Flow Rate Sensor Design and Development (Flux)

By

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Forward to

UNIVERSITI SAINS MALAYSIA

To fulfill part of the terms for graduating in Bachelor Degree with Honor

Bachelor Degree in Engineering (Electronic Engineering)

Pusat Pengajian Kejuruteraan
Elektrik dan Elektronik
Universiti Sains Malaysia **March 2006**

Abstract

Flow measurement is essential in many industries such as the oil, power, chemical, food, water, and waste treatment industries. These industries require the determination of the quantity of a fluid, either gas, liquid, or steam, that passes through a check point, either a closed conduit or an open channel, in their daily processing or operating. The quantity to be determined may be volume flow rate, mass flow rate, flow velocity, or other quantities related to the previous three. The instrument to conduct flow measurement is called flow meter. The development of a flow meter involves a wide variety of disciplines including the flow sensors, the sensor and fluid interactions through the use of computation techniques, the transducers and their associated signal processing units, and the assessment of the overall system under ideal, disturbed, harsh, or potentially explosive conditions in both the laboratory and the field. The purpose of this final year project is to design and developed a flow rate sensor system using flux characteristic. The scope of this project is to measure the flow rate of a clean tap water; witch is flowing through a pipe in a reasonable range of flow rate. Other types of fluid or moving mass are not taken into consideration when designing the sensor and system. Only the linear characteristic of the flow rate sensor are calculated. The designing processes begin with designing the electromagnetic induced circuit, after that and amplifier circuits will be design to amplifier the sensor output signal. An ADC circuits than are taken into considerations to convert the analog signal into digital signal, so that it could be process digitally using microprocessor circuits. All the circuits are combined

Acknowledgements

I would like to than many people for their help in completing this report. First and foremost I would like to thank my supervisor, Dr Mohd Rizal Arshad for his guide and advice. Secondly I would to thank my colleague in electronic engineering course for their support and helping hand. Thirdly I would like to than all the technicians that willing to spend their time in helping me with my experiment in the laboratory. Finally I would like to thank my family for their prayer and blessing. Without all the support and help that I get from the people I meet, this report won't be complete. Again I would like to than all the people who had contribute to make this report complete.

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Chapter 1 Introduction

1.1 Background

Flow rate measurement has been evaluated since few decades before. It is an important parameter in every day live, such as the amount of water we used every day are charges by the volume rate. It is even more important in the industry environment.

Most industries used flow rate to control certain process in their manufacturing procedure. In that case, the measurement of flow rate is crucial for them. Examples of such industries are food manufacturing, pharmaceutical and fertilizer industries.

There is all kind of flow rate sensor available in the market today. New one will evaluate from the old device once in 5 to 7 years. The purpose of these devise are the same, witch is to measure the different in the flow rate of a fluid or moving mass. Different kind of applications will used different kind of flow rate sensor; this is because of the limitations in some flow rate sensor parameter.

Different kind of flow rate sensor will used different parameter as it reference measurement variable. Some of the parameter that is been used to measured the flow rates are pressure, velocity, vibrations and angle.

The sensor will closely monitor these parameters differences to determine the rate of the fluid flowing through a certain system.

1.2 Objectives

The main objective of these final year project is to design and developed a flow rate sensor and system using magnetic flux as the sensor parameter.

The sensor is them incorporate into a measuring system, to make an instrumentations device for measuring a flow rate of a fluid flow.

The output of the system is displayed using LCD.

1.3 Scope

The scope of the project is to measure the flow rate of a clean tap water; witch is flowing through a pipe in a reasonable range of flow rate.

Other types of fluid or moving mass are not taken into consideration when designing the sensor and system.

Only the linear characteristic of the flow rate sensor are calculated.

Chapter 2 Literature review

2.1. Flow rate measurement

Flow measurement is the quantification of bulk fluid movement. It can be measured in a variety of ways.

Dependent on the quantity measured different symbols are used. The volumetric flow rate is usually given the symbol Q and the mass flows rate the symbol.

2.1.1 Units of measurement

Volumetric flow rate is sometimes measured in "standard cubic centimeters per minute" (abbreviation sccm), a unit acceptable for use with SI except that the additional information attached to the unit symbol. The SI standard would be m3/s (with any appropriate prefix, with temperature and pressure specified. The term "standard" indicates that the given flow rate assumes a standard temperature and pressure. Many other similar abbreviations are also in use, such as standard cubic feet per minute or per second. Other units used include gallons (U.S. liquid or imperial) per minute, liters per second, bushels per minute, and acre-feet per day.

2.1.2 Mechanical flow meters

2.1.2 a) Piston Meter

Piston meters, or Semi-Positive displacement meters are the most common in the UK and are used for almost all meter sizes up to and including 40mm (1 1/2"). The piston meter operates on the principle of a piston rotating within a chamber of known volume. For each rotation, an amount of water passed through the piston chamber.

[S. Morris “Principles of measuring and instrumentations”, Prentice Hall, second editions]

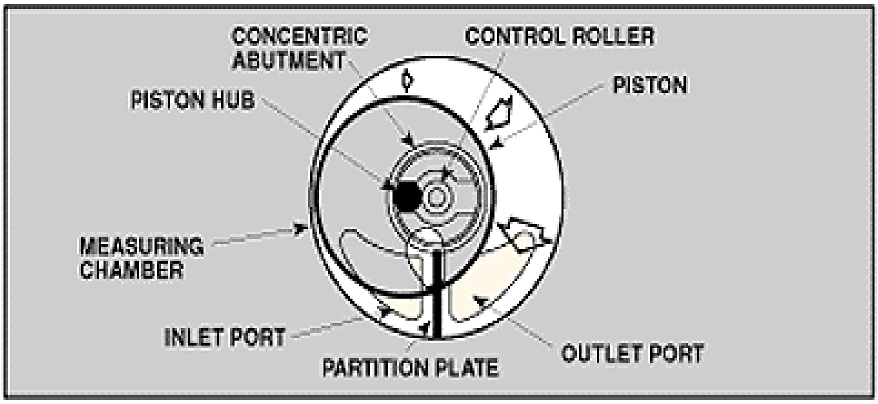

Figure 2.1.2.a1 Piston Meter

2.1.2 b) Venturi meter

Another method of measurement, known as a venturi meter, is to constrict the flow in some fashion, and measure the differential pressure that results across the constriction. This method is widely used to measure flow rate in the transmission of gas through pipelines, and has been used since Roman Empire times.

2.1.2 c) Pitot tube

Measurement of the pressure within a pitot tube in the flowing fluid, or the cooling of a heated element by the passing fluid is two other methods that are used. These types of sensors are advantageous in that they are rugged, so not easily damaged in an extreme environment.

A pitot tube is an L shaped tube which is also able to measure fluid flow. An advantage is that it does not disturb the flow as much as a venturi meter or an orifice plate would. It works by measuring the difference between the static pressure and the dynamic pressure. *[S. Morris "Principles of measuring and instrumentations", Prentice Hall, second editions]*

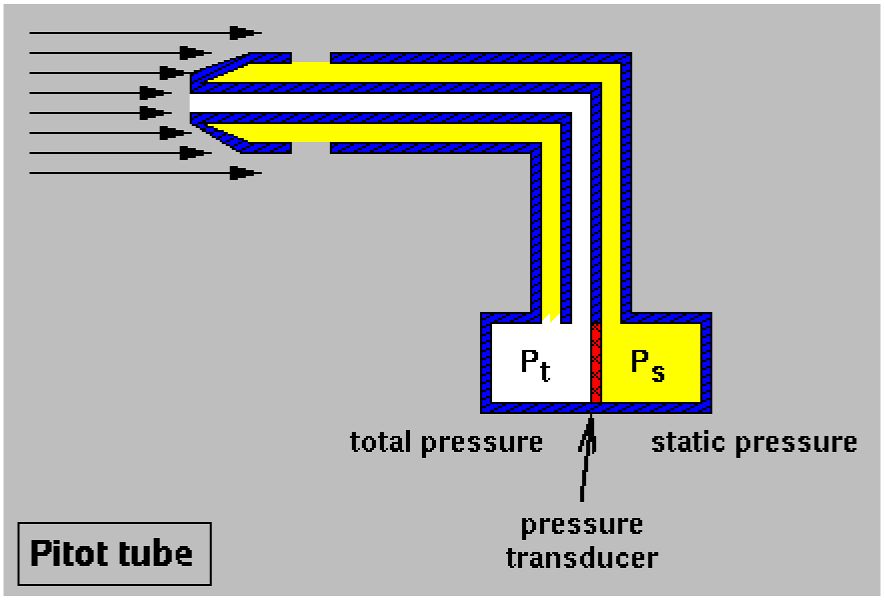

Figure 2.1.2.c1 Pitot tube

2.1.3 Modern electronic devices measurement

Modern innovations in the measurement of flow rate incorporate electronic devices that can correct for varying pressure and temperature conditions, non-linearity, and for the characteristics of the fluid.

2.1.3 a) Magnetic flow meters

The most common flow meter a part from the mechanical flow meters is the magnetic flow meter. A magnetic field is applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines. The physical principle at work is electromagnetic induction. The magnetic flow meter requires a conducting fluid, e.g. water, and an electrical insulating pipe surface, e.g. a rubber lined steel tube.

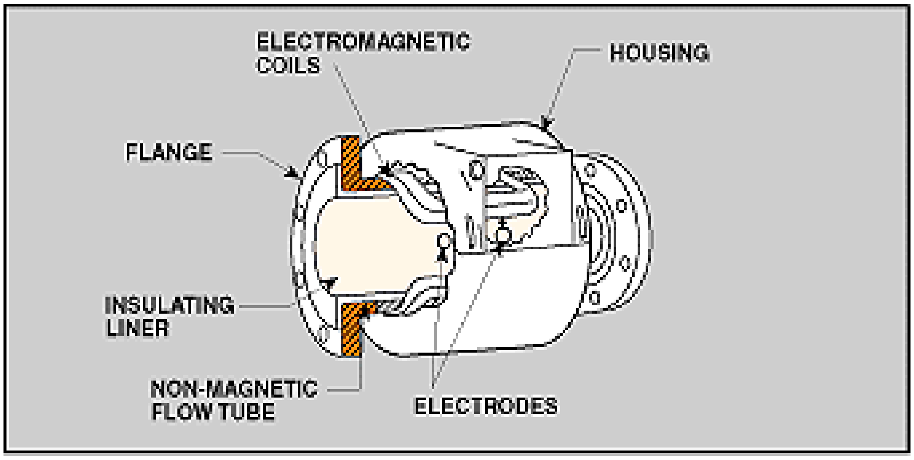

Figure 2.1.3.a1 Magnetic flow meter

2.1.3 b) Ultrasound flow meters

Transit time ultrasound flow meters work by measuring the time difference between an ultrasound pulse sent in the flow direction and an ultrasound pulse sent opposite the flow direction. This time difference is a measure for the speed of the fluid in the path of the ultrasound beam in terms of the speed of sound, c, in the fluid. By using the absolute transit time and the length between the ultrasound transducers, the current speed of sound is easily found.

Measurement of the doppler shift resulting in reflecting an ultrasonic beam off the flowing fluid is another recent, accurate innovation made possible by electronics.

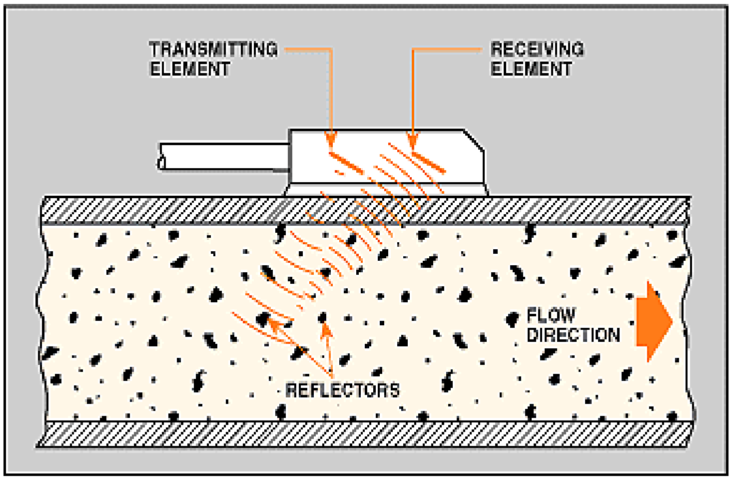

Figure 2.1.3.b1 Ultrasound flow meter

2.1.3 c) Coriolis flow meters

Using the Coriolis effect that causes a laterally vibrating tube to distort, a direct measurement of mass flow can be obtained in a Coriolis flow meter. Futhermore a direct measure of the density of the fluid is obtained. Coriolis measurement can very accurate and is very insensitive to variations in the medium that is measured; the same measurement tube can be used for measuring anything between Hydrogen gas and for instance Peanut butter without recalibration.

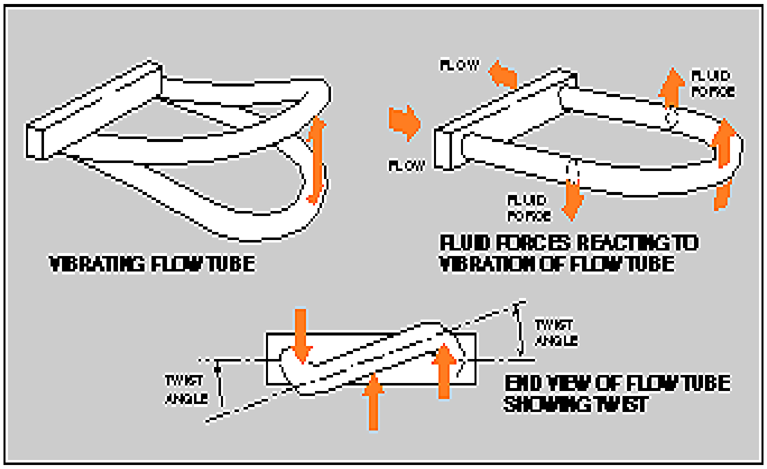

Figure 2.1.3.c1 Coriolis flow meter

2.2 Magnetic flow rate sensor

In 1831, the English scientist Michael Faraday discovered the dynamo when he noted that, if a copper disk is rotated between the poles of a permanent magnet, electric current is generated. Faraday's law of electromagnetic induction is the basis for the operation of the magnetic flow meter. As shown in Figure 2.2.1, when a liquid conductor moves in a pipe having a diameter (D) and travels with an average velocity (v) through a magnetic field of B intensity, it will induce a voltage (E) according to the relationship:

$$E = BvDC \qquad \text{eq.2.2.1}$$

where C is the constant for units conversion.

Over the past several years, the performance of magnetic flow meters has improved significantly. Among the advances are probe and ceramic insert designs and the use of pulsed magnetic fields, but the basic operating principle of Faraday's law of electric induction has not changed.

In 1883, the British mechanical engineer Osborne Reynolds proposed a single, dimensionless ratio to describe the velocity profile of flowing fluids:

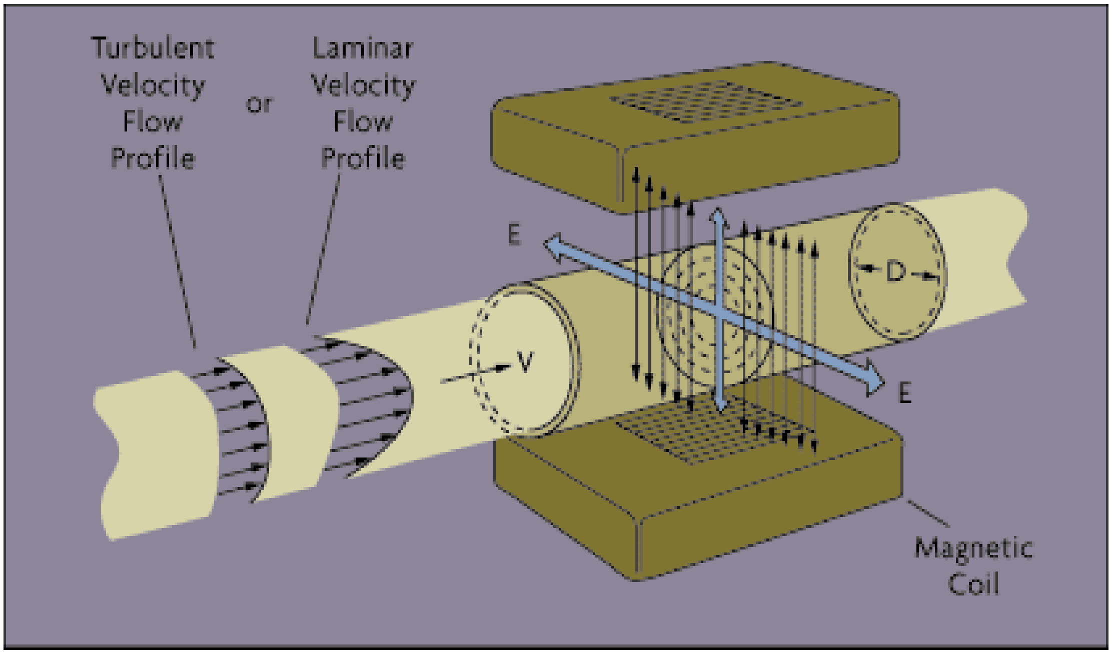

Figure 2.2.1 Magnetic flow rate sensor

Where D is the pipe diameter, v is the fluid velocity, ρ is the fluid density, and μ is the fluid viscosity.

He noted that, at low Reynolds numbers (below 2,000)), flow is dominated by viscous forces and the velocity profile is (elongated) parabolic. At high Reynolds numbers (above 20,000), the flow is dominated by inertial forces, resulting in a more uniform axial velocity across the flowing stream and a flat velocity profile.

[Alan S. Morris "Principles of measuring and instrumentations", Prentice Hall, second editions]

2.3 Applications of magnetic flow rate measurement

Magnetic flow meters have been widely used in industry for many years. Its is commonly used in situations where:

a) High percentage of solids

b) Sludge, slurries, minerals, paper, sewage - flows with high levels of solids which cannot be measured other types of meters.

c) Obstruction less measurement

d) Nothing projects into the flow stream, no head loss, no parts to maintain.

e) Very corrosive liquids

f) Acids, caustics and corrosive chemical additives are isolated from the meter by inert linings and electrodes.

g) Conductive liquids

Chapter 3 Methodology

3.1 Investigations and analysis

3.1.1 Investigations

3.1.1 a) Electromagnetic induction

In electronics, the production of an electromotive force (emf) in a circuit by a change of magnetic flux through the circuit or by relative motion of the circuit and the magnetic flux. As a magnet is moved in and out of a coil of wire in a closed circuit an induced current will be produced. All dynamos and generators produce electricity using this effect. When magnetic tape is driven past the playback head (a small coil) of a tape recorder, the moving magnetic field induces an emf in the head, which is then amplified to reproduce the recorded sounds.

Electromagnetic induction takes place when the magnetic field around a conductor changes. If the magnetic field is made to change quickly, the size of the current induced is larger. A galvanometer can be used to measure the direction of the current. As a magnet is pushed into a coil, the needle on the galvanometer moves in one direction. As the magnet is removed from the coil, the needle moves in the opposite direction.

If the change of magnetic flux is due to a variation in the current flowing in the same circuit, the phenomenon is known as self-induction; if it is due to a change of current flowing in another circuit it is known as mutual induction.

3.1.1 b) Lenz's law

The direction of an electromagnetically-induced current (generated by moving a magnet near a wire or by moving a wire in a magnetic field) will be such as to oppose the motion producing it. This law is named after the German physicist Heinrich Friedrich Lenz (1804–1865), who announced it in 1833

3.1.1 c) Faraday's laws

Michael Faraday proposed three laws of electromagnetic induction;

(1) a changing magnetic field induces an electromagnetic force in a conductor;

(2) the electromagnetic force is proportional to the rate of change of the field; and

(3) the direction of the induced electromagnetic force depends on the orientation of the field.

3.1.1 d) Fleming's right hand rule

Fleming's right hand rule (for generators) shows the direction of induced current flow when a conductor moves in a magnetic field.

The right hand is held with the thumb, first finger and second finger mutually at right angles, as shown in the diagram below.

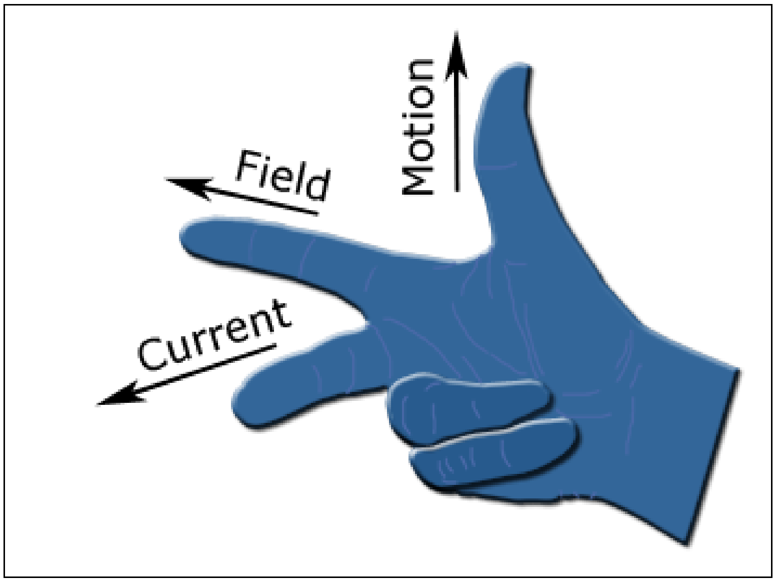

Figure 3.1.1.d1 Fleming's right hand rule

The Thumb represents the direction of Motion of the conductor.

The First finger represents Field.

The Second finger represents Current

3.1.2 a) Theoretical analysis

Magnetic flow meters operate based upon Faraday's Law of electromagnetic induction, which states that a voltage will be induced in a conductor moving through a magnetic field.

Faraday's Law: $E=kBDV$

E = The voltage generated in a conductor
V = The velocity of the conductor
B = The magnetic field strength
D = The length of the conductor

The magnitude of the induced voltage E is directly proportional to the velocity of the conductor V, conductor width D, and the strength of the magnetic field B. As shown in Figure 2.2.1, magnetic field coils are placed on opposite sides a pipe to generate a magnetic field. As the conductive process liquid moves through the field with average velocity V, electrodes sense the induced voltage. The distance between electrodes represents the width of the conductor. An insulating liner prevents the signal from shorting to the pipe wall. The only variable in this application of Faraday's law is the velocity of the conductive liquid V because field strength is controlled constant and electrode spacing is fixed. Therefore, the output voltage E is directly proportional to liquid velocity, resulting in the linear output of a magnetic flow meter.

To apply this principle to flow measurement with a magnetic flow meter, it is necessary first to state that the fluid being measured must be electrically conductive for the Faraday principle to apply. As applied to the design of magnetic flow meters, Faraday's Law indicates that signal voltage (E) is dependent on the average liquid velocity (V) the magnetic field strength (B) and the length of the conductor (D) (which in this instance is the distance between the electrodes).In the case of wafer-style magnetic flow meters, a magnetic field is established throughout the entire cross-section of the flow tube (Figure 2.2.1). If this magnetic field is considered as the measuring element of the magnetic flow meter, it can be seen that the measuring element is exposed to the hydraulic conditions throughout the entire cross-section of the flow meter. With insertion-style flow meters, the magnetic field radiates outward from the inserted probe

[Alan S. Morris “Principles of measuring and instrumentations”, Prentice Hall, second editions]

3.1.2 b) Mathematical analysis

According to Faraday's law of electromagnetic induction: any change in the magnetic field with time induces an electric field perpendicular to the changing magnetic field:

$$E = -N\frac{d\left(BA\right)}{dt} = -N\frac{d\Phi}{dt} \qquad \text{eq.3.1.2.1}$$

where E is the voltage of induced current, B is the external magnetic field, A is the corss section area of the coil, N is the number of turns of the coil, $\Phi = BA$ is the magnetic flux, and finally the negative sign indicates that the current induced will create another magnetic field opposing to the buildup of magnetic field in the coil based on Lenz's law.

When applying the above equation to magnetic flow meters, the number of turns N and the strength of the magnetic field B are fixed. The Faraday's law becomes

$$E = -NB\frac{dA}{dt} = -NB\frac{dl}{dt}D = -NBVD \qquad \text{eq.3.1.2.2}$$

Where D is the distance between the two electrodes (the length of conductor), and V is the flow velocity.

If we combine all fixed parameters N, B, and D into a single factor , $K = -NBD$ we have

$$V = \frac{E}{K} \qquad \text{eq.3.1.2.3}$$

It is clear that the voltage developed is proportional to the flow velocity.

A prerequisite of using magnetic flow meters is that the fluid must be conductive. The electrical conductivity of the fluid must be higher than 3 µS/cm in most cases. A lining of nonconductive material is often used to prevent the voltage from dissipating into the pipe section when it is constructed from conductive material.

[Alan S. Morris "Principles of measuring and instrumentations", Prentice Hall, second editions]

3.2 Design and constractions

3.2.1 System Block Diagram

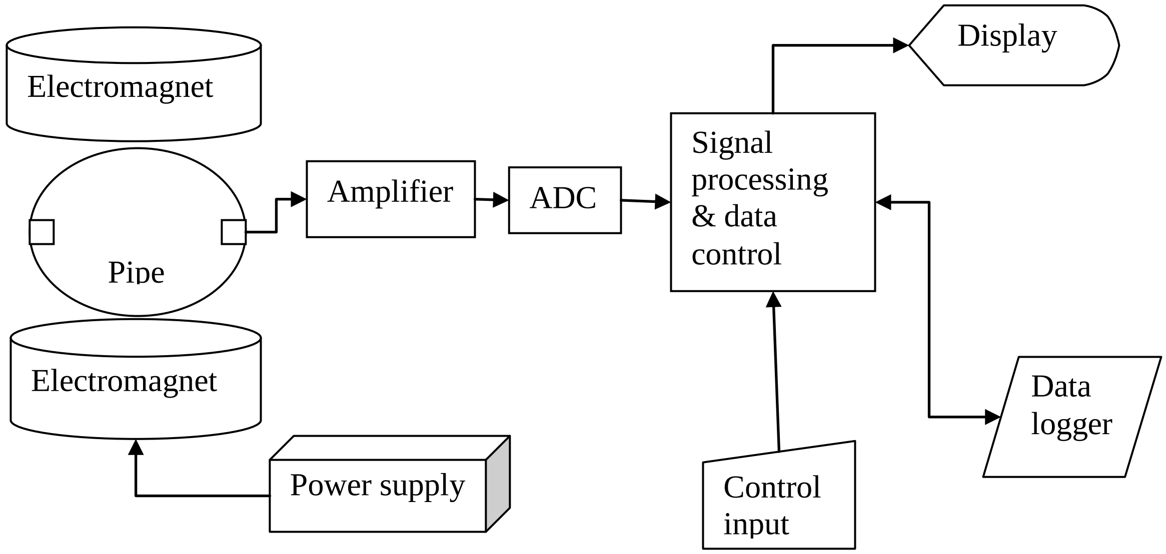

Figure 3.2.1 Magnetic flow rate system block diagram

There are three main component of the system. The electromagnet induced circuits, digitizing circuit, signal processing. The signal processing block is the main component that will control the flow of the system.

The electromagnet will be induced with DC power supply. It will create the magnetic field needed to induce the flow sensor voltage across the electrode. The strength of the magnetic field can be control by varying the current that flow through the coil turns.

The signal that been induced by the flowing fluid are then be amplifying because the signal that had been pick up by the electrode are too small to work with. The signal then is run through an analogue to digital converter circuits. The processor will process the signal and send a copy to the data logger.

Data logger will record the raw data that come from the electrode. This data can be used for processing later on with a computer. The data logger is an external device that supports the system. The system will work without it but user can’t record their data.

All processing result will be display by a LCD display. This is the interface device that will be used to communicate with the user. An input device will be used to control the system.

The processing process are done with a microprocessor that had been programmed with a predefine process.

3.2.2 Electromagnet induced circuits

An electromagnet is built on the principle of solenoid; approximately 100 meters of wire are winded around a stack of nut and bolt, 50mm of diameters and 65 mm of length. There are approximately 450 turn of winding.

The electromagnet will be power by a DC power supply. The current from the power supply will control the strength of the electromagnet field.

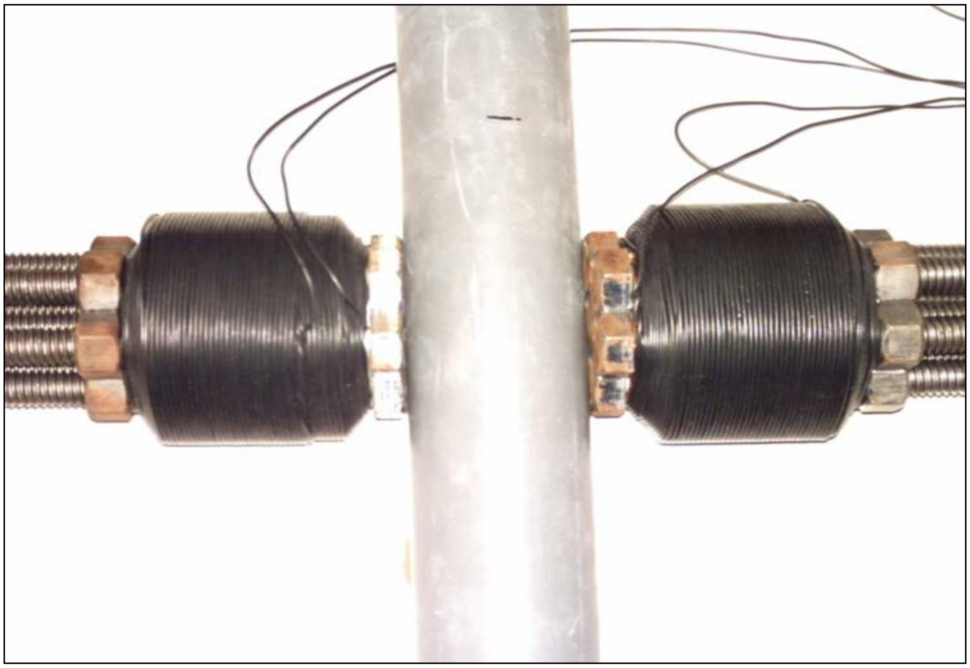

Figure 3.2.2.1 Electromagnet

3.2.3 Amplifier circuits

The signal that the electrode picks up from the induced voltage is too small to handle. It has to be amplified before the signal processing take place.

A common emitter circuits is design to amplifier the signal with a voltage gain of 10V/V or 20 dB of gain. The input range of the amplifier is from 1mV until 500mV before a cutoff of the signal occur.

The circuit is as in the figure below

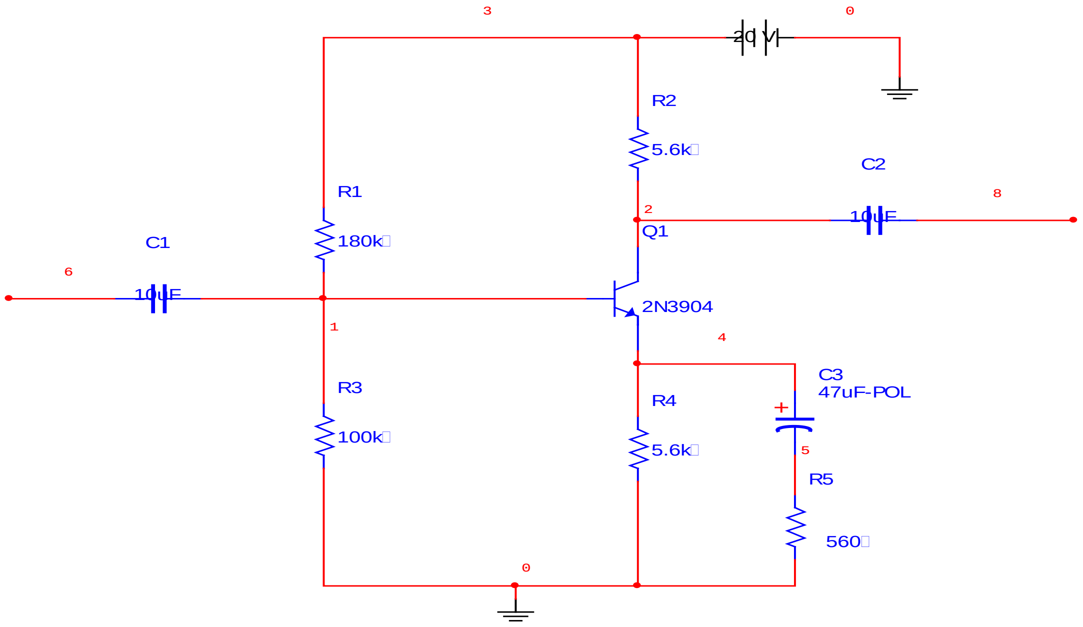

Figure 3.2.3.1 Common emitter amplifier circuit with 20 dB of gain

3.2.4 Analog to digital circuit

In order to process the signal using a microprocessor, the signal has to be digitizing using an ADC circuit.

An 8 bit resolutions ADC is used to converted the signal into digital signals, the reference voltage for the ADC is 1.28V. This will make the ADC to have a 10mV of step size. Witch mean that every 10mV of change in the input signal the ADC circuits will convert the signal into its digital equivalent. The input signal for the ADC is from 0 V to 2.56 V.

The circuit is as in the figure below

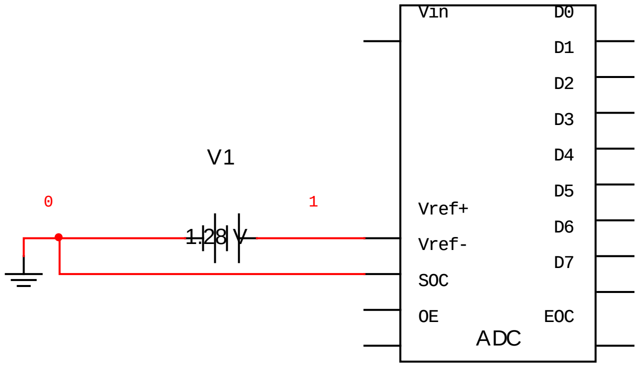

Figure 3.2.4.1 ADC circuit

3.2.5 Signal processing circuit

The digitized signal is process using a FPGA board, witch is using Xilinx series chip as the core of the board.

The chip is program to compare the input signal and display the result using a LCD. The entire system block is control by this chip.

Xilinx Foundations Series 2.1 is used to program the chip.

3.3 Software development

The processing part of the system is done by a FPGA board, Xilinx 4000XL series is used in this system.

The chip is program by using Xilinx Foundations Series 2.1 software.

The circuits module are as follow :

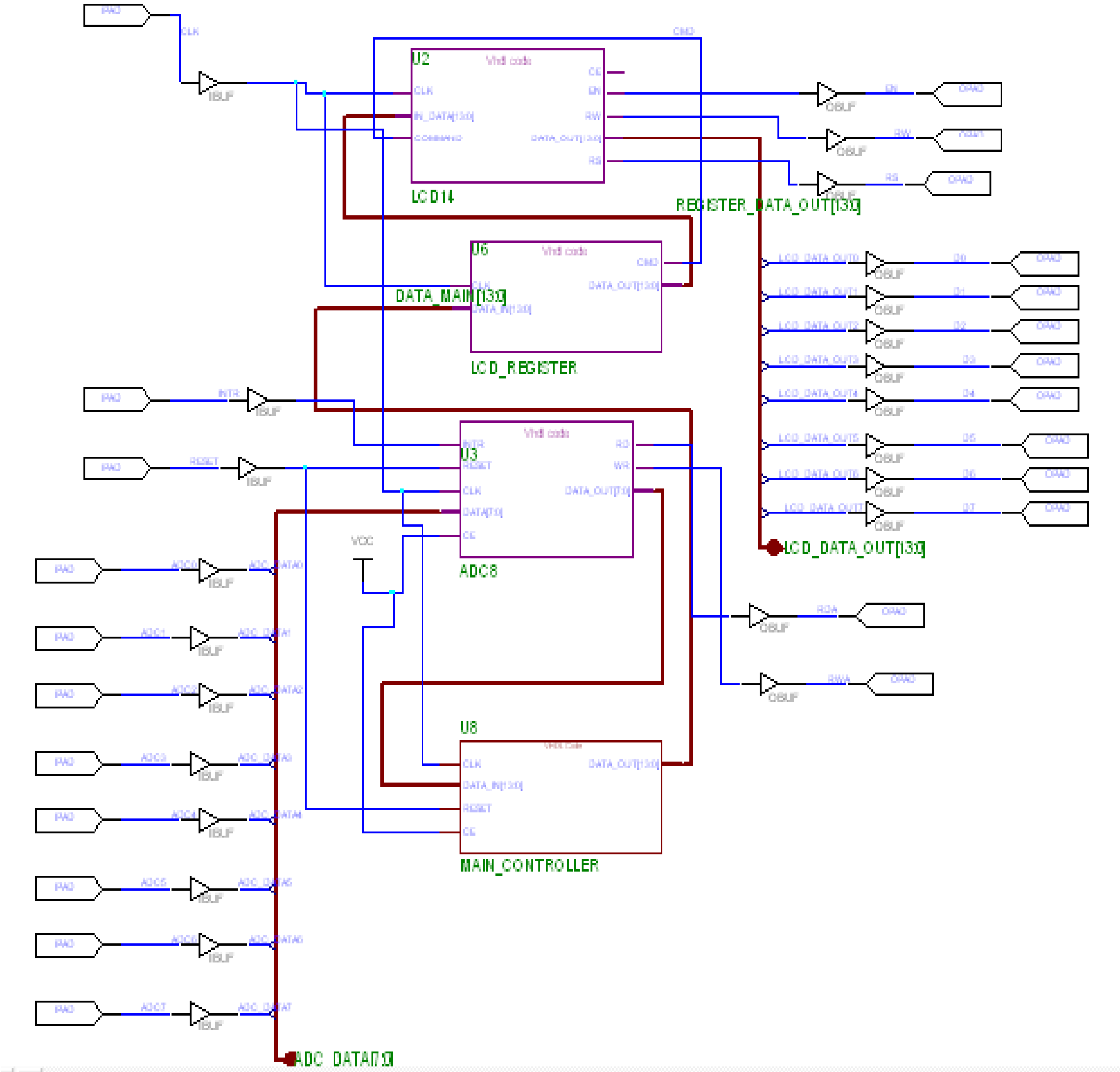

Figure 3.3.1 Xilinx signal processing circuits module

The main modules in the circuit are MAIN_CONTROLLER, ADC8, LCD14 The functions of MAIN_CONTROLLER is to process the digitize signal that been send by the ADC8 module. Its will compare the input and send an output to the LCD_REGISTER.

ADC8 module is an interface with the output of the ADC circuit in the system.This module will read the output from the ADC circuit and send it to the MAIN_CONTROLLER module.

LCD14 is a LCD driver module. Its will interface with the LCD on the system . Output will be display on the LCD trough LCD14.

All of the codes for the modules are in the appendix.

3.4 Constrictions

The hardware circuits and layout are as follow .

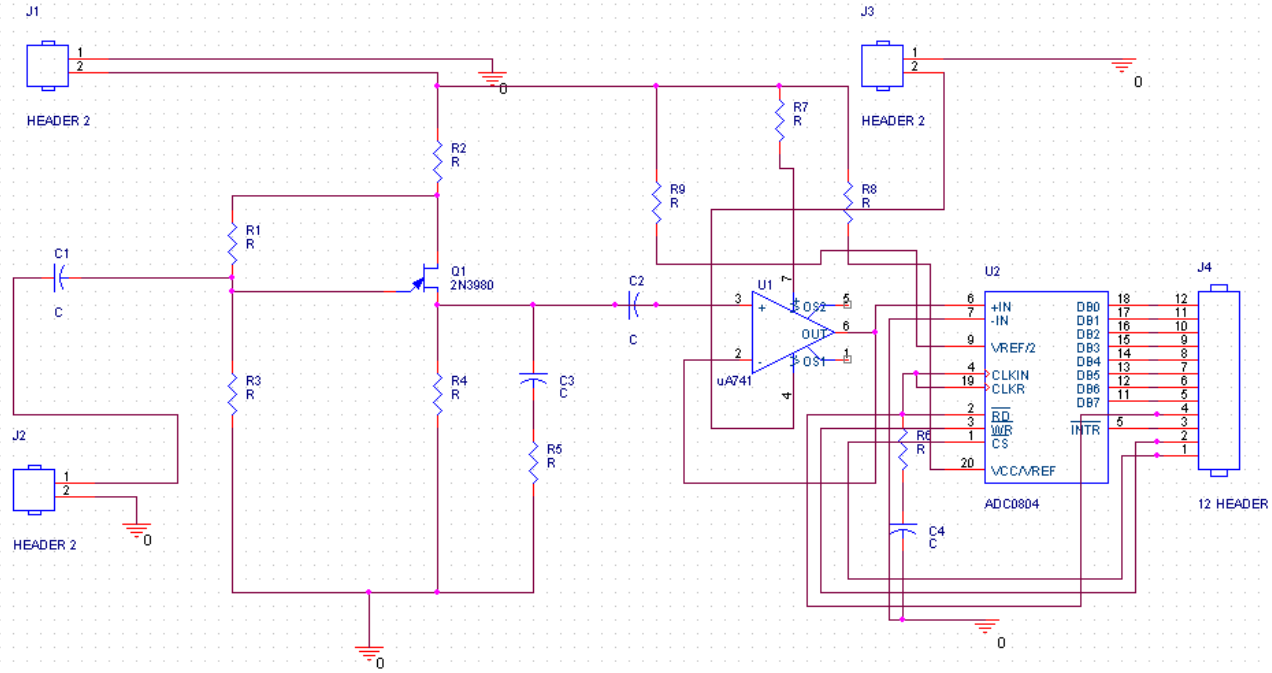

Figure 3.4.1 complete system circuits

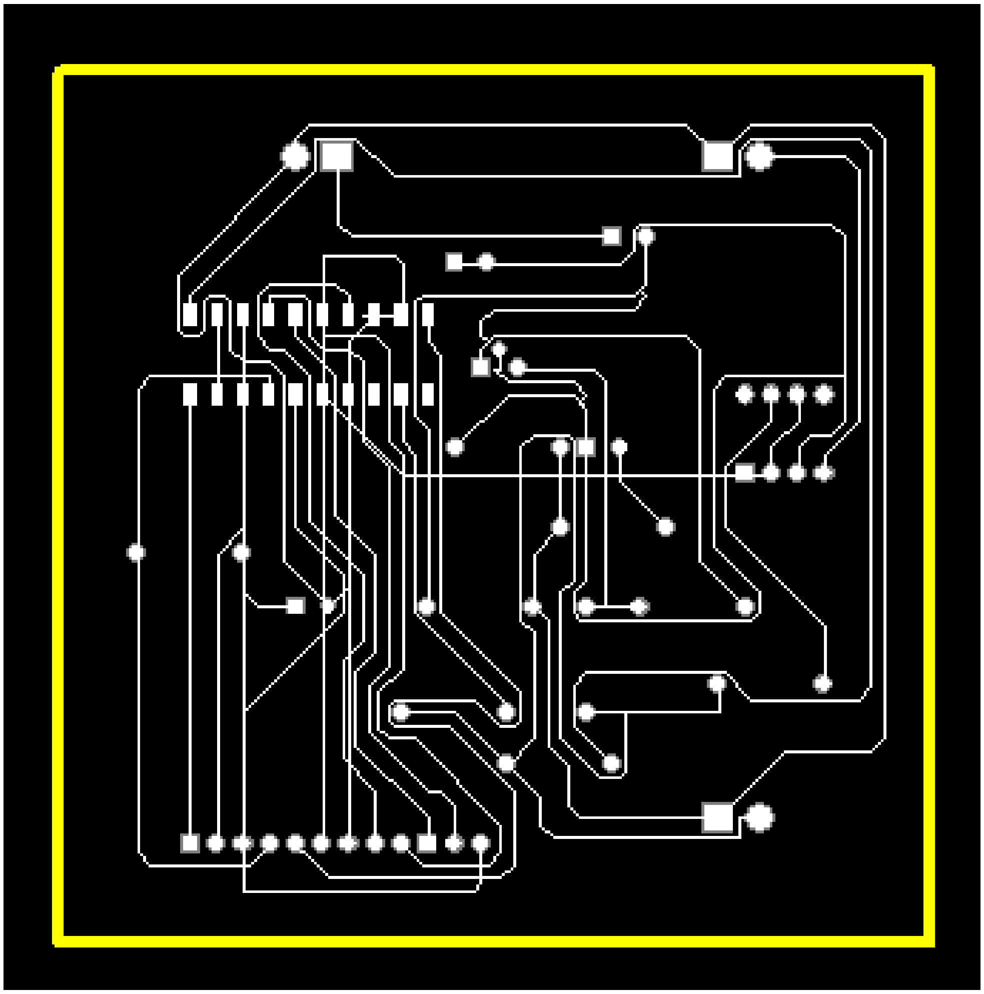

Figure 3.1.2 PCB layout

Chapter 4 Result

4.1 Simulations result

Amplifier circuit simulations

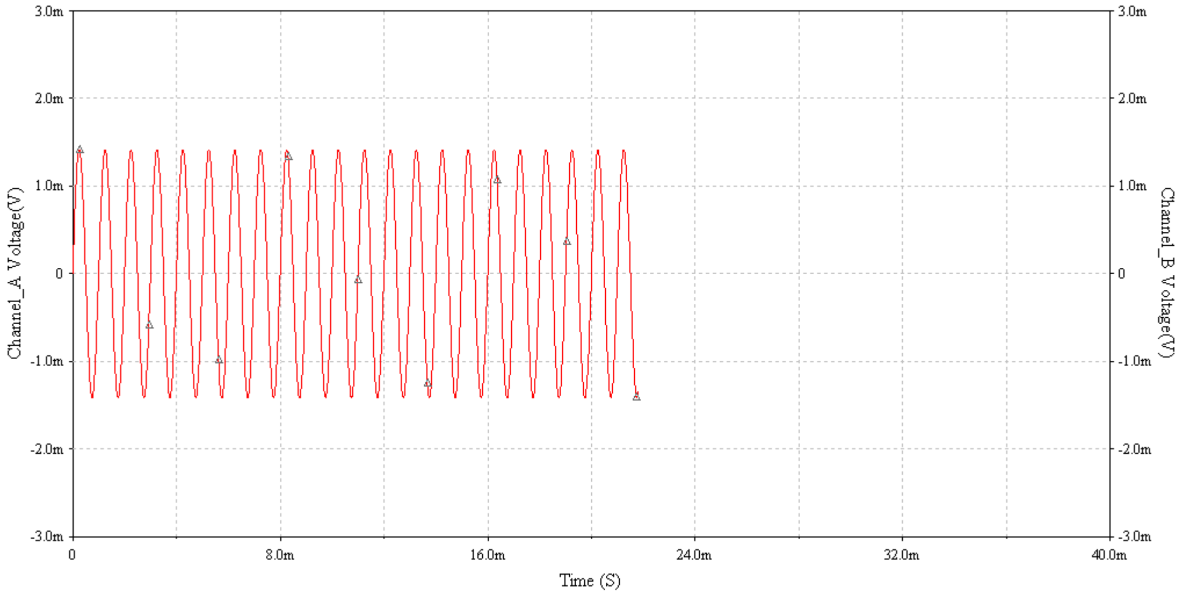

Figure 4.1.1 Amplifier input signal

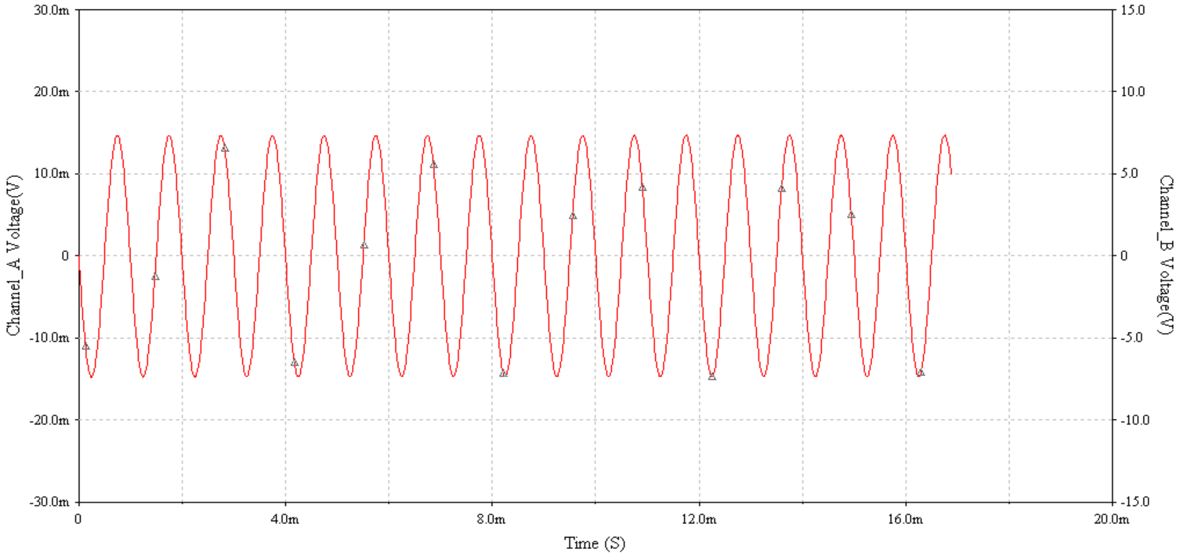

Figure 4.1.2 Amplifier output signal

Gain calculations

$$V_A = \frac{V_{out}}{V_{in}}$$

$$= \frac{14.6981\times 10^{-3}}{1.4140\times 10^{-3}}$$

$$= 10.39$$

ADC test circuit

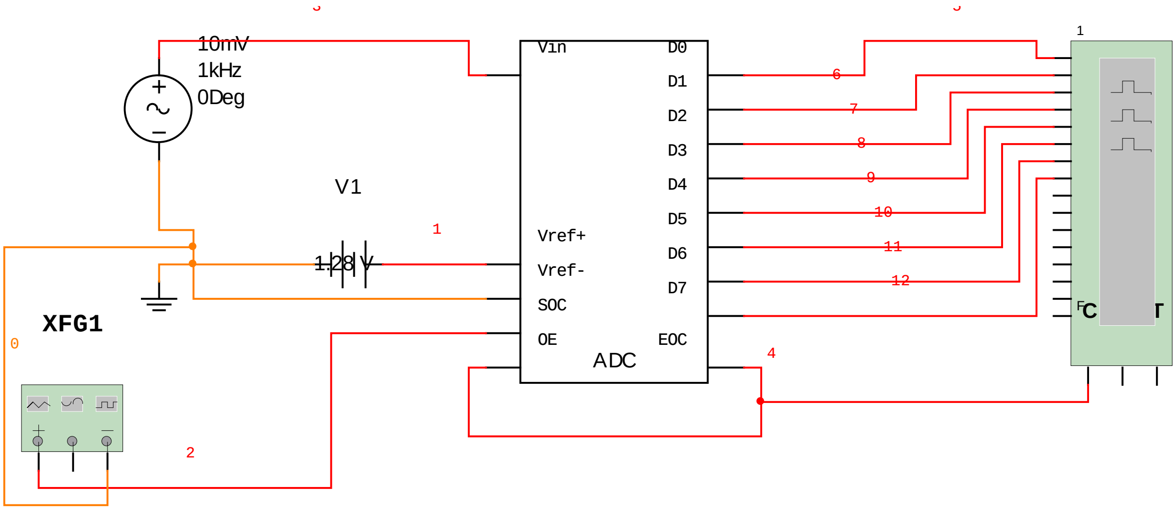

Figure 4.1.3 ADC test circuits

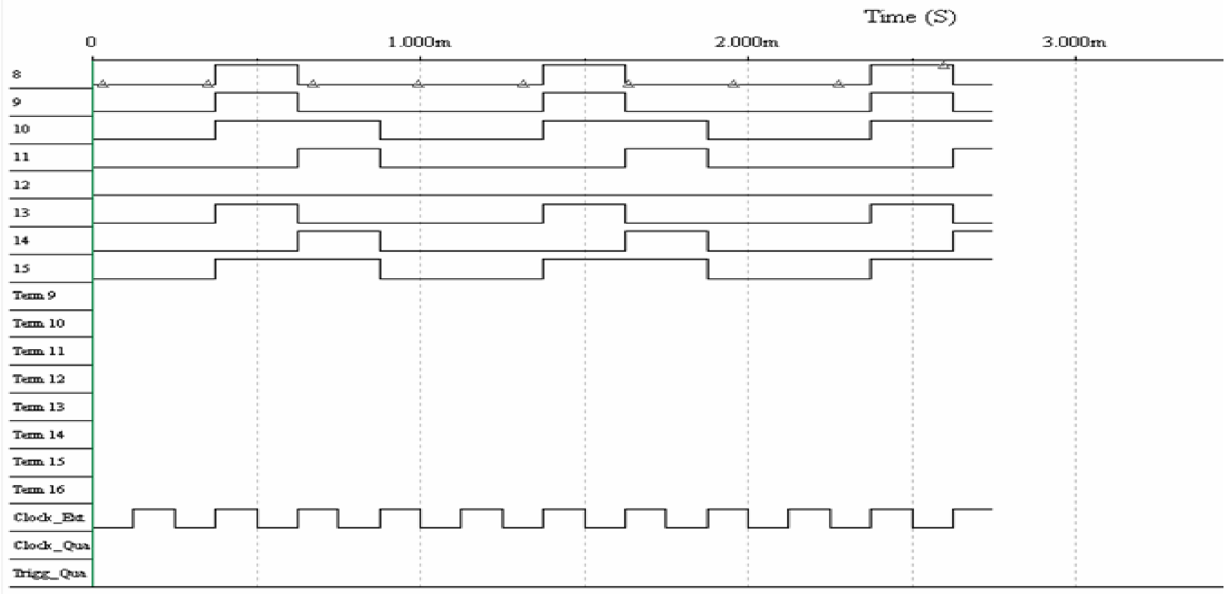

Figure 4.1.4 ADC simulations result

4.2 Experiment result

Table 4.2.1 Amplifier outputs

No.	Input Voltage(V)	Output Voltage(V)	Voltage Gain(V/V)
1	1m	11.3m	11.3
2	10m	0.11	11
3	20m	0.21	10.5
4	30m	0.29	9.67
5	40m	0.41	10.25
6	50m	0.53	10.6
7	100m	0.97	9.7
8	200m	2.1	10.5
9	400m	3.8	9.5
10	500m	4.7	9.4

Average voltage gain =(11.3+11+10.5+9.67+10.25+10.6+9.7+10.5+9.5+9.4)/ 10
=10.242 V/V

Table 4.2.2 ADC outputs

No.	Input Voltage(V)	ADC output (8 bits)
1	1m	00000001
2	10m	00000010
3	20m	00000011
4	30m	00000100
5	40m	00000101
6	50m	00000110
7	100m	00001011
8	200m	11111011
9	400m	11111111
10	500m	11111111