LINEARISING THE OUTPUT OF A THERMISTOR

A Thesis
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THESIS CERTIFICATE

This is to certify that the thesis titled **"Linearising the output of a Thermistor",** submitted by **Mr. Anshul Jain**, to the Indian Institute of Technology Madras, Chennai for the award of the degree of **Master of Technology**, is a bona fide record of research work done by him under my supervision. The contents of this thesis, in full or a part has not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

The resistances of thermistors vary to a great extent even with a small temperature change. Numerically, it can be between 3 to 5% per °C as against up to 0.4% per °C for RTDs . As a result, the sensitivity of thermistors is very high even towards small temperature changes. Therefore, they can sense variation in temperature changes as low as 0.1°C or even smaller. Thermistors show an exponential relation between the temperature and resistance. Therefore, they require essentially the employment of circuits leading to linearization for proper measurements, whenever they are used as a sensor for temperature measurement. Some of the frequent uses of these are as listed below:

(1) Automobiles where they are used to monitor parameters such as temperature of coolant and/or engine oil and give the information to the Electronic Control Unit and subsequently display for consumption of the user.

(2) Monitoring the temperature of an incubator.

(3) Monitoring the variation in temperature of battery banks while they are being charged.

This thesis focuses on the design, fabrication and testing of the linearising method. It is an endeavor to develop a method, which uses a thermistor as an input to a resistance to digital converter and gives a digital output linear to the temperature being sensed by the thermistor. The practicality of the proposed linearising method with the help of dual slope analog to digital converter is done by building the signal conditioning circuit on NI ELVIS board and testing it at different temperature values.

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CHAPTER 1

INTRODUCTION

1.1 Temperature Sensors

Temperature is one of the most frequently measured parameter in any system. In the present scenario, there are three most commonly used electronic temperature sensors. These are thermocouples, resistance temperature detectors (RTDs), and thermistors. The resistance of thermistors varies to a great extent even with a small temperature change. Numerically, it can be between 3 to 5% per °C as against up to 0.4% per °C for RTDs. As a result, the sensitivity of thermistors is very high even to small temperature changes. Therefore, they can sense variation in temperature changes as low as 0.1°C or even smaller. Thermistors are significantly smaller in size in comparison to the RTDs. In this chapter, the fundamentals of thermistor are discussed.

1.2 Thermistors

The principle characteristic of the 'Thermistors' is that their electrical resistance changes according to the change in the temperature of the environment of their operation. The term "Thermistor" is described as "thermally sensitive resistor". Thermistors can be further bifurcated as:

(1) Positive Temperature Coefficient (PTC) thermistors

(2) Negative Temperature Coefficient (NTC) thermistors

The resistance of PTC thermistors increases with increase in their temperature while in case of NTC thermistors, resistance decreases as their temperature increases. NTC thermistors are made from a mixture of metal oxides pressed into a bead, wafer or other shape which is subsequently heated under pressure, at high temperatures, and then encapsulated with epoxy or glass.

1.3 Thermistor Materials

The Positive Temperature Coefficient thermistors are further split into two sub categories. The first one is the thermally sensitive silicon resistors, also known as "silistors". They show an almost constant positive temperature coefficient which is approx. +0.77% /°C through most of their operational range. However, they can also show negative temperature coefficient when the temperatures are beyond 150°C. They are commonly used for temperature compensation of silicon semi conducting devices in the temperature range of -60°C to +150°C. The other major category is known as the switching PTC thermistors. These are normally highly resistive polycrystalline ceramic materials but are made semi conductive by the addition of dopants. They are usually made of compositions of barium, lead and strontium titanates along with additives such as yttrium, manganese, tantalum and silica.

On the other hand, NTC thermistors are usually made of metal oxides. Manganese, nickel, cobalt, iron, copper and titanium are some of the most commonly used oxides. The commercial NTC thermistors are fabricated using basic ceramic technology and the same continues today much as it has for decades. In this technology, a mixture of two or more metal oxide powders are joint together along with required binding material, so as to give the required geometry. It is subsequently dried and sintered at a higher temperature. In order to obtain a wide range of resistivities and temperature coefficient characteristics, the types of oxides used, their relative proportions, the sintering atmosphere, and the sintering temperature scan be varied. A thermistor's R/T characteristic and R_{25} value are determined by the particular formulation of oxides.

1.4 Basic concepts related to thermistor

In order to understand the selection of thermistor components required in the designing of a thermistor circuit, it is important to be aware of some of the basic concepts and definitions. This section covers some of these topics.

1.4.1 Slope of resistance versus temperature curve (Resistance Ratio)

There are various important concepts to be known while considering the relationship between resistance and temperature of thermistors. The rate of change of the resistance of the component with temperature is one such concept , which is an indication of the slope. This is exhibited in the diagram as shown below:

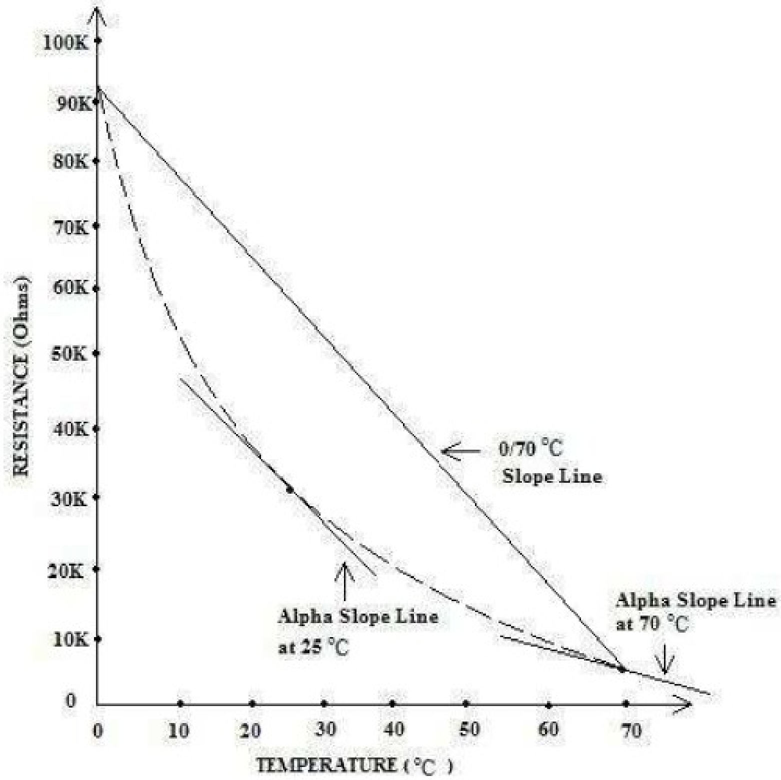


Figure 1.1. Relationship between Thermistor Resistance and Temperature

The ratio of resistance at one temperature (usually 0˚c) to the resistance at a second and higher temperature (usually 70˚C) is defined as the slope or resistance ratio for thermistors. The concept of resistance / slope concept is as shown in Fig. 1.1, where the resistance value at 0˚C to the resistance value at 70˚Cis connected by the 0/70˚C slope line. The rate of change of resistance with temperature and the potential thermal sensitivity of the component is indicated by it. This provides a preview to the concept of rate of change of resistance with temperature and in turn the sensitivity of the resistance of thermistors to changes in the temperature. This idea is further substantiated by considering the more generic case of thermal sensitivity in terms of percentage change in resistance of a component per degree increase in temperature.

1.4.2 Temperature coefficient alpha (α)

A characteristic of the material 'Alpha ', is stated as the percentage change in resistance per degree

Centigrade. It is also defined as the temperature coefficient of the material. For example, in case of NTC thermistors, the typical values of alpha are in the range -3 %/ ˚C to -6%/˚C. It is one of the important concepts in thermistor calculations. The alpha value of a particular thermistor material is nonlinear across the relevant temperature range, since the resistance of NTC thermistors is also a nonlinear function of temperature, as shown in Fig. 1.1. The idea of using temperature coefficient values is sufficient if accurate alpha values and resistance values are available for the range of temperature points for the thermistor materials. It is a material constant and is independent of the resistance of the component at that temperature.

1.4.3. Exponential model of NTC thermistor (Beta value (β) or sensitivity index)

Using principles of solid state physics , we know that the resistance (R) of a piece of material of resistivity ρ (ohm-cm) is directly proportional to it's resistivity value.
Hence,

$$R = \rho \times l/A \qquad (1.1)$$

here
R = the resistance in ohms,
l = thickness of the material (length of current path),
A = the cross-sectional area.
Now the expression for resistance as a function of temperature can be written as

$$R_T = \exp(1/T) \qquad (1.2)$$

where R_T denotes resistance in ohms at temperature T Kelvin. As shown above, a simple approximation for the relationship between resistance and temperature for NTC thermistor exhibits an exponential relationship between them. The exponential approximation is a mathematical model that can be expressed in the form:

$$R_T = A \exp(\beta / T) \qquad (1.3)$$

Where
R_T is the resistance in ohms at temperature T

T is the absolute temperature in Kelvin

A is a linear factor

β is the exponential factor or sensitivity index of the thermistor material.

The β value is a very important parameter in the specification of thermistor materials and components. Now applying natural logarithm to both sides of the equation, the equation becomes:

$$\ln (R_T) = C + (\beta/T) \tag{1.4}$$

Where

C is a constant factor ie.C = ln(A).

Now if $\ln(R_T)$ is plotted v/s 1/T, then the slope of the resulting curve is equal to β **.** As it is seen, the equation shows a reasonable approximation to measured data,. However, the thermistor materials are not ideal. Therefore for the exponential model to be applicable over a large temperature range (greater than 50˚C), the beta value varies and therefore it is not constant over extensive ranges. In fact, the β value decreases with temperature as it is also temperature dependent. The concepts derived from this simple exponential model are important in the specification of NTC thermistors, although the relationship between the resistance and the temperature of a thermistor is limited to short temperature spans.

1.5 Objective and scope of the work

The main objective of the work is to design a temperature sensor that takes a thermistor as an input, linearise it and provides a digital output of the temperature. The resistance of the thermistor varies with the temperature, thus providing a varying input to the Log 112 amp. The output of the Log amp is given to ICLZ 7106 ADC which in turn gives a digital output of the corresponding temperature on the LCD display.

1.6 Organization of Work

A brief introduction on temperature sensors and thermistors is given in Chapter1. Chapter 2 deals with the mathematical analysis of the thermistor equation, study of NI ELVIS board and various components required for the circuit design. Chapter 3 explains the experimental set up of the temperature sensor and working of the signal conditioning. In chapter 4 we discuss about the experimental results. The conclusion of the work carried out is provided in Chapter 5.

CHAPTER 2

HARDWARE SETUP FOR EXPERIMENT

2.1 INTRODUCTION

The temperature is a vital parameter to be known and measured in any control or instrumentation system. Thermistors forms a widely popular choice for sensing the temperature due to their accuracy, high sensitivity, biocompatibility, ruggedness, low cost as well as low time constant. However, the major drawback of the highly nonlinear relationship between the resistance R_θ of the thermistor and the temperature θ it is subjected to, often overshadows the advantages that the thermistor offers for the measurement of temperature. Different means to linearise, along with the precise nature of this relationship have been a matter of study for a long time. Bosson *et al.* developed the three constant fit of the thermistor for the ln R_θ versus $1/\theta$ curve in 1950, though the exponential nature of the resistance–temperature relation of a thermistor dated back to 1946. The problem of linearising this relationship has persisted. A number of methods to linearise the temperature–resistance relationship of a thermistor were tried. One of the simplest was to put the thermistor in series and/or in parallel with the resistor. However, this method showed linearity only over a small range, that too with drastically reducing the sensitivity. This drawback was tried to be covered by the use of a reciprocal time generator in order to get a digital output proportional to the temperature. Further improvement in linearity was obtained by using a four-constant fit for the relationship between the temperature and the resistance of the thermistor. However it also made the system very complex as four simultaneous nonlinear equations had to be solved to obtain the constants. Subsequently, excellent linearity (~ 0.02%) was obtained by approximating Bosson's three-constant law to develop a linear temperature–time period converter, incorporating a thermistor. But the circuit provided over a very narrow range of 10 K, the reason being that such a small variation was one of the essential assumptions on which the approximation of the thermistor characteristic was based. Another method for the linearization of the output of a thermistor, where differing degrees of linearity were obtained over limited ranges of temperatures involved the use of different kinds of multi vibrators. Whatever methods were discussed, none of them achieves linearity over the entire dynamic range of operation of a thermistor while preserving its high sensitivity also.

These methods could achieve desirable levels of linearity over limited temperature ranges. The recent advancements in the field of digital technology along with the easy access of faster and economically viable processing power, soft wares making use of ‘look-up tables’ and ‘maps’ are increasingly being used in the linearization of transducer outputs. Evolutionary algorithms and artificial neural networks are among the new techniques that have been proposed to linearise the output of thermistor based circuits. These methods have an obvious flipside which is their heavy reliance on brute computing power to find the ‘best’ polynomial fit for the temperature–resistance relationship of a thermistor. The outputs of most of these linearising circuits are analog in nature except for the software-based techniques. However, they have to be converted to a digital form before being interfaced with digital instruments. Clearly, the system would be much simpler and robust if the analog-to-digital converter becomes an integral part of the linearizing circuit, so that the final output is linear as well as digitally compatible. A similar linearising digital converter incorporating such features is being shown here. Also, its efficacy is validated through hardware simulation.

2.2 MATHEMATICAL ANALYSIS OF THE THERMISTOR EQUATION

The equation relating the resistance R_θ of a thermistor and its temperature θ, as derived by Steinhart–Hart is

$$R_\theta = R_o e^{\beta(1/\theta - 1/T_0)} \tag{2.1}$$

Here

β is the sensitivity index constant specific to a particular type of thermistor

R_θ is the resistance at temperature θ

R_o is the resistance at temperature T_0

Now to linearize, we apply natural logarithm on both sides of equation (2.1)

We get

$$\text{Ln}(R_\theta/R_0) = \beta(1/\theta - 1/T_0) = \beta/\theta - \beta/T_0 \tag{2.2}$$

$$\beta/\theta = \text{Ln}(R_\theta/R_0) + \beta/T_0$$

$$\theta = \beta/(\text{Ln}(R_\theta/R_0) + \beta/T_0) \tag{2.3}$$

(2.1) simplifies to (2.3) with θ as the value to be calculated.

Now we know that the output of the Log Amp is given by

$$V_{log} = 0.5 \log_{10} (I_1/I_2) \quad (2.4)$$

Also

$$I_1 = V_{ref}/ R_1 \quad \text{and} \quad I_2 = V_{ref}/ R_2 \quad (2.5)$$

Therefore

$$V_{log} = 0.5 \log_{10} (R_2/R_1) \quad (2.6)$$

Let

$$R_\theta = R_2 \quad \text{and} \quad R_0 = R_1 \quad (2.7)$$

this implies

$$V_{log} = 0.5 \log_{10} (R_\theta/R_0) \quad (2.8)$$

Now we convert natural log to base 10 log in (3) and also include the factor of 0.5 in the same equation, we get:

$$\theta = \beta/ [\{2 \ln 10 (0.5 \text{Log}_{10} (R_\theta/R_0)\} + \beta/T_0] \quad (2.9)$$

But from (2.8) we know that

$$V_{log} = 0.5 \log_{10} (R_\theta/R_0)$$

Substituting the value of V_{log} in (2.9) , we get

$$\theta = \beta/ [4.6 V_{log} + \beta/T_0] \quad (2.10)$$

Dividing both numerator as well as denominator of equation (2.10) by β/100, we get

$$\theta = 100/ [(460 V_{log})/ \beta + 100/T_0] \quad (2.11)$$

The thermistor chosen for the experiment is NTCLE203E3272FB0. As per the datasheet of the above mentioned thermistor, the value of β is 3977 at R_{25}=2.7 Kohms.

Substituting the value in equation (2.11) above we get:

$$\theta = 100/ [\ 0.1V_{log} + 100/T_0] \tag{2.12}$$

Now consider the temperature value T_0 = 25˚ c or 298 K (the temperature is chosen such that the current in the Log Amp is in the working range and doesn't reach saturation)
Therefore equation (2.12) further reduces to

$$\theta = 100/ [\ 0.1V_{log} + 0.33] \tag{2.13}$$

$$\theta = 1000/ [\ V_{log} + 3.3] \tag{2.14}$$

This can be further written as

$$\theta = [\ 1/ (V_{log} + 3.3)]\ 1000 \tag{2.15}$$

Now consider the ADC (Intersil ICL 7106), the count of which is given by

$$N_2 = (V_{in}/V_{Ref})\ 1000 \tag{2.16}$$

If

$$V_{in} = 1\ V \quad \text{and} \quad V_{Ref} = (V_{log} + 3.3)V \tag{2.17}$$

Then we see that equation (2.15) and (2.16) are equal.
Hence

$$\mathbf{N_2 = \theta} \tag{2.18}$$

and therefore the output display of the ADC shall directly indicate the temperature of the thermistor (R_θ).

2.3 HARDWARE REQUIREMENT

In the previous section, we analysed mathematically, as to how we can linearise the temperature vis a vis the resistance of a thermistor. It was also proved mathematically that the count of ADC is equal to the temperature sensed by the thermistor. Here we shall discuss the hardware required for implementation of the same. The functional block diagram for the circuit is as shown in fig. 3.1 and fig. 3.2. It consists of the following main blocks:

(1) NI ELVIS II Board

(2) LOG 112

(3) ADC ICL 7106

(4) TL 084C

(5) 3.5 DIGIT LCD DISPLAY

2.3.1 NI ELVIS II

The National Instruments Educational Laboratory Virtual Instrumentation Suite II (NI ELVIS II) is a LabVIEW and computer based design and prototyping environment. NI ELVIS II consists of 34 accustom-designed bench top workstation, a prototyping board, a multifunction data acquisition device, and LabVIEW based virtual instruments. All these put together form an integrated platform for instrumentation. It gives similar functionality as the DMM, Oscilloscope, Function Generator, and power Supply found on the laboratory workbench. The NI ELVIS II Workstation can either be controlled through manual knobs given on the front or through the software virtual instruments. The virtual instrument provided on the NI ELVIS II software suite helps it in performing functions similar to a number of much more expensive instruments. They can be used in various fields as diverse as engineering, physical sciences or biological sciences laboratories. The software suite provides complete testing, measurement, and data logging capabilities .The environment consists of the following two components:

(1) Bench top hardware workspace for building circuits, shown in Figure 2.1

(2) NI Elvis software interface consisting of twelve soft front panels (SFP) instrument, shown in Figure 2.2.

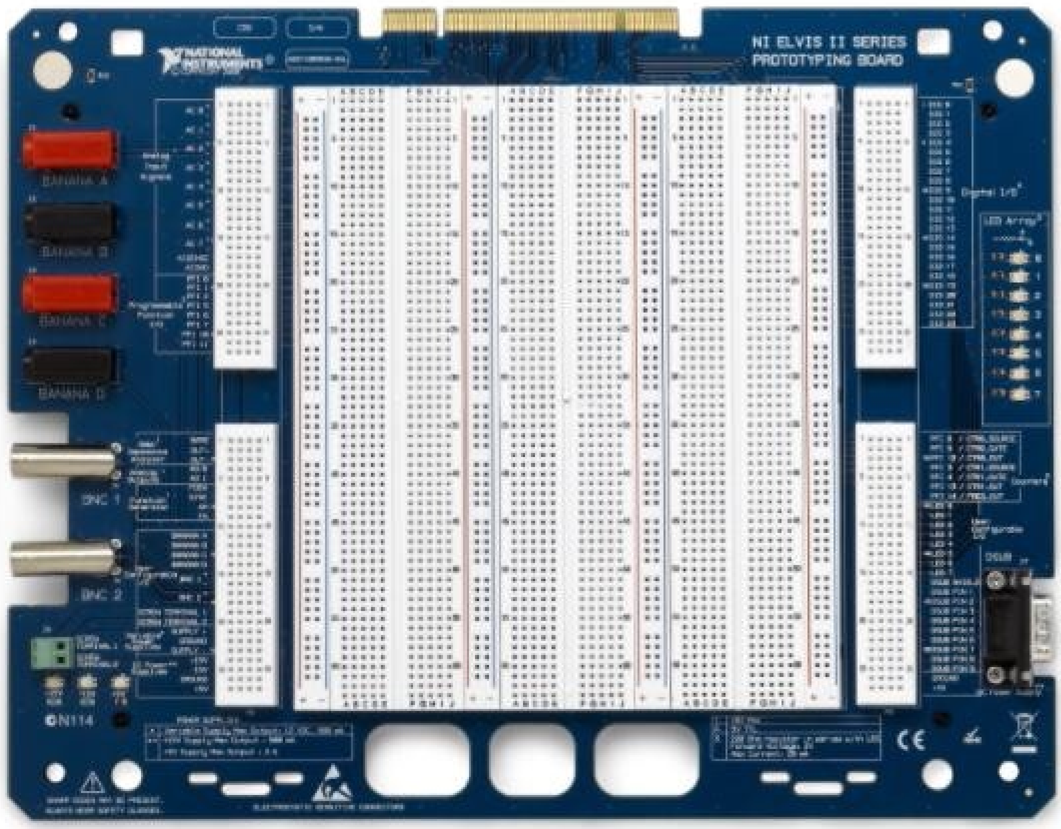


Figure 2.1: NI ElVIS II hardware

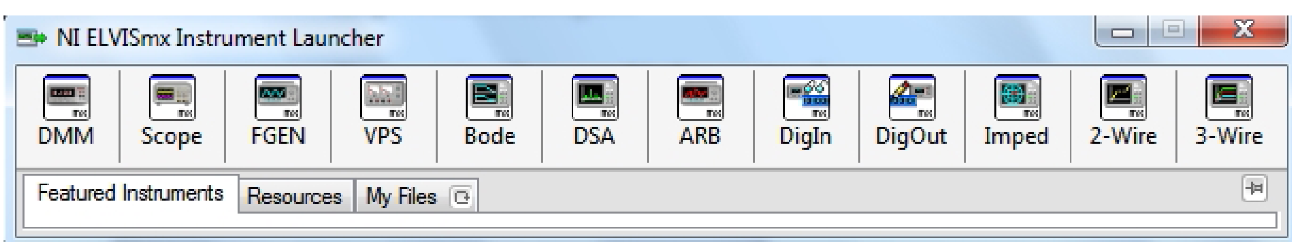


Figure 2.2: NI ELVIS II Soft Panel

The soft panels are:

• Digital Multimeter (DMM)

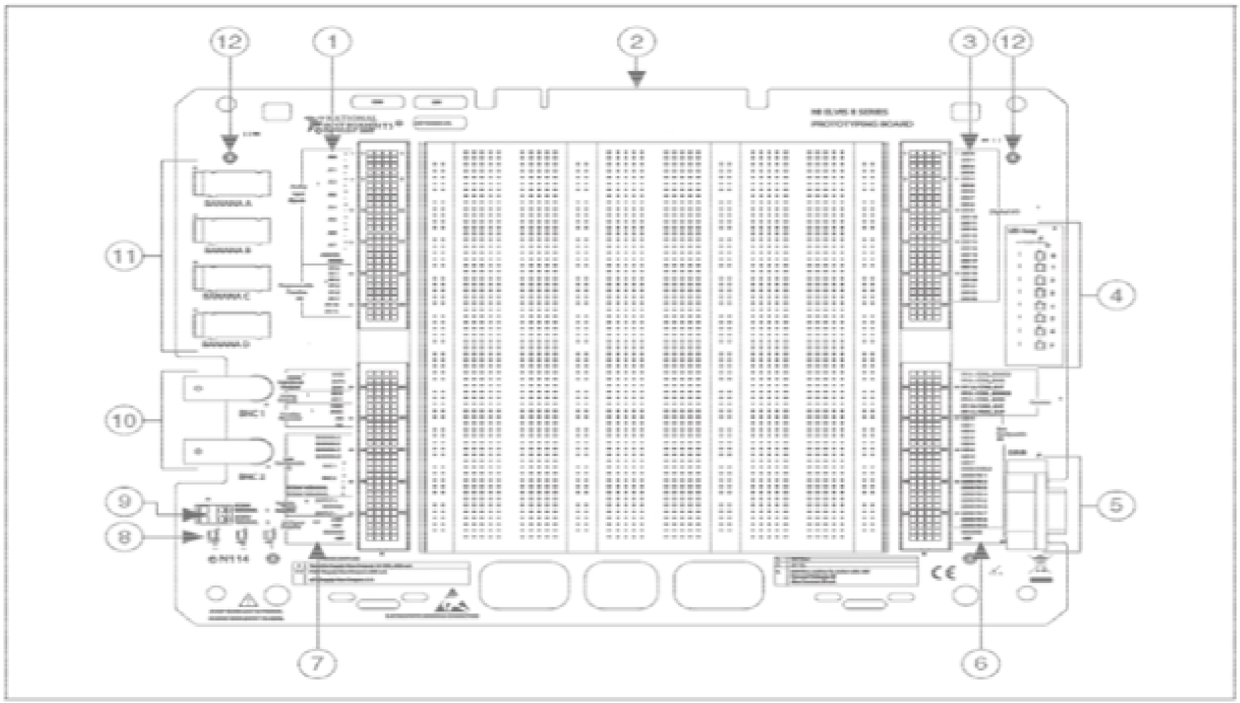
• Oscilloscope (Scope)
• Function Generator (FGEN)
• Variable Power Supply (VPS)
• Bode Analyzer
• Dynamic Signal Analyzer (DSA)
• Arbitrary Waveform Generator (ARB)
• Digital Reader (DigIn)
• Digital Writer (DigOut)
• Impedance Analyzer
• Two –wire Current-Voltage Analyzer
• Three –wire Current-Voltage Analyzer

2.3.2 NI ELVIS II Bench top Workstation

NI ELVIS II hardware consists of two parts namely the Bench top Workstation and Series Prototyping Board The workstation control panel provides easy-to-operate knobs for the variable power supplies and function generator and offers convenient connectivity and functionality in the form of BNC and banana-style connectors, shown in Figure 2.3, to the function generator, scope, and DMM instruments at the right side of the bench top.

2.3.3 NI ELVIS II Series Prototyping Board

In this section, we shall discuss how to connect circuits to NI ELVIS II Series Prototyping Board and how to use it. The Board is connected to the bench top workstation. It provides an area for building electronic circuitry and also provides the required connections to access signals for commonly used applications. Figure 2.3 shows the prototyping board with a brief description. Multiple prototyping boards can be used interchangeably with the NI ELVIS II Bench top workstation, removing it from the bench top workstation. The prototyping board connector can be used to install customised prototype boards which are developed by the user. This connector is mechanically the same as a standard PCI connector.



1 AI and PFI Signal Rows
2 Benchtop Workstation Interface Connector
3 DIO Signal Rows
4 User Configurable LEDs
5 User Configurable D-SUB Connector
6 Counter/Timer, User-Configurable I/O, and DC Power Supply Signal Rows
7 DMM, AO, Function Generator, User-Configurable I/O, Variable Power Supplies, and DC Power Supplies Signal Rows
8 DC Power Supply Indicators
9 User-Configurable Screw Terminals
10 User Configurable BNC Connectors
11 User Configurable Banana Jack Connectors
12 Screw Positions for Locking

Figure 2.3: Prototyping Board Description .

2.3.5 NI ELVIS Functions

A number of functions similar to real instruments used commonly in labs can be performed using NI ELVIS II. The hardware and software are integrated to perform multi functions as described below:

DMM

The primary DMM instrument on NI ELVIS II is isolated. It's terminals are the three banana jacks on the side of the bench top workstation. The V connectors are used for DC Voltage, AC and COM voltage, Resistance, Diode, and Continuity Test modes. The A and COM connectors are used for DC Current and AC Current modes. For easy access to circuits on the prototyping board, you can use banana-to-banana cables to wrap the signals from the user configurable banana jacks to the DMM connectors on the bench top workstation.

Oscilloscope

The two oscilloscope channels are available at BNC connectors on the side of the input impedance and can bench top workstation. These channels have robust 1 M be used with 1X / 10X attenuated probes. You can also use high-impedance Analog Input channels AI to AI7 available on the prototyping board.

Function Generator (FGEN)

The output of the function generator is given through either the FGEN/TRIG BNC connector or the FGEN terminal on the prototyping board. A +5 V digital signal is available at the SYNC terminal. The amplitude and frequency modulation of the function generator output can be achieved through the AM and FM terminals provided.

Power Supply

The DC power supply gives a fixed output of ±15 V and +5 V. However, through the variable power supply, an adjustable output voltage levels from 0 to +12 V on the + terminal, and 0 to – 12 V on the – terminal can be obtained. All power supplies on NI ELVIS II are referenced to ground .

Bode Analyzer

The Bode Analyzer uses the Function Generator to output a stimulus and then uses analog input channels AI 0 and AI 1 to measure the response and stimulus respectively.

2.4 LOGARITHMIC AMPLIFIER LOG 112

The LOG112 is a logarithmic amplifier that calculates the logarithm, or logarithmic ratio of a current ratio using the base-emitter voltage relationship of bipolar transistors. Figure 2.4 is showing the general connections required for operation of the LOG112. Each power supply shown is bypassed with a 10µF tantalum capacitor in parallel with a 1000pF ceramic capacitor so as to reduce the influence of lead inductance of power-supply lines, as shown in Fig. 2.4. Also the noise level can be reudced by connecting the capacitors as close to the LOG 112 as possible.

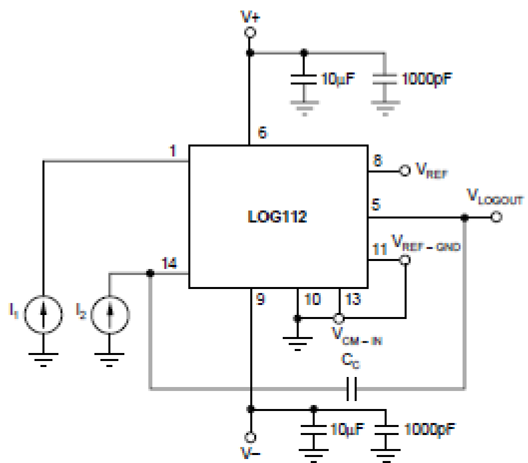


Figure 2.4 Connections of LOG 112

The pin configuration of LOG 112 is as shown below:

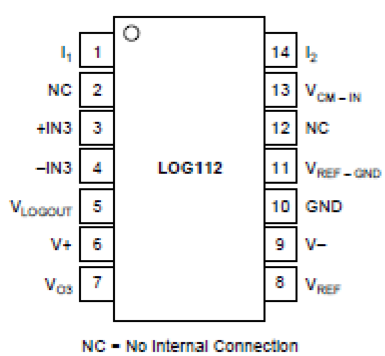


Figure 2.5: PIN CONFIGURATION OF LOG 112

2.4.1 ELECTRICAL CHARACTERISTICS OF LOG 112

Some of the major characteristics as provided by the manufacturer M/s Texas Instruments are as tabulated below:

PARAMETER	CONDITION	LOG112, LOG2112			UNITS
		MIN	TYP	MAX	
CORE LOG FUNCTION					
V_{IN}/V_{OUT} Equation			$V_{LOGOUT} = (0.5V)LOG(I_1/I_2)$		V
LOG CONFORMITY ERROR[1]					
Initial	1nA to 100µA (5 decades)		0.01	0.2	%
	100pA to 3.5mA (7.5 decades)		0.13		%
over Temperature	**1nA to 100µA (5 decades)**		0.0001		%/°C
	100pA to 3.5mA (7.5 decades)		0.005		%/°C
GAIN[2]					
Initial Value	1nA to 100µA		0.5		V/decade
Gain Error	1nA to 100µA		0.10	±1	%
vs Temperature	**T_{MIN} to T_{MAX}**		**0.003**	**0.01**	%/°C
INPUT, A_{1A} and A_{1B}, A_{2A}, A_{2B}					
Offset Voltage			±0.3	±1.5	mV
vs Temperature	**T_{MIN} to T_{MAX}**		**±2**		**µV/°C**
vs Power Supply (PSRR)	V_S = ±4.5V to ±18V		5	20	µV/V
Input Bias Current			±5		pA
vs Temperature	**T_{MIN} to T_{MAX}**		**Doubles Every 10°C**		
Voltage Noise	f = 10Hz to 10kHz		3		µVrms
	f = 1kHz		30		nV/√Hz
Current Noise	f = 1kHz		4		fA/√Hz
Common-Mode Voltage Range (Positive)		(V+) – 2	(V+) – 1.5		V
(Negative)		(V–) + 2	(V–) + 1.2		V
Common-Mode Rejection Ratio (CMRR)			10		µV/V
OUTPUT, ($V_{LOG\ OUT}$) A_{2A}, A_{2B}					
Output Offset, V_{OSO}, Initial			±3	±15	mV
vs Temperature	**T_{MIN} to T_{MAX}**		**±10**		**µV/°C**
Full-Scale Output (FSO)	V_S = ±5V	(V–) + 1.2		(V+) – 1.5	V
Short-Circuit Current			±18		mA
TOTAL ERROR[3][4]	I_1 or I_2 remains fixed while other varies.				
Initial	Min to Max				
	I_1 or I_2 = 5mA ($V_S \geq$ ±6V)			±150	mV
	I_1 or I_2 = 3.5mA			±75	mV
	I_1 or I_2 = 1mA			±20	mV
	I_1 or I_2 = 100µA			±20	mV
	I_1 or I_2 = 10µA			±20	mV
	I_1 or I_2 = 1µA			±20	mV
	I_1 or I_2 = 100nA			±20	mV
	I_1 or I_2 = 10nA			±20	mV
	I_1 or I_2 = 1nA			±20	mV
	I_1 or I_2 = 350pA			±20	mV
	I_1 or I_2 = 100pA			±20	mV
vs Temperature	**I_1 or I_2 = 3.5mA**		**±1.2**		**mV/°C**
	I_1 or I_2 = 1mA		**±0.4**		**mV/°C**
	I_1 or I_2 = 100µA		**±0.1**		**mV/°C**
	I_1 or I_2 = 10µA		**±0.05**		**mV/°C**
	I_1 or I_2 = 1µA		**±0.05**		**mV/°C**
	I_1 or I_2 = 100nA		**±0.09**		**mV/°C**
	I_1 or I_2 = 10nA		**±0.2**		**mV/°C**
	I_1 or I_2 = 1nA		**±0.3**		**mV/°C**
	I_1 or I_2 = 350pA		**±0.1**		**mV/°C**
	I_1 or I_2 = 100pA		**±0.3**		**mV/°C**
vs Supply	I_1 or I_2 = 3.5mA		±3.0		mV/V
	I_1 or I_2 = 1mA		±0.1		mV/V
	I_1 or I_2 = 100µA		±0.1		mV/V
	I_1 or I_2 = 10µA		±0.1		mV/V
	I_1 or I_2 = 1µA		±0.1		mV/V
	I_1 or I_2 = 100nA		±0.1		mV/V
	I_1 or I_2 = 10nA		±0.1		mV/V
	I_1 or I_2 = 1nA		±0.25		mV/V
	I_1 or I_2 = 350pA		±0.1		mV/V
	I_1 or I_2 = 100pA		±0.1		mV/V

Table 1: ELECTRICAL CHARACTERISTICS OF LOG 112

PARAMETER	CONDITION	LOG112, LOG2112 MIN	TYP	MAX	UNITS
FREQUENCY RESPONSE, CORE LOG[5]					
BW, 3dB					
I_2 = 10nA	C_C = 4500pF		0.1		kH
I_2 = 1µA	C_C = 150pF		38		kH
I_2 = 10µA	C_C = 150pF		40		kH
I_2 = 1mA	C_C = 50pF		45		kHz
Step Response					
Increasing					
I_1 = 10nA to 100nA	C_C = 120pF, I_2 = 31.6nA		1.1		ms
I_1 = 1µA to 100µA	C_C = 375pF, I_2 = 10µA		1.6		µs
I_1 = 1µA to 1mA	C_C = 950pF, I_2 = 31.6µA		1.5		µs
Decreasing					
I_1 = 100nA to 10nA	C_C = 120pF, I_2 = 31.6nA		2.1		ms
I_1 = 100µA to 1µA	C_C = 375pF, I_2 = 10µA		31.2		µs
I_1 = 1mA to 1µA	C_C = 950pF, I_2 = 31.6µA		39		µs
Increasing					
I_2 = 10nA to 100nA	C_C = 125pF, I_1 = 31.6nA		2.6		ms
I_2 = 1µA to 100µA	C_C = 750pF, I_1 = 10µA		113		µs
I_2 = 1µA to 1mA	C_C = 10.5nF, I_1 = 31.6µA		1.2		ms
Decreasing					
I_2 = 100nA to 10nA	C_C = 125pF, I_1 = 31.6nA		630		µs
I_2 = 100µA to 1µA	C_C = 750pF, I_1 = 10µA		6.6		µs
I_2 = 1mA to 1µA	C_C = 10.5nF, I_1 = 31.6µA		13.3		µs
OP AMP, A3					
Input Offset Voltage			+250	±1000	µV
vs Temperature	**T_{MIN} to T_{MAX}**		±2		µV/°C
vs Supply	V_S = ±4.5V to ±18V		5	50	µV/V
Input Bias Current			–10		nA
Input Offset Current			±0.5		nA
Input Voltage Range		(V–)		(V+) – 1.5	V
Input Noise, f = 0.1Hz to 10Hz			1		µVp-p
f = 1kHz			28		nV/√Hz
Open-Loop Voltage Gain			88		dB
Gain-Bandwidth Product			1.4		MHz
Slew Rate			0.5		V/µs
Settling Time, 0.01%	G = –1, 3V Step, C_L = 100pF		16		µs
Rated Output		(V–) + 1.5		(V+) – 0.9	V
Short-Circuit Current			±4		mA
VOLTAGE REFERENCE					
Bandgap Voltage			2.5		V
Error, Initial			±0.05	±0.5	%
vs Temperature	T_{MIN} to T_{MAX}		±25		ppm/°C
vs Supply	V_S = ±4.5V to ±18V		±10		ppm/V
vs Load	I_{LOAD} = 10mA		±600		ppm/mA
Short-Circuit Current			16		mA
POWER SUPPLY					
Operating Range	V_S	±4.5		±18	V
Quiescent Current	I_O = 0				
LOG112			±1.25	±1.75	mA
LOG2112			±2.5	±3.5	mA
TEMPERATURE RANGE					
Specified Range, T_{MIN} to T_{MAX}		–5		75	°C
Operating Range		–40		85	°C
Storage Range		–55		125	°C
Thermal Resistance, θ_{JA} SO-14			110		°C/W
SO-16			80		°C/W

Table 1 (cont.): ELECTRICAL CHARACTERISTICS OF LOG 112

2.4.2 INSIDE THE LOG 112

The following table highlights the basic functioning of a Log Amp. The internal circuit of the Log Amp is also highlighted along with it.

INSIDE THE LOG112

Using the base-emitter voltage relationship of matched bipolar transistors, the LOG112 establishes a logarithmic function of input current ratios. Beginning with the base-emitter voltage defined as:

$$V_{BE} = V_T \ln \frac{I_C}{I_S} \quad \text{where}: V_T = \frac{kT}{q} \qquad (1)$$

k = Boltzman's constant = $1.381 \cdot 10^{-23}$

T = Absolute temperature in degrees Kelvin

q = Electron charge = $1.602 \cdot 10^{-19}$ Coulombs

I_C = Collector current

I_S = Reverse saturation current

From the circuit in Figure 12:

$$V_L = V_{BE_1} - V_{BE_2} \qquad (2)$$

Substituting (1) into (2) yields:

$$V_L = V_{T_1} \ln \frac{I_1}{I_{S_1}} - V_{T_2} \ln \frac{I_2}{I_{S_2}} \qquad (3)$$

If the transistors are matched and isothermal and $V_{TI} = V_{T2}$, then (3) becomes:

$$V_L = V_{T_1} \left[\ln \frac{I_1}{I_S} - \ln \frac{I_2}{I_S} \right] \qquad (4)$$

$$V_L = V_T \ln \frac{I_1}{I_2} \text{ and since} \qquad (5)$$

$$\ln x = 2.3 \log_{10} x \qquad (6)$$

$$V_L = n\,V_T \log \frac{I_1}{I_2} \qquad (7)$$

where n = 2.3 (8)

also

$$V_{OUT} = V_L \frac{R_1 + R_2}{R_1} \qquad (9)$$

$$V_{OUT} = \frac{R_1 + R_2}{R_1} n\,V_T \log \frac{I_1}{I_2} \qquad (10)$$

or

$$V_{OUT} = (0.5V) LOG \left(\frac{I_1}{I_2} \right) \qquad (11)$$

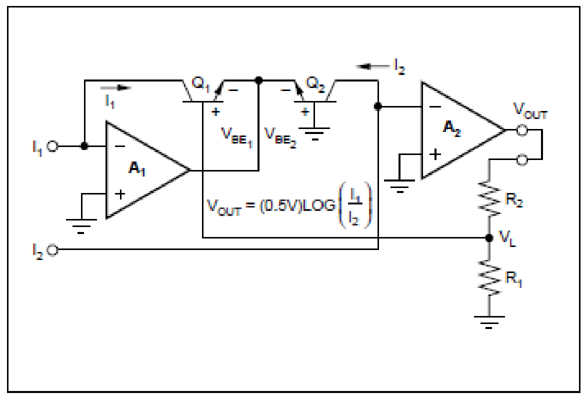


FIGURE 13. Simplified Model of a Log Amplifier.

NOTE: R_1 is a metal resistor used to compensate for gain over temperature.

Table 2: INSIDE THE LOG 112

2.5 3.5 DIGIT ADC (ICL 7106 BY M/S INTERSIL)

The Intersil ICL7106 is a 3.5 digit Analog to Digital converter (ADC) consuming low power while simultaneously giving high performance. It can be interfaced with a Liquid Crystal Display (LCD) and also has a multiplexed backplane drive. It has a seven segment decoders, display drivers, a reference and a clock.. All these features make it a potentially highly accurate, good versatility, and economical device. It is known that if we have true differential inputs and reference, they are very useful in all the processes. Along with it, they also give the designer an unusual edge in measurement of strain gauges, load cells and other bridge type transducers. Ultimately it shows a high performance with single power supply operation and built with additional only 10 passive components along with a display. The pin configuration of the ADC is as shown below:

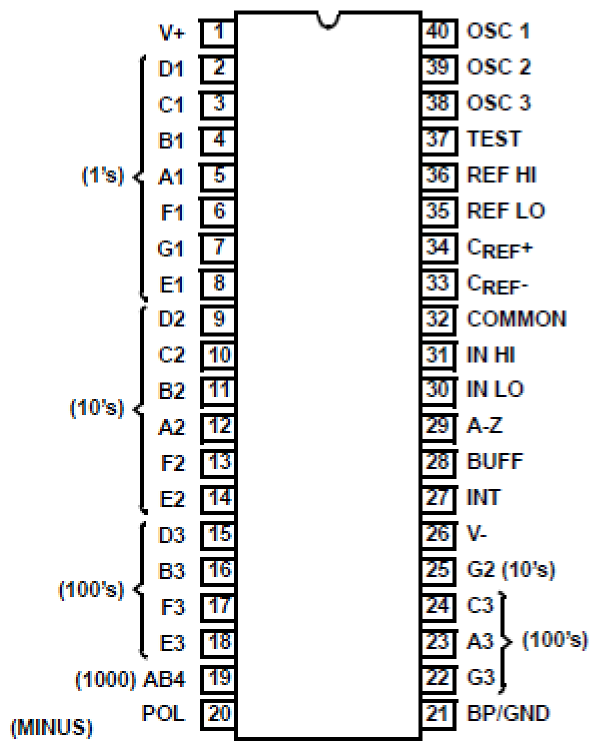


Figure 2.6: PIN CONFIGURATION OF THE ICL 7106 ADC

2.5.1 DETAILED DESCRIPTION

Here we shall discuss in detail the operation of ICL 7106. It works like a conventional DSADC. Before the start of any conversion cycle of V_{log} , it needs to be ensured that the output of the integrator is zero. Therefore, an auto zero phase precedes any conversion cycle. Each measurement cycle is divided into two phases. They are :

(1) Auto-zero (A-Z)- On issue of a fresh conversion signal, it is possible that the output

of the integrator V_{oi} is negative, which in turn means that the comparator output Vc is low. This condition is sensed by the TLU and the control logic gives a signal such that a current ic= Vr/R starts flowing through the capacitor C. This leads to the output of the integrator to ramp up toward zero. The integrator output V_{oi} reaches zero and the TLU changes the comparator output from low to high marking the end of auto zero phase. Similarly, if that the output of the integrator V_{oi} is positive, which in turn means that the comparator output Vc is high. This condition is sensed by the TLU and the control logic gives a signal such that a current ic= -Vr/R starts flowing through the capacitor C. This leads to the output of the integrator to ramp down towards zero. The integrator output V_{oi} reaches zero and the TLU changes the comparator output from high to low marking the end of auto zero phase.

(2) Conversion Phase- It has two analog signals one is the input voltage (Vin) ans the other is the reference voltage (Vref). These two signals are processed through a switching module. Then the analog signal (continuous in time) are sampled and integrated through the integrator module. Subsequently, the reference signal, which has a negative polarity, is integrated. The integration process stops as and when the comparator determines that the voltage level has become zero. The time taken for integration of the reference signal is proportional to the value of the analog signal sample. Subsequently, the counter gives a digital output of the input signal, which is converted into a decimal code and displayed on the unit.

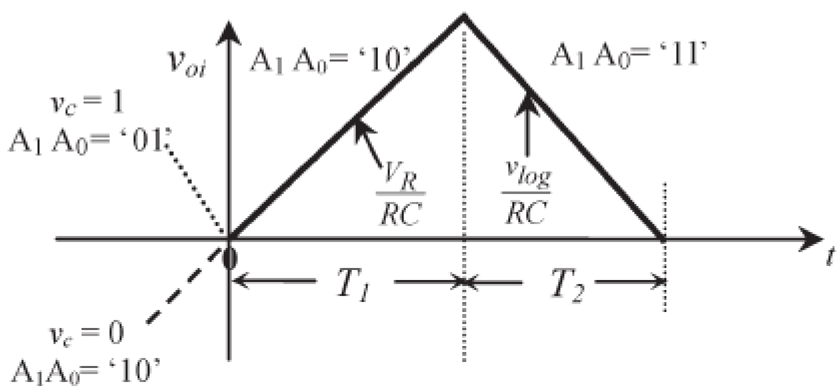


FIGURE 2.7: AUTOZERO ,INTEGRATION & DE-INTEGRATION PHASE

The decimal count displayed on the screen is given by

$$\text{DISPLAY COUNT } (N_2) = 1000\ (V_{IN}/V_{REF})$$

.

2.5.2 ELECTRICAL SPECIFICATIONS

The electrical specifications with respect to ICL 7106 are as mentioned in the table below:

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
SYSTEM PERFORMANCE					
Zero Input Reading	V_{IN} = 0.0V, Full Scale = 200mV	-000.0	±000.0	+000.0	Digital Reading
Stability (Last Digit) (ICL7106S, ICL7107S Only)	Fixed Input Voltage (Note 6)	-000.0	±000.0	+000.0	Digital Reading
Ratiometric Reading	V_{IN} = V_{REF}, V_{REF} = 100mV	999	999/1000	1000	Digital Reading
Rollover Error	$-V_{IN} = +V_{IN} \cong$ 200mV Difference in Reading for Equal Positive and Negative Inputs Near Full Scale	-	±0.2	±1	Counts
Linearity	Full Scale = 200mV or Full Scale = 2V Maximum Deviation from Best Straight Line Fit (Note 5)	-	±0.2	±1	Counts
Common Mode Rejection Ratio	V_{CM} = 1V, V_{IN} = 0V, Full Scale = 200mV (Note 5)	-	50	-	μV/V
Noise	V_{IN} = 0V, Full Scale = 200mV (Peak-To-Peak Value Not Exceeded 95% of Time)	-	15	-	μV
Leakage Current Input	V_{IN} = 0 (Note 5)	-	1	10	pA
Zero Reading Drift	V_{IN} = 0, 0^oC To 70^oC (Note 5)	-	0.2	1	$\mu V/^oC$
Scale Factor Temperature Coefficient	V_{IN} = 199mV, 0^oC To 70^oC, (Ext. Ref. 0ppm/×°C) (Note 5)	-	1	5	$ppm/^oC$
End Power Supply Character V+ Supply Current	V_{IN} = 0 (Does Not Include LED Current for ICL7107)	-	1.0	1.8	mA
End Power Supply Character V- Supply Current	ICL7107 Only	-	0.6	1.8	mA
COMMON Pin Analog Common Voltage	25kΩ Between Common and Positive Supply (With Respect to + Supply)	2.4	3.0	3.2	V
Temperature Coefficient of Analog Common	25kΩ Between Common and Positive Supply (With Respect to + Supply)	-	80	-	$ppm/^oC$
DISPLAY DRIVER ICL7106 ONLY					
Peak-To-Peak Segment Drive Voltage Peak-To-Peak Backplane Drive Voltage	V+ = to V- = 9V (Note 4)	4	5.5	6	V

Table 3: ELECTRICAL SPECIFICATIONS OF ICL 7106

The ADC has various other design data. Some of the important ones are as tabulated below:

- **OSCILLATOR FREQUENCY**

  $f_{OSC} = 0.45/RC$
  $C_{OSC} > 50pF$; $R_{OSC} > 50k\Omega$
  f_{OSC} (Typ) = 48kHz

- **OSCILLATOR PERIOD**

  $t_{OSC} = RC/0.45$

- **INTEGRATION CLOCK FREQUENCY**

  $f_{CLOCK} = f_{OSC}/4$

- **INTEGRATION PERIOD**

  $t_{INT} = 1000 \times (4/f_{OSC})$

- **60/50Hz REJECTION CRITERION**

  t_{INT}/t_{60Hz} or t_{INT}/t_{60Hz} = Integer

- **OPTIMUM INTEGRATION CURRENT**

  $I_{INT} = 4\mu A$

- **FULL SCALE ANALOG INPUT VOLTAGE**

  V_{INFS} (Typ) = 200mV or 2V

- **INTEGRATE RESISTOR**

  $$R_{INT} = \frac{V_{INFS}}{I_{INT}}$$

- **INTEGRATE CAPACITOR**

  $$C_{INT} = \frac{(t_{INT})(I_{INT})}{V_{INT}}$$

- **DISPLAY COUNT**

  $$COUNT = 1000 \times \frac{V_{IN}}{V_{REF}}$$

- **CONVERSION CYCLE**

  $t_{CYC} = t_{CLOCK} \times 4000$
  $t_{CYC} = t_{OSC} \times 16,000$
  when $f_{OSC} = 48kHz$; $t_{CYC} = 333ms$

- **COMMON MODE INPUT VOLTAGE**

  $(V- + 1V) < V_{IN} < (V+ - 0.5V)$

- **AUTO-ZERO CAPACITOR**

  $0.01\mu F < C_{AZ} < 1\mu F$

- **REFERENCE CAPACITOR**

  $0.1\mu F < C_{REF} < 1\mu F$

- **V_{COM}**

  Biased between Vi and V-.

- **$V_{COM} \cong$ V+ - 2.8V**

  Regulation lost when V+ to V- < ≅6.8V
  If V_{COM} is externally pulled down to (V+ to V-)/2, the V_{COM} circuit will turn off.

- **ICL7106 POWER SUPPLY: SINGLE 9V**

  V+ - V- = 9V
  Digital supply is generated internally
  $V_{GND} \cong$ V+ - 4.5V

- **ICL7106 DISPLAY: LCD**

  Type: Direct drive with digital logic supply amplitude.

2.6 THERMISTOR NTCLE203E3272FB0

The thermistor used for the experiment is NTCLE203E3272FB0 from Vishay BC components and is made of ceramic material. It consists of a chip with two projecting nickel leads as shown in the figure below. There is color band marking on top.

FIGURE 2.8: THERMISTOR

Some quick reference data with respect to the chosen thermistor is shown in the table below:

PARAMETER	VALUE	UNIT
Resistance value at 25 °C	2K to 470K	Ω
Tolerance on R_{25}-value	± 1; ± 2; ± 3; ± 5	%
$B_{25/85}$-value	3528 to 4570	K
Tolerance on $B_{25/85}$-value	± 0.5 to ± 2.0	%
Operating temperature range at: Zero dissipation (continuously) Zero dissipation (for short periods) (2) Maximum power dissipation	 - 40 to + 125 ≤ 150 0 to + 55	°C
Maximum power dissipation	100	mW
Dissipation factor δ	2.2	mW/K
Response time (1)	≈ 1.7	s
Thermal time constant τ	13	
Climatic category (LCT/UCT/days)	40/125/56	
Mass	≈ 0.11	g

Table 4: THERMISTOR PARAMETERS

RESISTANCE VALUES AT INTERMEDIATE TEMPERATURES WITH R_{25} AT 2.7 kΩ , 4.7 kΩ, 5.0 kΩ , AND 10 kΩ						
T_{OPER} (°C)	PART NUMBER NTCLE203E3272*B0	PART NUMBER NTCLE203E3472*B0	PART NUMBER NTCLE203E3502*B0	PART NUMBER NTCLE203E3103*B0	TCR (%/K)	Δ*R*/*R* DUE TO $B_{Tol.}$ (%)
	R_T (Ω)	R_T (Ω)	R_T (Ω)	R_T (Ω)		
- 40	89 665	156 084	166 047	332 094	- 6.62	2.79
- 35	64 773	112 753	119 950	239 900	- 6.39	2.52
- 30	47 304	82 344	87 600	175 200	- 6.18	2.26
- 25	34 907	60 765	64 643	129 287	- 5.98	2.02
- 20	26 017	45 288	48 179	96 358	- 5.78	1.78
- 15	19 575	34 075	36 250	72 500	- 5.60	1.55
- 10	14 862	25 872	27 523	55 046	- 5.42	1.33
- 5	11 382	19 814	21 078	42 157	- 5.25	1.12
0	8790	15 300	16 277	32 554	- 5.09	0.92
5	6841	11 909	12 669	25 339	- 4.93	0.72
10	5365	9340	9936	19 872	- 4.79	0.53
15	4239	7378	7849	15 698	- 4.64	0.35
20	3372	5869	6244	12 488	- 4.51	0.17
25	2700	4700	5000	10 000	- 4.38	0.00
30	2176	3788	4030	8059	- 4.25	0.17
35	1764	3071	3267	6535	- 4.13	0.32
40	1439	2505	2665	5330	- 4.02	0.48
45	1180	2055	2186	4372	- 3.91	0.63
50	973.4	1694	1803	3605	- 3.80	0.77
55	806.9	1405	1494	2989	- 3.70	0.91
60	672.3	1170	1245	2490	- 3.60	1.05
65	562.8	979.7	1042	2084	- 3.51	1.18
70	473.3	823.9	876.5	1753	- 3.42	1.31
75	399.8	696.0	740.5	1481	- 3.33	1.44
80	339.2	590.5	628.2	1256	- 3.25	1.56
85	289.0	503.0	535.2	1070	- 3.17	1.68
90	247.2	430.2	457.7	915.4	- 3.09	1.79
95	212.2	369.4	393.0	786.0	- 3.01	1.90
100	182.9	318.3	338.6	677.3	- 2.94	2.01
105	158.2	275.3	292.9	585.7	- 2.87	2.12
110	137.2	238.9	254.2	508.3	- 2.80	2.22
115	119.5	208.0	221.3	442.6	- 2.74	2.32
120	104.4	181.7	193.3	386.6	- 2.67	2.42
125	91.46	159.2	169.4	338.7	- 2.61	2.51
130	80.38	139.9	148.8	297.7	- 2.55	2.61
135	70.84	123.3	131.2	262.4	- 2.50	2.70
140	62.62	109.0	116.0	231.9	- 2.44	2.78
145	55.49	96.60	102.8	205.5	- 2.39	2.87
150	49.31	85.84	91.32	182.6	- 2.34	2.96

Table 5: THERMISTOR RESISTANCE (COLUMN 2) AT VARIOUS TEMPERATURES

2.7 TL084C OP AMP

This is a low costing operational amplifier. It has a two useful technologies implanted on a single monolithic integrated circuit. It has four internal op amps and each one is internally compensated for low input offset voltage. The BIFET technology provides wide bandwidths and fast slew rates with low input bias currents, input offset currents, and supply currents. There are four op amps used in the circuit as shown in fig. 3.1. These are utilized from TL 084 C as it is having four op amp. The pin configuration of TL084C is as shown below in fig. 2.9.

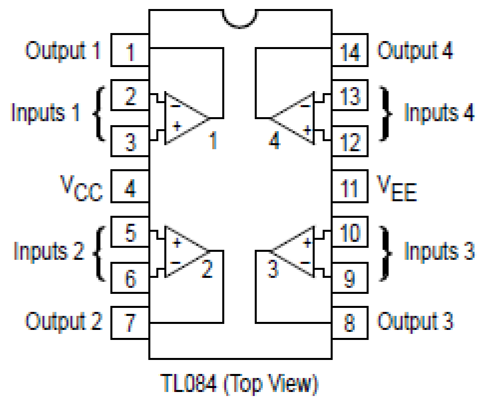


Figure 2.9: Pin configuration of TL 084C

2.8 3.5 Digit LCD Display

This display finally shows the N_2 count or the temperature of the thermistor. It is a 40 pin display as shown below.

Figure 2.10: LCD Display screen

CHAPTER 3

EXPERIMENTAL SETUP AND WORKING OF SIGNAL CONDITIONING CIRCUIT

3.1 Introduction

In the previous chapter, we had a preview of the entire hardware requirement for the experimental setup. It gave us an insight into the characteristics and other parameters of the various components used in the circuit along with the NI ELVIS II board. In this chapter we shall integrate all the components discussed so far on the NI ELVIS board to achieve the complete setup. We shall also discuss the functioning of each and every component individually and how they are contributing to the circuit.

3.2 Experimental Setup

In chapter 2, we had a mathematical analysis of the thermistor equation. The temperature given by the equation was calculated as:

$$\theta = [\ 1/\ (V_{log} + 3.3)]\ 1000 \tag{3.1}$$

Now consider the ADC (Intersil ICLZ7106), the count of which is given by

$$N_2 = (V_{in}/V_{Ref})\ 1000 \tag{3.2}$$

Now if

$$V_{in} = 1\ V \tag{3.3}$$

$$V_{Ref} = (V_{log} + 3.3)\ V \tag{3.4}$$

Then we see that equation (3.1) and (3.2) are equal.

Hence

$$N_2 = \theta \tag{3.5}$$

and therefore the output display of the ADC shall directly indicate the temperature of the thermistor (R_θ).

$$N_2 = \theta = [\ 1/ (V_{log} + 3.3)]\ 1000 \qquad (3.6)$$

So, as we can see our objective is to give supply V_{in} and V_{Ref} to the ADC as given by equations (3.3) and (3.4) . We shall first design a circuit for generating V_{Ref} as per equation (3.4). Subsequently, we shall give a supply $V_{in} = 1$ V to the ADC. Once we have given these supplies to the ADC, the LCD display connected to the ADC shall directly display the temperature or the N_2 count as given by equation (3.2).

3.3 CIRCUIT DESIGN FOR V_{Ref}

The circuit designed for V_{Ref} in order to obtain results as per equation (3.4) is as shown in the circuit diagram below:

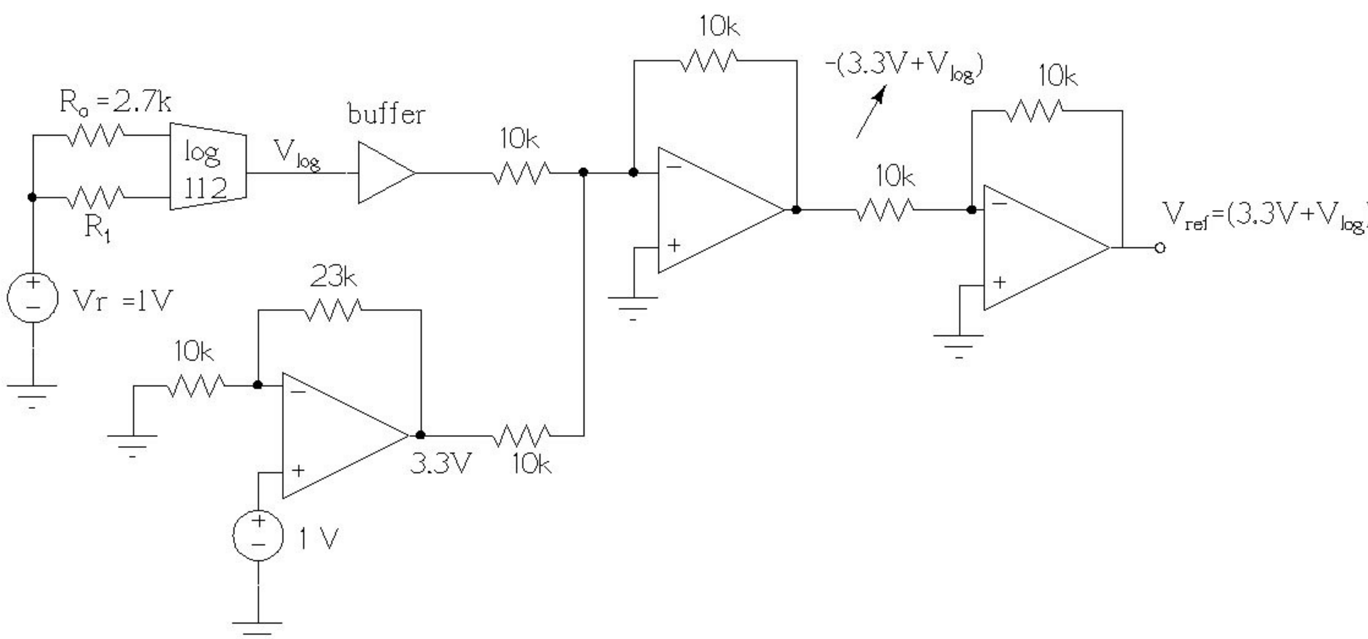


Figure 3.1: Circuit for generation of $V_{Ref} = (V_{log} + 3.3)$ V

The first component in the circuit is LOG 112, to linearise the exponential relationship between the temperature and resistance of the thermistor. Vr given is 1 V (given through VPS of the NI ELVIS board) so that the currents (I_1 and I_2) flowing through both the arms of the Log Amp are within the limits ie 100pA to 3.5 mA. Resistance R_0 was chosen at temperature $T_0 = 298^\circ$ K and its value was 2.7K ohms .These values are again chosen to keep the values of current within the saturation levels. The power supply of 15 volts to the Log Amp is given by NI ELVIS board.

The ouput of the Log Amp is given as:

$$V_{log} = 0.5 \log_{10} (R_\theta/R_0) \quad (3.7)$$

This output of the Log Amp is given to a unity gain buffer just to ensure that there is no attenuation in the output voltage signal ie. V_{log}. Simultaneously, we have another Non Inverting Op Amp generating 3.3 V. This Op Amp is given an input voltage of 1 V through VPS of the NI ELVIS board to it's positive terminal. The resistances in the feedback loop are chosen in such a fashion, that the output voltage achieved is 3.3 volts. Once we have both the output voltages ie. V_{log} and 3.3 V, we need to sum them. This is achieved by giving the output of the two aforementioned Op Amps as input to another Op Amp in the ADDER configuration. Though it adds the two signals, however it also inverts them to give the output as – (V_{log} + 3.3) V. So in order to get the desired signal, we pass it through another Op Amp configured as Inverting amplifier with gain -1. Therefore the final output obtained through this Op Amp is (V_{log} + 3.3) V which is same as V_{Ref} . The power supply to all the op amps is given by the 15 volt supply available on the NI ELVIS board. Also any other voltage required such as 1V is also given through the VPS available on the same board.

3.4 Circuit for the ADC and LCD display

Once we have obtained V_{Ref} as shown in the above circuit, we simply need to supply V_{in} equal to 1 V to the ADC. The circuit diagram for the same is as shown below:

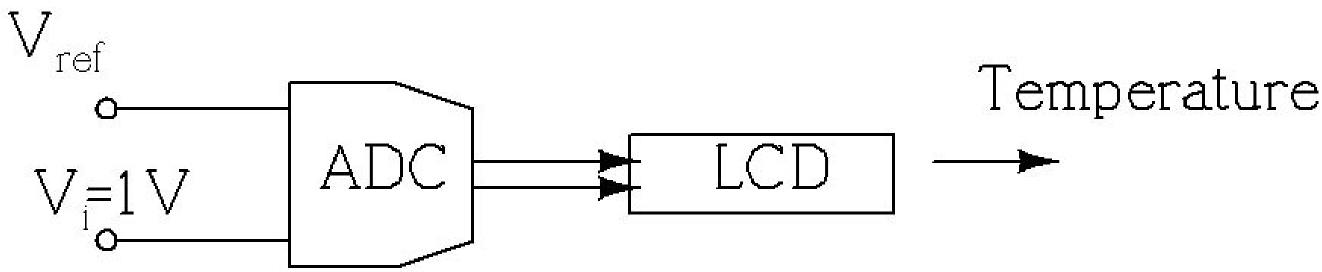


Figure 3.2: Circuit diagram for the ADC and LCD display

The connections given to the LCD display through ADC are standard connections as shown below:

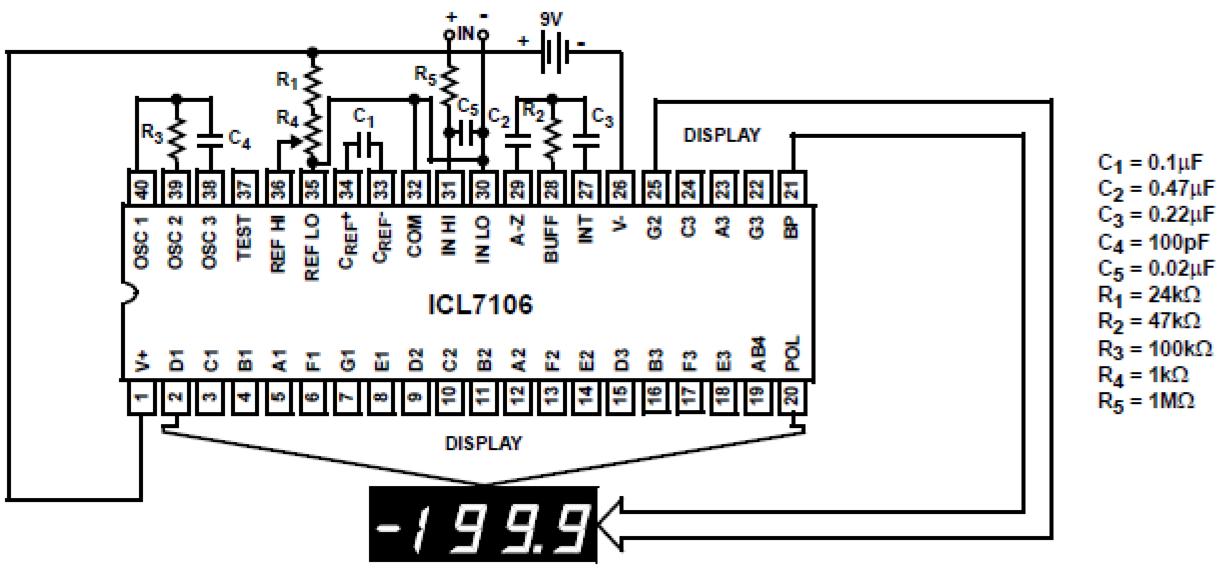


Figure 3.3: ICL7106 test circuit with LCD display components

On powering the circuit, we can see the temperature on the LCD digital display. On varying the temperature of the thermistor, we can see the change in the corresponding output on the screen.

The integrated circuit for the experiment as developed on the NI ELVIS II board is as shown below:

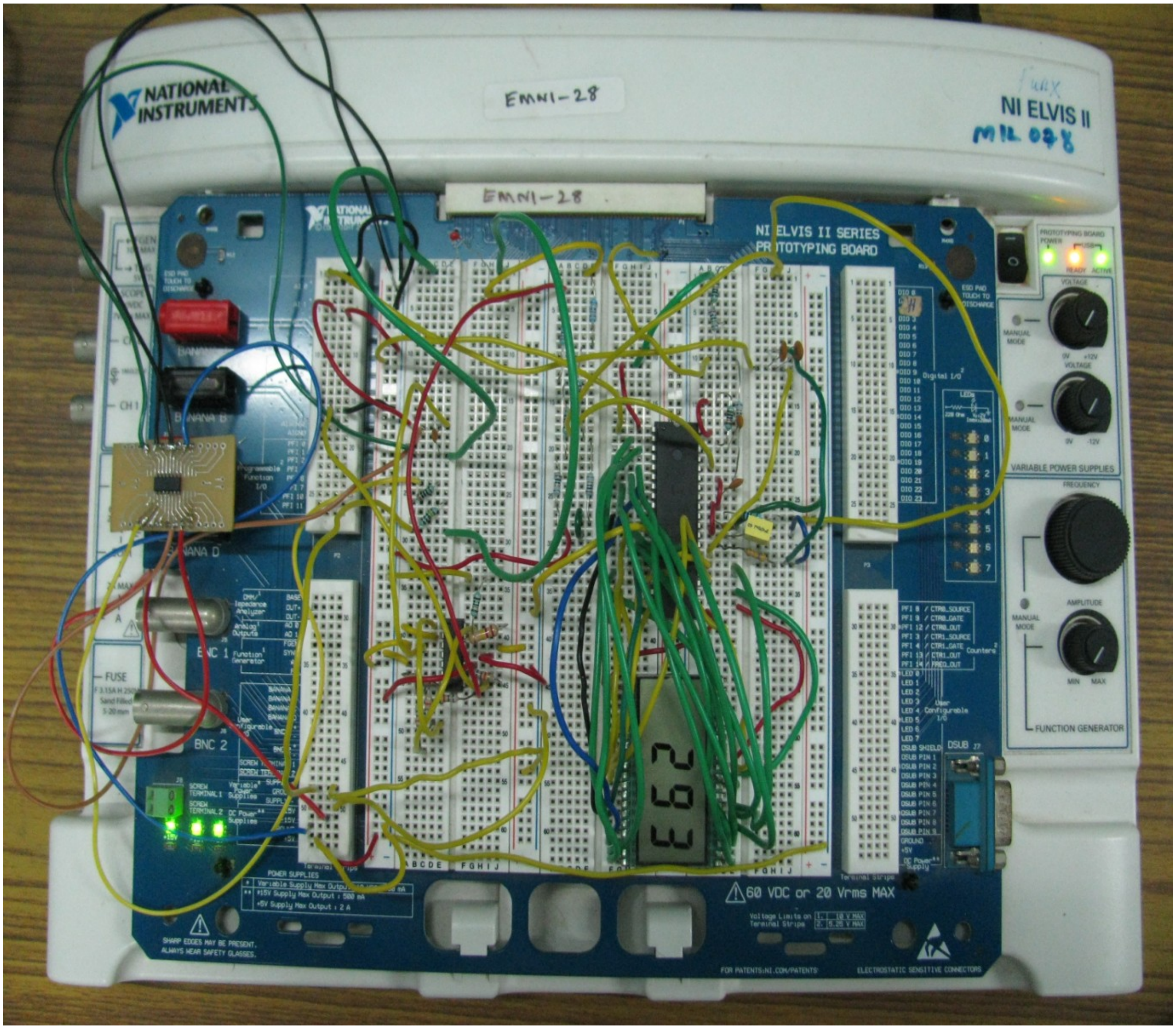


Figure 3.4: Experimental Setup on NI ELVIS II board

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Experimental Results

To study the efficacy of the proposed method , a prototype unit was built and studied under different temperature conditions by varying it . The hardware set up of the discussed linearising methodology for a thermistor, as shown in Figure 3.1 and 3.2, was done on an NI ELVIS II prototyping board in the electrical lab.

The logarithmic amplifier chosen was LOG112 from Messrs Texas Instruments due to it's various advantages such as high accuracy, low offset voltage, temperature drift and precision over a wide dynamic range.

The thermistor used in the prototype was the NTCLE203E3272FB0 NTC thermistor manufactured by Messrs Vishay Electronics.

The ADC used was ICLZ 7106 from Messrs Intersil. The temperature was switched in steps of 10 °C in the range -30 to 60 °C and N_2 was displayed using the LCD display screen.

The measurements were repeated five times to eliminate any random errors that could be present in the hardware implemented. It was observed that the errors in the five consecutive readings were found to be negligible. The actual temperature, measured temperature and percentage error are shown in table 6. The graph corresponding to the readings taken along with the percentage error is plotted in Figure 4.1. It is also observed that the maximum error that occurred was of ± 2.2% in the entire set of readings. Therefore, we can aptly conclude that the results obtained were matching closely with the results predicted.

S. No.	Actual Temperature (K) (AT)	Measured Temperature(K) (MT)	Difference (D)=AT-MT	% Error= (D/AT)100
1	243	248	-5	-2.0
2	253	250	3	1.2
3	263	258	5	1.9
4	273	267	6	2.2
5	283	277	6	2.1
6	293	288	5	1.7
7	303	296	7	2.3
8	313	308	5	1.6
9	323	316	7	2.2

Table 6: Temperature measured by the experimental setup

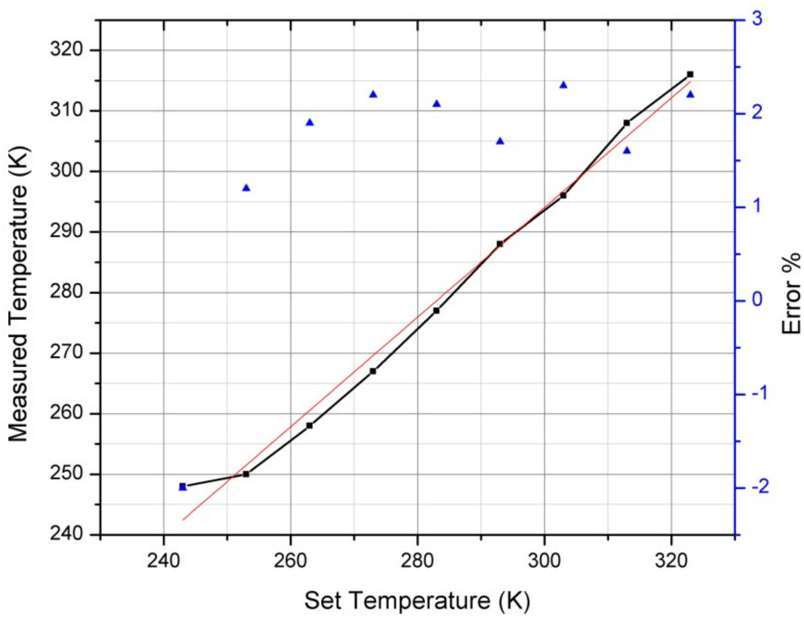


Figure 4.1: Graphical representation of the measured temperature

CHAPTER 5

CONCLUSION

5.1 Conclusion

In the above work, a circuit has been successfully devised that takes a thermistor having inverse exponential resistance–temperature characteristic as an input and gives a linearised digital output directly proportional to the temperature being sensed. The methodologies in selection of various components, their effects due to the use of practical circuit elements which are usually having non ideal characteristics have also been discussed.

The circuit discussed was set up on NI ELVIS II prototyping board and its performance was studied under controlled environment along with the non idealities of the various components. The output achieved has been very accurate (error of ± 2.2%) as well as almost linear over the entire range of readings(-30 to 60 °C) . Therefore, it can be safely concluded that the prototype circuit simulated performed as per the expectations and also justified that thermistors can be used effectively for accurate and reliable measurement of temperature over a wide range of temperatures.

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