A NOVEL CONDITIONING CIRCUIT FOR CONTACT-FREE RESISTIVE TYPE DISPLACEMENT TRANSDUCER WITH DIGITAL OUTPUT

A THESIS

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Under the guidance of

Professor Jagadeesh Kumar V

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNLOGY MADRAS

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CERTIFICATE

This is to certify that the thesis titled **"A NOVEL CONDITIONING CIRCUIT FOR CONTACT-FREE RESISTIVE TYPE DISPLACEMENT TRANSDUCER WITH DIGITAL OUTPUT",** submitted by **Mr. Manish Rastogi**, 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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Manish Rastogi

EE15M009

ABSTRACT

Displacement sensing and position sensing are essential for various applications in many different fields. Conventional potentiometer based resistive transducers are simple to construct and use but has a disadvantage of sliding contact which results in wear and tear during the operation of wiper as it has to make a physical contact with the resistive element which limits the repeatability.

In this thesis, a “Resistance Voltage Divider” (RVD) type displacement transducer is proposed which uses a contactless slide. A novel self balancing signal conditioning circuit is proposed here which operates on the contactless wiper RVD and provides a digital output that directly indicates the wiper’s displacement. The digital output has several advantages over analog output. The proposed signal conditioning circuit was implemented and verified on prototype hardware. The signal conditioning circuit for this sensor is based on the self balancing principle. The results obtained after implementation demonstrate the feasibility of the signal conditioning circuit and establish the efficacy of the proposed scheme.

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Chapter 1: Introduction

1.1 Displacement Sensors and their Applications

1. Displacement transducers are the measuring transducer that converts a linear or angular displacement into a mechanical, electrical, or other signals which are suitable for recording or further conversion.Resisitive sensors,Capacitance sensors and Inductance sensors can be used as displacement transducers. Displacements associated with deformations in mechanical components are measured by strain gauges, which usually have amplifiers [15].

2. Displacement sensing and position sensing are essential for various applications in automobile industry, defence equipments, silicon wafer technology assembly line testing and several others. Most of these applications require sensors which can accurately determine the position of an object, and the displacement from its original position. A large number of different types of sensors have been developed over the years to fulfill this requirement. Displacement transducers based on (i) inductive sensing element [1] [2], (iii) capacitive sensor element [3] and (iii) Hall effect type sensing element [4] have been developed over the years. Sensors which use laser or laser interferometer principle for displacement measurements have also been proposed in the recent past. Sensors which depend on optical techniques for measurement are not suited for dusty environments as light is easily scattered by dust. Contactless capacitive sensors have been developed for applications involving dimensional analysis of surfaces [5] and measurement of human tremors [6]. A capacitive type displacement transducer proposed earlier has good linearity and can be used in dusty environment as well [7].

3. In addition to the above sensors, resistive potentiometric type displacement transducers with a contactless wiper are in use for a variety of applications where linear or angular position sensing is required. These type of sensors are widely used for sensing displacement and velocity (both linear and angular) [8], largely for applications in the automotive industry as they possess high linearity over a wide range, high resolution, high repeatability and low cost. Recently, an Inductive Voltage Divider (IVD) based displacement transducers with a floating wiper have been proposed [9]. The sensor part of an Inductive Voltage Divider based transducer is formed using an inductive element attached to a sliding contact. The output of the sensor, is proportional to the

displacement of the wiper. The same concept of voltage divider can be applied to resistive voltage divider based transducer attached to a sliding contact.

1.2 Motivation

4. Though the conventional resistive divider type displacement transducers (on the same principle of inductive voltage divider [9]) are simple to design, easy to operate and possess high linearity over a wide range, their usage is limited only due to the necessity for physical contact between the wiper and the resistive element. These type of wipers are spring loaded and possess following disadvantages:

(a) Due to the contact and friction between the resistive element and the slide, some energy is extracted from the measurand for moving the slide which results in large errors in the measurement.

(b) Due to the friction, there will be wear and/or tear in the contact surfaces of the resistive element and the slide. This may lead to a reduction in the operational lifetime and repeatability of the transducer.

5. Thus, the presence of firm contact using a spring loaded slide between the moving wiper and the resistive element of a resistive voltage divider type displacement transducer as per Figure 1.1 results in wear and tear in usage which will further introduce errors in the output due to jitter in the contact resistance.

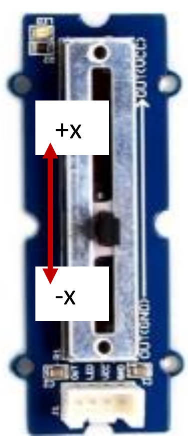


Fig1.1: A conventional potentiometric linear displacement sensor element

6. A solution to this problem is to keep the slide close to the resistive element and employ a contactless slide as shown in Figure 1.2. Once the need for a physical (ohmic) contact between the wiper and the resistive element is dispensed with, the wiper need not be in contact with the resistive element. In such a situation, a small air gap will be present between the resistive element and the slide which will result in a coupling capacitor.

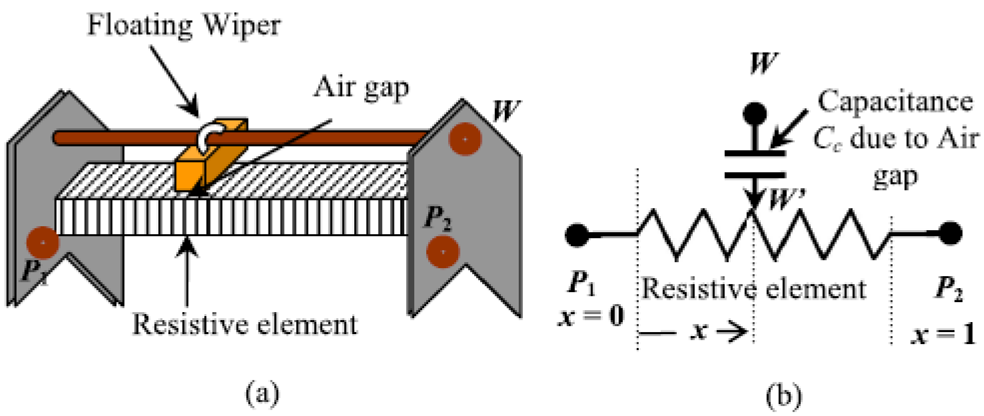


Fig 1.2:Resistive potentiometric sensor with floating wiper (a) Sensing Element (b) Electrical Equivalent Circuit

7. Compared to the other types of contactless displacement transducers described above, a Resistive Voltage Divider type displacement transducer with a contactless slide will possess long life and contact free operation. It also brings in all the advantages of a inductive voltage divider type and resistive potentiometric type displacement transducer such as: (i) simplicity in design, (ii) low cost, (iii) easy operation and (iv) high linearity over a wide range of operation. These contactless displacement transducers are preferred over contact type displacement transducers, especially for applications in harsh environments such as automobiles, robotics and manufacturing plants.

1.3 Objectives of the Work

8. The objectives of this work are to:

(i) Design a simple analog signal conditioning circuit operating on the contactless resistive voltage divider type displacement sensor and provides a digital 12-bit output that varies linearly with the displacement of the wiper in either direction

(ii) Develop a prototype hardware which can provide the same output and withstand repeated operation resulting in long operational life without any wear and/or tear.

1.4 Organization of Thesis

Chapter 1 introduces displacement sensors, their applications in several areas and limitations. Motivation for the present work and details of the organization of the thesis are listed.

Chapter 2 describes the theoretical model of a resistive voltage type displacement transducer with a contactless slide. A dedicated signal conditioning circuit is presented here which operates with contactless wiper, on the resistive element and provides a digital output voltage directly proportional to the quantity being sensed (displacement or velocity).

Chapter 3 includes and explains the specifications of hardware setup requirements consisting of NI ELVIS II Board, QPSD (CD4053BE), ARDUINO UNO board, MDAC AD 7945 and Unity gain Differential and Inverting Amplifier (OP07).

Chapter 4 explains the hardware experimental studies and working of the dedicated signal conditioning circuit of the proposed sensor that moves, without having a physical contact, on the resistive element and provides a digital output voltage directly proportional to the displacement of the wiper.

Chapter 5 concludes the thesis work carried out with a scope of future work.

Chapter 2 : A Resistive Voltage Divider Type Transducer With Contactless Slide

2.1 Sensing Linear or angular Displacement

1. A variety of sensors of different types have been developed over the years for sensing linear or angular displacement. Popular transducers includes, Resistive potentiometric type, Linear Variable Differential Transformers type and Capacitive type transducers [1] to [4]. Capacitive types transducers are appropriate for small displacements [10] and LVDT type transducers are bulky in nature [11].Though conventional potentiometer based resistive transducers are simple to construct and use, they are not much popular due to a sliding contact which needs to be employed resulting in wear and tear during operation of wiper as it has to make a physical contact with the resistive element which finally limits the repeatability. Also resistive potentiometric type displacement transducers with contactless slides have been proposed which results in non wear and tear during operation [10]. Recently an Inductive Voltage Divider (IVD) based displacement transducers with a floating wiper have been proposed [9] which results in an advantage of considerable reduction in power dissipation of the sensing element and hence reduction in operating temperature of the sensor.

2. The solution for fulfilling the need of contactless wiper (floating type) over a resistive element can also be implemented by Resistive Voltage Divider (RVD) type contactless transducer. The employment of proposed RVD type contactless displacement transducer eliminates the limitation of physical contact of wiper.

2.2 RVD Type Displacement Sensor with Contactless Slide

3. A conventional resistive voltage divider type displacement transducers are simple to construct and use. It is made up of a resistive element on which a contacting wiper moves and traverses the entire length of the resistive element as shown in Figure 2.1. Here, the reference point is considered as midpoint O on the resistive element, where the displacement $x = 0$. At point O, the values of the resistances R1 (between point O and terminal P1) and R2 (between point O and terminal P2) are equal.

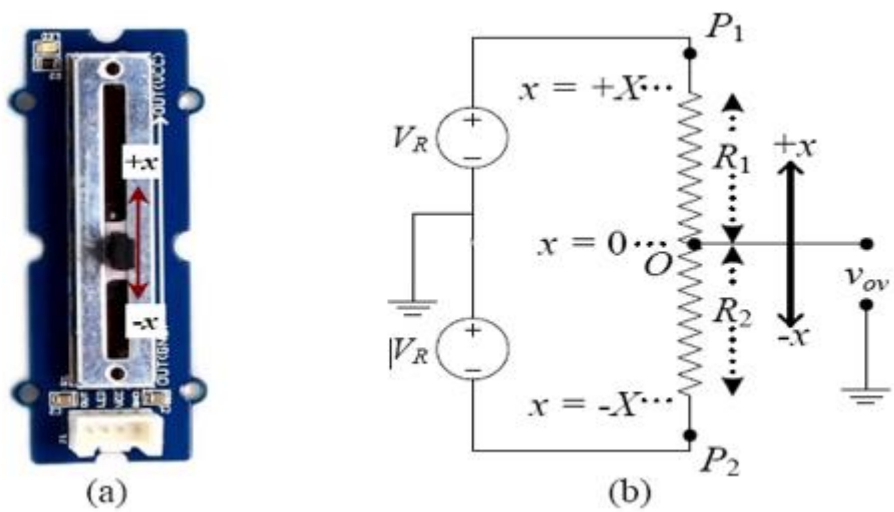


Figure 2.1: (a) A conventional resistance voltage divider type displacement sensor
(b) Circuit for obtaining output proportional to X

4. A conventional resistive voltage divider type displacement transducers with a contacting wiper can be used with both AC and DC power supplies as shown in Fig 2.2. The displacement of the wiper for upward movement is indicated as +x with reference to point O and –x for downward movement of the wiper. The value of x varies in the range 0 to X. The X is the maximum displacement of the wiper which can be traversed by the wiper in both directions i.e. positive or negative direction. The terminal A and B needs to be excited by two sinusoidal input voltage sources of equal magnitude ($v_s = \sqrt{2}V_s \sin \omega t V$) .The output v_x as indicated, is proportional to the displacement x of the wiper which can be derived as:

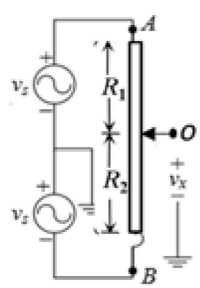


Figure 2.2: A conventional resistive voltage divider type displacement transducer

$$v_x = \left(\frac{v_s}{X}\right)x \text{ where } \frac{x}{X} = \frac{R_2 - R_1}{R_2 + R_1} \tag{2.1}$$

5.. With this arrangement the voltage across the resistive voltage divider is $2v_s$. This arrangement is not so popular owing only to the fact that a sliding contact needs to be employed which results in wear and tear due to physical contact between them which further restricts the repeatability. If by some arrangement the wiper is made contactless (floating over the resistive element) then the problem of wear and tear can be eliminated thus increasing the applicability of the proposed sensor.

6. To obtain a resistive voltage divider type displacement sensor with a contactless slide, the contacting wiper is replaced by contactless wiper such that slide moves along the resistive element, without making any physical contact to it. The air gap introduces a coupling capacitance (Cc) between the slide and the resistive element as indicated in the equivalent circuit of the sensor shown in Figure 2.3.The point O which is equidistant from both terminal ends of the resistive element as the starting point as shown in electrical equivalent circuit. The terminals A and B are excited by a sinusoidal voltage of equal magnitude. The voltage at point O' will be v_x as defined earlier. However, the coupling capacitor Cc introduced due to the presence of the non contacting slide makes it difficult to access the voltage v_x of point O' at the terminal O as was the case in a contacting type. An added challenge is to obtain a voltage proportional to the displacement x of the wiper. As the wiper moves, the distance between the wiper and the resistive element will vary, resulting in the value of Cc changing as x varies.

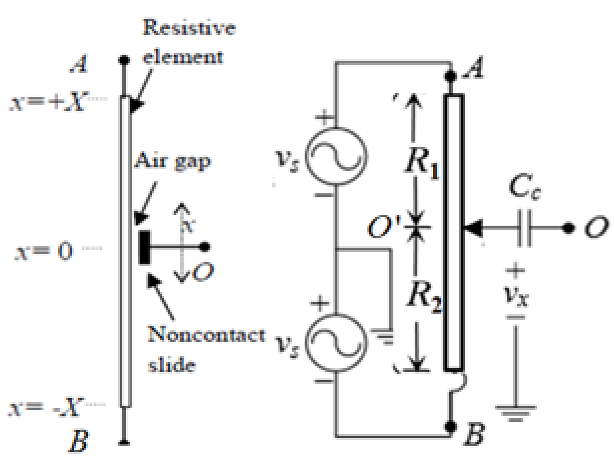


Figure 2.3: RVD with contactless slide and its electrical equivalent

7. A self balancing signal conditioning circuit is projected herein which operates on the RVD type displacement sensor with a contactless wiper of Figure 2.4 and provides an output Vo that linearly varies with the displacement x. The Digital output Vo of the signal conditioning circuit presented here is independent of Cc and hence any variations in Cc will not affect the output.

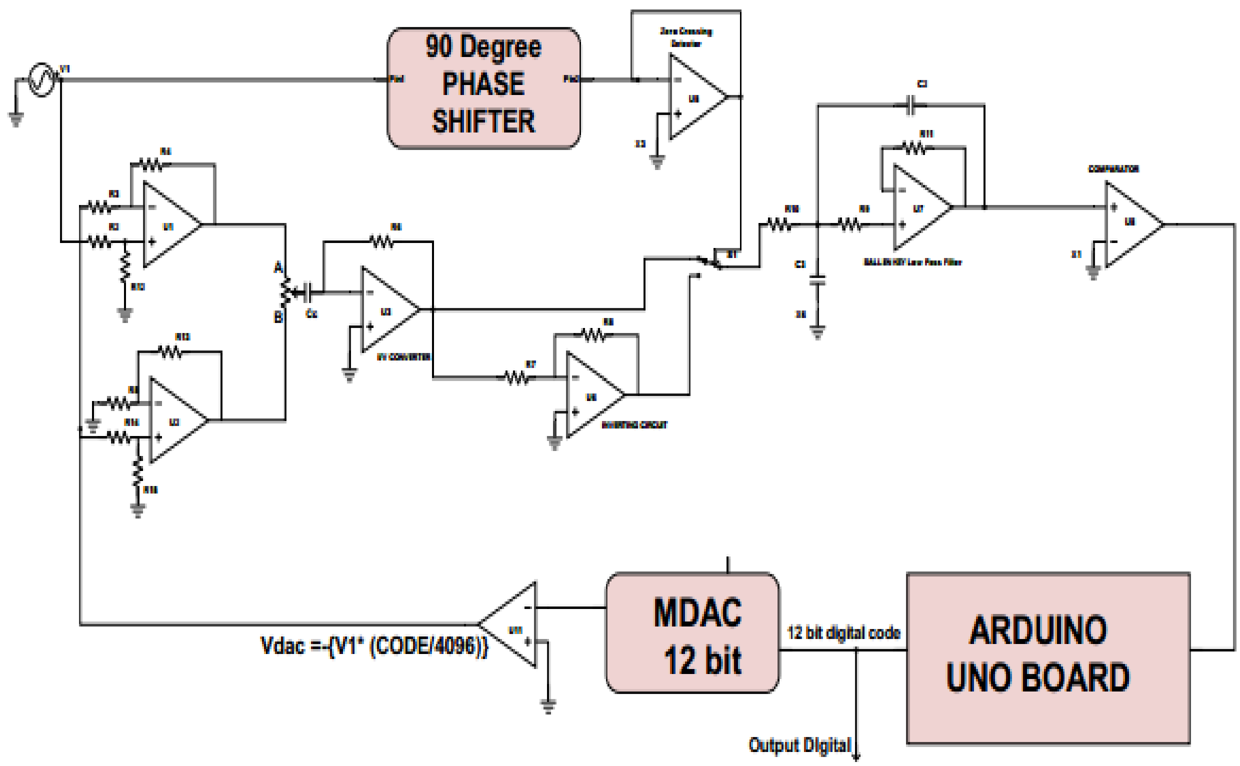


Fig 2.4 : Block schematic of the proposed self balancing signal conditioning circuit

2.3 The Self Balancing Signal Conditioning Circuit

8. Figure 2.4 shows the functional block diagram of the self balancing signal conditioning circuit suitable for RVD type displacement sensor with a contactless slide. It is seen from the circuit that the RVD with a contactless wiper is excited by a sinusoidal voltage v_s ($v_s = \sqrt{2}V_s \sin \omega t V$) ,through the combination of unity gain inverting amplifier and a summing amplifier, both being fed the output of the op amp connected to the MDAC for converting current output to voltage. Terminal A is connected to the output of the unity gain differential

amplifier fed with the input voltage v_s and the output of the Op amp connected with the MDAC. The voltage at terminal A is:

$$v_a = v_s(1 - x / X) \tag{2.2}$$

where V_{dac} is the output of the MDAC and Op amp. The voltage V_{dac} varies from 0 to $-V_s$ as the digital output code from the arduino varies from (*000)H* to (*FFF)H.* The terminal B is connected directly to the output fed from the MDAC and amplifier. The voltage at terminal B is:

$$v_b = V_{dac} \tag{2.3}$$

9. The output of the amplifier connected with the MDAC for converting current output to voltage is

$$\begin{aligned} v_{dac} &= -\{v_s * (code/4096)\} \\ v_{dac} &= -\{v_s * (x / X)\} \end{aligned} \tag{2.4}$$

This code generated by the arduino is equivalent to the displacement x of the transducer.

10. With this arrangement the voltage v_{ba} (v_a- v_b) across RVD is always v_s. The input to i-to-v converter constituted by operational amplifier U3, is fed from terminal O of the sensor. The output from i-to-v converter is given as input to a synchronous switching type quadrature phase sensitive detector (QPSD) whose reference voltage is v_s. The switch S1, 90° phase shifting network, zero crossing detector U5, the inverter U6 and operational amplifier U7 together constitute an inverting quadrature phase sensitive detector. The output of the QPSD will be:

$$V_q \sin\theta, \text{ where } V_q = \left(\frac{\sqrt{2}Vi}{\pi X}\right)x \tag{2.5}$$

11. Here, *Vi* is the magnitude of the input signal to the QPSD and θ is the angle between the reference voltage signal of the QPSD and the input signal. If x is negative then this angle will be +90 degree and for positive x, the angle will be -90 degree.

2.4 Operation of signal conditioning circuit

12. To understand the operation and functioning of proposed signal conditioning circuit, let us assume that initially the displacement 'x' of the sensor is zero and the wiper is at the centre of the sensor. For this condition, the output of the i-to-v converter will be zero and therefore the output of QPSD will also be zero. The comparator output will also be zero and this is the initial condition. At this initial condition, the digital output Vo of the microcontroller is fixed at $(2048)_{10}$ such that the output of the MDAC module (MDAC and amplifier U11) is

$$v_{dac} = -v_s(2048/4096) = -v_s/2 \quad (2.6)$$

where, 4096 is equivalent to the total displacement of the wiper from A to B such that at point A x=4095 and at point B x=0.

13. In this condition, the terminal A will be excited by -0.5v_s and similarly terminal B will be excited by 0.5v_s. The voltage across both terminals v_{ba} (v_b-v_a = 0.5v_s-{-0.5v_s}) remains v_s and the output at O' remains to be zero. Hence circuit will settle down at the operating point as shown in Figure 2.5.

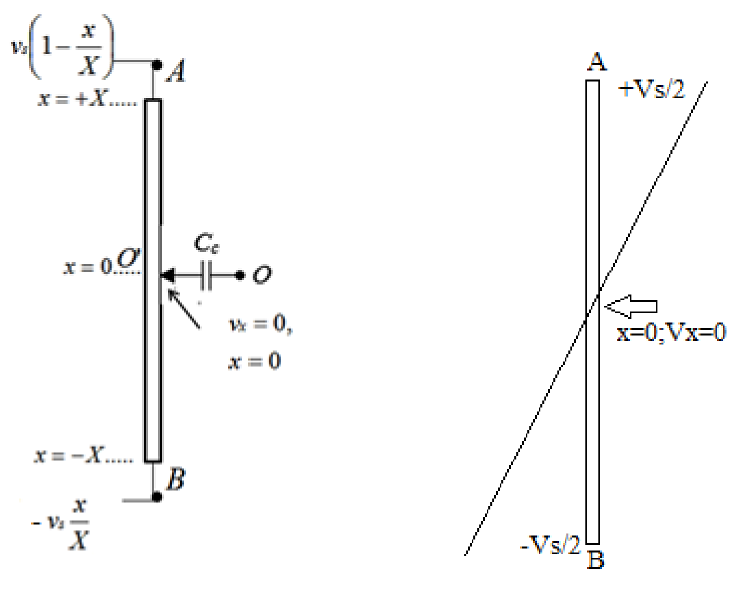


Figure 2.5: The change in the excitation voltages v_a and v_b for x=0

14. As the wiper moves to 0.5X the voltage at O' will increase from zero to :

$$v_s\left(\frac{x}{X}\right) = 0.5v_s \tag{2.7}$$

15. The output of the i-to-v converter will vary depending on this movement of the wiper and thus the output of the QPSD will also change. Since x (displacement) is in positive direction, therefore the angle θ will be -90 degree and thus the output of the QPSD would be –ve. Initially when the circuit is balanced, the output of the comparator is 0. The output of the comparator will not change as Vq becomes negative because the output of Vq is given to the +ve terminal of the amplifier, hence transition / change will only happen when Vq becomes positive. Now, as the wiper is moved up, the program fed to the arduino microcontroller will increase the counter from its initial value of $(2048)_{10}$ and at each change of the counter value will compare with the output of the comparator. At a point where the circuit gets balanced because of the feedback and the self balancing nature of the circuit, the transition from LOW to HIGH would take place at the output of the comparator and at this particular instance the counter would stop. This is the required output V_O. Figure 2.6 shows the condition when wiper is moved in the positive direction to 0.5X.

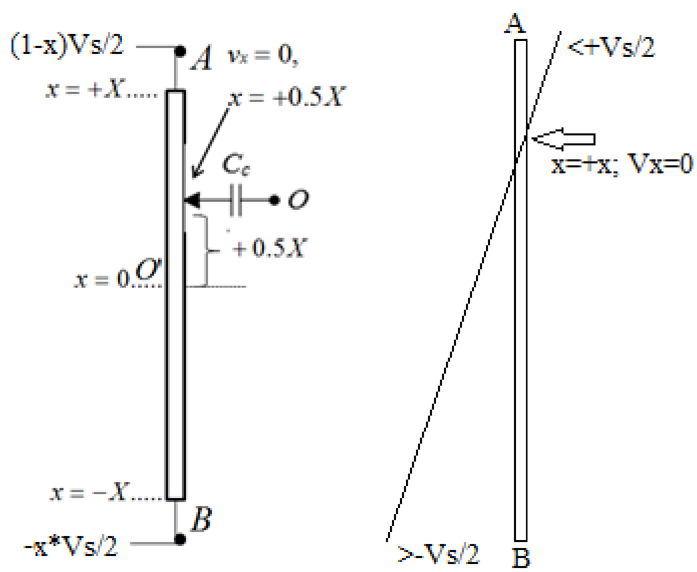


Figure 2.6: The change in the excitation voltages v_a and v_b for x=0.5X

As the output of the MDAC amplifier is directly connected to point B, thus because of positive movement of the wiper, voltage at B increases while voltage at A decreases to ensure that voltage between A and B is v_s.

16. Similarly, when the wiper is moved downwards, the voltage at O would decrease, the voltage Vq would be positive as x is negative so θ will be +90 degrees and hence transition of the comparator output will take place from LOW to HIGH. The program fed to the arduino microcontroller will decrease the counter from its initial value of $(2048)_{10}$ and at each change of the counter value will compare with the output of the comparator. At a point where the circuit gets balanced because of the feedback and the self balancing circuit, the transition from HGH to LOW would take place at the output of the comparator and at this particular instance the counter would stop. This is the required output V_O. Figure 2.7 shows the condition when wiper is moved in the negative direction to -0.5X.

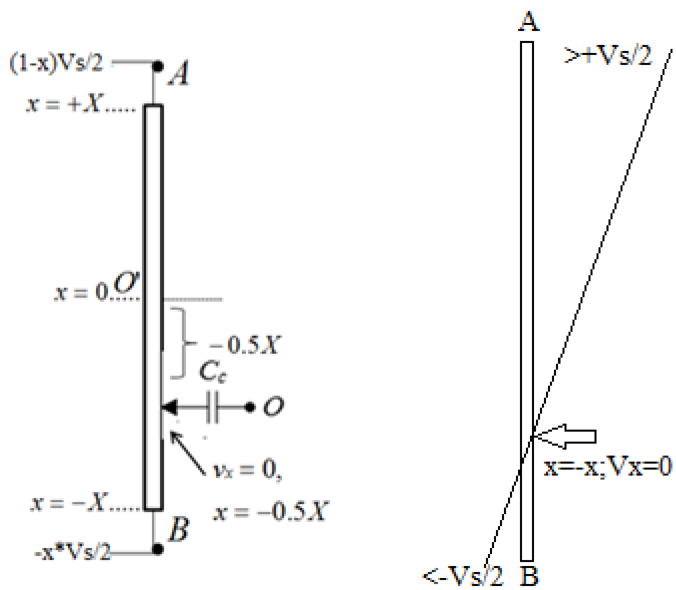


Figure 2.7: The change in the excitation voltages v_a and v_b for x= -0.5X

As the output of the MDAC amplifier is directly connected to point B, thus because of negative movement of the wiper, voltage at B decreases while voltage at A increases to ensure that voltage between A and B is v_s.

17. With the arrangement as shown above, the code or the output of the arduino is directly proportional to the displacement x of the wiper as per (2.8)

$$\frac{x}{X} = (b_{11}b_{10}b_9 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. b_0)/4096 \quad (2.8)$$

Chapter 3 : Hardware Requirements

3.1 Hardware Required

1. In the previous chapter we have analyzed the working of the signal conditioning circuit mathematically. It was also proved mathematically that the output of the circuit is independent of the coupling capacitor Cc and depends linearly on the position of the wiper i.e. measurand 'x', hence any variation in Cc will not affect the output. Also, the MDAC controls the voltages at the terminals of the sensor. In this chapter we shall discuss the hardware requirements of the signal conditioning circuit as shown in Figure 2.4 of chapter 2 which consists of following main blocks:-

(a) NI ELVIS II Board

(b) QPSD

(c) MDAC

(d) ARDUINO UNO Board

(e) Unity gain Summing Amplifier (OP07)

3.2 NI ELVIS II

2. 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 multifunction data acquisition device, a prototyping board and LabVIEW based virtual instruments [12]. All these put together forms an integrated platform for circuits and 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 facilitates it in performing functions similar to a number of much more expensive instruments. They can be used in various fields of 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 3.1

(2) NI ElVISMX Instrument Launcher consisting of eighteen soft front panels (SFP) instrument, shown in Figure 3.2.

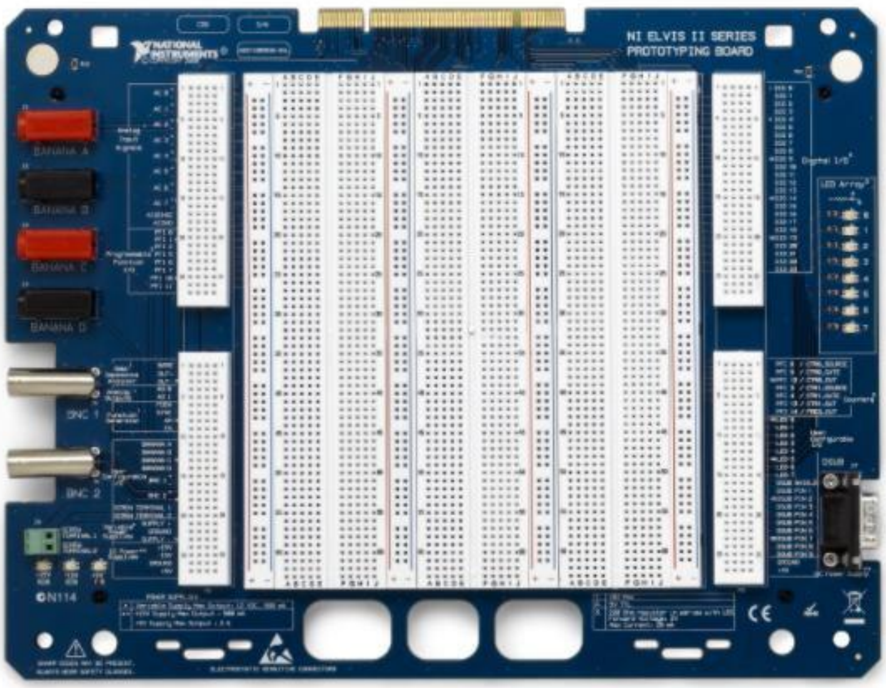


Figure 3.1: NI ElVIS II hardware

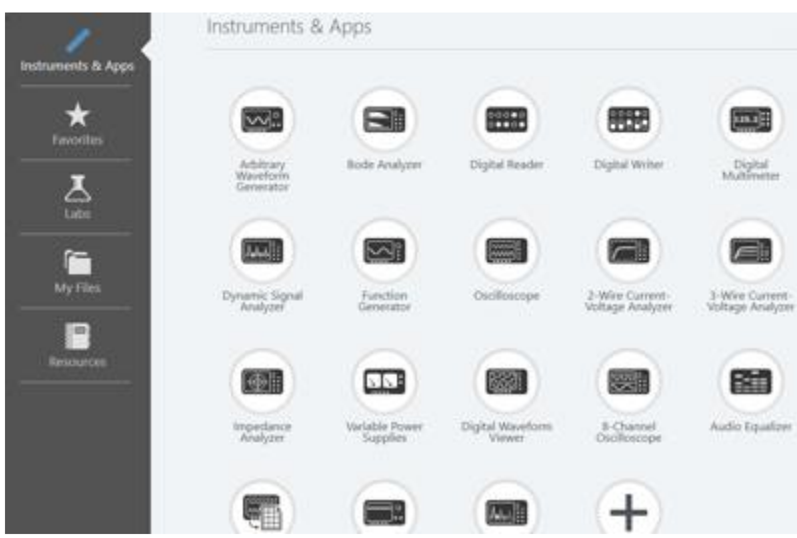


Figure 3.2: NI ELVIS II Soft Panel

3.2.1 NI ELVIS Functions

3. 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

4. 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

5. 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)

6. 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

7. 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

8. 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.

Digital Reader / Writer

9. This instrument reads digital data from the NI ELVIS II Series digital lines. Eight consecutive lines can be read at a time: 0..7, 8..15, 16..23 either continuously or as a single reading. This instrument also updates the NI ELVIS II Series digital lines with user-specified digital patterns. One can manually create a pattern or select predefined patterns, such as ramp, toggle, or walking 1s. This instrument can control eight consecutive lines and either continually output a pattern or just perform a single write. The output of the NI ELVISmx Digital Writer SFP stays latched until another pattern is output, the lines it is using are configured for read, or the power is cycled on the NI ELVIS II Series workstation.

3.3 QPSD

10. Quadrature phase sensitive detector has been analysed by a combination of a 90 degree phase shifter and CD4053BE multiplexer. OP07 and a combination of resistors and capacitor are used for 90 degree phase shifter. The pin configuration of OP07 and is shown in Figure 3.3.

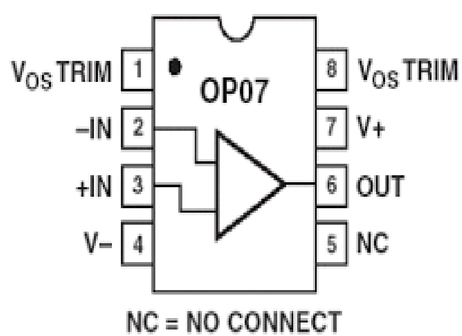
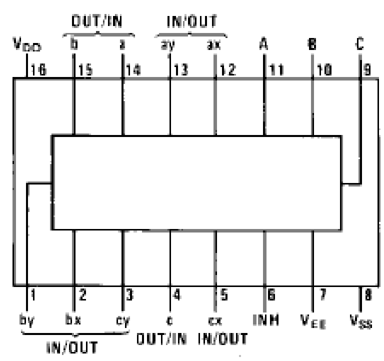


Figure 3.3: Pin configuration of OP07

3.3.1 CD4053BE

11. CD4053 analog multiplexer / demultiplexer is a digitally controlled analog switch having low “ON” impedance and very low “OFF” leakage currents. CD4053BE is a triple 2-channel multiplexer having three separate digital control inputs, A, B, and C, and an inhibit input [12]. Each control input selects one of a pair of channels which are connected in a single-pole double-throw configuration. The pin configuration and the truth table is shown in Figure 3.4

CD4053B



TOP VIEW

Truth Table

INPUT STATES				"ON" CHANNELS		
INHIBIT	C	B	A	CD4051B	CD4052B	CD4053B
0	0	0	0	0	0X, 0Y	cx, bx, ax
0	0	0	1	1	1X, 1Y	cx, bx, ay
0	0	1	0	2	2X, 2Y	cx, by, ax
0	0	1	1	3	3X, 3Y	cx, by, ay
0	1	0	0	4		cy, bx, ax
0	1	0	1	5		cy, bx, ay
0	1	1	0	6		cy, by, ax
0	1	1	1	7		cy, by, ay
1	*	*	*	NONE	NONE	NONE

*Don't Care condition.

Fig 3.4: Pin Configuration and truth Table for CD 4053

3.4 MDAC

12. Multiplying Digital to Analog Converter (MDAC) is a current output digital-to-analog converter. The output current is converted into a voltage by including an op-amp in a trans-

impedance configuration at the MDAC current output terminal. MDAC's offer both flexibility and simplicity, and hence can be used in a broad range of applications. The benefit of a discrete DAC and op amp solution is that the op amp selection can be custom tailored to suit the application requirements. Multiplying DACs are ideal building blocks for fixed reference applications, where the user wants to generate a waveform from a fixed dc voltage. They are also ideally suited for varying reference applications, where the user wants to digitally condition an ac or arbitrary reference voltage.

3.4.1 AD7945

13. The AD7945 is a fast 12-bit multiplying DACs that operate from a single +5 V supply (Normal Mode) and a single +3.3 V to +5 V supply (Biased Mode). The AD7945 has a 12-bit parallel interface. The AD7945 is available in 20-lead DIP, 20-lead SOP and 20-lead SSOP package [13]. The pin configuration is shown in Fig 3.5

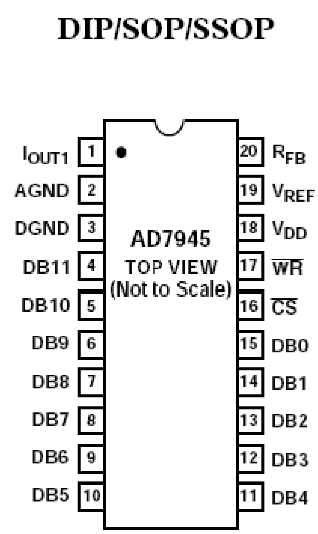


Fig 3.5: **Pin configuration of AD7945**

14. Functional Block Diagram, a typical MDAC application and unipolar binary code based on unipolar binary operation is as shown in the Fig 3.6, Fig 3.7and Fig 3.8 respectively.

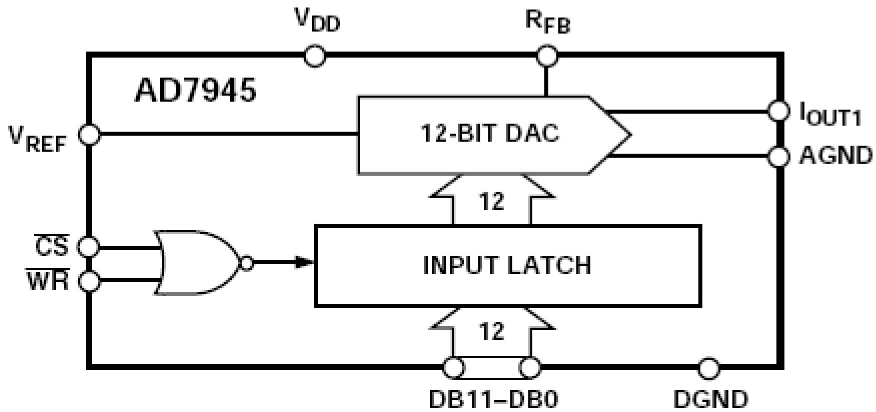


Fig 3.6: **Functional Block Diagram**

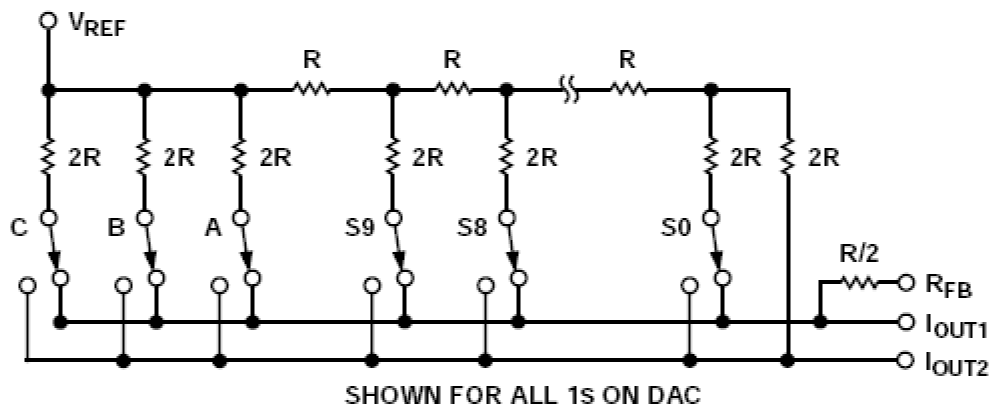
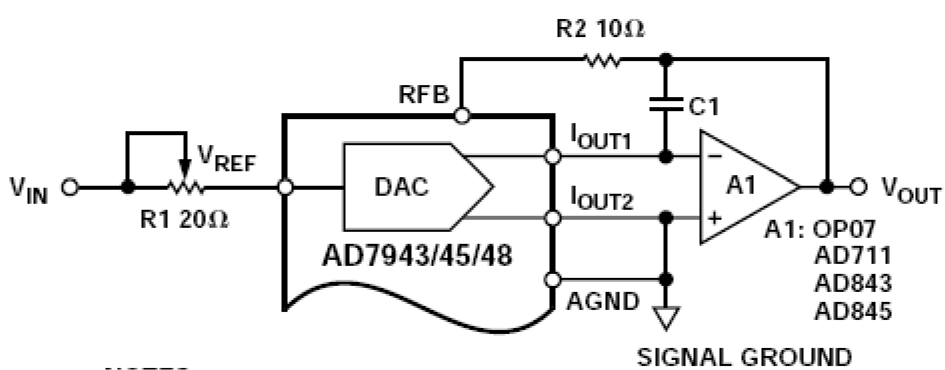


Fig 3.7: **Typical MDAC application**



$$V_{OUT} = -D \times V_{REF}$$

Digital Input MSB LSB	Analog Output (V_{OUT} as Shown in Figure 14)
1111 1111 1111	$-V_{REF}$ (4095/4096)
1000 0000 0001	$-V_{REF}$ (2049/4096)
1000 0000 0000	$-V_{REF}$ (2048/4096)
0111 1111 1111	$-V_{REF}$ (2047/4096)
0000 0000 0001	$-V_{REF}$ (1/4096)
0000 0000 0000	$-V_{REF}$ (0/4096) = 0

Fig 3.8: **Unipolar Binary operation with Output expression and Unipolar Binary Code**

3.5 ARDUINO UNO

15. Arduino/Genuino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. Fig 3.9 shows an Arduino Uno board.

Fig 3.9: Arduino Uno Board

16. The technical specifications of the arduino board are tabulated below:

TABLE 1

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25gm

3.6 Unity gain Inverting and Summing amplifier

1. This is implemented by combination of OP07 and few resistors. The OP07 has very low input offset voltage (75 μV maximum for OP07E) which generally eliminate any need for external nulling. The OP07 also features low input bias current (±4 nA for the OP07E) and high open-loop gain (200 V/mV for the OP07E) [15]. The low offset and high open-loop gain make the OP07 particularly useful for high gain instrumentation applications.

Chapter 4: Experimental Setup and Results

4.1 Introduction

1. In the previous two chapters, we had analysed the working of the signal conditioning circuit and the entire hardware requirement for the experimental setup. The previous chapter gave us an impending into the characteristics and other parameters of the various components along with the NI ELVIS II board used in the signal conditioning circuit. In this chapter we shall integrate all the components discussed so far on the NI ELVIS II board to achieve the complete setup of the circuit. We shall also discuss the functioning of each and every component individually and their contribution to the circuit.

4.2 Experimental Setup

2. The prototype of the proposed signal conditioning circuit of the transducer was tested and implemented on NI ELVIS-II board to validate the practicality. Commercially available IC's were used for the implementation of the circuit. The unity gain differential amplifier was implemented using OP amp and resistors. The Low offset operational amplifier OP07 was used to realize the amplifier, phase shifter, charge amplifier and the inverters. The comparator for the circuit was realized using IC LM311. The QPSD was implemented using 90 degree phase shifter, IC CD4053BE, zero crossing detector and a filter circuit. The resistance R1 and R2 were realized by combination of resistances in series summing upto 1kΩ. The MDAC was implemented using AD7945 IC along with the digital input from the arduino board. The block diagram of the signal conditioning circuit is shown in Figure 4.1.

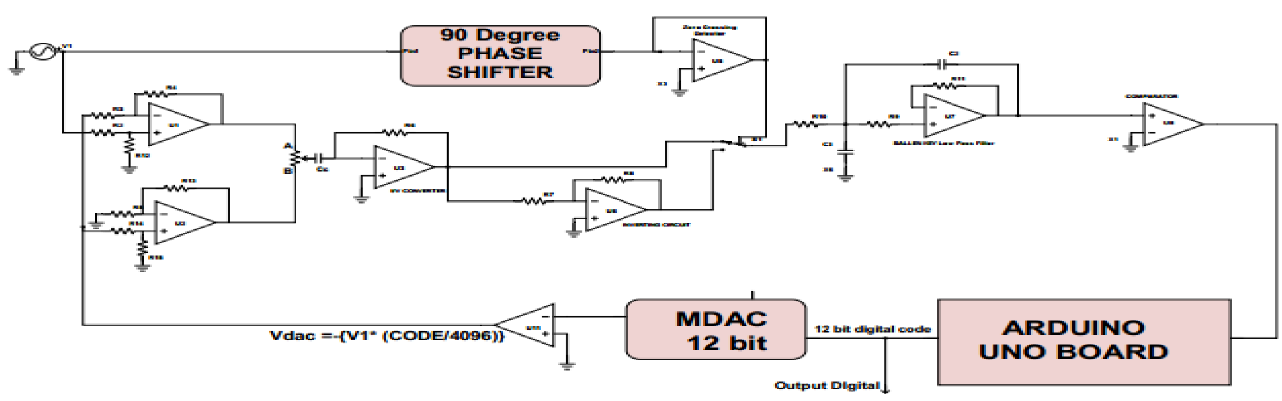


Fig 4.1: **Signal Conditioning Circuit**

4.2.1 QPSD

3. As discussed earlier QPSD (Quadrature phase sensitive detector) comprises of 90 degree phase shifter, IC CD4053BE and a low pass filter circuit. The 90 degree phase shifter was implemented by using OP07, resistances and a capacitance as shown in Figure 4.2. The value of R and C was chosen to be 10K and 16nF respectively for 1Khz input frequency such that phase shift θ between input and output is set as 90 degree as:

$$\tan\frac{\theta}{2} = \omega RC \tag{4.1}$$

4. The sinusoidal input of magnitude 1V was given to phase shifter and output waveform was recorded in LABVIEW as shown in Figure 4.3. The output of phase shifter was given as one of the input to IC CD 4053BE. The other input to IC CD 4053BE was given from the output of i-to-v converter as shown in Figure 4.1. The output waveform was recorded, as shown in Figure 4.4.

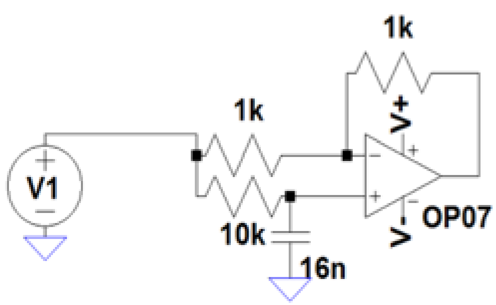


Figure 4.2: Circuit diagram of 90 degree phase shifter

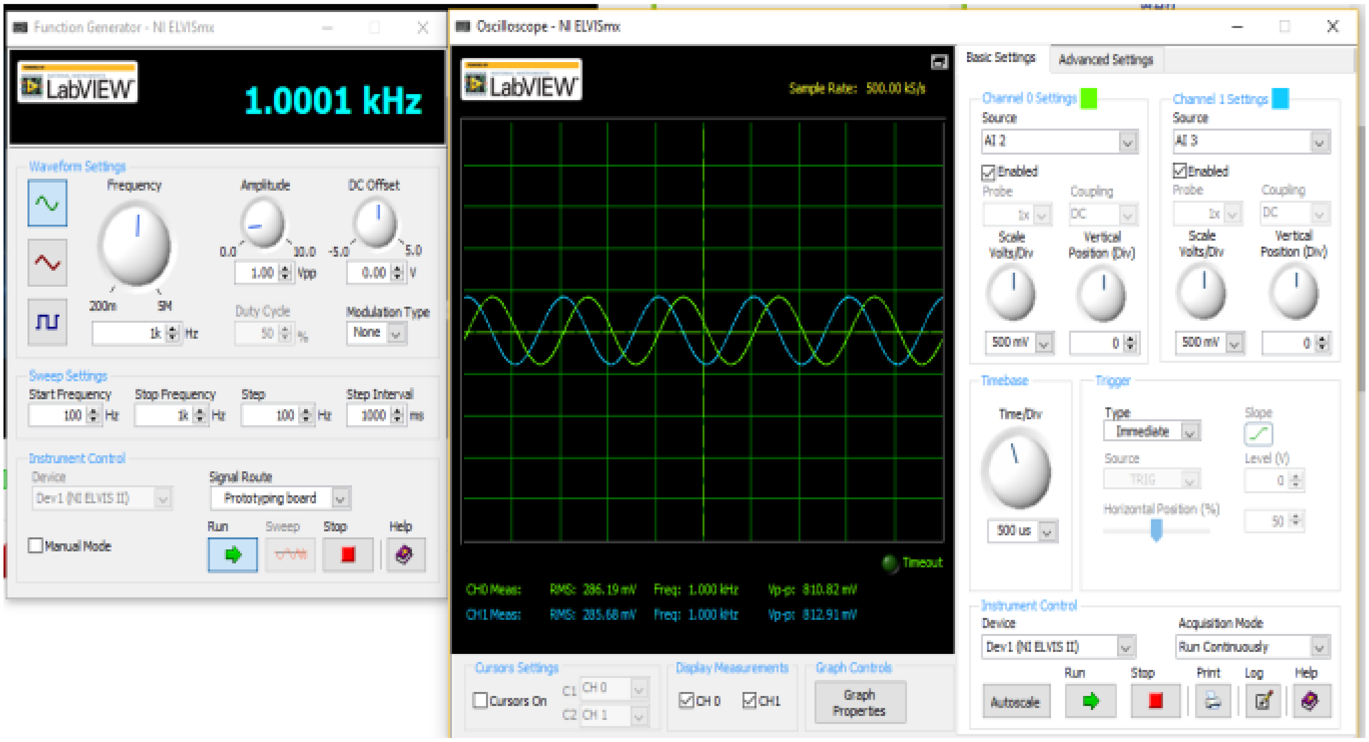


Figure 4.3:Output waveform of 90 degree phase shifter

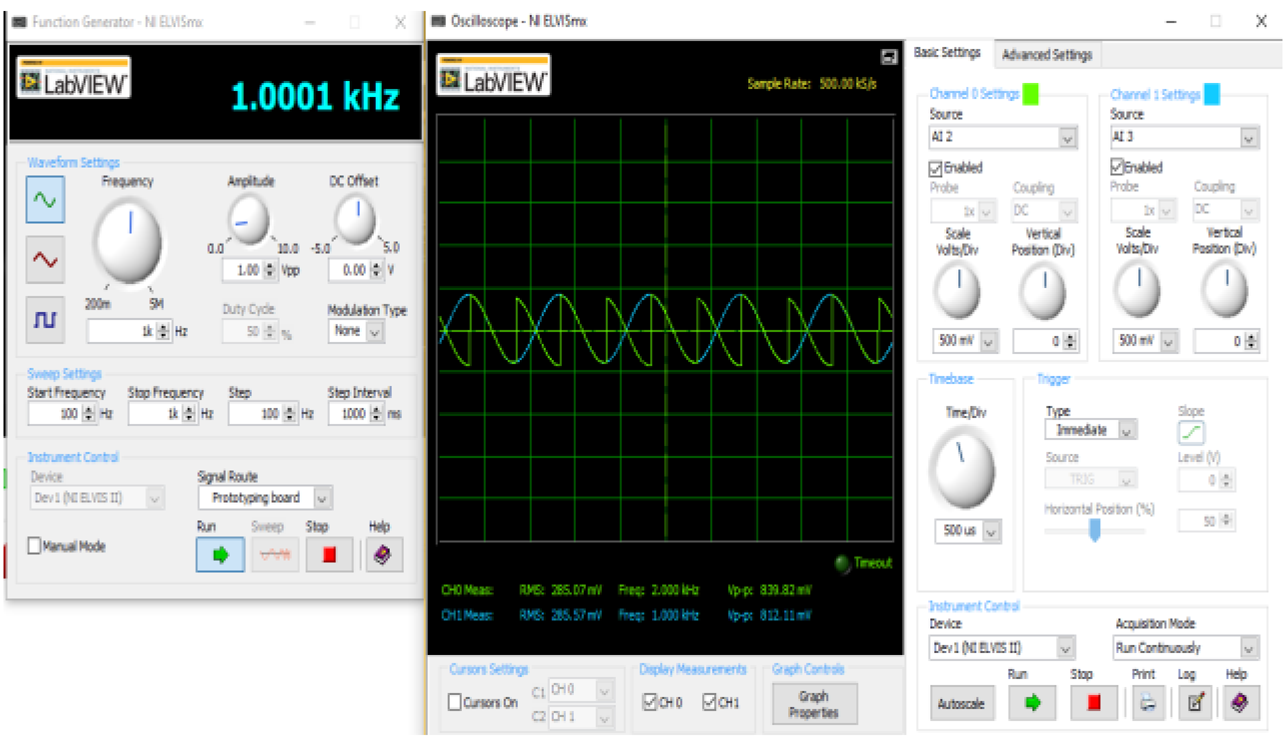


Figure 4.4: Waveform showing output of QPSD

4.2.2 Arduino Uno Board

5. Arduino/Genuino Uno is a microcontroller board based on the ATmega328P microcontroller. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. Here, 12 digital pins are used for converting the displacement of the wiper into a digital code through a software logic and this is further fed to the 12 serial pins of the MDAC. The Flowchart for Arduino Logic and the program code for the microcontroller is placed at Appendix A and Appendix B respectively.

4.2.3 Multiplying Digital to Analog Converter

6. AD7945 is used as a multiplying DAC. It gets the digital code from the 12 digital pins of the arduino and converts it into current output which is further fed to an operational amplifier OP07 as shown in Figure 4.5 to convert it into a analog voltage Vout used for driving point A and B of the sensor.

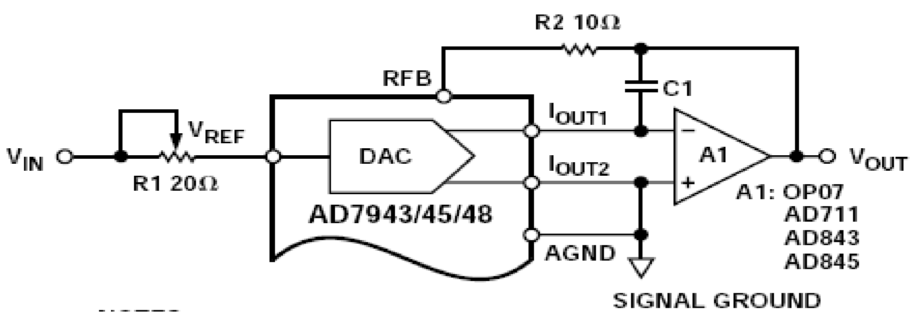


Fig 4.5: **MDAC Application**

$$Vout = -Vref * code /4096 \tag{5.2}$$

7. The MDAC was tested with various configurations of digital input and the expected and the actual voltages are tabulated in table II and plotted in Figure 4.6

TABLE II

Sl. No.	Decimal Equivalent of Digital Code	Actual value	Expected value (Vout = Vref * Code /4096)

1.	4095	309.98	310.96
2.	4080	309	309.82
3.	2303	174.72	174.86
4.	2184	165.53	165.84
5.	2049	154.55	155.59
6.	2047	155.39	155.44
7.	255	19.46	19.36
8.	0	1.06	0

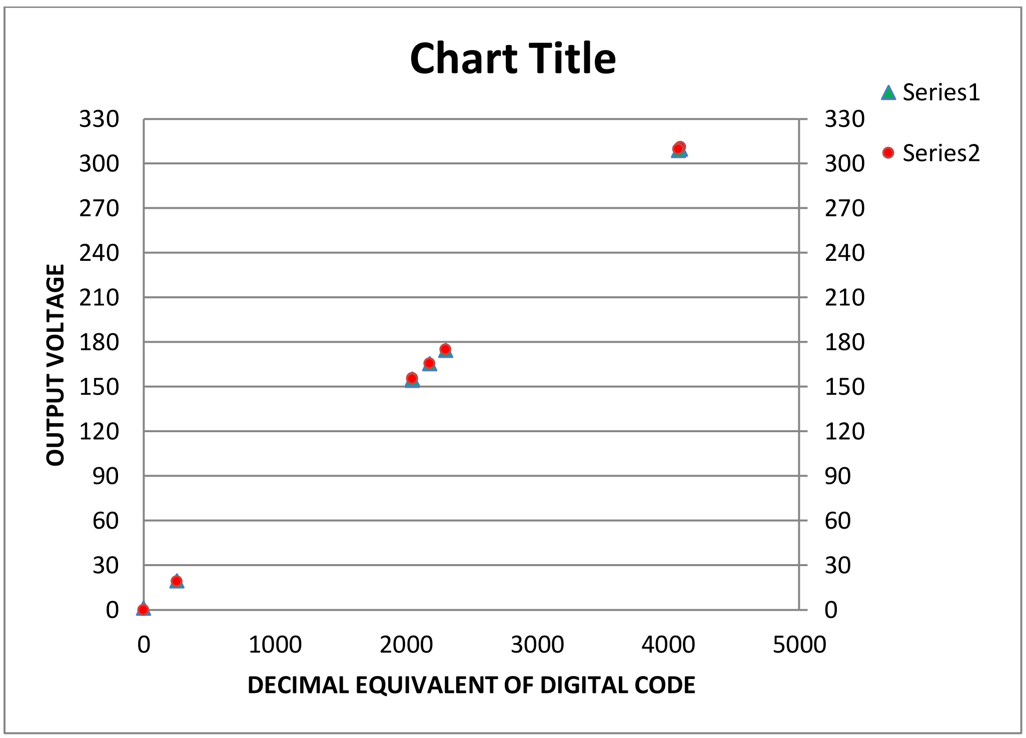


Fig 4.6: **Plot of Actual and Expected Value v/s Decimal Equivalent of Digital Output**

4.3 Testing the Prototype circuit with Fixed Resistances

8. After individual testing of the QPSD , MDAC and other blocks of the circuit, all the sub blocks were integrated together on NI ELVIS prototyping board. For testing and verifying, the efficacy of the circuit, the resistors $R1$ and $R2$ of the sensor of Figure. 2.2 were emulated with standard resistance boxes manufactured by Otto Wolff Berlin, Germany as shown in Figure 4.7. A 10 pF ceramic capacitor connected at the junction of resistors $R1$ and $R2$ emulated the

coupling capacitor *Cc*. The excitation signal v_s was generated from a function generator available in ELVIS board. The frequency of excitation was chosen to be 1KHz.The resistors *R*1 and *R*2 were varied as given below:

(i) First the values of *R*1 and *R*2 were kept at 500 Ω each to emulate the condition *x* = 0 and the offset at the output was nulled.

(ii) Next *R*1 was decreased in steps of 50Ω as 450Ω , 400Ω, …….., 50Ω and simultaneously *R*2 was increased in steps of 50Ω as 550Ω , 600Ω, …….., 950Ω For each set of *R*1 and *R*2 values (*R*1 = 450 Ω and *R*2 = 550 Ω, *R*1 = 400 Ω and *R*2 = 600 Ω, … *R*1 = 50 Ω and *R*2 = 950 Ω), the output of the circuit was recorded. This process emulated the variation in the per unit value of the measurand (*x/X*) in the range 0 to +0.9 in steps of 0.1.

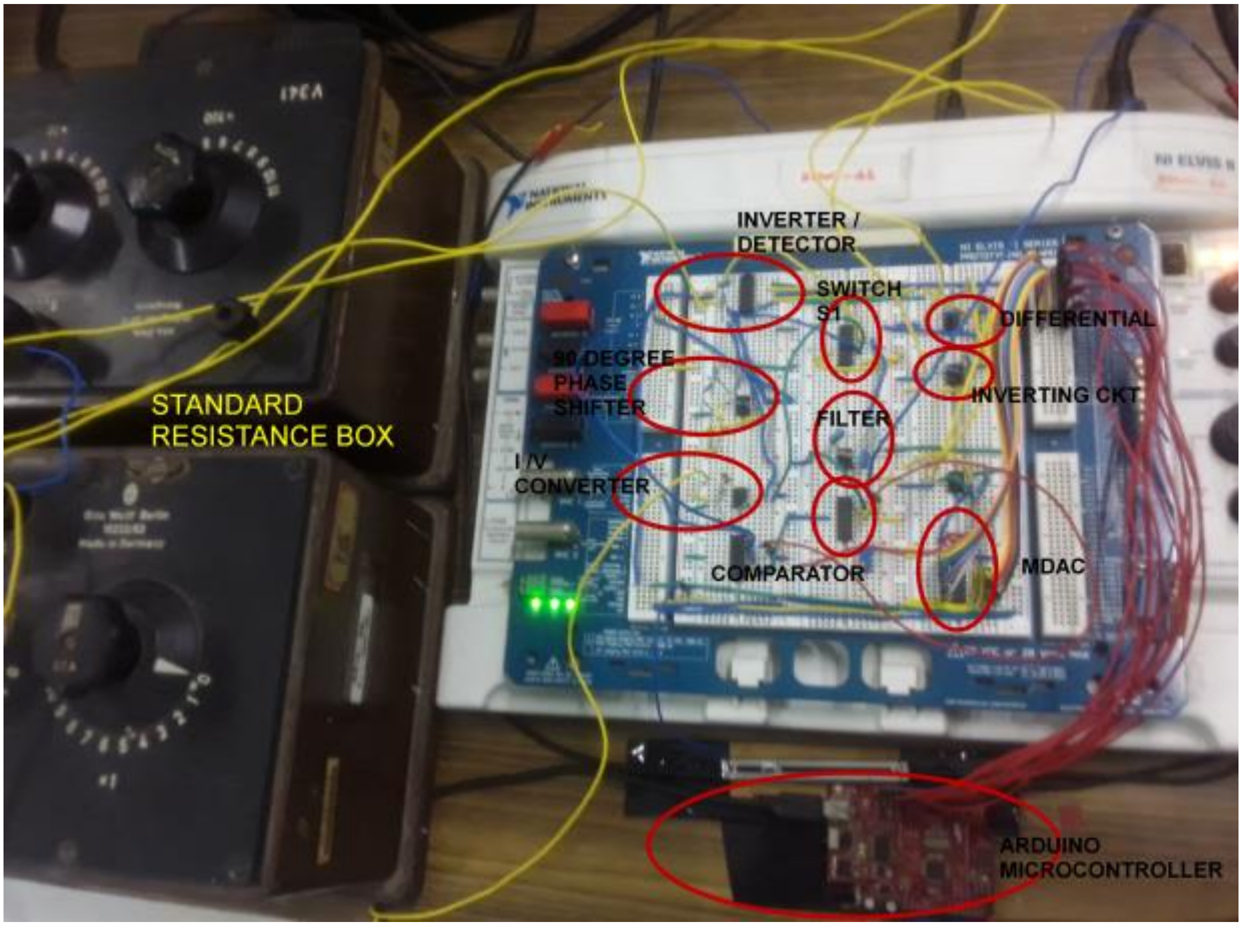


Fig 4.7: **Experimental Hardware Setup with Standard Resistance Boxes**

(iii) Next $R1$ was increased from 500 Ω in steps of 50 Ω as 550 Ω, 600 Ω, … 950 Ω and simultaneously the resistor $R2$ was decreased in steps of 50 Ω as 450 Ω, 400 Ω, … 50 Ω. For each set of $R1$ and $R2$ values the output of the circuit was recorded. This process emulated the variation in the per unit value of the measurand (x/X) in the range 0 to -0.9 in steps of -0.1.The results obtained are tabulated in Table III. It is seen from Table III that the proposed transducer possesses a good degree of linearity and accuracy over the entire range of input displacement.

TABLE III

Sl.No.	RATIO (x/X)	Digital Output in decimal equivalent	Error (%)
1.	-1.0	0	-0.1297
2.	-0.9	210	0.0033
3.	-0.8	412	-0.0591
4.	-0.7	618	-0.0238
5.	-0.6	825	0.0359
6.	-0.5	1030	0.0468
7.	-0.4	1230	-0.0644
8.	-0.3	1440	0.0685
9.	-0.2	1650	0.2015
10.	-0.1	1855	0.2124
11.	0	2048	-0.0698
12.	0.1	2253	-0.0589
13.	0.2	2459	-0.0236
14.	0.3	2664	-0.0127
15.	0.4	2867	-0.0507
16.	0.5	3072	-0.0398
17.	0.6	3280	0.0443
18.	0.7	3481	-0.0425
19.	0.8	3685	-0.056
20.	0.9	3894	0.0526
21.	1.0	4095	-0.0343

The plot of the output voltage and error % v/s the ratio of measurand is as shown in the plot below

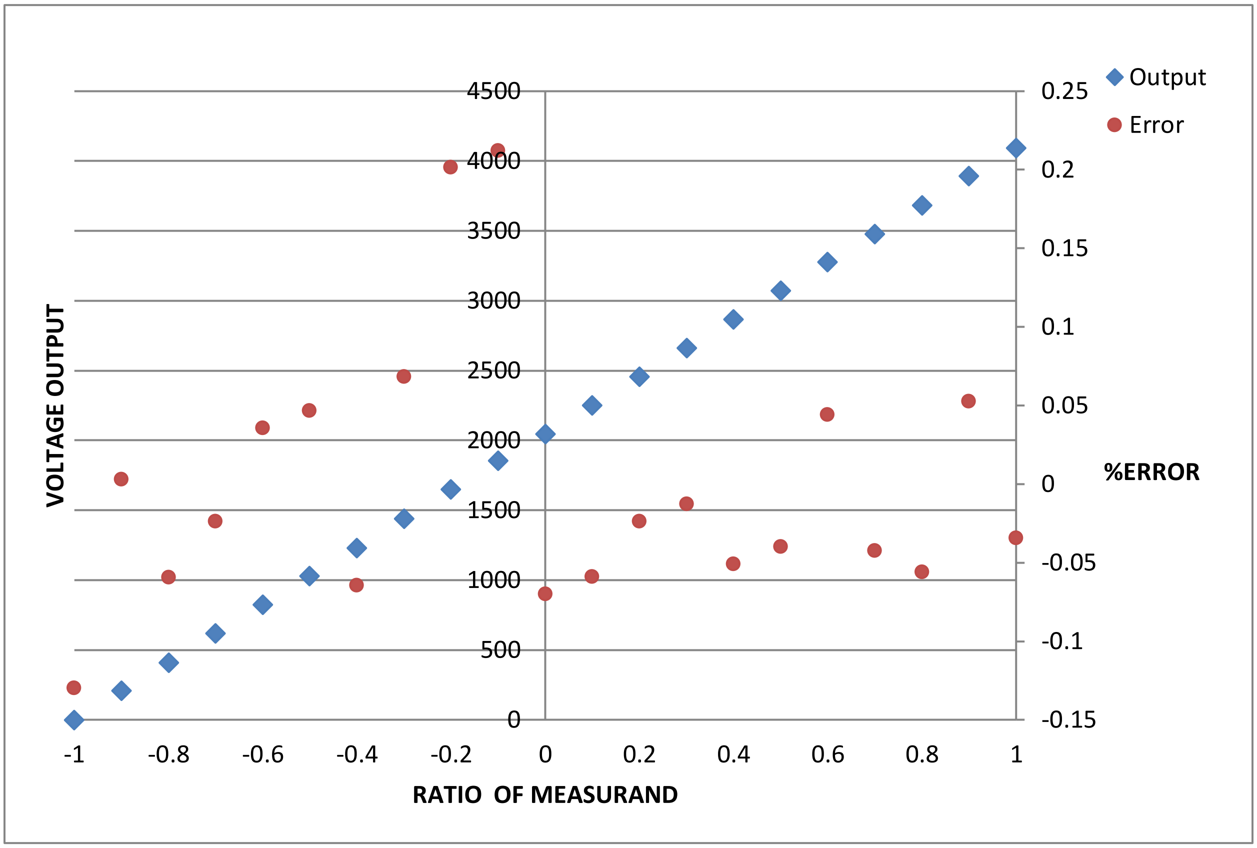


Fig 4.8: **Digital output and error v/s ratio of measurand**

4.4 Experimental Results with Designed Sensor

9. After having tested the circuit with the standard resistances, a prototype unit was built using a 10 KΩ resistor after replacing the wiper with a copper and mylar sheet to give a capacitance Cc of approximately 3 pF. This was then studied under different positions of the wiper by changing the value of resistance R1 and R2. This was achieved by displacing the wiper from its initial rest position (i.e x=0). The wiper was changed to positions +/- 0.5mm, +/- 1.0mm……upto +/-2.5mm of displacement in either direction from its initial position A photograph of the experimental setup is shown in Figure 4.9 The input Vs was chosen to be 1V sinusoidal with a frequency of 1KHz and the wiper was displaced in either directions and output

measurements taken at every 5mm of the wiper position. The outputs are then recorded and the results are tabulated in table IV below along with the error % as shown in Figure 4.10

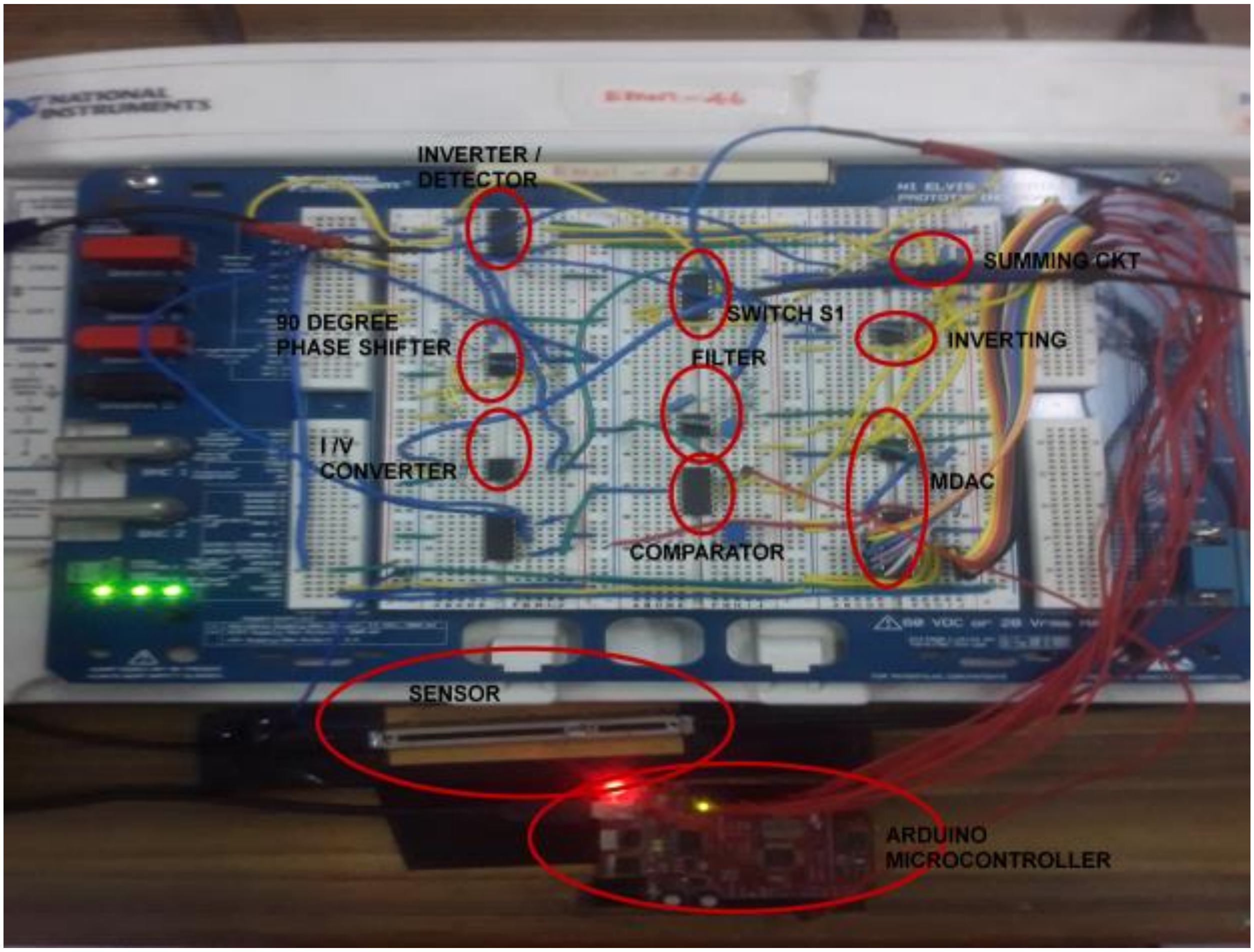


Fig 4.9: **Experimental Setup with Prototype Sensor**

TABLE IV

Value of measurand (x)	**Output (V)**	**% Error**
-2.5	0	0.0433
-2.0	412	0.0839
-1.5	818	-0.022
-1.0	1225	-0.1034

-0.5	1638	-0.0384
0	2048	-0.0466
0.5	2459	-0.0304
1.0	2869	-0.0386
1.5	3285	0.0997
2.0	3700	0.2135
2.5	4095	-0.1609

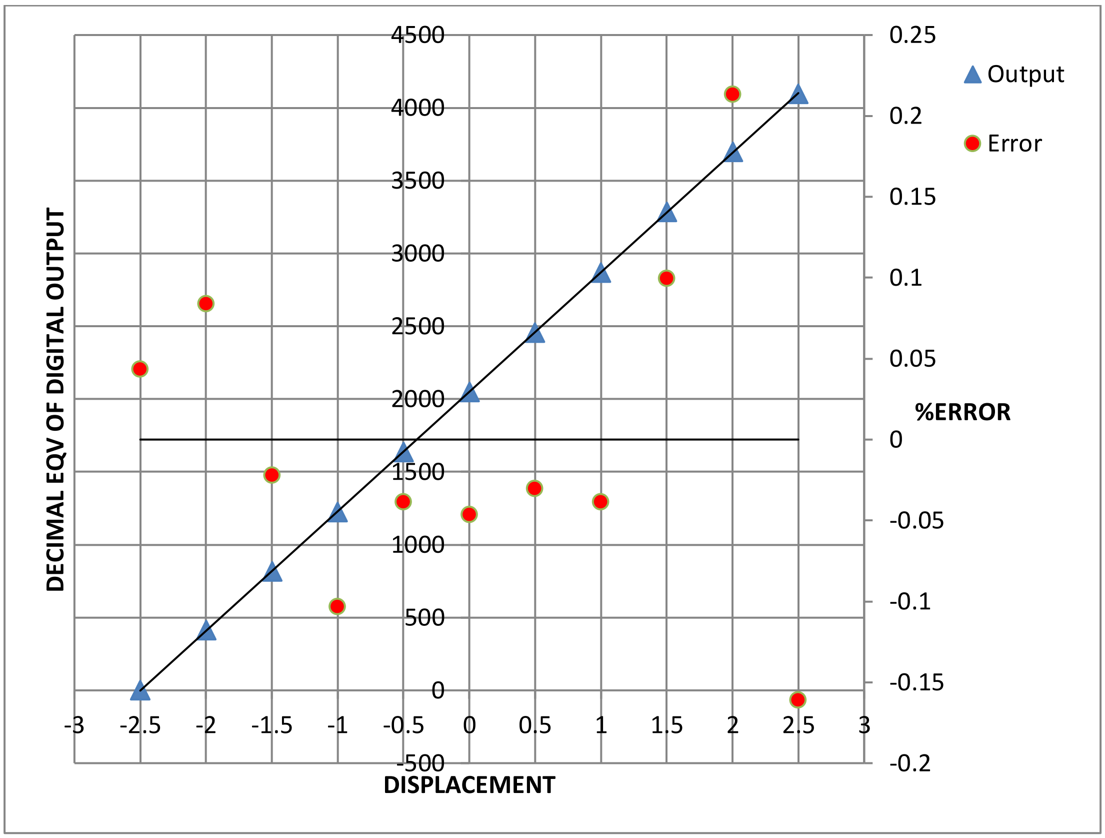


Figure 4.10: Experimental Results obtained from Hardware

Chapter 5 : CONCLUSION

5.1 Conclusion

1. In the above work a novel resistive voltage divider type displacement transducer with a contactless wiper, has been presented. Making the contacting wiper in a RVD floating introduces an air gap and hence a capacitance between the RVD and the output terminal. A novel self balancing signal conditioning circuit proposed here which operates on the contactless wiper RVD and provides an output that directly indicates the wiper's displacement. The proposed signal conditioning circuit was implemented and verified on prototype hardware. The results obtained after implementation demonstrate the functionality and feasibility of the signal conditioning circuit. The signal conditioning circuit for this sensor is based on the self balancing principle and is designed in such a way that the current through coupling capacitor is zero at steady state.

2. The final output is not affected by small variations in the coupling capacitance and other circuit parameters, hence we can safely conclude that the excellent linearity and accuracy were obtained as the output voltage is only proportional to the displacement of the floating wiper.

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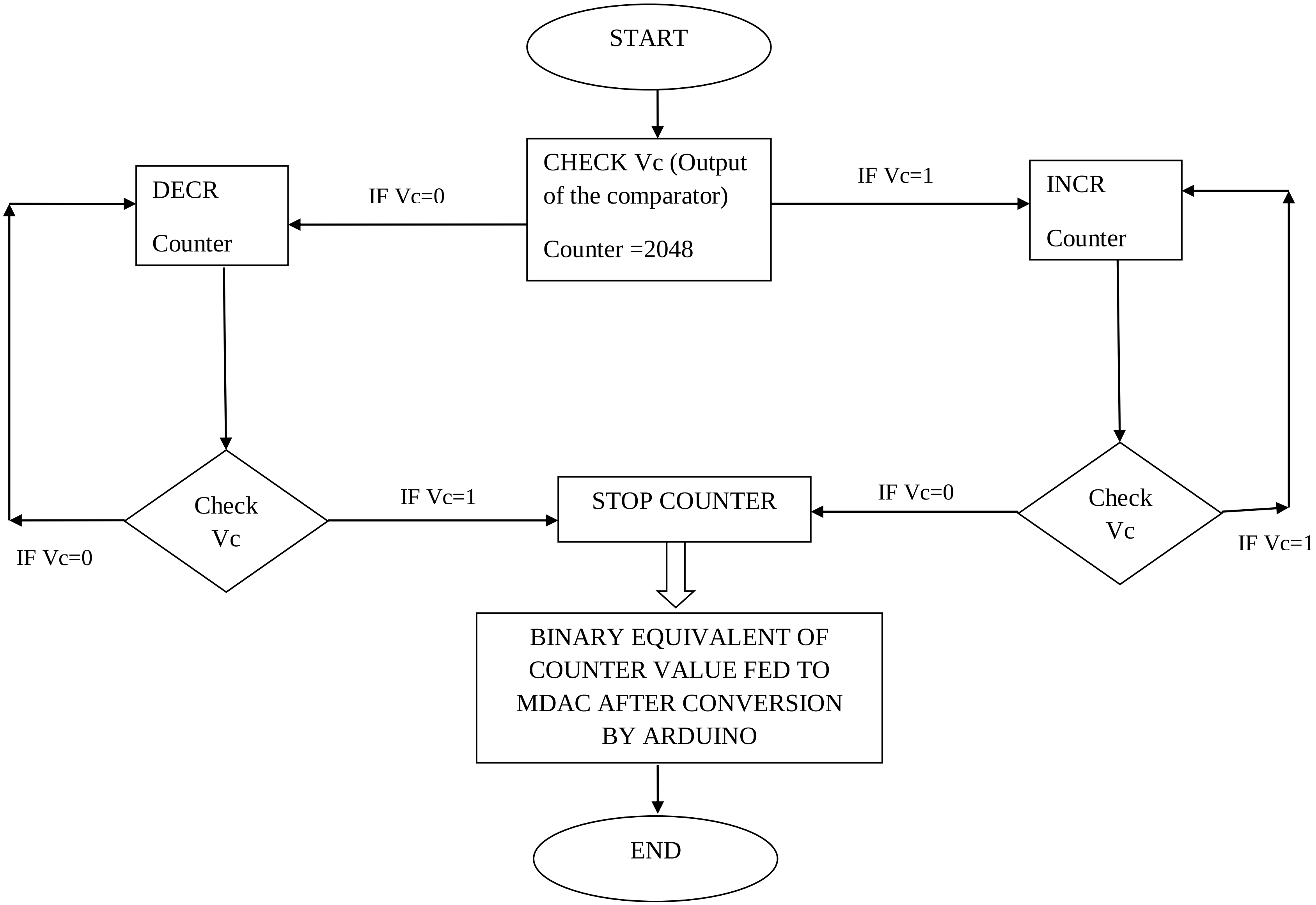
APPENDIX A

FLOW CHART FOR ARDUINO LOGIC



APPENDIX B

CODE FOR PROGRAMMING ARDUINO UNO

1. The program is written for comparing the digital output with the position of the wiper and incrementing or decrementing the counter depending on the position of the wiper. Counter stops as soon as steady state is reached.

```
//////////////////////////////////////////////////main initialisation //////////////////////////////////////////////////////////

// constants won't change. They're used here to set pin numbers:
const int PinA0 = 12;     // the number of the input pin:
const int Pin2  = 0;      // initilaising numbers for pins for 12 bit digital output:
const int Pin3  = 1;
const int Pin4  = 2;
const int Pin5  = 3;
const int Pin6  = 4;
const int Pin7  = 5;
const int Pin8  = 6;
const int Pin9  = 7;
const int Pin10  = 8;
const int Pin11 = 9;
const int Pin12 = 10;
const int Pin13 = 11;
int counter=2048;
int counter1=2047;          // initialising a variable counter to a fixed value:
int Vc= digitalRead(PinA0);

////////////////////////////////////////////////// declaring//////////////////////////////////////////////////////////////////////////

void setup() {
  // the setup routine runs once when you press reset:
  pinMode(Pin2, OUTPUT);
  pinMode(Pin3, OUTPUT);
  pinMode(Pin4, OUTPUT);
  pinMode(Pin5, OUTPUT);
  pinMode(Pin6, OUTPUT);
  pinMode(Pin7, OUTPUT);
  pinMode(Pin8, OUTPUT);
  pinMode(Pin9, OUTPUT);
  pinMode(Pin10, OUTPUT);
  pinMode(Pin11, OUTPUT);
  pinMode(Pin12, OUTPUT);
  pinMode(Pin13, OUTPUT);
```

```
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  digitalRead(PinA0) ;// sets the pin 12 as the pin for digital read from the comparator output:
  Serial.begin(9600); // initialize serial communication at 9600 bits per second:
}

////////////////////////////////////////////////////////////
void loop()                                   //the main code to be run repeatedly:
{
  int temp,remainder;
  int bin[12]={0,0,0,0,0,0,0,0,0,0,0,0};    // array for 12 bit binary output
  int n,c=0,i,x,y,z;
  int Vc,Vc1;                                  // initilaising variables for reading the pinstate:
  Vc = digitalRead(A0);                        // reading digital input at pin no 12:
  Vc1= digitalRead(A1);
  delay(1);

 ////////////////////////////////////////////////// up movement of the wiper
    if (Vc==0&&counter<=4095)
    {
    Serial.println (counter);
    temp=counter;
    while (temp != 0)// for converting fixed decimal value of counter to binary:
      {
        remainder= temp % 2;
        bin[c] = remainder;
        temp = temp /2;
        c++;
      }

      for(i = c - 1 ; i >= 0 ; i--)// for printing the digital code wrt decimal value
      {
        Serial.print(bin[i]);
      }
      //delay(1000);
      Serial.println();
      counter++;
        }
     else
     {
      Serial.print("Vc is high");
      Serial.println();
      Serial.print(counter);
      Serial.println();
      temp=counter;
    while (temp != 0)// for converting fixed decimal value of counter to binary:
      {
```

```
      remainder= temp % 2;
      bin[c] = remainder;
      temp = temp /2;
      c++;
     }

     for(i = c - 1 ; i >= 0 ; i--)// for printing the digital code wrt decimal value
     {
      Serial.print(bin[i]);
     }

    }
     Serial.println();
     digitalWrite(2, bin[0]);
     digitalWrite(3, bin[1]);
     digitalWrite(4, bin[2]);
     digitalWrite(5, bin[3]);
     digitalWrite(6, bin[4]);
     digitalWrite(7, bin[5]);
     digitalWrite(8, bin[6]);
     digitalWrite(9, bin[7]);
     digitalWrite(10, bin[8]);
     digitalWrite(11, bin[9]);
     digitalWrite(12, bin[10]);
     digitalWrite(13, bin[11]);
     delay(10);        // delay in between reads for stability


//////////////////////////////////////////// down movement of the wiper
   if (Vc==1&&counter1>=0)
   {
   Serial.print(counter1);
   Serial.println();
   temp=counter1;
   while (temp != 0)// for converting fixed decimal value of counter to binary:
     {
      remainder= temp % 2;
      bin[c] = remainder;
      temp = temp /2;
      c++;
     }

     for(i = c - 1 ; i >= 0 ; i--)// for printing the digital code wrt decimal value
     {
      Serial.print(bin[i]);
     }
     //delay(1000);
```

```
      Serial.println();
      counter1--;
        }
     else
     {
      Serial.print("Vc is low");
      Serial.println();
      Serial.print(counter1);
      Serial.println();
      temp=counter1;
    while (temp != 0)// for converting fixed decimal value of counter to binary:
      {
        remainder= temp % 2;
        bin[c] = remainder;
        temp = temp /2;
        c++;
      }

      for(i = c - 1 ; i >= 0 ; i--)// for printing the digital code wrt decimal value
      {
        Serial.print(bin[i]);
      }
    Serial.println();
     }
      Serial.println();
      digitalWrite(2, bin[0]);
      digitalWrite(3, bin[1]);
      digitalWrite(4, bin[2]);
      digitalWrite(5, bin[3]);
      digitalWrite(6, bin[4]);
      digitalWrite(7, bin[5]);
      digitalWrite(8, bin[6]);
      digitalWrite(9, bin[7]);
      digitalWrite(10, bin[8]);
      digitalWrite(11, bin[9]);
      digitalWrite(12, bin[10]);
      digitalWrite(13, bin[11]);
      delay(1000);        // delay in between reads for stability

}
```