 = 10 KΩ

R_3 = 161.3 KΩ

R_F = 4.17 KΩ

$IC_1 = IC_2$ = μA741CN

Display unit;

R_1 = 100 kΩ

R_2 = 8 KΩ

R_3 = 10 KΩ

R_4 = 1 MΩ

R_5 = 47 KΩ

C_1 = 100 nF

C_2 = 100 nF

C_3 = 10 nF

C_4 = 220 nF

C_5 = 470 nF

R_{f1} = 5 ΩK

R_{f2} = 10 ΩK

R_{i1} = 10 ΩK

R_{i2} = 10 ΩK

The complete circuit diagram of the Digital Temperature Measuring Instrument is thus presented in Appendix C.

CHAPTER FOUR

CONSTRUCTION, TESTING AND RESULT

4.1 INTRODUCTION

This chapter deals with the construction and testing of the digital temperature measuring instrument using specified components as analyzed and designed in the previous chapter.

The different stages of the design were arranged on a project board (bread board) for testing and was later transferred and soldered onto a vero board.

4.2 CONSTRUCTION

The design was first simulated on a microcomputer using electronic simulating software – Electronic Workbench (EWB), version 5.0 before the actual construction took place. The construction of the design was carried out in stages as analysed in the system block diagram, viz; power supply unit, processing unit and the display unit.

4.2.1 Power Supply Unit (PSU)

The power supply unit was constructed using the following electronic components: step-down transformer, rectifier IC, voltage regulators, filtering capacitors, light indicators and current limiting resistors. These components were inserted properly according to design onto the bread-board.

The primary side of the step-down transformer was connected to the mains supply and the voltage across each output terminal with respect to the ground was measured using a multi-meter. The output voltages were compared with standard values.

Having compared the values obtained, with satisfactory results, each of the elements of the power circuit was transferred and soldered firmly into place on vero board.

4.2.2 Processing Unit

The processing unit comprises of the temperature sensor and the shifting and scaling circuit. The transducer used is a negative temperature coefficient thermistor as stated earlier. The sensor is a rod type with two pins.

The two pins of the sensor were inserted into different socket of the bread board with a 100 Ω resistor to form a voltage divider network. The op-amps were also inserted into place on the bread board with the input and feedback resistors in place. Following the manufacturer's instruction sheets for the electronic components being used, all necessary connections to the power supply and interconnection between the sensor and the op-amps were carried out in line to the design in the previous chapter.

Having tested the outputs of the op-amps varying the temperature conditions of the sensor, the elements of the circuit were transferred and soldered onto a vero-board. IC sockets were also soldered onto the vero-board to accommodate the op-amps. This is to ensure the op-amps were not damaged due to excess heat while soldering.

4.2.3 Display Unit

The analog to digital converter integrated circuit (ICL7107CPL), the light emitting diode (seven-segment display LED) and the supporting components were properly inserted and arranged according to the design onto the bread board. The required electrical potentials were supplied to the unit from the PSU and were tested.

With the satisfactory performance of the circuit, each of the components (excluding the ICL 7107), were transferred and soldered in place, firmly on to the vero board. A 40-pin IC socket was soldered at the appropriate place on the vero board to accommodate the ADC ICL7107 IC.

4.3 TESTING

The constituting units of the instrument under construction were simulated one after the other using electronic simulating software on a microcomputer. This was followed by another series of tests when arranged on the project board, and after being soldered onto the vero board used for the construction.

The output voltages of various units were measured employing a multi-meter connected in parallel across the output terminals.

To test for the performance of the Instrument upon construction, a soldering iron was plugged into the ac mains supply outlet. This was brought close enough to the temperature sensor to measure its varying temperature, as it gets hotter. The output of the sensor was observed varying and the equivalent temperature differences displayed on the display unit. The results indicated by the constructed instrument were compared to those obtained using a standard thermometer. The results are presented in table 4.0.

4.3.1 Results

Table 4.0 below shows the results obtained from the Digital Temperature Measuring Instrument compared with that of a standard thermometer.

Table 4.0: Comparison of results obtained using a standard thermometer and the constructed Instrument.

Standard Thermometer (T °C)	Constructed DTMI (T °C)
0	0
30	31.2
50	50.1
70	70.0
90	89.6

4.3.2 Discussion of Results

The deviations of the readings obtained by the Instrument from those of a standard thermometer are very small as shown in the table above. This shows how accurate digital systems could be in measuring or processing desired quantities or piece of information.

However, the deviations could have resulted from the non-linearity of the components used in the construction work. The use of higher resolution ADC and IC sensor would improve on the accuracy of the design

4.3.3 Precautions

Amongst the precautions taking while constructing the system in order to ensure a successful and effective design are given below:

- All components were properly soldered to the vero board to avoid shorting of components' legs and opening of circuit.
- Excess heat damage components, hence care was taken to ensure that the heat supplied to the components while soldering was not too much.
- Polarized components such as electrolytic capacitors were soldered into circuit with their correct polarities to ensure best performance.
- In order to reduce power consumption and to improve on the longevity of components, power was not supplied to the circuit when no reading was being taken.
- In order to ensure the IC was not damage while soldering (due to excess heat), an IC socket was soldered in its place on the vero board, onto which the IC was inserted. This also facilitates their replacement or removal incase of damages.

4.3.4 CONSTRUCTION TOOLS AND EQUIPMENTS

During the construction of DTMI designed in this project, some electronics tools and equipment were used. These tools are briefly discussed in this section.

Soldering Iron: A modular soldering iron with 40 watts heating element was used for the project. Any higher wattage may damage the electronic component especially the sensors.

Soldering stand: This was used for keeping the soldering iron in a safe, upright position.

The stand use is made up of metal and it is constructed so that the bit of the soldering iron does not touch any metallic or plastic parts.

Lead: Flux - core solder type was used for the soldering of the various electronic components.

Lead – sucker: This was used for sucking up molten solder. It also served to a great extent in removing bad components out of Vero board.

Wire cutters: Cutters were used to cut wires to required length and to rip off the excess leg of electronic components after soldering

Digital Multi-meter: This was used for quite a number of functions. It was used to test the continuity of electronics links, to test logic level, to measure resistance, capacitance and voltage in various part of the circuit.

Vero Board: This allows permanent prototyping of an electronic design. The Vero board was pre - etched, therefore the various electronic components were simply soldered in place, using connector wires to make continuity, wherever necessary.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSION

The main objective of this project was to design a simple digital temperature measuring instrument that can measure temperature in the range of 0 °C to 100 °C. The various units, the system is made up were constructed in stages and tested to be working perfectly according to design. These were coupled together to realize the system in view. This was then tested and the results obtained were almost as accurate as the design values.

Also there exists negligible disparity between values obtained from the design when compared with standard thermometer`s values.

The design and construction of the Digital Temperature Measuring Instrument (*DTMI*) was indeed a success as the objectives of the work were achieved satisfactorily.

5.2 RECOMMENDATIONS

Electronic field is continually dynamic and thus, it is widely possible with little or no limitations to modify designs and constructions of electronic devices for better performance.

In view of the above, and in line with the designed system, the following recommendations are proffered:

- ✓ IC sensors which can measure negative temperatures and temperatures above 100 °C can be utilized, such as LM35CZ.
- ✓ Temperature measurement and control are of great importance for effective operation of some complex engineering devices/equipments. Hence the constructed instrument can be modified to in corporate automatic regulation and control of measured temperature.
- ✓ The instrument could be interfaced with a microcomputer and have the temperature displayed and controlled with the aid of structured program written in Visual Basic or C++.
- ✓ Rather than temperature being displayed in degree Celsius, the system can also be modified to display temperature in Fahrenheit or degree Kelvin.

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APPENDIX A

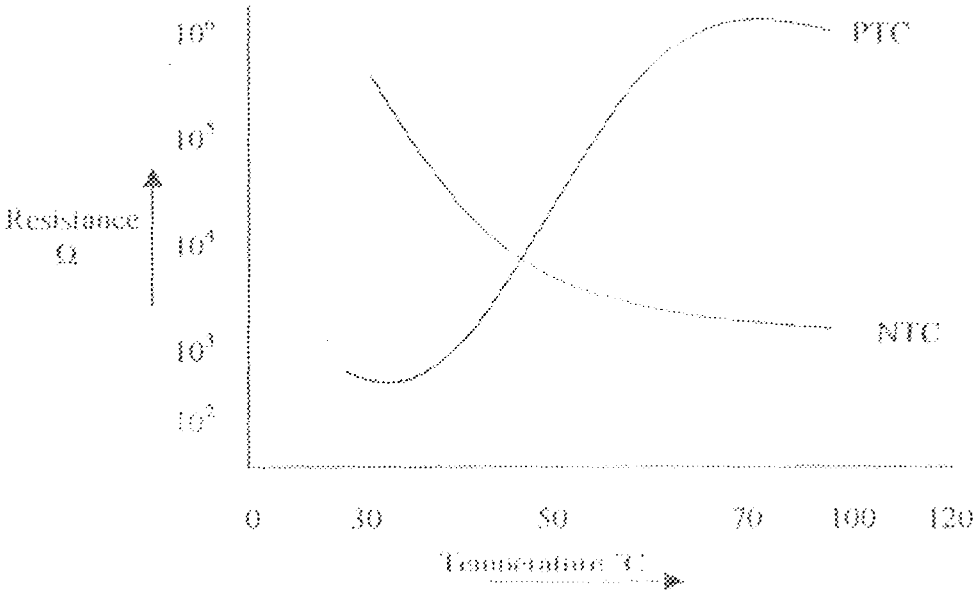

Table A1: Resistance (R_T) of the Thermistor and voltage drop (V_{R1}) across R_1 at various temperatures.

T (°C)	R_T (Ω)	V_{R1} (V)
0	1500	-0.312
10	1360	-0.343
20	1240	-0.373
30	1000	-0.415
40	843	-0.530
50	576	-0.740
60	502	-0.830
70	400	-1.000
80	346	-1.120
90	285	-1.300
100	213	-1.500

Table A2 - Characteristics of the 741 op-amps from the manufacturers' data sheet:

PARAMETERS	VALUE	UNITS
Saturation voltage, V_{sat}	15	V
Saturation current, I_{sat}	2	mA
Slew rate SR	0.5	V/μs
Bias current, I_b	80	nA
Offset current, Iqs	20	nA
Input offset voltage, Vos	1	mV
Input resistance, Ri	2	MΩ
Output resistance, Ro	75	Ω
Differential gain, A	200	V/mV
Common mode rejection ratio, CMRR	31.6	V/mV
Gain bandwidth product, B	1	MHz

APPENDIX B

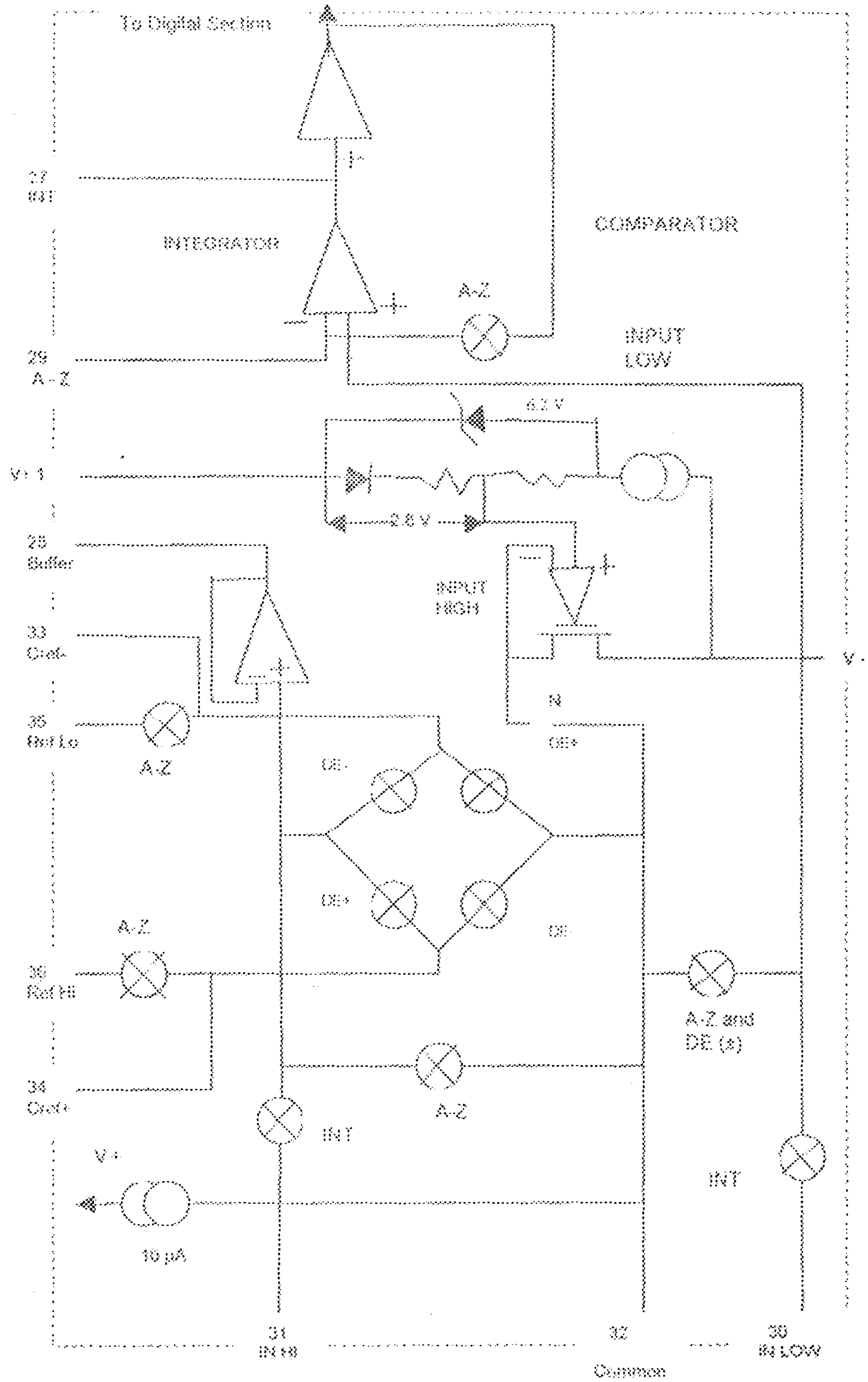

Fig. B1 Analog Section of 7107 ADC

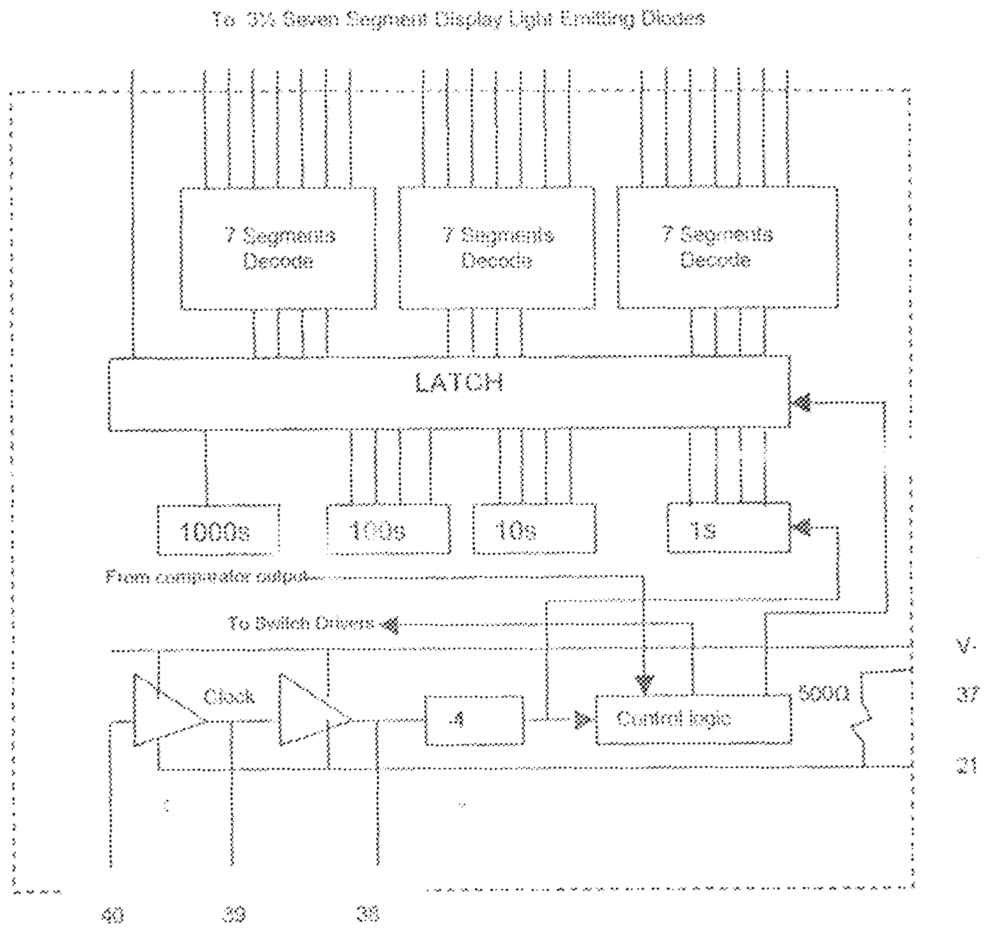

Fig. B2 Digital Section of the 7107 ADC

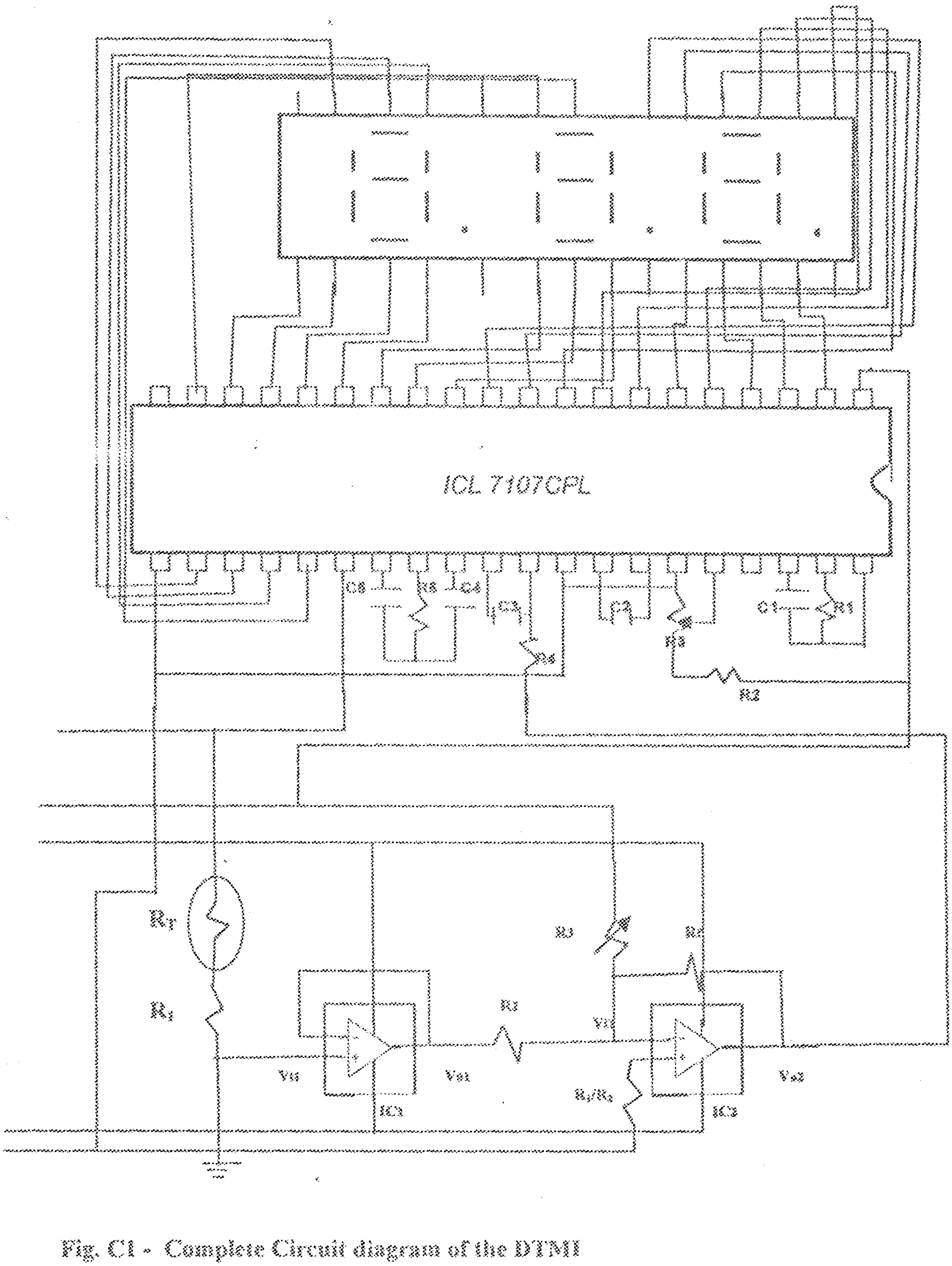

Fig. C1 - Complete Circuit diagram of the DTMI

APPENDIX D

Fig. D1: Photographic Illustration of the Constructed Instrument