Design of a Low-maintenance Continuous Liquid Level Measurement Sensor using a Float and Magnetic Sensors

A Thesis
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Ashwani Kumar
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THESIS CERTIFICATE

This is to certify that the thesis titled "Design of a Low-maintenance Continuous Liquid Level Measurement Sensor using a Float and Magnetic Sensors", submitted by Mr. Ashwani Kumar, 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.

Dr. Boby George
Associate Professor
Dept. of Electrical Engineering
IIT-Madras, Chennai-600036

Place: Chennai
Date:

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Ashwani Kumar

EE15M044

ABSTRACT

This thesis presents a reliable and low-cost level sensing system. It has a floating part and a fixed part. The floating part has a permanent magnet with known field pattern as a function of the axial distance from the float. The float has a vertical guide, which is a fixed non-magnetic tubular structure. Multiple numbers of magnetic sensors are positioned inside the tube with a spacing of about 20 cm. A measurement system obtains the field seen by those sensors and computes the position of the float accurately. As the fixed part and the float are linked magnetically, no mechanical link is between those two. This helps to achieve long life space without maintenance. A prototype has been built in the laboratory and tested in detail. The results show that the proposed scheme is feasible and accurate.

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CHAPTER 1

INTRODUCTION

Liquid level is a very important parameter that is measured in various industries across wide range of applications. In simple terms, level measurement is the measurement of the height of particular media with respect to a reference point or the base of the containing vessel. Broadly, there are two types of level measurement, continuous level measurement and point level measurement. In continuous level measurement, the actual level of the media is known at all times from a level transducer. Here, we are mainly concerned with the continuous liquid level measurement in a tank.

1.1. Existing sensors for liquid level measurement

- **Level Detection using a Float and Reed Switches**

  Level detection of liquids is often done with a float and magnetic reed Switch. The float transfers on a mechanical guide. The float itself contains a small magnet that changes the state of a switch when the liquid level gets close to the position of reed switch. This type of level sensor is limited by the life expectancy of reed switch which is 10^5-10^6 switching cycles [1].

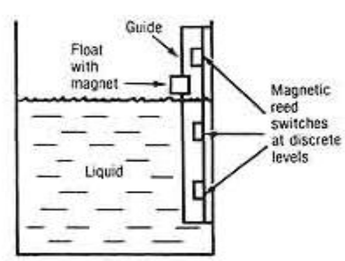


Figure 1.1: Level Detection by Using a Float and reed Switch [2]

- **Level Detection by using capacitive probe [3]**

In a basic capacitive level sensing system, capacitive sensors have two conducting terminals that establish a capacitor. If the gap between the two rods is fixed, the fluid level can be determined by measuring the capacitance between the conductors immersed in the liquid. Since the capacitance is proportional to the dielectric constant, fluids rising between the two parallel rods will increase the net capacitance of the measuring cell as a function of fluid height. To measure the liquid level, an excitation voltage is applied with a drive electrode and detected with a sense electrode..

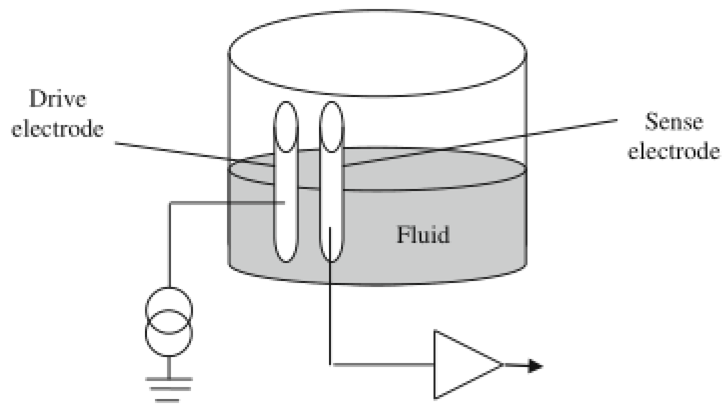


Figure 1.2: Capacitive probe method [3]

Physical construction of the tank and probe is critical. Obvious errors will crept in if probes are not in parallel with each other. There are chances of corrosion of probe if liquid is of corrosive nature.

Apart from that dielectric constant of liquid is a function of temperature, moisture etc. which can result in erroneous readings. The transducer will work satisfactorily only with liquids with relatively high dielectric constant.

- **Ultrasonic level sensor [4]**

Ultrasonic level measurement is one of a number of non-contact techniques available. The principle of the ultrasonic level gauge is that energy from an ultrasonic source above the liquid is reflected back from the liquid surface into an ultrasonic energy detector, as illustrated in Figure. Measurement of the time of flight allows the liquid level to be inferred.

They consist of fixed components only hence require less maintenance. Ultrasonic level measurement technique cannot be suitably applied in all fields since use of ultrasonic level sensors includes few setbacks too. Many factors exist which have the tendency to influence the returned echo signal back to the sensor. Some of them include:

- Materials like powders etc.
- Heavy vapors
- Surface turmoil
- Foam
- Ambient noise and temperature

Also, ultrasonic level measurement devices do not work satisfactorily in areas involving vacuum or high pressure conditions.

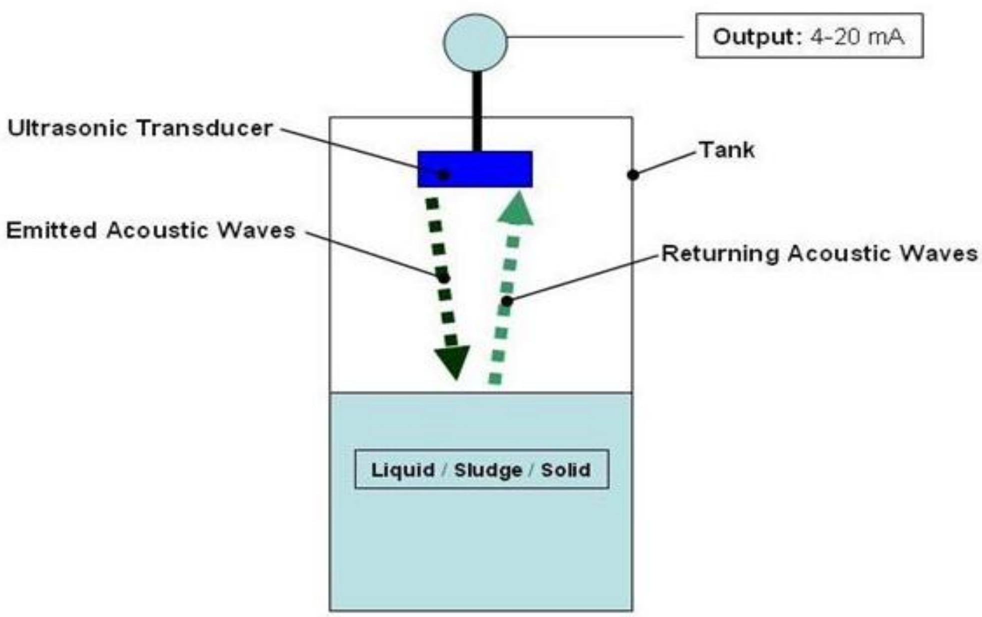


Figure 1.3: Working of ultrasonic level sensor [4]

1.2. Objective and scope of work

The objective of the work is to design and develop a contactless liquid level sensor using magnetic sensors and a magnet of known strength inside a float for:

- Continuous liquid level measurement between two consecutive magnetic sensors
- Identifying the position of magnetic sensors

This sensor is intended to be robust, low-cost and overcome limitations and errors due to changes in environmental factors and liquid properties.

1.3. Organization of the thesis

A brief introduction of level sensors and objective of this thesis is given in chapter 1.Chapter 2 describes the block diagram of the measurement systems and hardware components such as Hall Effect sensor, INA 129, and a cylindrical magnet used for prototyping in-detail. Chapter 3 discusses about simulation of cylindrical magnet using COMSOL Multiphysics and selection of characteristics suitable for this sensor. Chapter 4 is about experimental setup and results and chapter 5 gives conclusion and talks about future scope.

CHAPTER 2

Continuous Liquid Level Measurement System

This chapter describes the block diagram of the measurement system and hardware components used for prototyping such as Hall Effect sensor, INA 129, CY8CKIT-059 PSoC 5LP Prototyping Kit and a cylindrical magnet used for prototyping in-detail.

2.1 Block diagram of the measurement system

Schematic diagram of the proposed Continuous Liquid Level Measurement System is shown in figure 2.1.In that, we have 5 magnetic sensors placed at uniform distance of 20 cm from each other inside an enclosed pipe. Pipe is enclosed in order to ensure that liquid does not come in contact with the electronic components of the system. Connections for Vcc, gnd and sensor output are taken out from pipe and given to the measurement unit. System also has a float which travels along the pipe with changing liquid level and it incorporates a cylindrical magnet of known strength. Magnetic sensors read changes in magnetic field and pass it on to the measurement unit.

Measurement unit consist of instrumentation amplifier followed by low pass filter for each hall sensor. Liquid level is known to be varying very slowly. Therefore, low pass filter only removes noise at higher frequencies and does not affect the signal from hall sensor. Signals from low pass filter are passed on to the ADC through multiplexer. Output of ADC stage is read and used by LabVIEW VI/microcontroller program to infer the position of float or liquid level. Block diagram of measurement unit is shown in figure 2.2.

Next section onwards, hardware components used for prototyping the Continuous Liquid Level Measurement System will be discussed in detail.

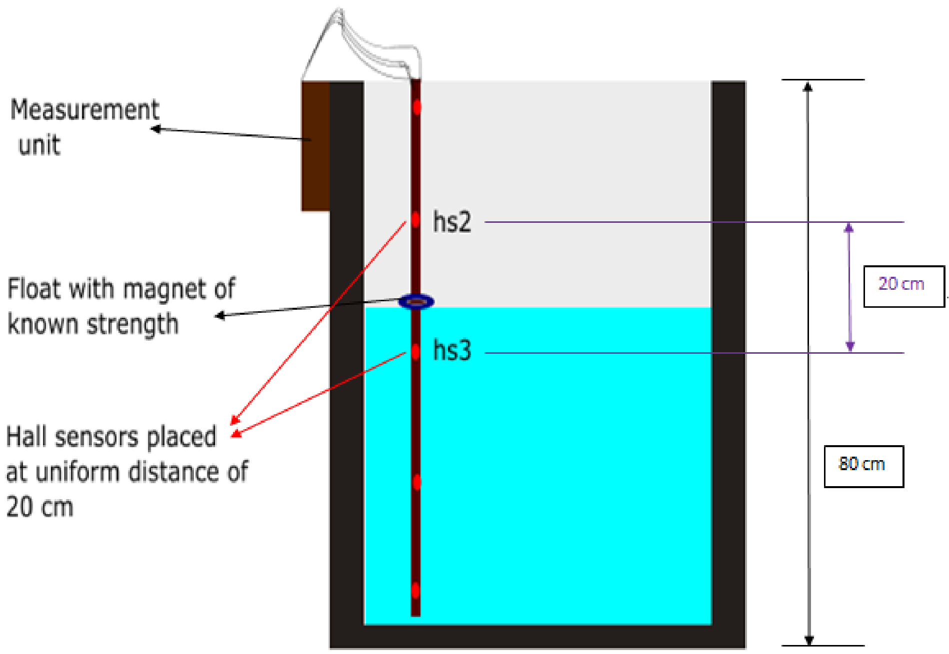


Figure 2.1: Schematic diagram of proposed continuous liquid level measurement system

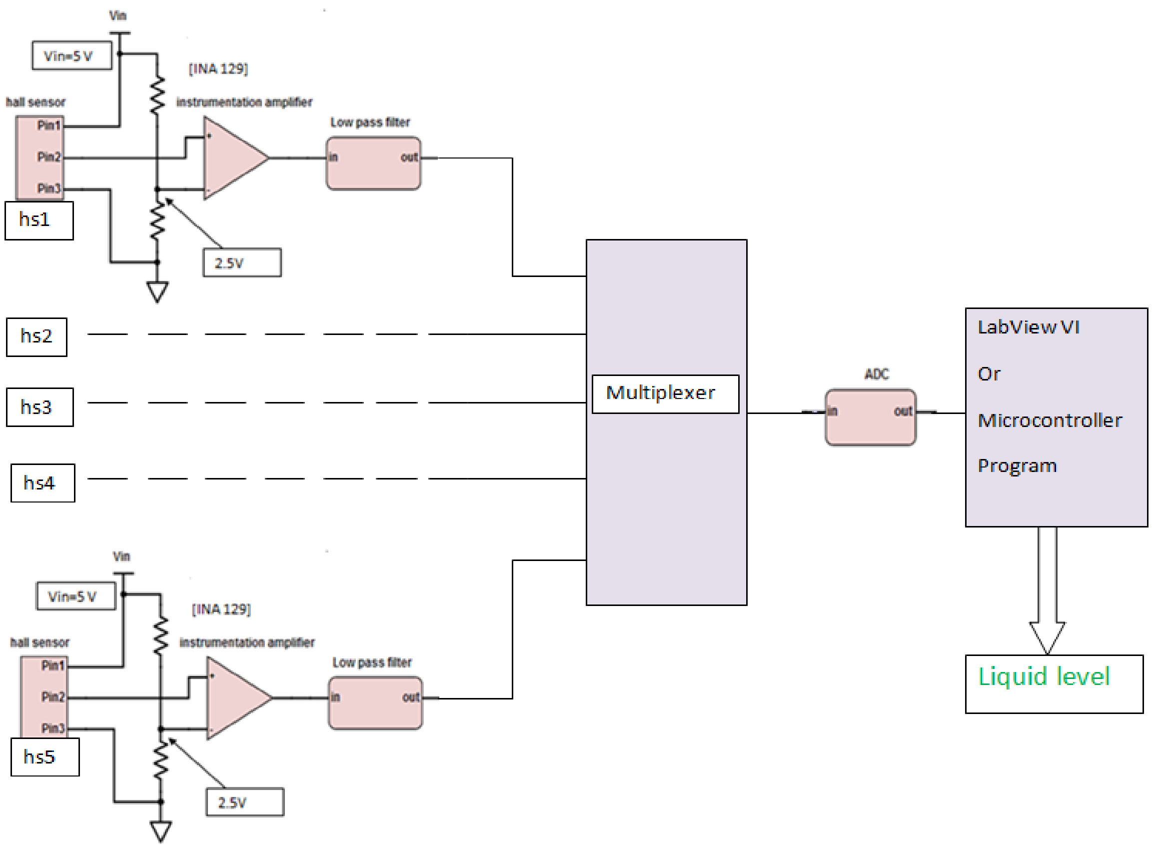


Figure 2.2: Block diagram of continuous liquid level measurement system

2.2 Hall Sensor

We have used Hall sensors as magnetic sensors for implementing the system shown in figure 2.1 and 2.2.

2.2.1 Hall Effect Demonstration

Conceptually, a demonstration of the Hall Effect is simple to set up and is illustrated in Figure 2.3. Figure 2.3 (a) shows a thin plate of conductive material, such as copper, that is carrying a current (I), in this case supplied by a battery. One can position a pair of probes connected to a voltmeter opposite each other along the sides of this plate such that the measured voltage is zero.

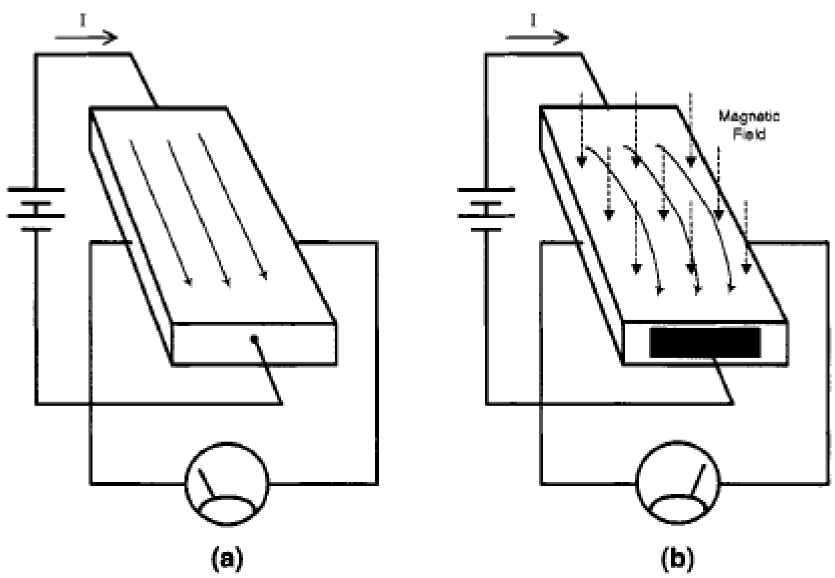


Figure 2.3: The Hall Effect in a conductive sheet [5]

When a magnetic field is applied to the plate so that it is at right angles to the current flow, as shown in Figure 2.3(b), a small voltage appears across the plate, which can be measured by the probes. If you reverse the direction (polarity) of the magnetic field, the polarity of this induced voltage will also reverse. This phenomenon is called the Hall Effect, named after Edwin Hall.

2.2.2 Hall Effect

In order to understand the Hall Effect, one must understand how charged particles, such as electrons, move in response to electric and magnetic fields. The force exerted on a charged particle by an electromagnetic field is described by [5]:

$$\vec{F} = q_0\vec{E} + q_0\vec{v} \times \vec{B} \tag{2.1}$$

Where $\vec{F}$ is the resultant force, $\vec{E}$ is the electric field, $\vec{v}$ is the velocity of the charge, $\vec{B}$ is the magnetic field, and q_0 is the magnitude of the charge. This relationship is commonly referred to as the Lorentz force equation. Note that, except for q_0, all of these variables are vector quantities, meaning that they contain independent ***x,*** y, and z components. This equation represents two separate effects: the response of a charge to an electric field, and the response of a moving charge to a magnetic field.

In the case of the electric field, a charge will experience a force in the direction of the field, proportional both to the magnitude of the charge and the strength of the field. This effect is what causes an electric current to flow. Electrons in a conductor are pulled along by the electric field developed by differences in potential (voltage) at different points.

In the case of the magnetic field, a charged particle doesn't experience any force unless it is moving. When it is moving, the force experienced by a charged particle is a function of its charge, the direction in which it is moving, and the orientation of the magnetic field it is moving through. Note that particles with opposite charges will experience force in opposite directions; the signs of all variables are significant. In the simple case where the velocity is at right angles to the magnetic field, the force exerted is at right angles to both the velocity and the magnetic field. The cross-product operator (×) describes this relationship exactly. Expanded out, the force in each axis *(x, y, z)* is related to the velocity and magnetic field components in the various axes by:

$$Fx = q_0(v_y B_z - v_z B_{yz}) \qquad Fy = q_0(v_x B_z - v_z B_x) \qquad Fz = q_0(v_x B_y - v_y B_x)$$

The forces a moving charge experiences in a magnetic field cause it to move in curved paths, as depicted in Figure 2.4. Depending on the relationship of the velocity to the magnetic field, the motion can be in circular or helical patterns.

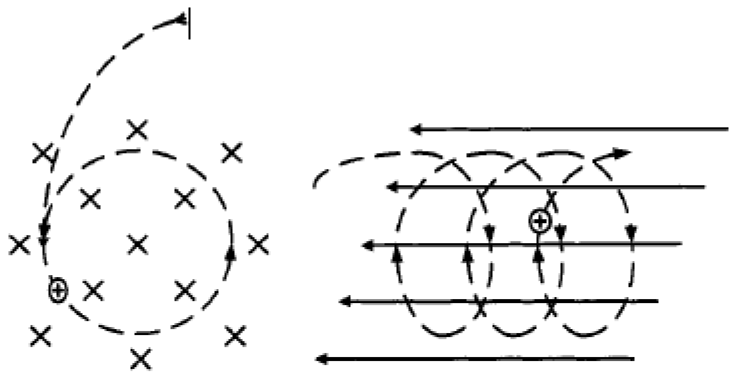


Figure 2.4: Magnetic fields cause charged particles to move in circular (a) or helical (b) paths [5]

In the case of charge carriers moving through a Hall transducer, the charge carrier velocity is substantially in one direction along the length of the device and the sense electrodes are connected along a perpendicular axis across the width. By constraining the carrier velocity to the ***x*** axis (v_y = 0, v_z= 0) and the sensing of charge imbalance to the *z* axis, we can simplify the above three sets of equations to one:

$$Fz = q_0(v_x B_y) \tag{2.2}$$

Which implies that the Hall-effect transducer will be sensitive only to the ***y*** component of the magnetic field. This would lead one to expect that a Hall-effect transducer would be orientation sensitive, and this is indeed the case. Practical devices are sensitive to magnetic field components along a single axis and are substantially insensitive to those components on the two remaining axes.

Although the magnetic field forces the charge carriers to one side of the Hall transducer, this process is self-limiting, because the excess concentration of charges to one side and consequent depletion on the other gives rise to an electric field across the transducer. This field causes the carriers to try to redistribute themselves more evenly. It also gives rise to a voltage that can be measured across the plate. Equilibrium develops where the magnetic force pushing the charge carriers aside is balanced out by the electric force trying to push them back toward the middle.

$$q_0 E_z + q_0 (v_x B_y) = 0 \quad (2.3)$$

This can be further written as: $$E_z = -v_x B_y \quad (2.4)$$

For a transducer with a given width ***l*** between sense electrodes, the Hall electric field can be integrated over ***l*** assuming it is uniform, giving us the Hall voltage.

$$\boxed{V_h = v_x B_y l} \quad (2.5)$$

The Hall voltage is therefore a linear function of:

a) The charge carrier velocity in the body of the transducer,

b) The applied magnetic field in the “sensitive” axis,

c) The spatial separation of the sense contacts, at right angles to carrier motion.

2.2.3 Minimal Hall-effect Sensor:

A minimal Hall-effect sensor (Figure 2.5) consists of three parts: a means of powering or biasing the transducer, the transducer itself, and an amplification stage.[5]

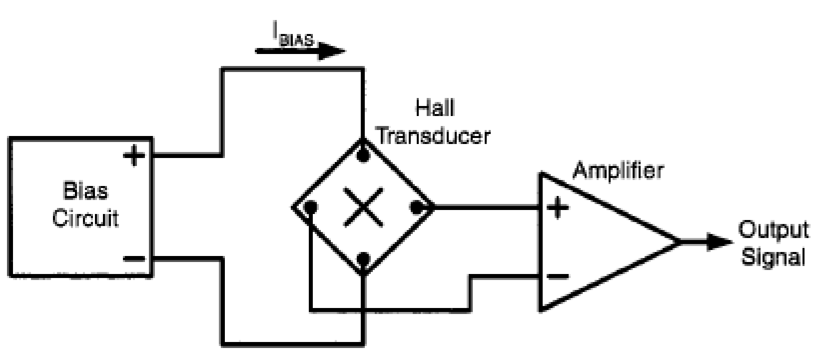


Figure 2.5: Minimal components of Hall-effect sensor system [5].

2.2.4 Hall Sensor IC used:

For this project, analog hall sensor (SS49E) from Honeywell has been used. It provides an output voltage that is proportional to the magnetic field to which it is exposed. Figure 2.6 illustrates a ratio metric analog sensor that accepts a 4.5 to 10.5 V supply[6]. This sensor has a sensitivity (mV/Gauss) and offset (V) proportional (ratio metric) to the supply voltage. This device has “rail-to-rail” operation. That is, its output varies from almost zero (0.2 V typical) to almost the supply voltage (Vs - 0.2 V typical) [6].Perpendicular to the plane of paper is the sensitivity axis of the sensor.

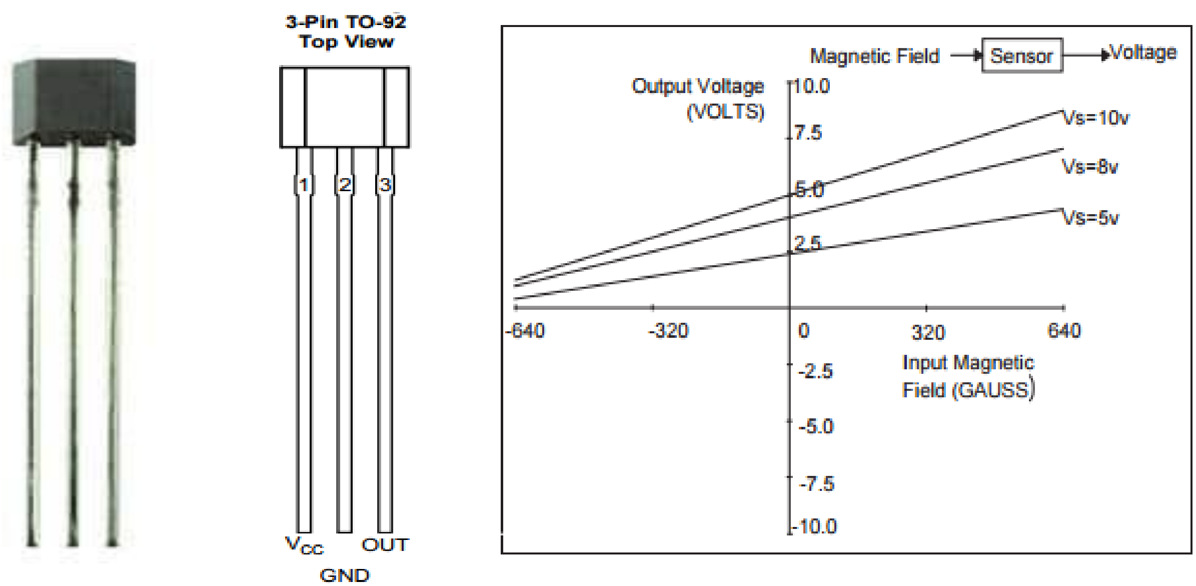
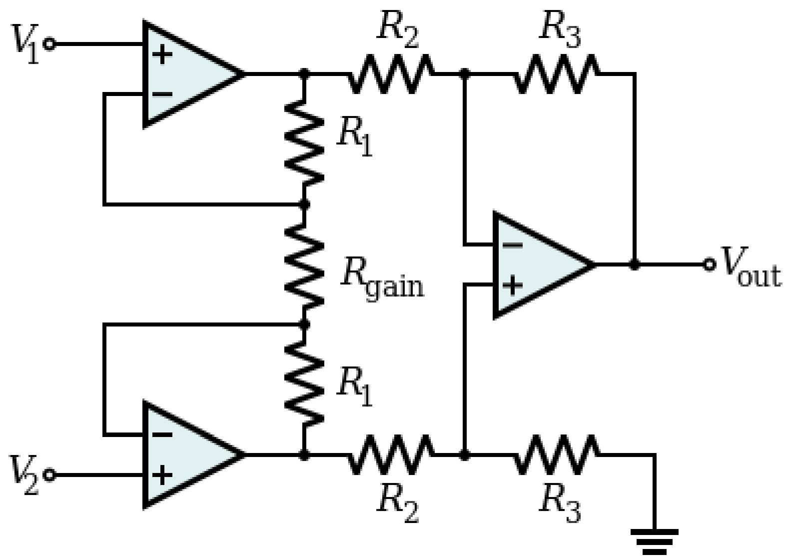


Figure 2.6: Hall Sensor (SS49E), its pin functions and transfer characteristics [6]

2.3 Instrumentation Amplifier

2.3.1 Instrumentation Amplifier

An instrumentation amplifier is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short and long-term are required.



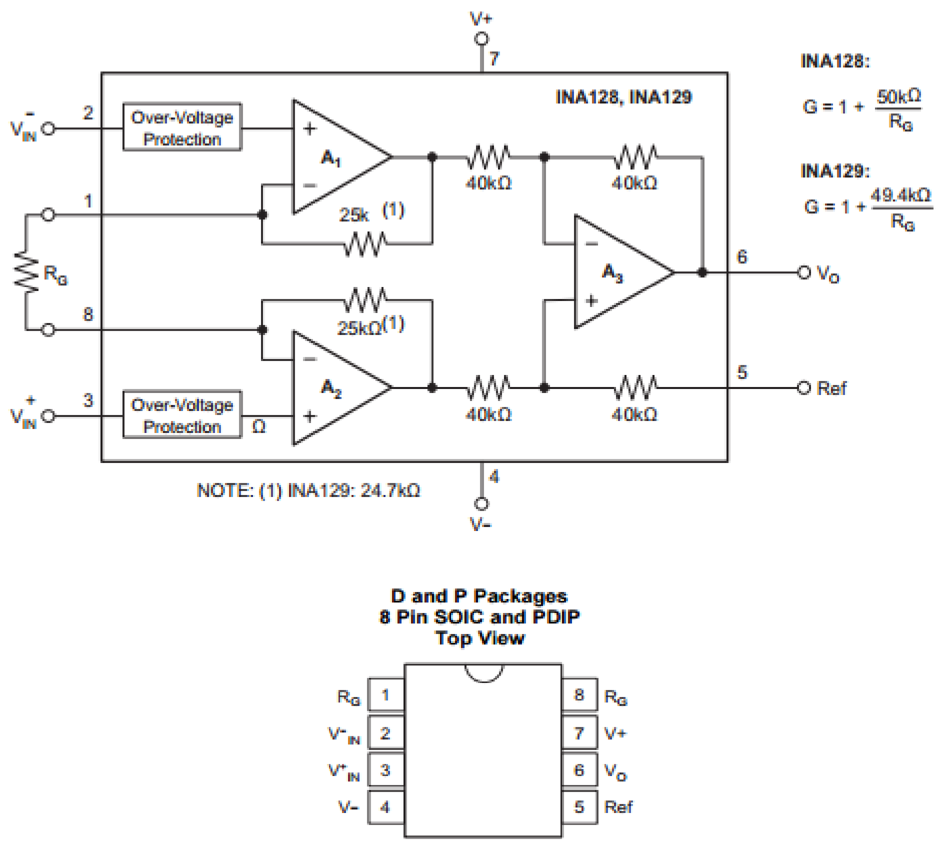
$$\frac{V_{out}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}$$

Figure 2.7: Typical Instrumentation amplifier and its gain [7]

The rightmost amplifier, along with the resistors labeled R_2 and R_3 is the standard differential amplifier, with gain $\frac{R_3}{R_2}$ and differential input resistance 2*R_2. The two amplifiers on the left are the buffers. With R_{gain} removed (open circuited), they are simple unity gain buffers; the circuit will work in that state, with gain simply equal to $\frac{R_3}{R_2}$and high input impedance because of the buffers. The buffer gain could be increased by putting resistors between the buffer inverting inputs and ground to shunt away some of the negative feedback; however, the single resistor R_{gain} between the two inverting inputs is a much more elegant method: it increases the differential-mode gain of the buffer pair while leaving the common-mode gain equal to 1. This increases the CMRR of the circuit and also enables the buffers to handle much larger common-mode signals without clipping than would be the case if they were separate and had the same gain. Another benefit of the method is that it boosts the gain using a single resistor rather than a pair, thus avoiding a resistor-matching problem, and very conveniently allowing the gain of the circuit to be changed by changing the value of a single resistor. A set of switch-selectable resistors or even a potentiometer can be used for R_{gain} , providing easy changes to the gain of the circuit, without the complexity of having to switch matched pairs of resistors[7].

2.3.2 INA 129P

The INA129P is low-power, general purpose instrumentation amplifier from TI with excellent accuracy. The INA129 is laser-trimmed for very low offset (50 µV), drift (0.5 µV/°C) and high mode rejection (120 dB at G ≥ 100)[8]. The INA129 operates with power supplies as low as ±2.25 V, and quiescent current is only 700 µA, ideal for battery-operated systems[8]. Internal input protection can withstand up to ±40 V without damage[8].



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
REF	5	I	Reference input. This pin must be driven by low impedance or connected to ground.
R_G	1,8	—	Gain setting pin. For gains greater than 1, place a gain resistor between pin 1 and pin 8.
V-	4	—	Negative supply
V+	7	—	Positive supply
V_{IN-}	2	I	Negative input
V_{IN+}	3	I	Positive input
V_O	6	I	Output

Figure 2.8: INA 129 and its pin functions [8]

2.4 Neodymium Magnets

2.4.1 Introduction to Neodymium Magnets

Rare Earth Neodymium Magnets are extremely powerful. They are among the strongest of all magnets, and are relatively affordable, making them very popular. They are considered permanent magnets, although some rare earth magnets will lose their magnetic field at high temperatures. They are made out of a neodymium-iron-boron material, or Nd2Fe14B, of which iron is the main component. Their field strength has been measured at 12.5 kilogauss, or 1.25 Tesla (tens of thousands of times stronger than the earth's magnetic field). Their incredible strength makes them a constant source of wonder as well as ideal demonstrators of the force of magnetism in traditional, and some not so traditional, experiments.

2.4.2 Neodymium Magnets used in experiments

Cylindrical neodymium magnets of grade 52 of different sizes have been used during the test phase. Finally, magnet with the dimension of 13×13 mm was found to be suitable.

2.5 NI Elvis II [9]:

The National Instrument's Educational Laboratory Virtual Instrumentation Suite II (NI ELVIS II) is a Lab VIEW and computer based design and prototyping environment. NI ELVIS II consists of a custom-designed bench top workstation, a prototyping board, a multifunction data acquisition device and Lab VIEW based virtual instruments. This combination provides an integrated, modular instrumentation platform that has comparable functionality to the DMM, Oscilloscope, Function Generator, and power Supply found on the laboratory workbench. The NI ELVIS II Workstation can be controlled either VI manual dials on the stations front or through software virtual instruments. The NIELVIS II provides full testing, measurement, and data logging capabilities by setting up an environment of virtual instruments. This can perform functions similar to a number of much more expensive instruments used in the lab. NI ELVIS II find applications in engineering, physical sciences, and biological sciences laboratories. NIELVIS II consists of a Bench top hardware workspace and NI Elvis software.

2.6 LabVIEW VI used for inferring liquid level:

A LabVIEW VI has been designed which infers liquid level based on various thresholds set for data from magnetic sensors. Tank is divided in regions based on the pair of magnetic sensors float is in. If float is in between sensors hs1 and hs2, that is region1.If float is in between sensors hs2 and hs3, that is region 2 and so on. Like this, whole tank is divided in 4 regions. If float is in region 1; then data from hs1 and hs2 will be more than certain threshold level. Data from hs1 and hs2 is taken and an equation particular to the region 1 will be applied to obtain the float position or liquid level. Chapter 3 discusses more in detail about various regions and equations particular to them.

Same logic has been used while programming PSoC 5LP prototyping kit. LabVIEW VI used for this purpose and microcontroller programs have been incorporated in the appendix.

2.7 CY8CKIT-059 PSoC 5LP Prototyping Kit [10]

The PSoC 5LP prototyping kit is designed as an easy-to-use and inexpensive prototyping platform. The PSoC 5LP Prototyping Kit supports the PSoC 5LP device family, delivering a complete system solution for a wide range of embedded applications at a very low cost. The PSoC 5LP is the industry's most integrated SoC with an ARM® Cortex™-M3 CPU. It combines programmable and reconfigurable high-precision analog and digital blocks with flexible automatic routing. The unique flexibility of the PSoC 5LP architecture will be helpful for those who want to rapidly develop products using the PSoC 5LP device family.

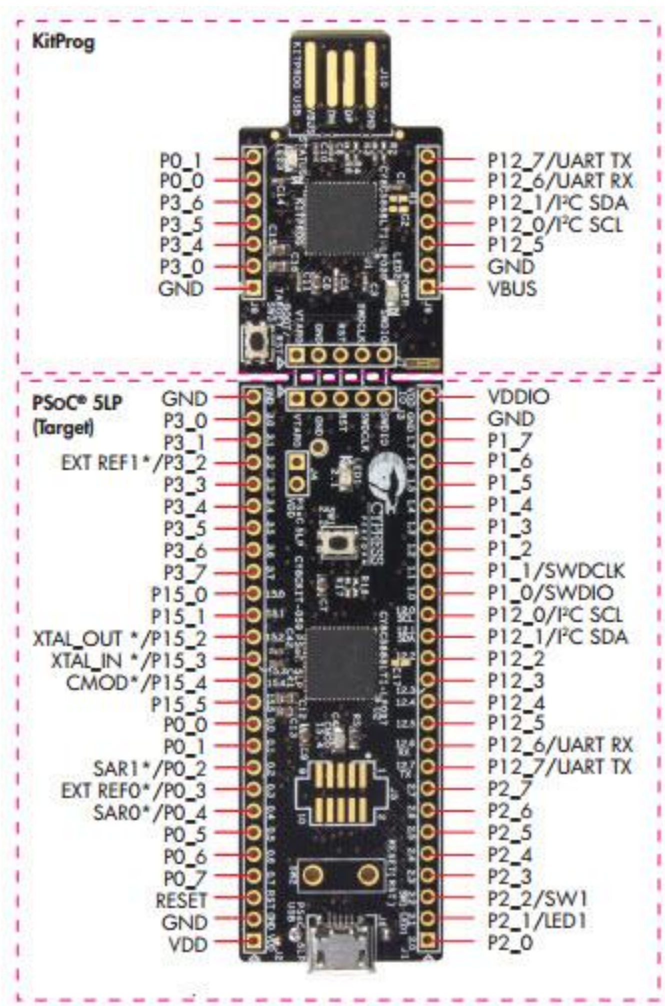


Figure 2.9: CY8CKIT-059 PSoC 5LP Prototyping Kit [10]

CHAPTER 3

Cylindrical Magnet Simulation

This chapter discusses how COMSOL Multiphysics software was used to simulate the behavior of cylindrical magnet. Cylindrical magnet simulations are used to get an idea of what to expect when magnet interacts with hall sensor. This information helps in deciding how hall sensor and magnet should be places with respect to each other for our prototype.

3.1 A Short Introduction to COMSOL Multiphysics

COMSOL Multiphysics is a powerful interactive environment for modeling and solving all kinds of scientific and engineering problems based on partial differential equations (PDEs)[11]. With this software, conventional models for one type of physics can be easily extended into multiphysics models that solve coupled physics phenomena - and do so simultaneously. It is possible to build models by defining the physical quantities - such as material properties, loads, constraints, sources, and fluxes - rather than by defining the underlying equations. These variables, expressions, or numbers can be applied directly to solid domains, boundaries, edges, and points independently of the computational mesh. COMSOL then internally compiles a set of PDEs representing the entire model[11]. The power of COMSOL is accessible through a flexible graphical user interface.

It has various modules such as acoustics, electromagnetic, chemical reactions, mechanics, fluid flow, heat transfer etc. Modules to be used during simulation can be chosen to account for variety of factors in a physical phenomenon. Then geometry of the phenomenon and various conditions under which it is happening needs to be defined. Then mesh is created. Mesh can be made finer if more accurate results are desired. There are various study nodes based on the type of selected physics which automatically defines a solution sequence. Run a study node and simulation takes some time to complete. Results can be seen under the result node.

3.2 Cylindrical magnet simulation

3.2.1 Geometry required

First of all, magneto-statics was selected as the type of physics under 3-D modeling and a cylindrical object with the 4 mm radius and 20 mm height was made. Around that, in order to simulate the open air environment, sphere of dimension 25 cm was created and was made infinite element. [x, y and z scaling in figure 3.1 and 3.2 is in cm]

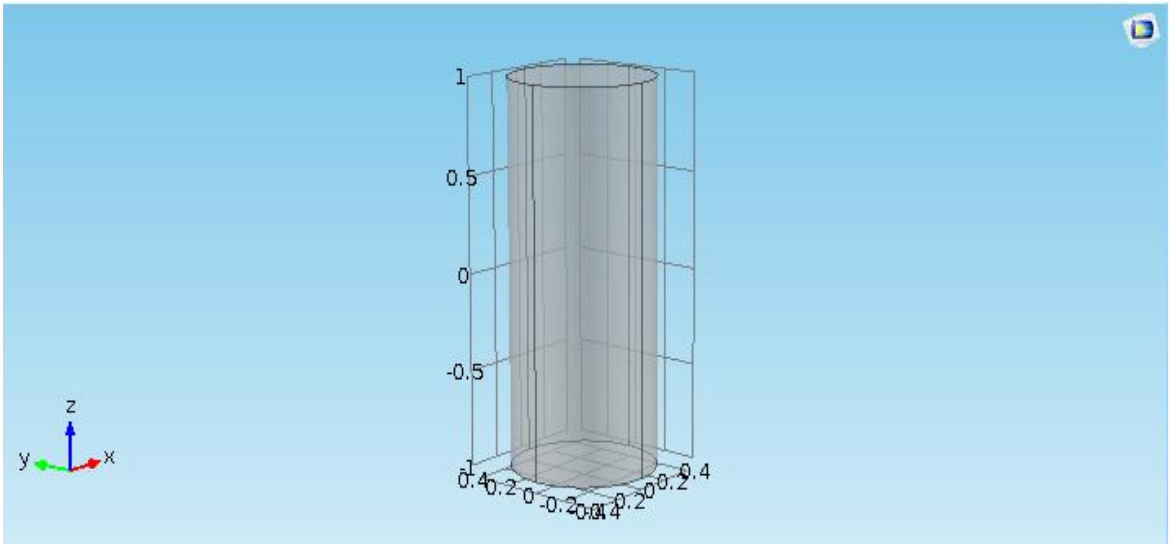


Figure 3.1: Cylindrical Object with 4 mm radius and 20 mm height

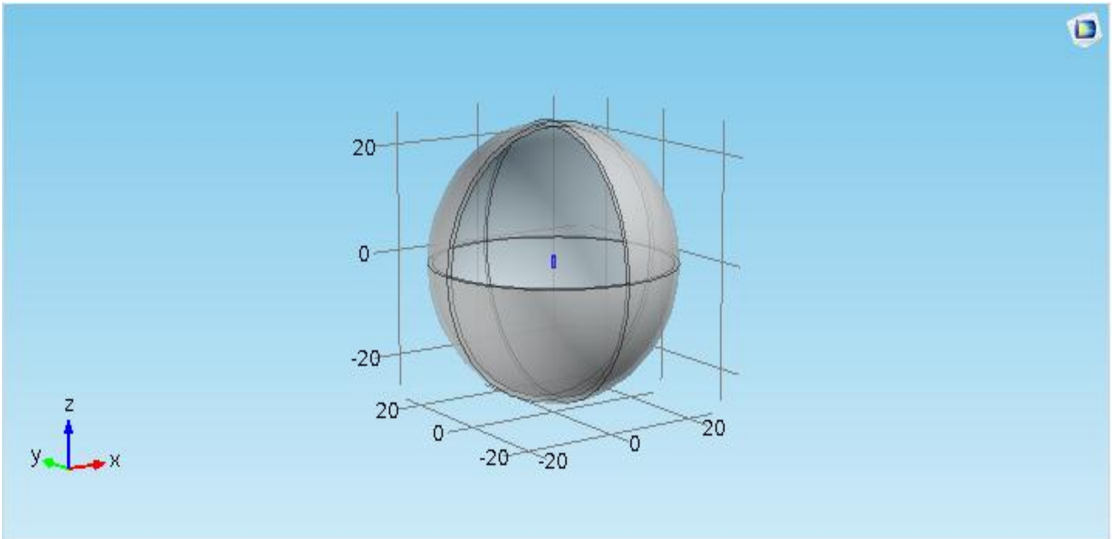
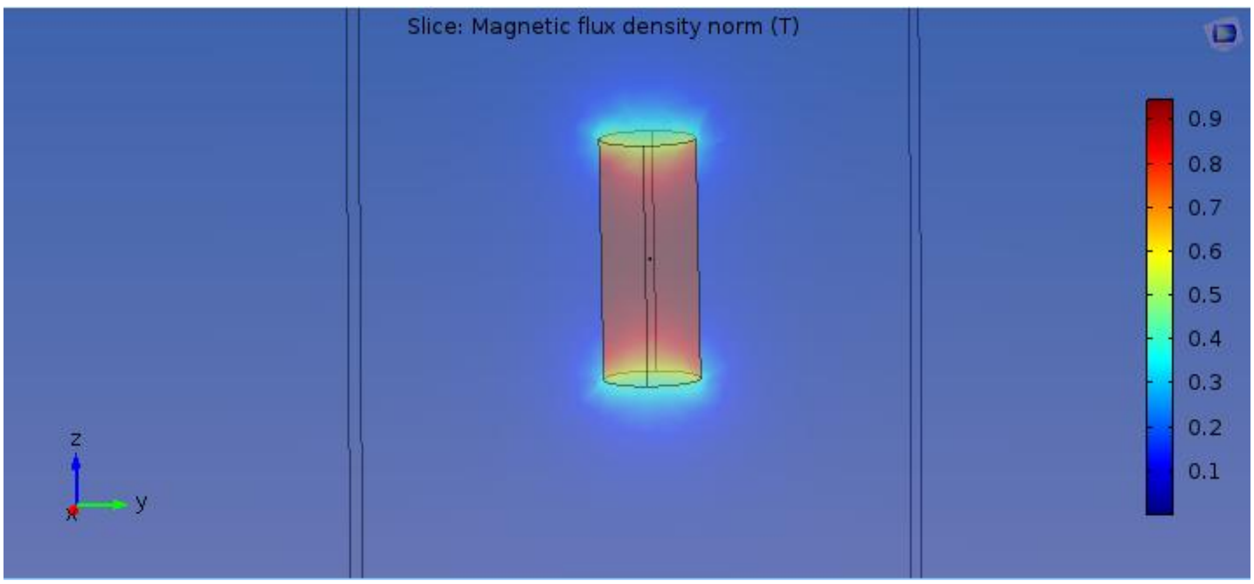


Figure 3.2: Cylindrical Object in the center of infinite element

3.2.2 Assigning magnetic field to cylindrical object

The cylindrical object in the above figure can be assigned a magnetic field in the ampere's law section. For our studies, magnetization corresponding to 1 Tesla was assigned.

(a)



(b)

Figure 3.3: (a) Assigning magnetization to cylindrical object

(b)Result of study

3.3 Post processing Results

Here, various possibilities of how relative positioning of magnet and hall sensor can give rise to different type of responses from hall sensor are considered. Later in the same section, one of these configurations will be selected for our liquid level sensor prototype. Magnet in below figure 3.4, 3.5 and 3.6 is shown in y-z plane and each axis is scaled in meters.

3.3.1 First possibility

Assuming hall sensor is moved along red line (y axis) with its sensitivity axis perpendicular to that line, we can expect output voltage in following shape. Here only z component of field is of concern and only that is shown in the Figure 3.4.

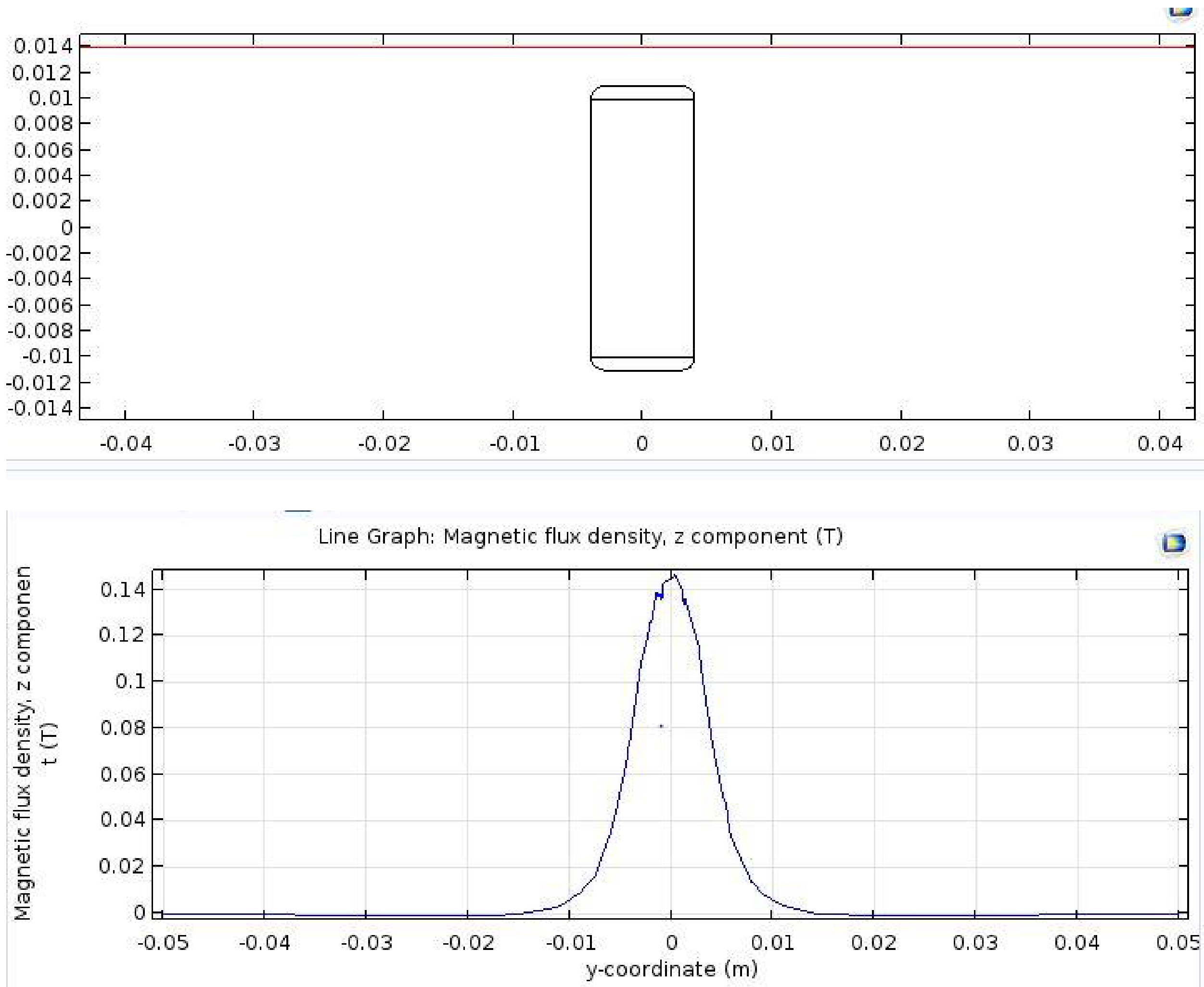
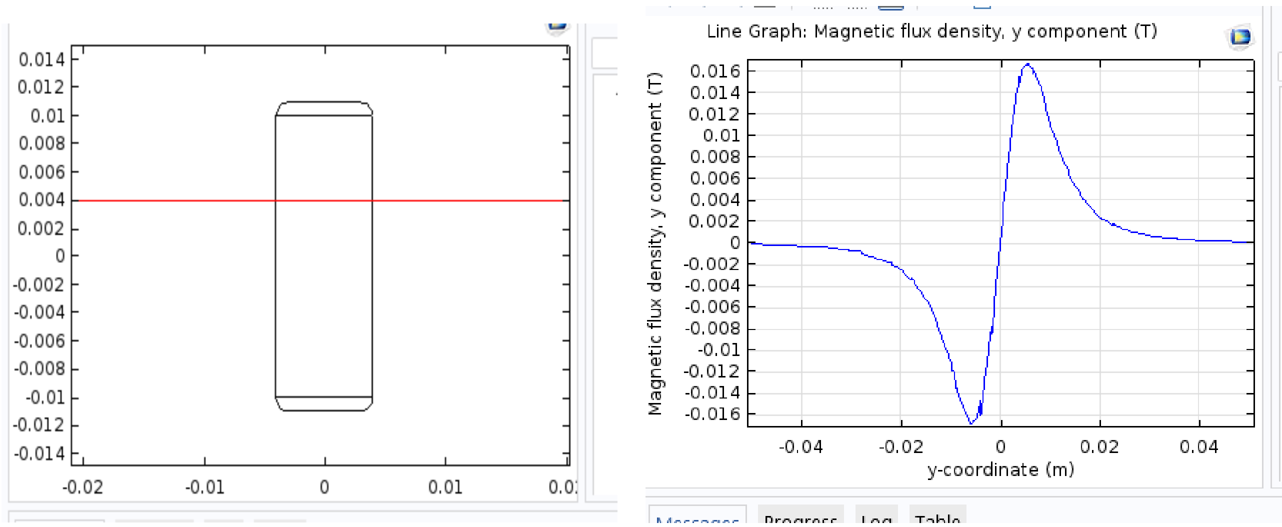


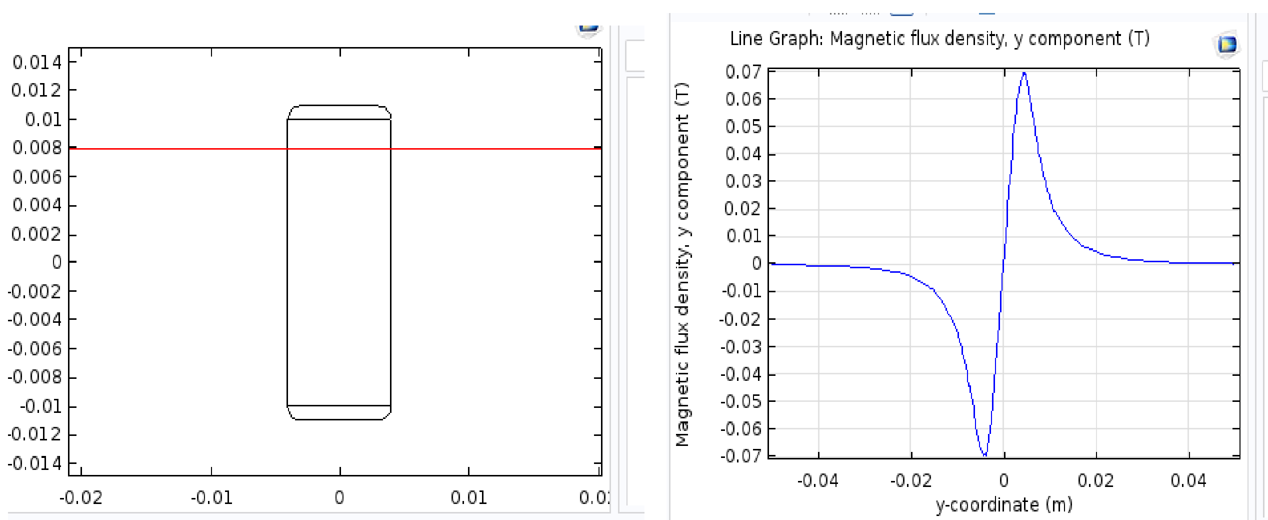
Figure 3.4: First possibility

3.3.2 Second possibility

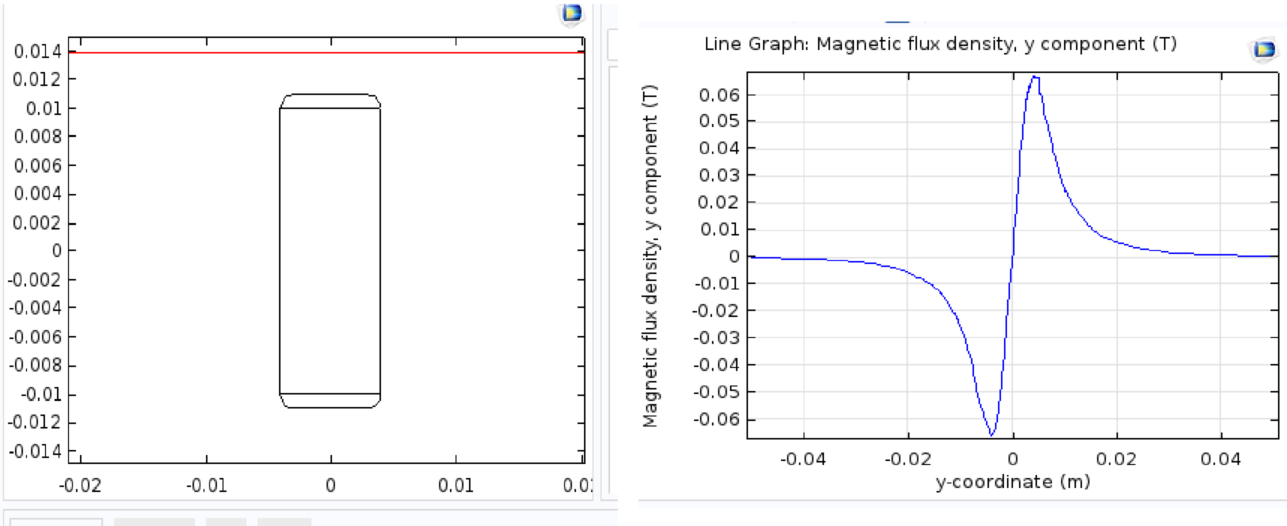
Assuming hall sensor is moved along red line (y axis) with its sensitivity axis along that line, we can expect output voltage in following similar shapes. Here only y component of field is of concern and only that is shown in the Figure 3.5.



(a)



(b)

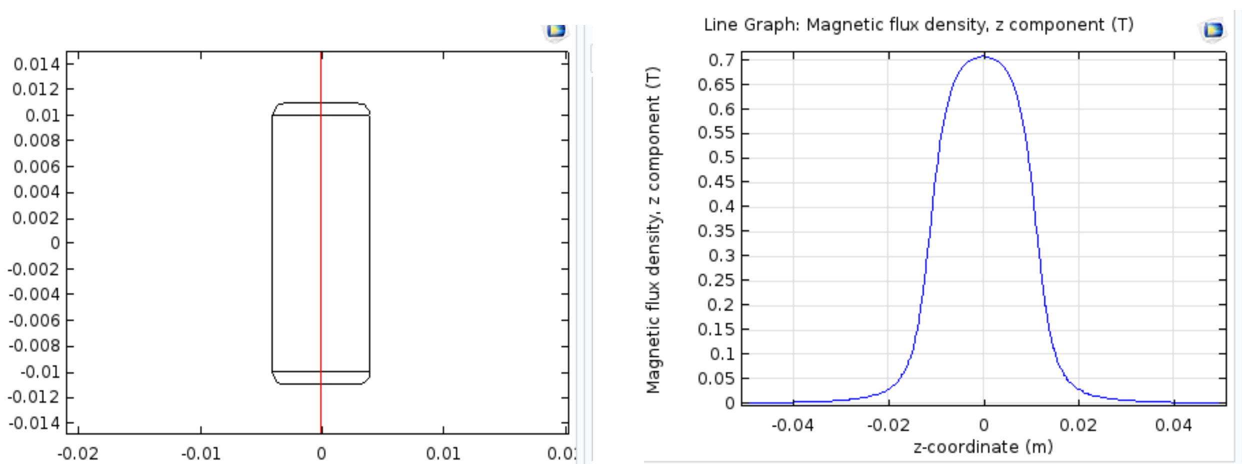


(c)

Figure 3.5: Second possibility

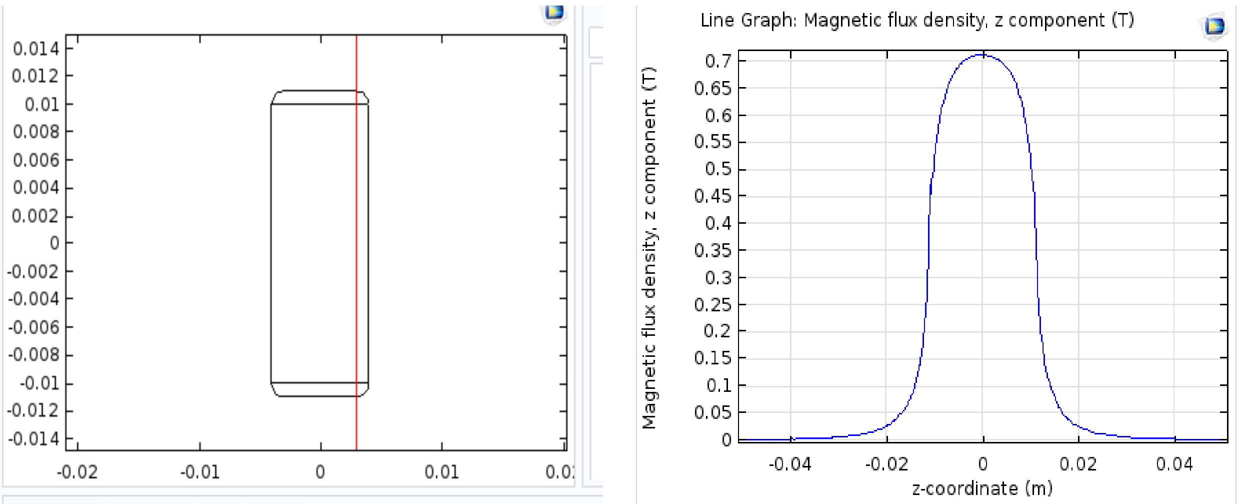
3.3.3 Third possibility

Assuming hall sensor is moved along red line (z axis) with its sensitivity axis along that line, we can expect output voltage in following similar shapes. Here only z component of field is of concern and only that is shown in the Figure 3.6.

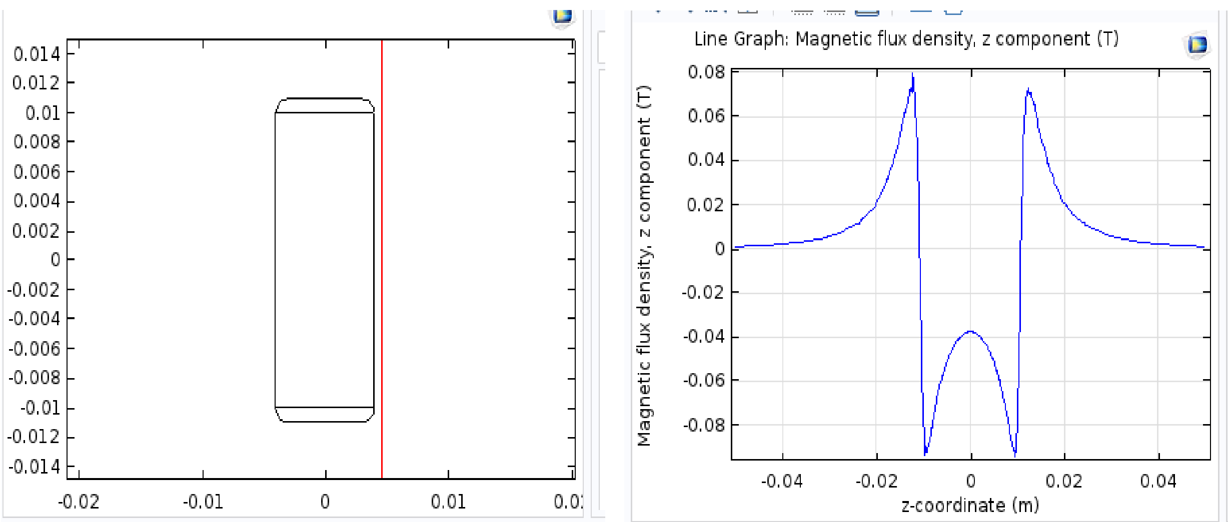


(a)

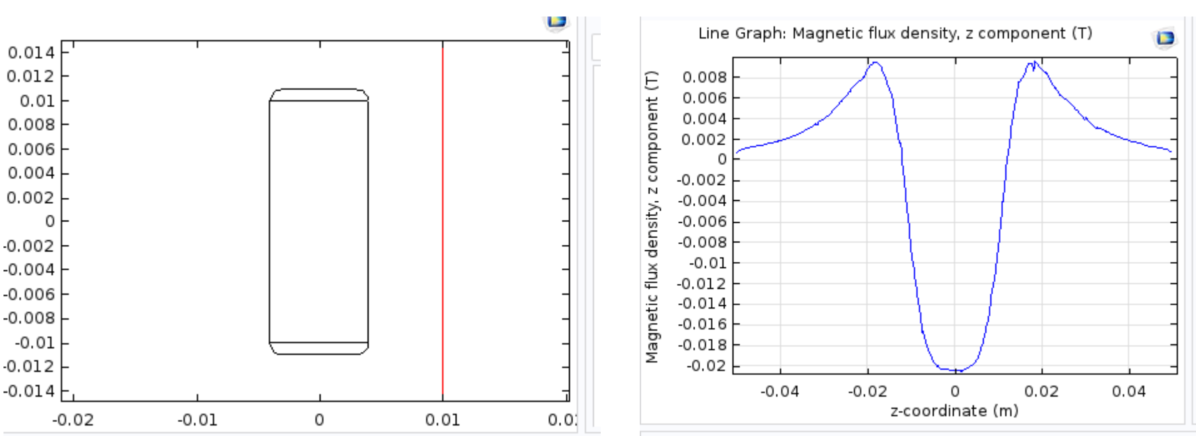
Figure 3.6: Third possibility


Line Graph: Magnetic flux density, z component (T)
Magnetic flux density, z component (T)
z-coordinate (m)

(b)


Line Graph: Magnetic flux density, z component (T)
Magnetic flux density, z component (T)
z-coordinate (m)

(c)


Line Graph: Magnetic flux density, z component (T)
Magnetic flux density, z component (T)
z-coordinate (m)

(d)

3.3.4 Selection for prototype

In the prototype, we have 5 hall sensors places at a distance of 20 cm. with their sensitivity axis aligned along a perpendicular line on a pipe of 1 meter. Considering the distance between hall sensors and after efforts in linearization (experimental results of which are in next chapter), Figure 3.6(d) was found to be suitable for prototype.

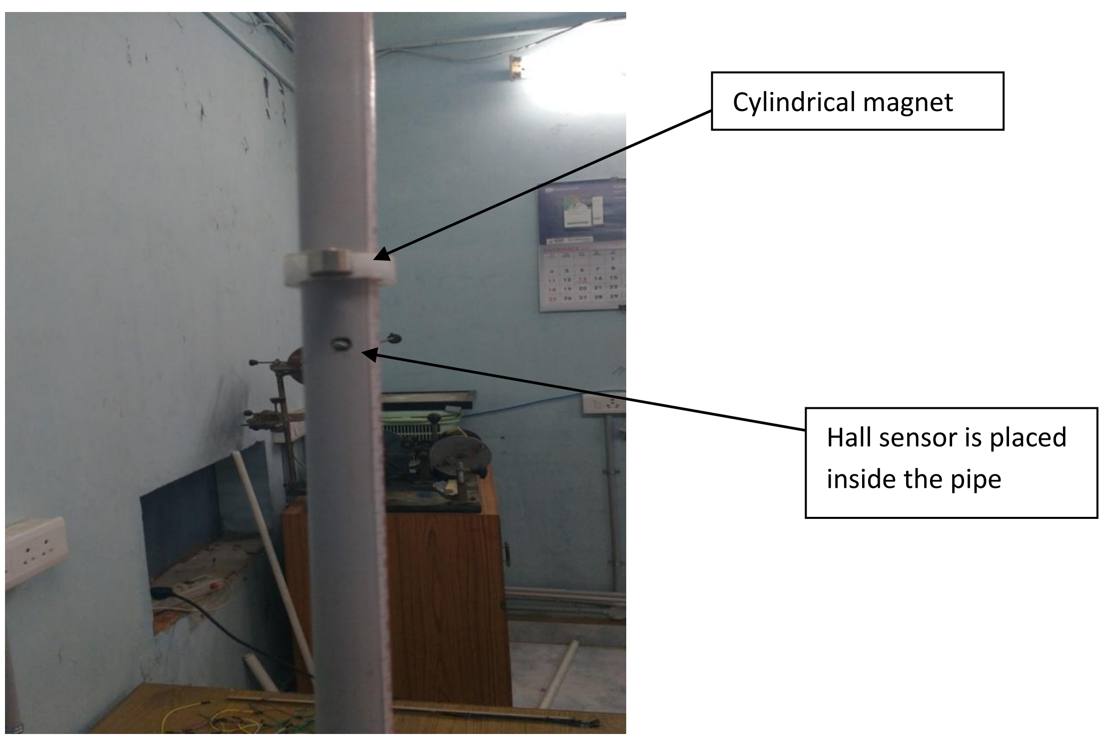
CHAPTER 4

Experimental Setup and Results

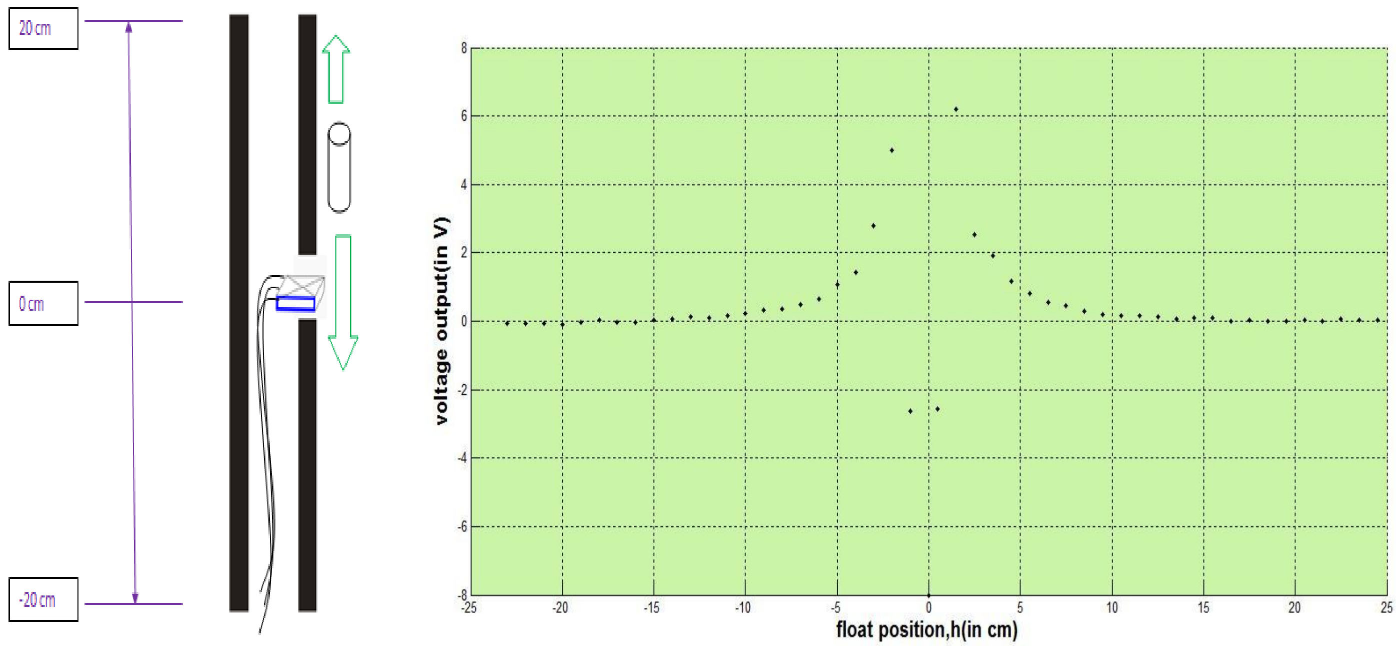
In the second chapter, we had a preview of the entire hardware requirement for the experimental setup. It gave us a brief discussion of the various components used in the circuit along with the NI ELVIS II board. In this chapter we shall integrate all the components discussed so far on the NI ELVIS board to achieve the complete setup and discuss signal conditioning circuit used.

4.1 Hall Sensor –Magnet Interaction and linearization

4.1.1 Interaction of single hall sensor with magnet: In chapter 3, it was said that characteristics of Figure 3.6(d) were selected due to various reasons. Setup as shown in figure below was made and data from hall sensor was found to be consistent with the simulations of Figure 3.6(d).



(a) Set up with one hall sensor and cylindrical magnet



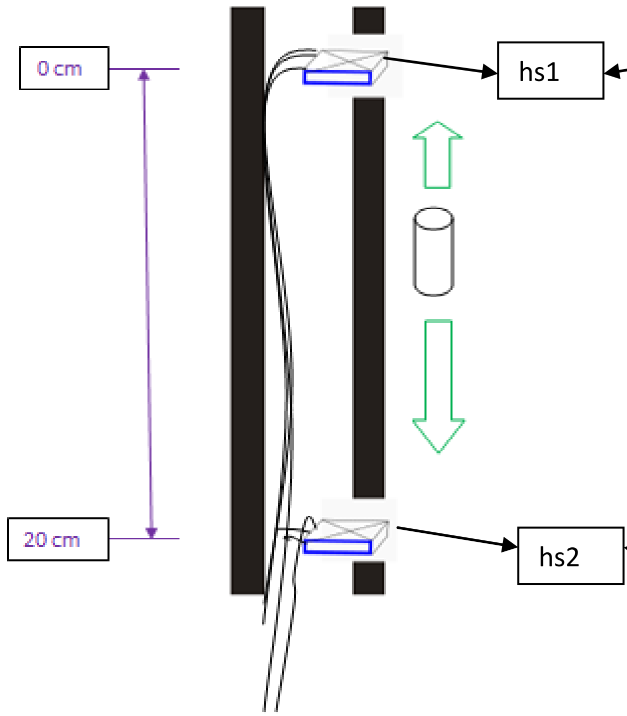
(b) Schematic diagram showing relative position of hall sensor and magnet

(c) Hall senor output with respect to float position, h

Figure 4.1

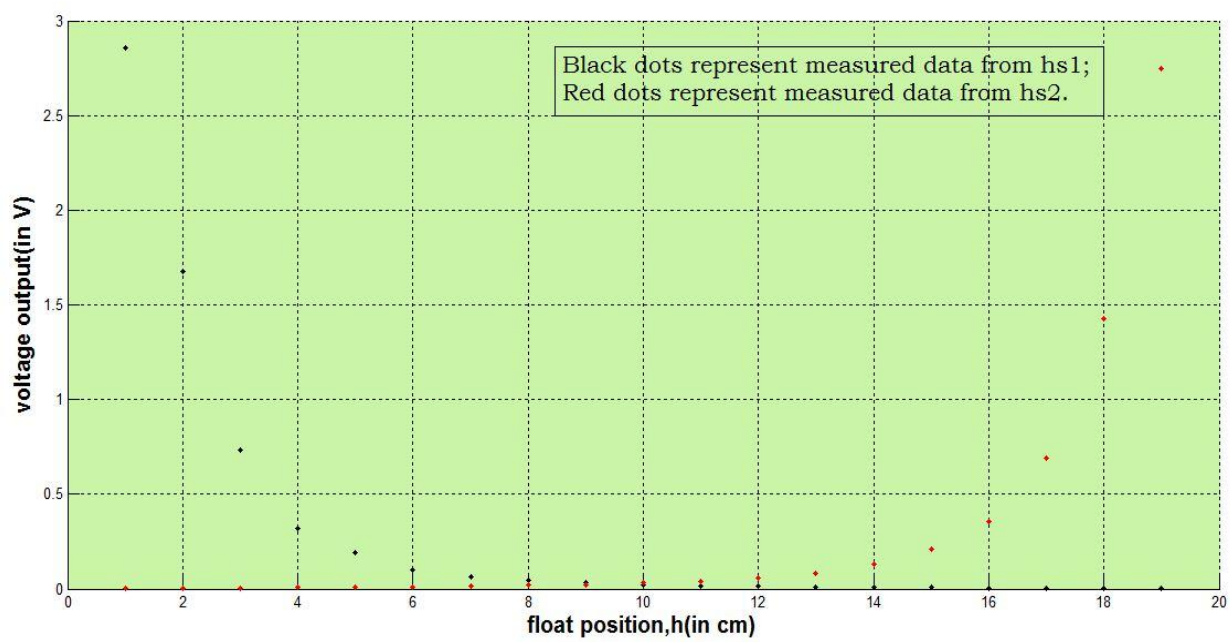
4.1.2 Introducing a second sensor and linearization:

Second sensor was introduced at a distance of 20 cm from the first one. As expected, response from hs1 falls in somewhat exponentially manner while response from hs2 rises in the same manner as magnet goes from 2 to 18 cm. We use (hs1-h2)/(hs1+hs2+k) which results in pole cancellation to ultimately provide a linear output in the range of 2 to 18 cm.

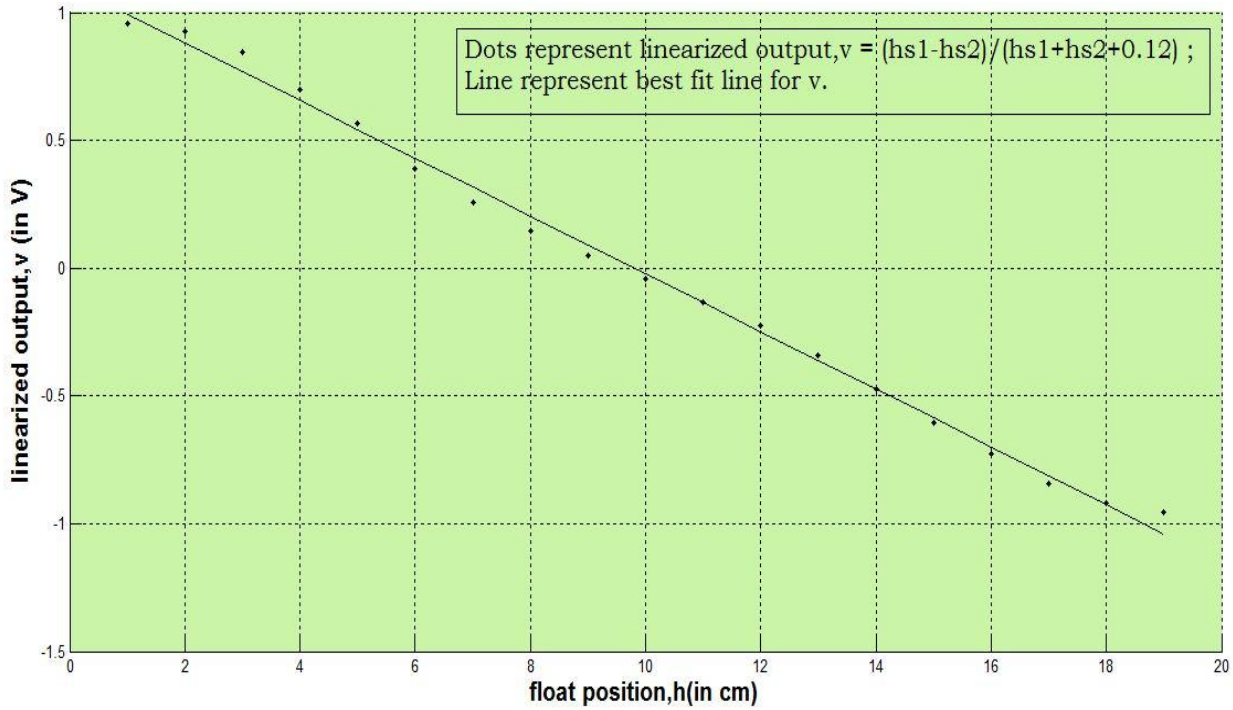


(a) Schematic diagram showing relative position of hall sensors wrt magnet

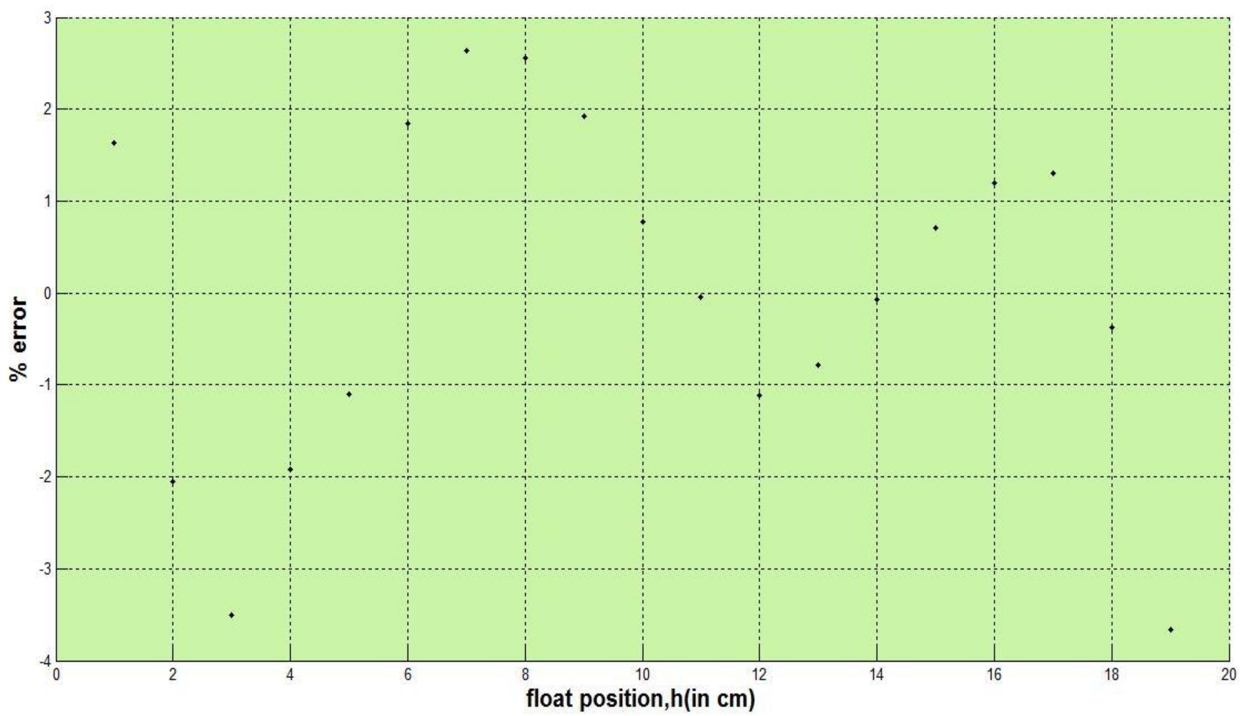
(b) Set up with hall sensor hs1, hs2 and and magnet



(c) Output from hs1 and hs2 with respect to float position, h



(d) Result of (hs1-h2)/(hs1+hs2+k)   with k=0.12



(e) % full scale error

Figure 4.2

The equation of best fit line in Figure 4.2 (d) is

`v= -0.11293*h + 1.1069;` Where v is linearized output

And maximum full scale % error in Figure 4.2 (e) was found to be 3.66 %.

The measured values of hs1, hs2 with the corresponding float position,h are tabulated in table 4.1.This is the data which has been used in plotting graphs of Figure 4.2.

h	Vo1	Vo2
0	-8.1083	0.0037
1	2.8549	0.0041
2	1.6759	0.0053
3	0.7352	0.0057
4	0.321	0.0076
5	0.1887	0.0087
6	0.1027	0.0118
7	0.066	0.0145
8	0.045	0.0183
9	0.0323	0.024
10	0.024	0.031
11	0.0179	0.0421
12	0.0144	0.0571
13	0.0108	0.0849
14	0.0088	0.132
15	0.0068	0.2097
16	0.0055	0.3543
17	0.0043	0.691
18	0.004	1.4255
19	0.003	2.7458
20	0.0022	-8.4238

Table 1: Value of hs1, hs2 output at different magnet positions

4.1.3 Signal Conditioning Circuit Used: For hs1 and hs2, signal conditioning circuit as shown in Figure 4.3 was used. Instrumentation amplifier is used for amplifying the signal from hall sensor. Output of hall sensor is at 2.5 Volts when no magnetic field is there. Instrumentation amplifier also biases the output of circuit at 0 Volts in that case.2^{ND} Order low pass filter of cut of frequency1.5Hz has been used to remove noise at high frequencies. It does not affect signal from hall sensor as liquid level changes very slowly resulting in a low frequency response from hall sensor.

Also, when multiple hall sensors are there, a multiplexer is there before ADC stage to ensure that multiple signals can be accommodated.

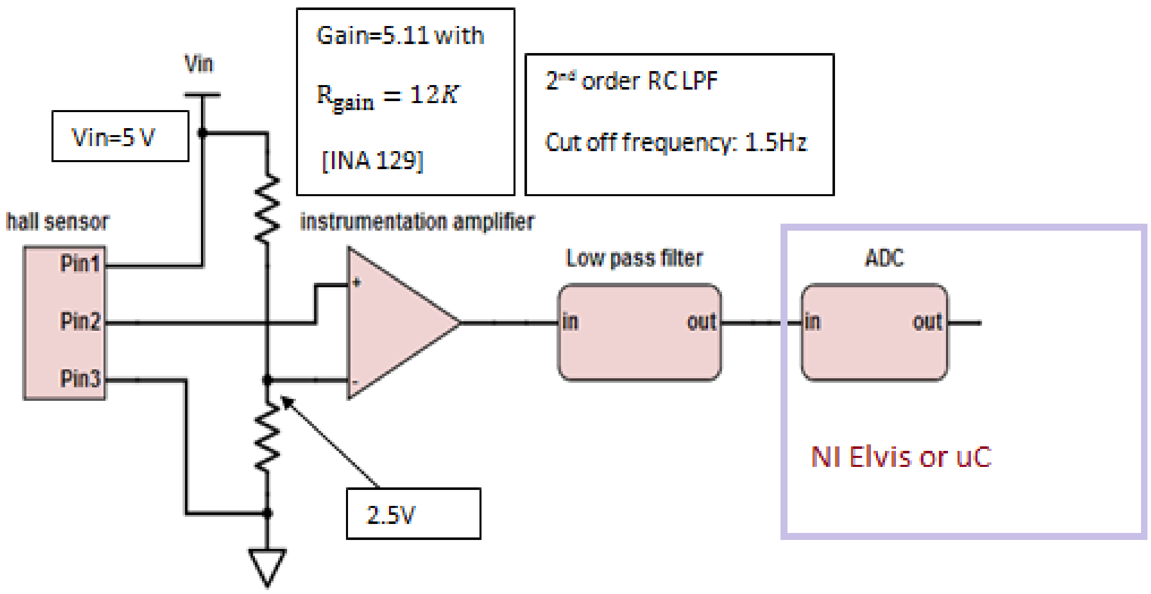


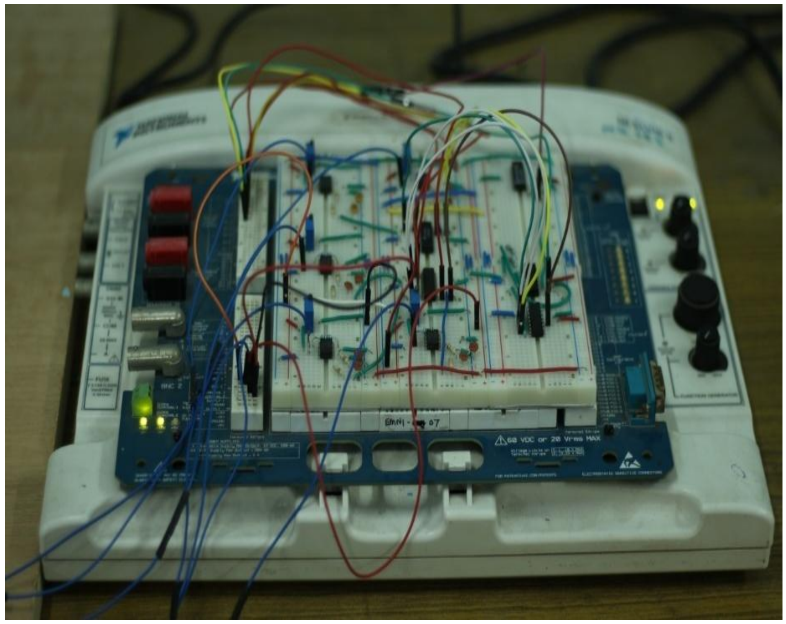
Figure 4.3: Signal Conditioning Circuit Used for Each Hall Sensor

4.2 Complete Experimental set up:

As described in last section we observed how we were able to get linear output in the range of 16 cm when two hall sensors are placed at a distance of 20 cm. So, we introduced 3 more hall sensors covering a range of 80 cm. Relative positioning of hall sensor and magnet is same as described in cases above throughout the pipe.

In the final setup, hall sensors are placed at 25 cm, 45cm, 65cm, 85 cm and 105 cm (top to bottom) in a hollow pipe which covers range of 80 cm.Vcc and gnd of all the hall sensors are connected together. All the signals including output of hall sensors hs1, hs2, hs3, hs4, hs5, Vcc and gnd are taken out through a T-joint and connected to the signal conditioning circuit on the NI Elvis board.

(a)



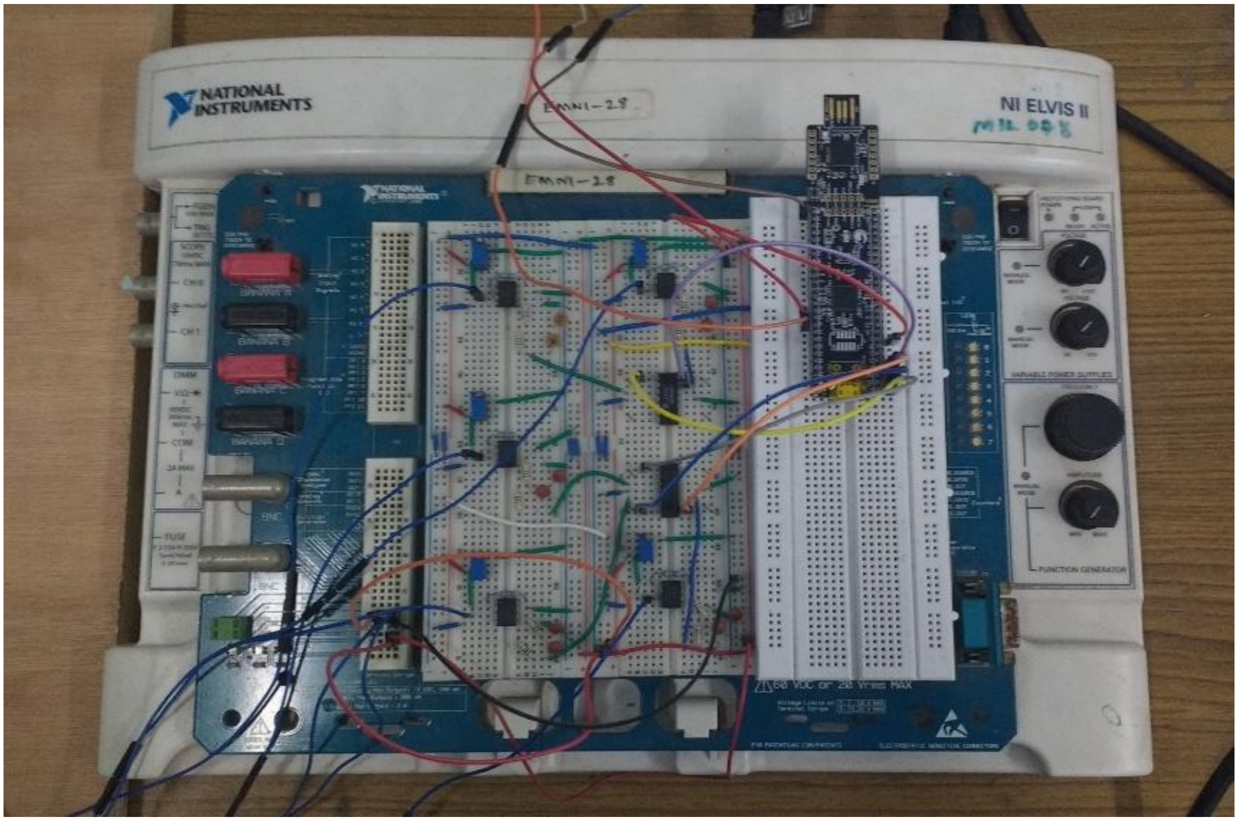
(b)

(c)

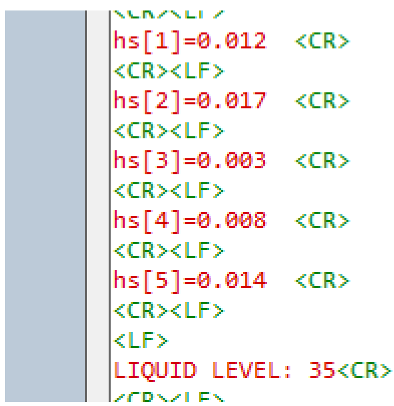
Figure 4.4: (a) Pipe with hall sensors placed inside and a magnet of known strength (red arrows show the position of hall sensors)

(b) Signal conditioning circuit for hall sensors when Elvis board ADC was used

(c)Lab view Front panel indicating the position of float



(a)



(b)

Figure 4.5: (a) Signal conditioning circuit for hall sensors when cy8ckit 059 was used (b) Results are displayed on pc by using uart serial communication protocol (software used on pc is Docklight; in addition to that, usb to uart converter was used)

4.2.1 Input Output characteristics of liquid level sensor:

Sensor which has been described in this section can be divided four regions. As we know we have five hall sensors at 25 cm, 45cm, 65cm, 85 cm and 105 cm. In between each pair of consecutive sensors we have derived a linearly proportional output by combining the output of those hall sensors as described in section 4.1.

- Between hs1 and hs2 (25 and 45 cm) : output in this region can be described by

  ```
  v= -0.1138*h + 3.96
  ```

  Where v is linearized output given by

  ```
  v= (hs1-hs2)/ (hs1+hs2+0.11)
  ```

- Between hs2 and hs3 (45 and 65 cm) : output in this region can be described by

  ```
  v= -0.1145*h + 6.313
  ```

  Where v is linearized output given by

  ```
  v= (hs2-hs3)/ (hs2+hs3+0.15)
  ```

- Between hs3 and hs4 (65 and 85 cm) : output in this region can be described by

  ```
  v= -0.1117*h + 8.39
  ```

  Where v is linearized output given by

  ```
  v= (hs3-hs4)/ (hs3+hs4+0.14)
  ```

- Between hs4 and hs5 (85 and 105 cm) : output in this region can be described by

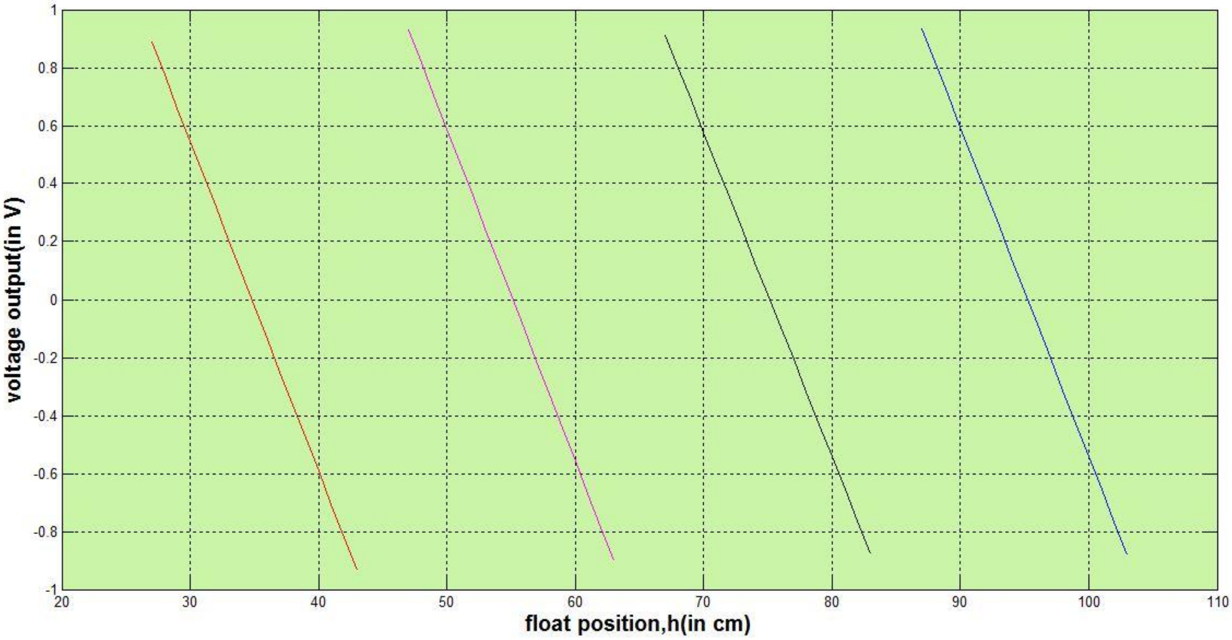
  ```
  v= -0.1131*h + 10.79
  ```

  Where v is linearized output given by

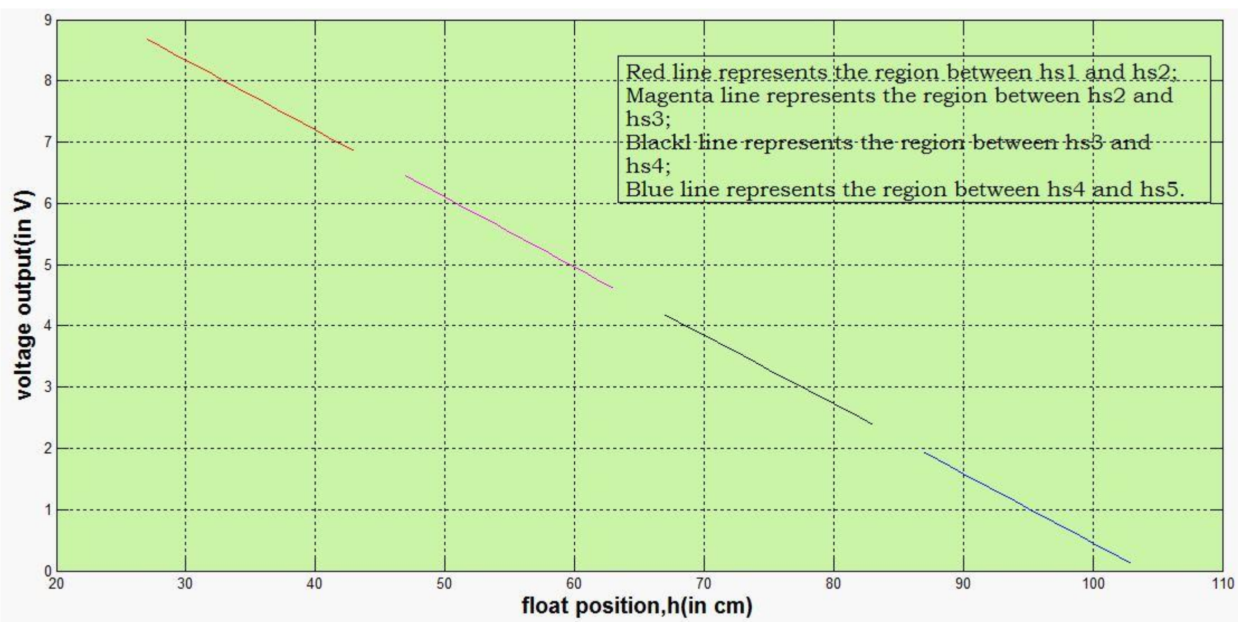
  ```
  v= (hs4-hs5)/ (hs4+hs5+0.12)
  ```

Characteristics from each region can be shifted appropriately in order to obtain overall linear characteristics of liquid level senor as shown in figure 4.6.

Also, when magnet is at sensor position output after signal conditioning stage is about -8 Volts. Using that we can deduce point of sensor position.



(a)



(b)

Figure 4.6: (a) Linearized output in four different regions of liquid level sensor
(b) Overall input-output characteristics of liquid level sensor when Figure 4.6 (a) graphs are shifted appropriately

CHAPTER 5

Conclusion and Future Scope

5.1 Conclusion

A non-contact continuous liquid level sensor was successfully designed and tested. The hardware testing was carried out in which signal conditioning circuit was built on **NI ELVIS** board and a **LabVIEW VI** was used for determining float position. LabVIEW VI had been designed such that it infers liquid level based on various thresholds set for data from magnetic sensors. Later in place of LabVIEW VI, **CYCKIT-059** prototyping kit with psoc-5lp microcontroller was tested successfully. The float (which contains cylindrical magnet) position was found to be varying linearly between two-20cm apart- consecutive hall sensors for the range of 16 cm.

5.2 Future Scope

Some additional improvements can be done in the work described in this thesis. Few of them are listed below:

There is a possibility of extending linearization to areas $\{sensor\ position \pm 2cm\}$ which are not covered in work presented.

Signal conditioning circuit can be miniaturized and accommodated in measurement unit so as to use it in the actual scenario.

The transducer can be made independent of the computer by using LCD display for displaying the float position and a solar panel for powering the prototype.

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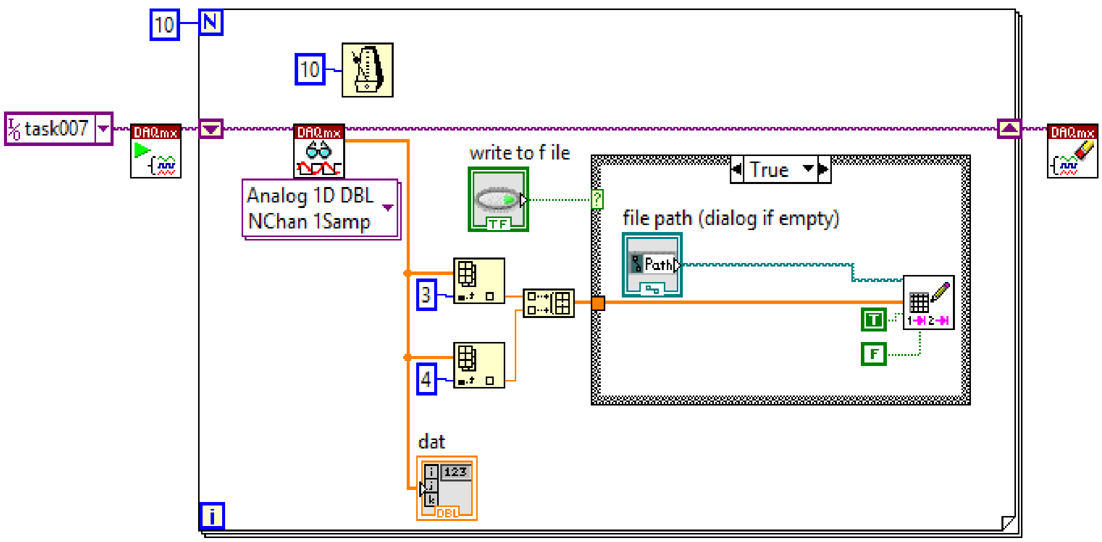
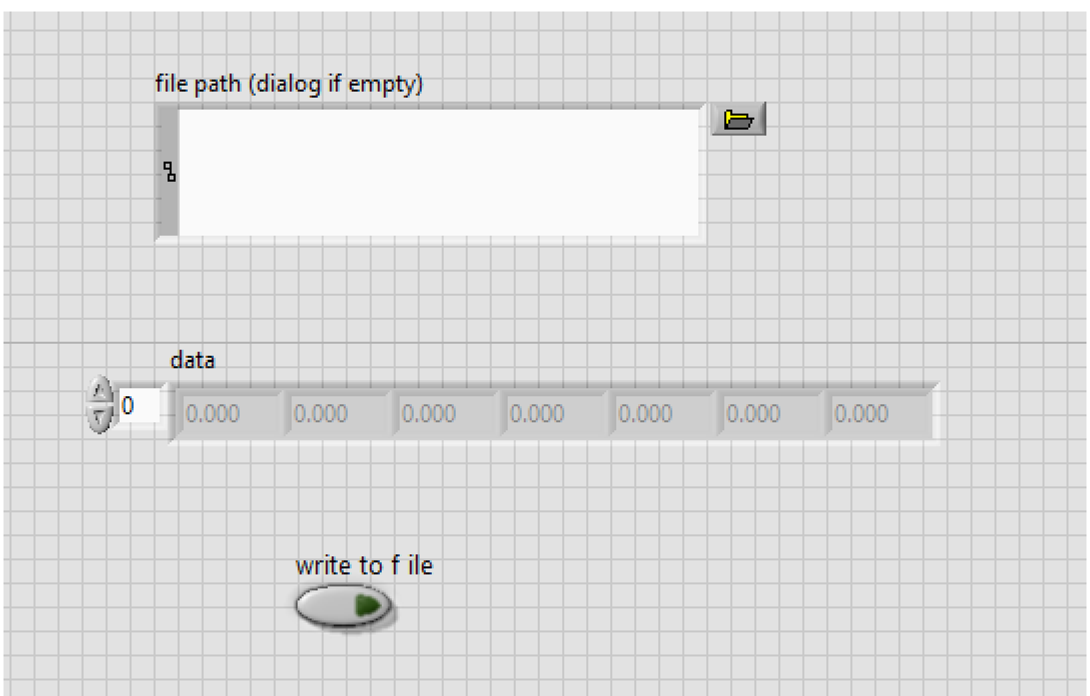
Appendix

1. LabVIEW VI used for data acquisition:

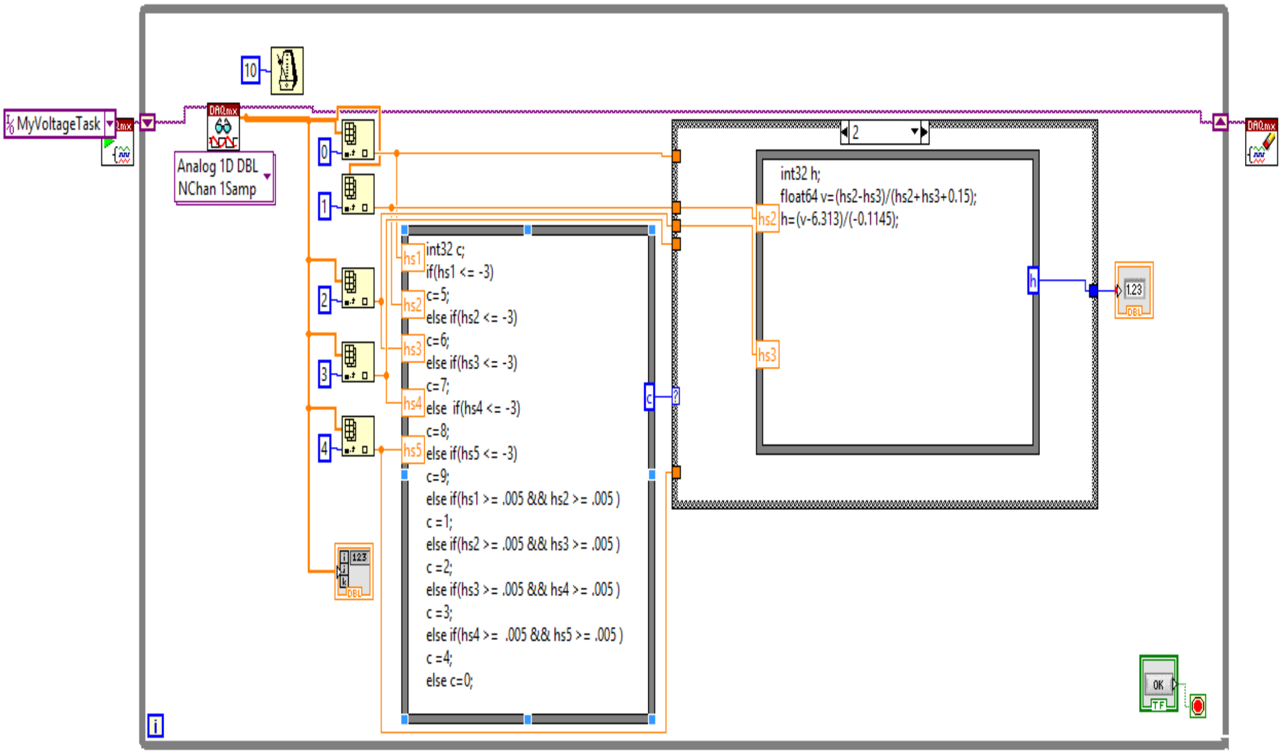


(a) Block diagram

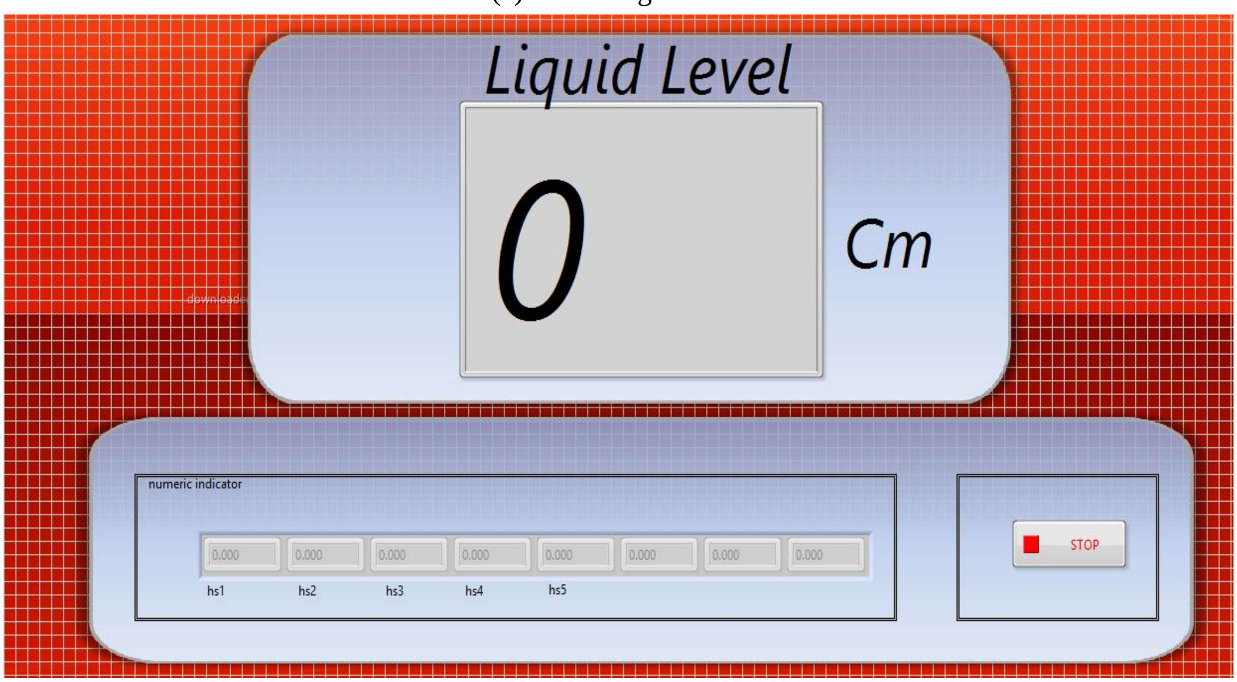


(b)Front Panel

2. LabVIEW VI used for indicating float position:

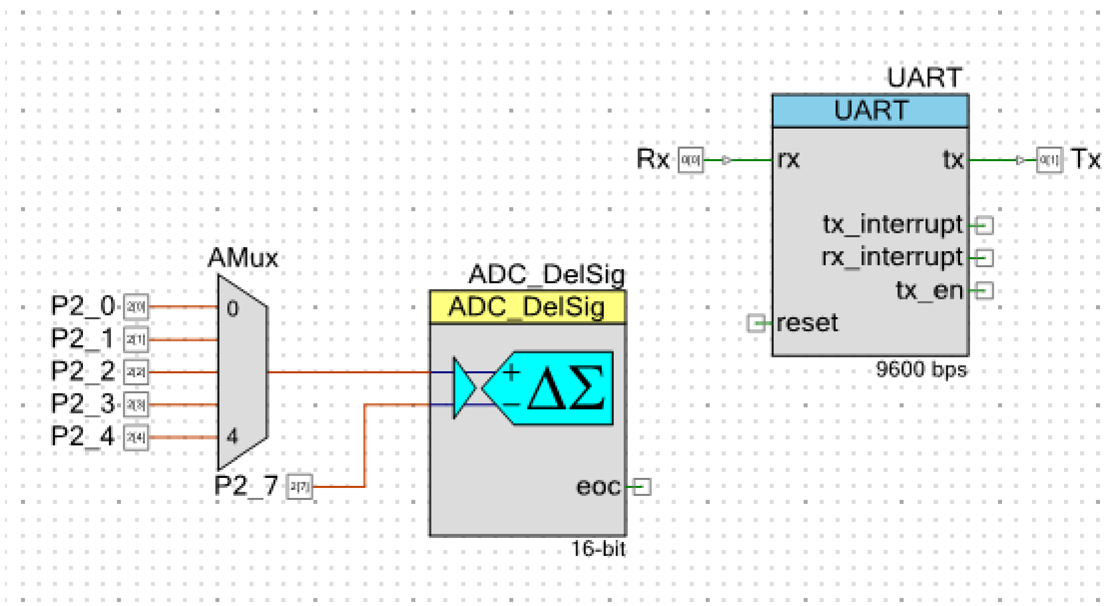


(a)Block diagram



(b)Front Panel

3. Program for CYCKIT-059 prototyping kit with psoc-5lp:




```
/* ========================================
 *
 * Copyright YOUR COMPANY, THE YEAR
 * All Rights Reserved
 * UNPUBLISHED, LICENSED SOFTWARE.
 *
 * CONFIDENTIAL AND PROPRIETARY INFORMATION
 * WHICH IS THE PROPERTY OF your company.
 *
 * ========================================
*/
#include <project.h>
#include <stdio.h>
char buf[128];
int32 codeADC,h,c;
float32 V,hs[5],v;
int ch;
int main()
{
CyGlobalIntEnable; /* Enable global interrupts. */
/* Place your initialization/startup code here (e.g. MyInst_Start()) */
UART_Start();
AMux_Start();
ADC_DelSig_Start();
while (1)
{
for(ch = 0; ch < 5; ch++)
```

```
{
/* Place your application code here. */
AMux_Select(ch);
codeADC = ADC_DelSig_Read32();
V = ADC_DelSig_CountsTo_Volts(codeADC);
hs[ch]=V;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "hs[%d]=%.3f  ", ch+1, hs[ch]);
UART_PutString(buf);
UART_PutCRLF(0xD);
CyDelay(100);
}



if(hs[0] <= -.010)
{
h=25;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else if(hs[1] <=-.010)
{
h=45;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else if(hs[2] <= -.010)
{
h=65;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else  if(hs[3] <= -.010)
{
h=85;
memset(buf, 0, sizeof(buf));
```

```
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else if(hs[4] <= -.010)
{
h=105;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else if(hs[0] >= .005 && hs[1] >= .005 )
{
   v=(hs[0]-hs[1])/(hs[0]+hs[1]+.11);
h=(v-3.96)/-0.1138;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}

else if(hs[1] >= .005 && hs[2] >= .005 )
{
   v=(hs[1]-hs[2])/(hs[1]+hs[2]+0.15);
h=(v-6.313)/(-0.1145);
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else if(hs[2] >= .005 && hs[3] >= .005 )
{
   v=(hs[2]-hs[3])/(hs[2]+hs[3]+.14);
h=(v-8.3958)/(-0.111724);
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);

}
```

```
else if(hs[3] >=  .005 && hs[4] >= .005 )
{
    v=(hs[3]-hs[4])/(hs[3]+hs[4]+.12);
h=(v-10.7998)/(-0.1131);
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
else
{
h=0;
memset(buf, 0, sizeof(buf));
 sprintf(buf, "LIQUID LEVEL: %ld",h);
UART_PutString("\n");
UART_PutString(buf);
UART_PutCRLF(0xD);
}
CyDelay(3000);
}

}

/* [] END OF FILE */
```

REFERANCES

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