SYSTEM FOR ANALYZING FLUID VELOCITY IN HEAT EXCHANGER

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

Dr. Dennis Ling
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Amin Bin Ridzuan

ABSTRACT

Fouling of heat exchanger is concerned by industry especially in oil and gas industry. Slugs and rust in the heat exchanger will limit the flow of fluid in the pipeline and reduce the diffusion capability. Hence, affect the heat exchanger efficiency. Cleaning process will halt the refinery from going on and it will result in major cost penalties. Therefore, the best timing to perform the cleaning and maintenance process must be determined to avoid unnecessary cleaning by measuring the fluid velocity and the heat transfer coefficient. The objectives of this project is to design and build a system for monitoring the flow rate and temperature of flowing fluid in the heat exchanger and to design a computerized system to monitor the performance of heat exchanger. Experiments are conducted using distilled water and water containing 10% and 20% of soil. The result gained is analysed and the best timing to perform the cleaning process is determined. The objectives of this project are met and the project is successful.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, I managed to complete the dissertation for this semester.

The special thanks goes to my supervisor, Dennis Ling for the enlightening supervision and countless hours spent in sharing his insightful understanding, profound knowledge and valuable support throughout completing this project. Besides, his kind assistance and guidance from beginning to the end of the project really help me in completing the project successfully. During the period of time, it is very tough and challenging for me to complete the project without people behind me to give endless support..

Here, I would like to express my full appreciations towards lab technician for their assistance and knowledge sharing and several industry persons who involved indirectly for their information regarding my project. Their cooperation and guidance are highly appreciated.

Not forget, great appreciations go to Final Year Project coordinators for their reminder and warm supports that had made this project a memorable and an informative one. Last but not least, to all author's fellow friends who have directly or indirectly lent a helping hand here and there. The support and encouragements from the people above always be a pleasant memory throughout my life.

Thank you.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Over centuries, sensors have being used in industry for detection and measurement. It is reported that there has been an unprecedented growth of services and products which utilization of different types of sensor are vital for detecting and measuring. Sensor is a device to detect changes of a system or in the state of other device. The information gained will be recorded in a certain manner. Sensor technology is referred as the development of sensors to meet the need and its applicability in very broad area such as industry, medicine and environment.

In oil and gas industry, sensors are used to analyze some parameters of the heat exchanger such as pressure, temperature and flow rate. Hence the efficiency of heat exchanger can be determined. Fouling has become major problem for refiners and up graders during petroleum processing, refining and storage of finished products. In oil and gas industry, the main factor which are emphasis by most of the companies are profitability and the consequently process efficiency. In order to survive with marginal profits, the current operating trend for most of the major oil processing units in the world is to minimize cost/barrel of crude oil.

Since fouling and other corrosion issues can affect the efficiency of heat exchanger, refiners need to frequently shut down the heat exchanger for cleaning according to the regular maintenance schedule. However, this maintenance period and unnecessary cleaning will result in major cost penalties and causes ecological problems. This is due to the system downtime, waste of water and chemicals used for cleaning and energy used for pre-heating and heating crude oils.

Therefore, researches have been done regarding this issue (fouling) to either attempt to mitigate the fouling issues or at least elucidate the mechanism of fouling. This is helpful not only to the oil and gas industry but also other industry to improve the reliability and the integrity of the processing units and hence minimize the cost incurred by the affected companies. .

1.2 Problem Statement

Fouling of heat exchanger is concerned by industry especially in oil and gas refinery. Slugs and rust in the heat exchanger will limit the flow of fluid in the pipeline and reduce the diffusion capability. Hence, affect the heat exchanger efficiency.

Cleaning process will halt the refinery from going on and it will result in major cost penalties. Therefore, the best timing to perform the cleaning and maintenance process must be determined by measuring the fluid velocity and the heat transfer coefficient.

1.3 Objectives

The objectives are:

a) To design and build a system for monitoring the flow rate and temperature of flowing fluid in heat exchanger
b) To design a computerized system to monitor the performance of heat exchanger from distance.

1.4 Scope of Study

The scope of study is limited to the measurement of parameters at the inlet and outlet of the heat exchanger and will focused on heat and fluid velocity. Experiments will be done in order to identify the best solution that met the objectives.

1.5 Feasibility of Study

The lab scale flowmeter will be used to fabricate the mature sensor for monitoring the heat and fluid velocity.

CHAPTER 2
LITERATURE REVIEW

2.1 Renewable Energy

Over centuries, many researches and studies had been done in renewable energy area. The renewable energy sources such wind, solar and hydro (water) are important for future sustainable power production [1].Nowadays, the increasing price of oil and gasoline, and the increasing demand for electricity are the main factors why the development of alternative and renewable energy is needed [2].

Wind is one of the renewable energy sources. Wind energy use same theory as hydroelectric where kinetic energy is converted to electricity. The propeller blades for windmill construction are positioned vertically for rotation about a horizontal axis as the entire surface of each blade is exposed to the full force of the moving air when it is positioned into the wind. The number blades that being used can affect the efficiency of the machines. Accordingly, the more propeller blades, the efficient the machines become at low wind speed. However, the machine will become less efficient at high wind speed. This mainly because, at low wind speed, the multi blade windmills have high starting torque which it can harvesting up tp 30% of the kinetic energy. However, this type of renewable energy technology has problems with gyroscopic vibration when the machine veers with changing wind direction. High bending moments which happen at the base of the blades and the possibility of being braked during tempest conditions will result in frequent blade replacement. Therefore, it will result in high maintenance cost [2].

Among the renewable energy sources, hydropower is the most applied renewable energy source for the production of electricity. However, conventional hydropower is constrained by several factors such as high up front capitalization, environmental concerns and land use. Therefore, the introduction of underwater hydrokinetic energy system technology is the valuable part for the solution. The electricity are generated from the kinetic energy that are present in flowing water by located these technology under the water's surface (rivers, ocean's current and manmade channel). No civil work needed to disturb the natural ecology or to change the landscape as no impoundment or dam is needed when using this technology [1] .

However, in hydropower energy, kinetic energy of flowing water is converted to electricity by using turbine. In underwater hydropower technology, there several types of turbines that commonly being used which are:

a) Horizontal axis hydro turbine

Figure 1 shows the horizontal axis hydro turbine.This type of turbine has a runner with three to six blades where the water are constantly contact all of the blades.An alternator inside the main turbine housing is attached to the propeller mounted on the front of the turbine.The propeller is rotated when submerged in fast moving water source.However, these turbines are the less efficient among this type of turbines [2].

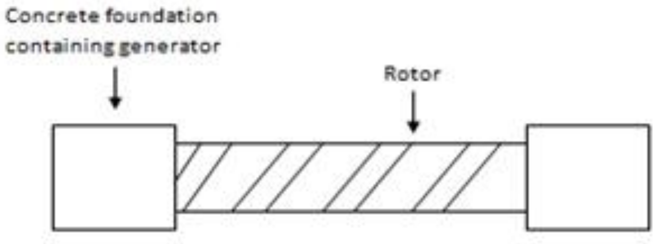


Figure 1: Horizontal axis hydro turbine

b) Helical turbine

Figure 2 shows the helical turbine.This turbine is a reaction cross flow hydraulic turbine where the blades have hydrofoils section. This section will provide tangential pulling forces in the cross water flow which the turbine will be rotated in the direction of leading edge of the blades. Therefore, the orientation of the blade will affect the direction of turbine rotation. Helical turbine are preferable to be used in free water as it has as efficiency of 35% [2].

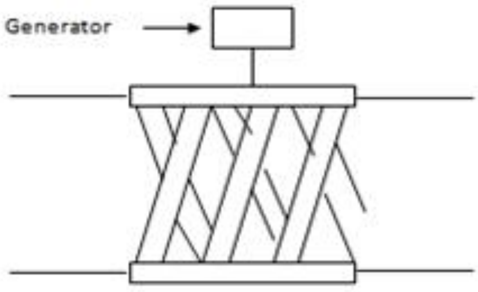


Figure 2: Helical turbine

c) Vertical axis hydro turbine

Figure 3 shows the vertical axis hydro turbine.The accelerations of its blades which passing through the higher pressure zone in the fluids make this turbine rotates with a strong pulsation.Therefore, it will lower the efficiency of this type of turbine [2].

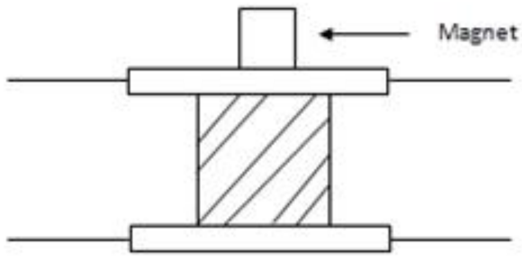


Figure 3: Vertical axis hydro turbine

2.2 Turbine Flow Meter

Flow meter is a measuring device which is being used to measure the quantity of a flowing fluid. Flow meter can be identified according to its operating principle such as positive displacement meter, differential pressure meter or by its applied technology (ultrasonic meter, turbine meter, orifice meter etc).It's also can be classified into twelve major groups.

Table 1: Basic flow meter classification

	Description	Category
1	Conventional DP types	Extractive
2	Other DP types	Extractive
3	Positive displacement types	Extractive
4	Rotary inferential types	Extractive
5	Fluid oscillatory types	Extractive
6	Electromagnetic types	Addictive
7	Ultrasonic types	Addictive
8	Direct mass types	Addictive/ Extractive
9	Thermal types	Addictive
10	Miscellaneous types	Addictive/ Extractive
11	Solids meter types	Extractive
12	Open channel types	Extractive

The operating principle for extractive category is the energy is extract from the flowing flow by having an obstacle in between in such as flow meter. On the other hand, for addictive category, energy is added to the flowing fluid in the form of light or sound [3].

Turbine flow meter as show in figure 4 consists of multiblade wheel mounted which is placed inside the pipe along parallel axis with the direction of the flowing fluid. The wheel will start rotates at a rate proportional to the volume flow rate when the fluid flows passing the wheel. Mounting the turbine wheel on low friction bearing can result in high accuracy turbine flow meter [4].A magnet is placed in the rotor body. Therefore, a voltage pulse at the output terminal is produced as the result of change in permeability of the magnetic circuit each time the rotating magnet passes the pole of pickup coil. These pulses are counted and then it will be converted into voltage and is fed to voltmeter to give the rate of the flowing flow [5].

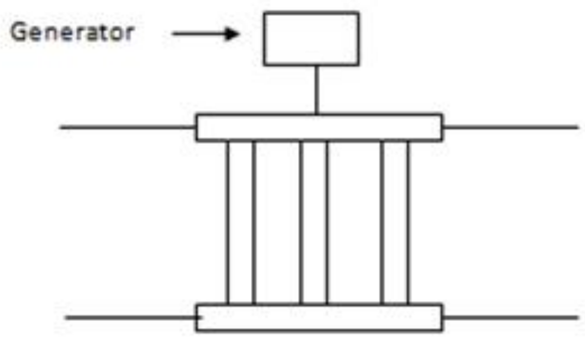


Figure 4: Turbine flow meter

The linear relationship between the volume flow rate and the angular velocity of the rotor is the main advantage of turbine flowmeter.This can be described as [5]:

2.3 Data Acquisition (DAQ) and LabView

Data acquisition is a process of measuring electrical or physical entities with a computer. Components that are needed in DAQ are transducers, programmable software which are compatible with the hardware and DAQ hardware. Transducers convert a physical portent to measurable electrical signals. The DAQ hardware is a connector between computer and the transducers.

Figure 5: DAQ system

Lab Virtual Instrument Engineering Workbench (LabVIEW) is programming software which is compatible with DAQ boards. It has been used widely as the standard software for data acquisition [6].

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The objective is to develop a miniature flow meter and monitoring system which allow operators or users to monitoring the flow rate of flowing fluid from a distant location. The advantages of the development of this project are it will help to reduce electricity usage, safety of workers and manpower for tasks.

A thorough research was done through the journals, books and internet on flow measurement, control system methods and the conversion of kinetic energy to electricity. The format and standard use to complete the documentation for this final year project (FYP) are analyzed by referencing to final reports from previous final year student.

A process flow chart is produced as per summation for the entire project. This flow chart will help for tracking each steps and stages for this project.

3.2 Project's Working Principle

There is few working principle that are being used in this project. The most important principles will be explained in this part of the report.

3.2.1 Flow meter

The flow meter type that being used in this project is the turbine flow meter. The turbine flow meter works differently compare to the other types of flow meter. The rotor in turbine flow meter is rotates by using the mechanical energy of the fluid in the flow stream. The energy from the flow is transform into rotational energy by the angled blades at the rotor. The rotor spins faster when the fluids flow faster. The movement of the blades is used to detect the shaft rotation as pulses are generated when the blades move More pulses are generated when the blades move faster.

Transmitter will then analyze the pulses to determine the flow rate of the flowing fluid.

3.3 Expected Results

Three major factors that need to be focused are the ability of the flow meter to function as expected, electricity can be generated by using the flowing fluid and measurement of the flow rate where it can be monitor from distant. Therefore continuous experiments and tuning need to be done until the objectives of this project are achieve. Several problems are also expected when working with this project such as not functioning circuit. Therefore troubleshooting need to be done as fast as possible to find the best solution for every problem occur to make sure this project is finish based on the time given.

3.4 Key Milestone

In carry out the tasks, there are several milestones that need to be focused so that it won't affect the project schedule. The milestones are the submission of documentation such as external proposal and interim report as well as the defense proposal. Therefore any problems regarding the submission need to be solved before the schedule date. The milestone are shows in the gantt chart below.

3.5 Project Activities

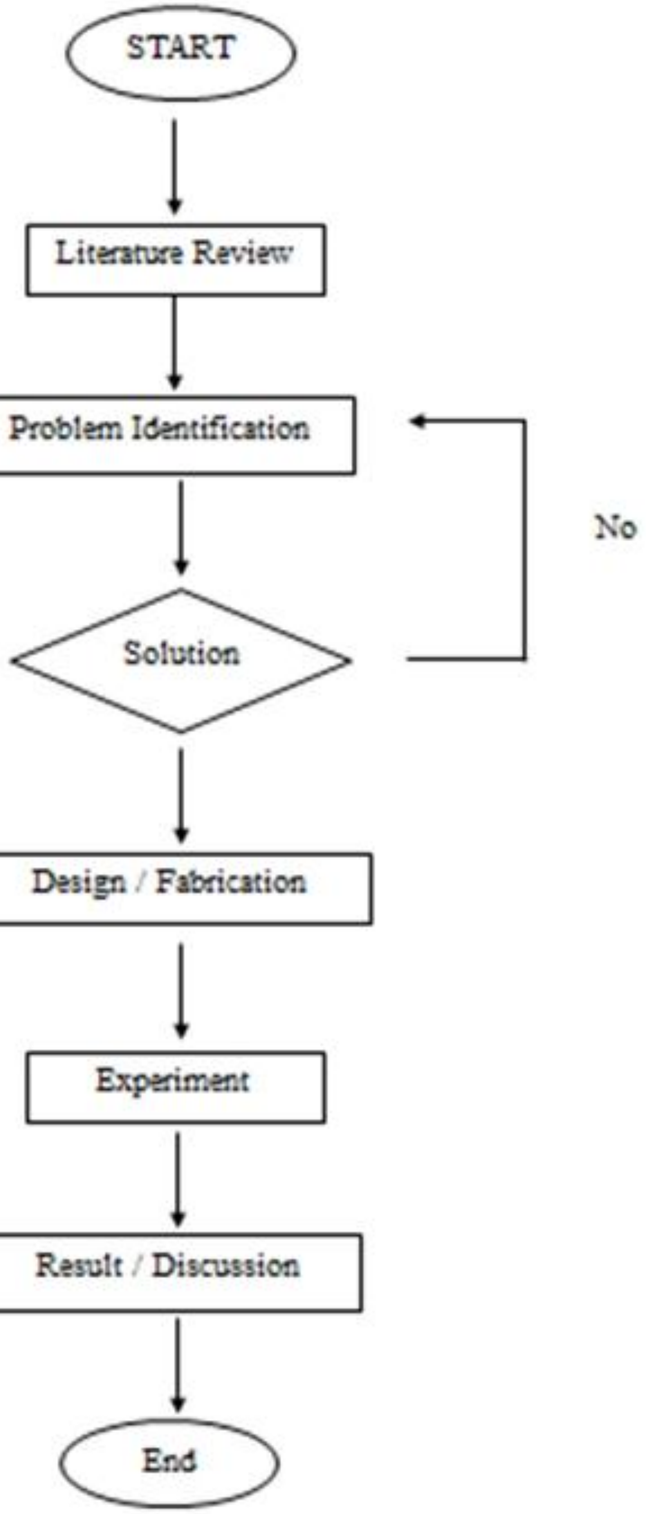


Figure 6: Research flow

The project started with the study on the literature review regarding this project. From the study, main problem is identified. Lots of sensors such as temperature, level, pressure and flow are used to monitor the efficiency of heat exchanger. Then few researches are done to find out the best solution to overcome this drawback. After all the brainstorming and study to find the best solution regarding the problem, the next step is to design the project. Experiments will be conducted continuously and the results gained will be analyzed to make sure that this project met the objectives. Finally, full prototype will be made.

3.6 Gantt Chart

Table 2: FYP 1 Gantt chart

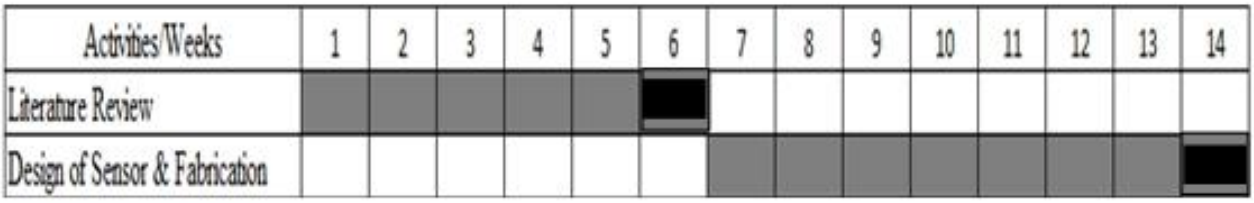
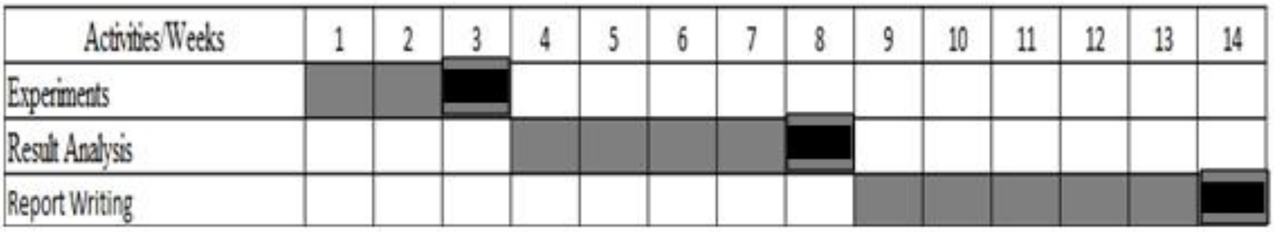


Table 3: FYP 2 Gantt chart



Work Progress

Milestones

3.7 Tools and Materials

There are few tools that are required for this project.

Table 4: Tools and materials

Components	Purposes
Turbine flow meter	Measure the flow rate of flowing fluid
PVC	Fabricated pipe
DAQ card	The interface device for software and hardware
Electrical components	Booster circuit
Pump	Water supply into pipe
DC power supply	Power supply (if needed)
National Instrument's LabView 6i	Programming software for the project
Microsoft Office 2010	Documentation

3.8 Project Progress and Next Planning

After completing the defence proposal presentation, the author had done few researches on the internet to find the best flow meter and temperature sensor which are the main parts in this project. Author has decided to buy those components from Cytron Technologies Sdn Bhd based on the budget and requirement. Currently, author is in the stage of getting familiarized with the Arduino Uno which is the main programming software for the project. Few basic programming is learnt through the internet and books.

The next planning for the project is to make sure that all the main components for the project are ready to be used. After the flow meter and temperature sensor can function as expected, author will continue with the programming part as the flow rate and temperature gained from the flow meter and temperature sensor will be monitored from distance. This step including getting the Arduino UNO and to make sure the communication link between the flow meter and the programming software is ready. Finally, prototype for this project will be constructed. However, experiments will be continuously conducted to make sure this project met the objectives before final prototype is constructed.

CHAPTER 4
RESULTS & DISCUSSION

4.1 Experimentation

The experiment was conducted at Electrical and Electronic Department Lab located at block 23 since all the equipment needed such as DC power supply, oscillator (Kenwood CS 4125) and multimeter (Pluke 167) can be found there. First, all the connections are ensure to be connected properly. This is important to avoid any possibility error and short circuit.

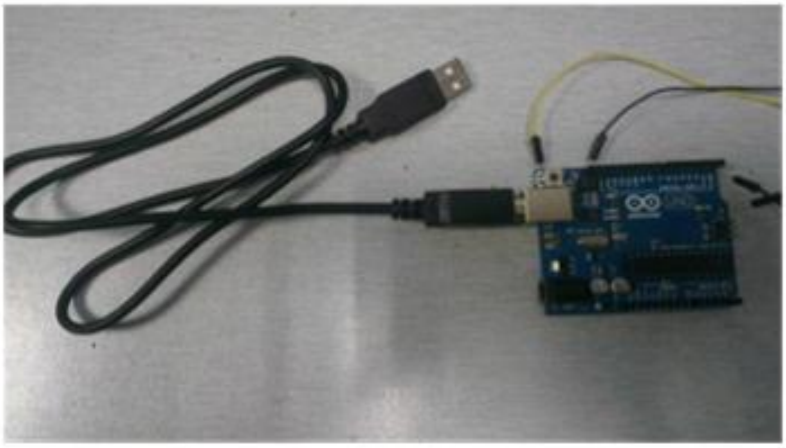


Figure 7: Arduino Uno Rev 3

Arduino Uno acts as the controller of this project. Arduino Uno is a microcontroller board circuit where it makes all the programing works become easier as it can be programed using C ++ language.

Figure 8: Hall effect sensor (U 18)

Hall effect sensor (U 18) is used to measure the flow rate. The output voltage for this sensor will change in response with the magnetic field. Therefore, in this project, a magnet is attached to the turbine. The rotation of the magnet will affect the output voltage for the hall effect sensor. Hence, the flow rate can be measured.

Figure 9: Final product

4.2 Data Gathering and Analysis

The progress for this project will be discussed in details in this chapter. As the experiments are conducted, the data gained are collected in three ways which are:

1) Wave profile
2) Voltage
3) Flow rate

4.2.1 Wave profile

The sine wave for the output can be gained using an oscilloscope. The oscilloscope used in the experiment is model Kenwood CS-4125. The sine wave behavior is completely different when the flow rate is increasing and decreasing.

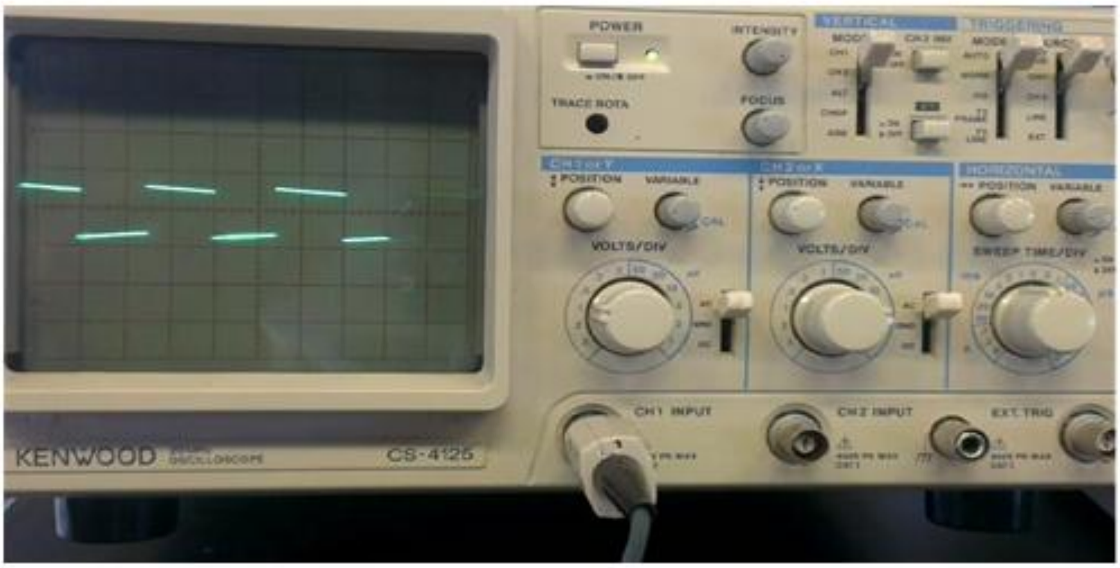


Figure 10: Output (sine wave) for high flow rate

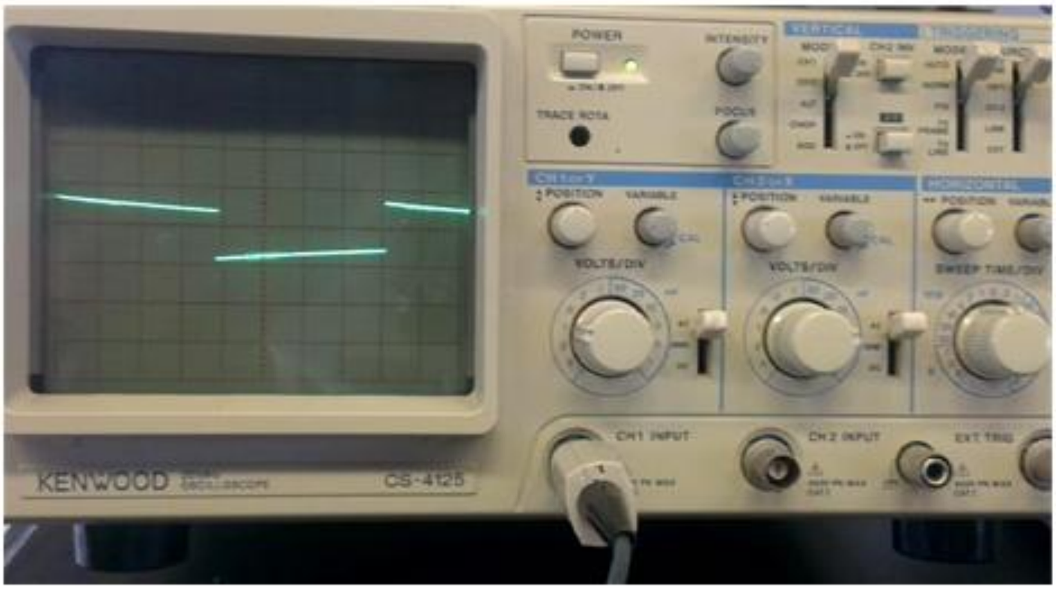


Figure 11: Output (sine wave) for low flow rate

From the figures shown above, the output peak to peak voltage for both results is same which is 1 V. However, their period are clearly different for a high flow rate and a low flow rate. Based on the results gained through the oscilloscope, time taken to complete one period for high flow rate is 6 ms while for low flow rate, the time taken is 16 ms. This means for high flow rate, it has shorter period while for the low flow rate, it have longer period.

4.2.2 The output voltage

Same like output sine wave for high and low flow rate, the output voltage for both flow rate are also different. The output voltage for both flow rates are are gained using a multimeter model Pluke 167.

Figure 12: Output voltage for high flow rate

Figure 13: Output voltage for low flow rate

. From the experiment conducted, the output voltage for high flow rate is 2.9899 V while for low flow rate, the output voltage is 4.9768 V. The different between both readings are 1.9869V. Therefore it clearly shown that high flow rate has low output voltage while low flow rate, it has higher output voltage.

4.2.3 Flow rate measurements

Experiments is done to check the efficiency of the flow meter. Hence, the best timing to perform cleaning process and maintenance works on heat exchanger can be determined. In the experiments, a car radiator is used as the heat exchanger since the working principle for the radiator are same as the heat exchanger.

Apparatus used in the experiments are :

- Car radiator (0.3m x 0.3m)
Water
- Soil
- Flow meter
- Stop watch

Firstly, distilled water is poured into the radiator. Then, time taken to get 1 liter of water coming out from the radiator is measured. The experiments is repeated by measuring the time taken to get 2,3,4 and 5 liter of water coming out from the radiator. A graph is produced by using the data gained from the experiments.

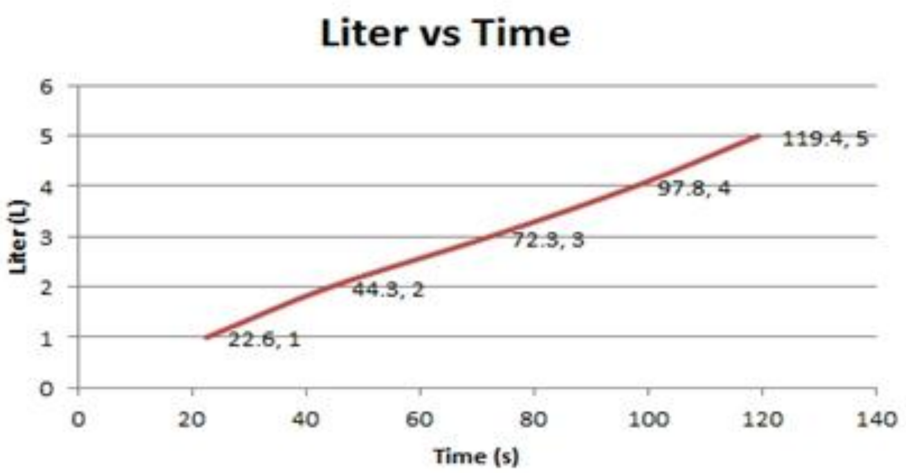


Figure 14: Flow rate of heat exchanger with distilled water

The same method of experiment is repeated by using water contained with 10% and 20% of soil. Then a graph is produced using the data gained from the experiment.

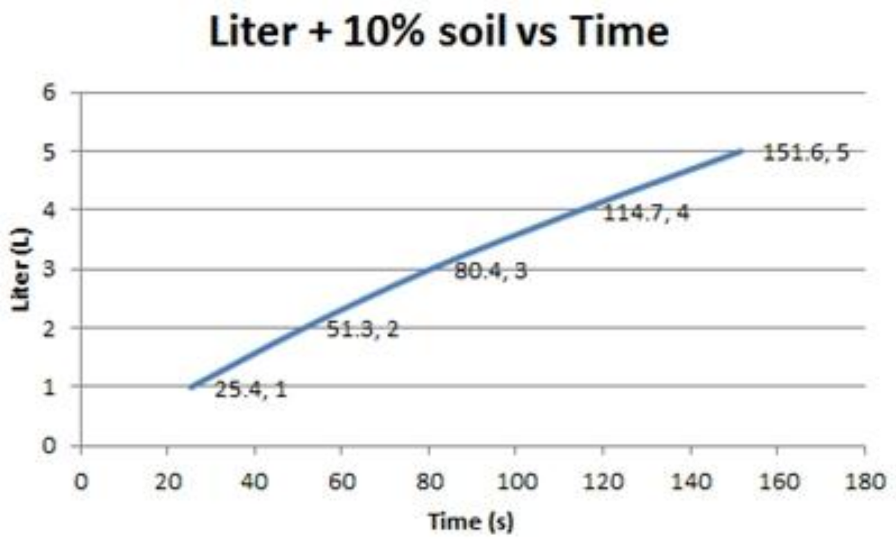


Figure 15: Flow rate of heat exchanger with 10% of soil

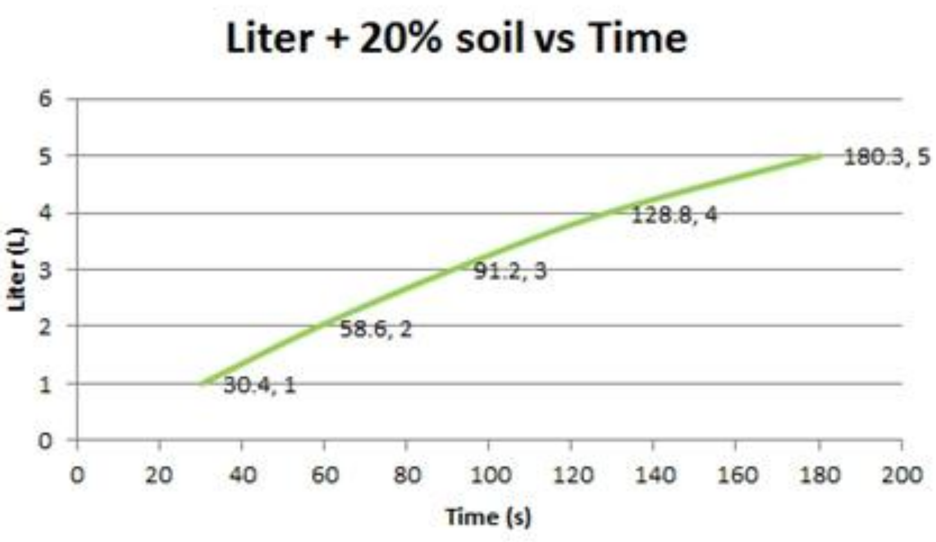


Figure 16: Flow rater of heat exchanger with 20% of soil

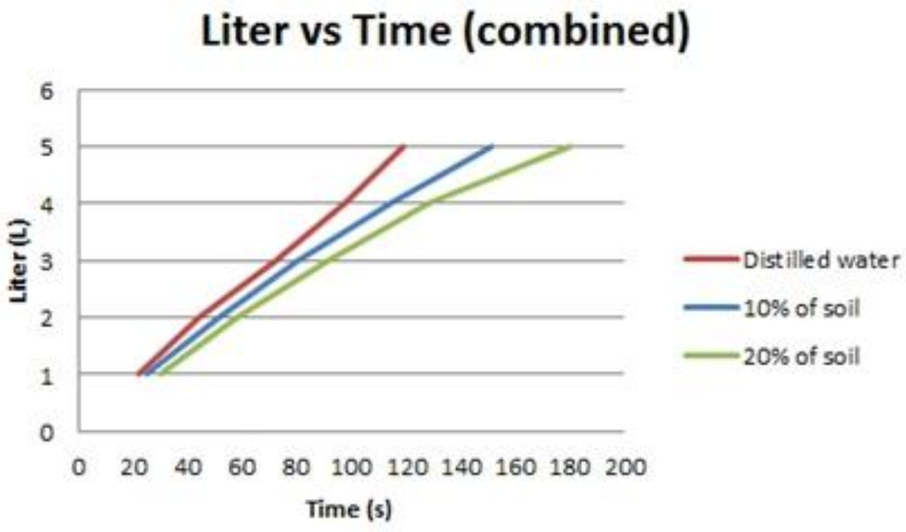


Figure 17: Flow rater of heat exchanger (combined)

All the results gained through the experiments are used to produce a combined graph as shown above. Based on the graph in figure 11, it clearly shows that the time taken to get certain amount of water coming out from the radiator is different when water containing with soil is being used in the experiment. As example, the time taken to get 5L of distilled water is only 119.4 s. However, the time taken become longer when 10% of soil is add up into the water which is 151.6 s and 180.3 s for 20% of soil. This is mainly because the soil has already accumulates inside the radiator and fouling has occurred. This also means that the increasing amount of particles in the water will increase the time taken for fouling to occur.

Therefore, the best timing to perform the cleaning process for the radiator can be determined based on the experiments conducted. The graph produced for experiment using distilled water is being used as reference. Hence,when comparing those three graphs, it can be concluded that the best timing to perform the cleaning process is at 4L.

CHAPTER 5
CONCLUSION

Fouling of heat exchanger is concerned by industry especially in oil and gas refinery. Slugs and rust in the heat exchanger will limit the flow of fluid in the pipeline and reduce the diffusion capability. For example, based on the experiment conducted, water containing 10% of soil will reduce the flow rate as much as 20.8% while for 20% of soil, the flow rate will be reduced as much as 33.6%.

Therefore, development of computerized flow meter for analyzing the flow rate and the efficiency of heat exchanger will give a major impact for the industries not only limited to oil and gas industry but also to others as well. This project will also benefit the industry on the safety of the workers as they do not need to go the site to get the readings for the flow rate and they can get the readings immediately.

Further study, research and experiments will be conducted to improve the function of this flow meter. It is recommend to develop a wireless sensor measurement for better performance.

REFERENCES

[1] Petrounevitch,E.,*Modular System For Generating Electricity From Moving Fluid*,2009,Toronto.

[2] Moore,B.,*Moving Fluid Energy Recovery System*,2008,Calgary.

[3] Chattopadhyaay,P., *Flowmeter & Flow Measurement*, First ed. 2006, New Delhi: Asian Books Private Limited.

[4] Bakshi,U.A., Bakshi,A.V., *Instrumentation Engineering*, First ed. 2009, New Delhi : Technical Publications Pune.

[5] Nakra,B.C., Chaudhry,K.K.,*Instrumentation,Measurement And Analysis*, Second ed. 2006,New Delhi : Tata Mc-Graw Hill Publishing Company Limited.

[6] Travis, J., Kring, J., *LabVIEW For Everyone : Graphical Programming Made Easy and Fun*. Third ed. Vol. T. 2007, New Jersey: Prentice Hall.

APPENDICES

APPENDIX A

U 18 HALL EFFECT SENSOR AND LM 35 DATASHEET

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

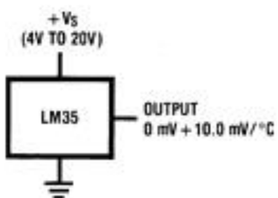
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1⁄4˚C at room temperature and ±3⁄4˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

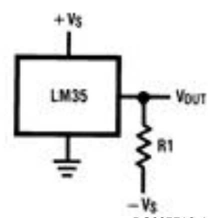
- n Calibrated directly in ˚ Celsius (Centigrade) n Linear + 10.0 mV/˚C scale factor
- n 0.5˚C accuracy guaranteeable (at +25˚C)
- n Rated for full −55˚ to +150˚C range
- n Suitable for remote applications
- n Low cost due to wafer-level trimming
- n Operates from 4 to 30 volts
- n Less than 60 µA current drain
- n Low self-heating, 0.08˚C in still air
- n Nonlinearity only ±1⁄4˚C typical
- n Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



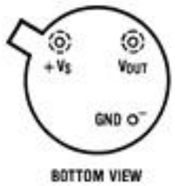
DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

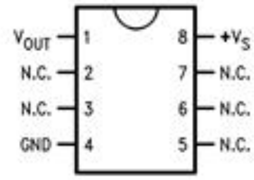


DS005516-1

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

SO-8
Small Outline Molded Package



DS005516-21

N.C. = No Connection

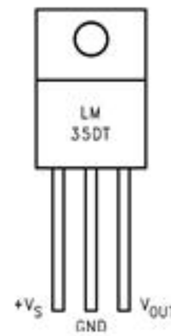
Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

DS005516-2

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

TO-220
Plastic Package*



DS005516-24

*Tab is connected to the negative pin (GND).

Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60˚C to +180˚C
TO-92 Package,	−60˚C to +150˚C
SO-8 Package,	−65˚C to +150˚C
TO-220 Package,	−65˚C to +150˚C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300˚C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260˚C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55˚C to +150˚C
LM35C, LM35CA	−40˚C to +110˚C
LM35D	0˚C to +100˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25˚C	±0.2	±0.5		±0.2	±0.5		˚C
	T_A=−10˚C	±0.3			±0.3		±1.0	˚C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		˚C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	˚C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	˚C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/˚C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V \le V_S \le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25˚C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V$, +25˚C	0.2	1.0		0.2	1.0		µA
	$4V \le V_S \le 30V$	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		˚C
	T_A=−10˚C	±0.5			±0.5		±1.5	˚C
	$T_A=T_{MAX}$	±0.8	±1.5		±0.8		±1.5	˚C
	$T_A=T_{MIN}$	±0.8		±1.5	±0.8		±2.0	˚C
Accuracy, LM35D (Note 7)	T_A=+25˚C				±0.6	±1.5		˚C
	$T_A=T_{MAX}$				±0.9		±2.0	˚C
	$T_A=T_{MIN}$				±0.9		±2.0	˚C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	˚C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/˚C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	T_A=+25˚C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V \le V_S \le 30V$	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	80		56	80		μA
	V_S=+5V	**105**		**158**	**91**		**138**	μA
	V_S=+30V, +25˚C	56.2	82		56.2	82		μA
	V_S=+30V	**105.5**		**161**	**91.5**		**141**	μA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V$, +25˚C	0.2	2.0		0.2	2.0		μA
	$4V \le V_S \le 30V$	**0.5**		**3.0**	**0.5**		**3.0**	μA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	μA/˚C
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, I_L =0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Note 1: Unless otherwise noted, these specifications apply: −55˚C≤T_J≤+150˚C for the LM35 and LM35A; −40˚≤T_J≤+110˚C for the LM35C and LM35CA; and 0˚≤T_J≤+100˚C for the LM35D. V_S=+5Vdc and I_{LOAD}=50 μA, in the circuit of Figure 2. These specifications also apply from +2˚C to T_{MAX} in the circuit of Figure 1. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/˚C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in ˚C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of Figure 1.

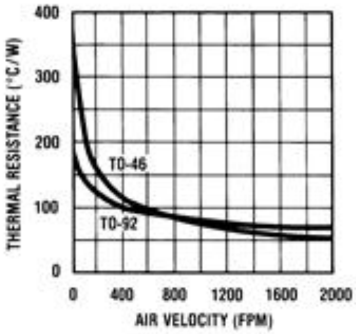
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

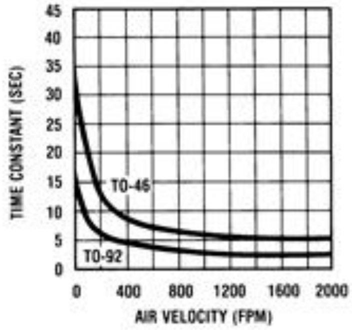
Typical Performance Characteristics

Thermal Resistance Junction to Air



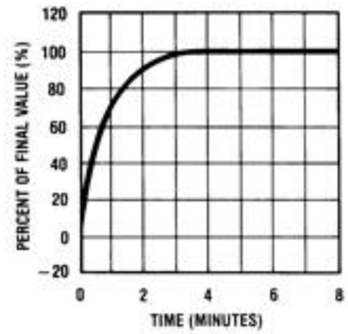
DS005516-25

Thermal Time Constant



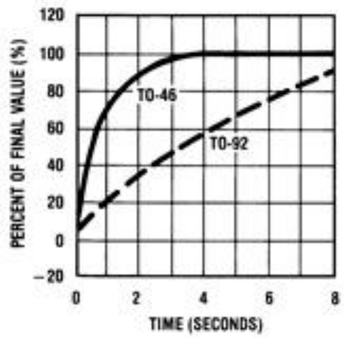
DS005516-26

Thermal Response in Still Air



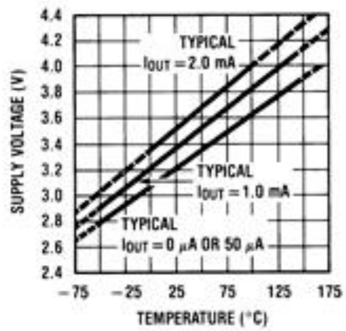
DS005516-27

Thermal Response in Stirred Oil Bath



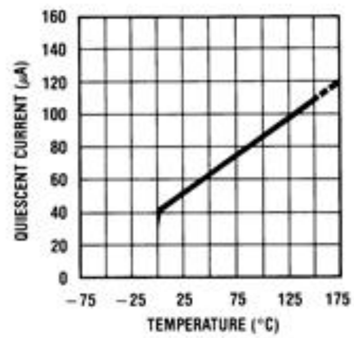
DS005516-28

Minimum Supply Voltage vs. Temperature



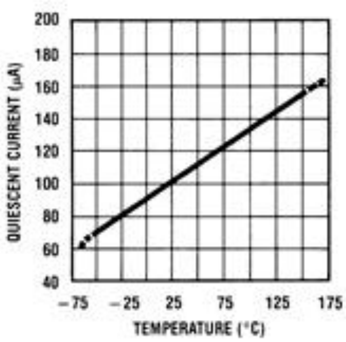
DS005516-29

Quiescent Current vs. Temperature (In Circuit of Figure 1**.)**



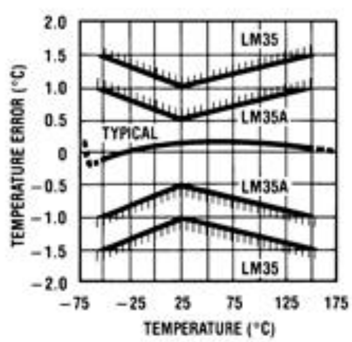
DS005516-30

Quiescent Current vs. Temperature (In Circuit of Figure 2**.)**



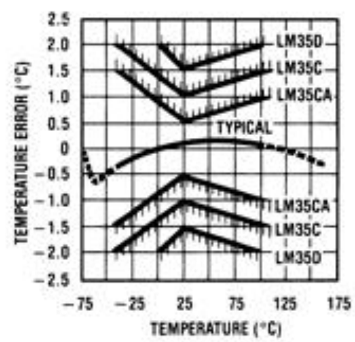
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

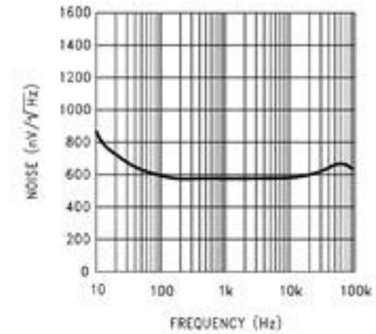
Accuracy vs. Temperature (Guaranteed)



DS005516-33

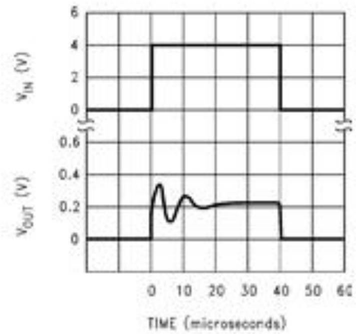
Typical Performance Characteristics (Continued)

Noise Voltage



DS005516-34

Start-Up Response



DS005516-35

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01˚C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	TO-46, no heat sink	**TO-46*, small heat fin**	**TO-92, no heat sink**	**TO-92**, small heat fin**	**SO-8 no heat sink**	**SO-8** small heat fin**	**TO-220 no heat sink**
Still air	400˚C/W	100˚C/W	180˚C/W	140˚C/W	220˚C/W	110˚C/W	90˚C/W
Moving air	100˚C/W	40˚C/W	90˚C/W	70˚C/W	105˚C/W	90˚C/W	26˚C/W
Still oil	100˚C/W	40˚C/W	90˚C/W	70˚C/W			
Stirred oil	50˚C/W	30˚C/W	45˚C/W	40˚C/W			
(Clamped to metal, Infinite heat sink)	(24˚C/W)				(55˚C/W)		

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications

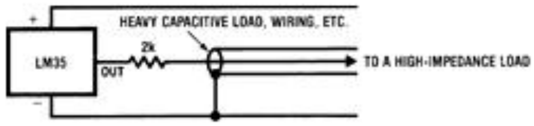


FIGURE 3. LM35 with Decoupling from Capacitive Load

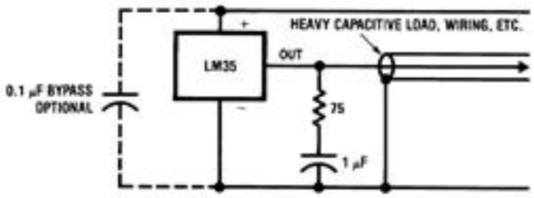


FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see Figure 3. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see Figure 4.

When the LM35 is applied with a 200Ω load resistor as shown in Figure 5, Figure 6 or Figure 8 it is relatively immune to wiring capacitance because the capacitance forms a bypass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 µF from output to ground are often useful. These are shown in Figure 13, Figure 14, and Figure 16.

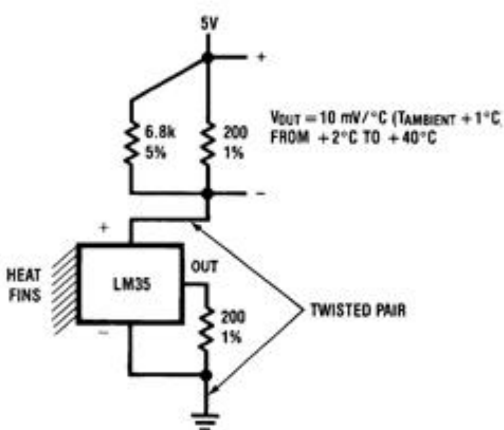


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

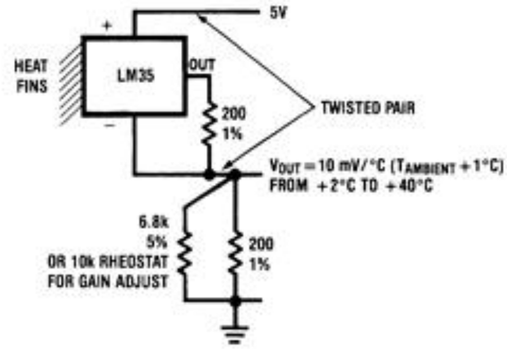


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

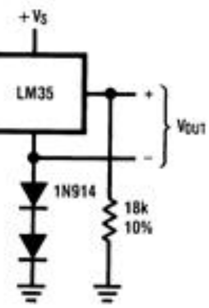


FIGURE 7. Temperature Sensor, Single Supply, −55˚ to +150˚C

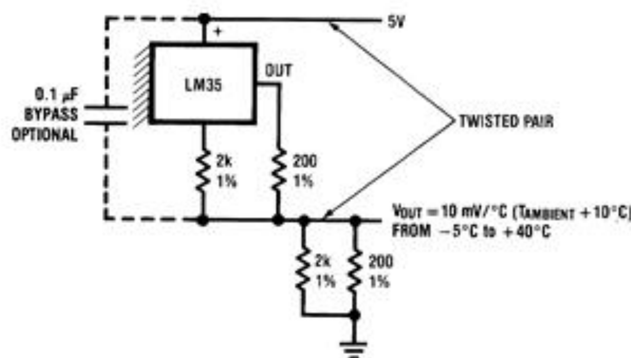


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

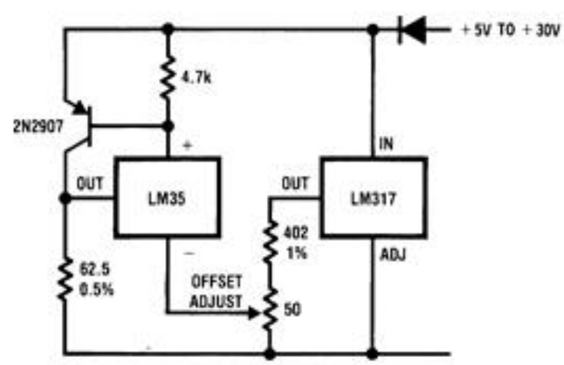
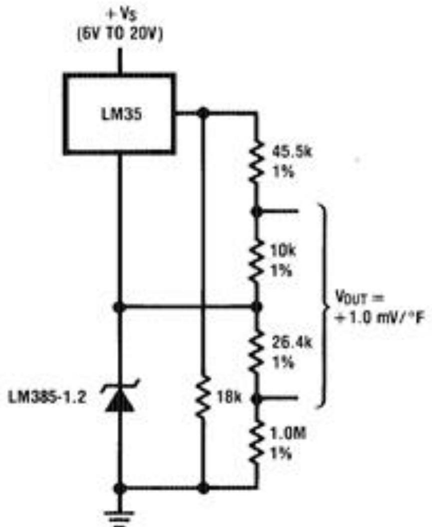


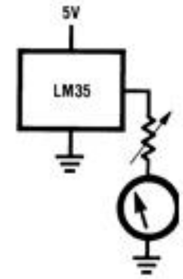
FIGURE 9. 4-To-20 mA Current Source (0˚C to +100˚C)

Typical Applications (Continued)



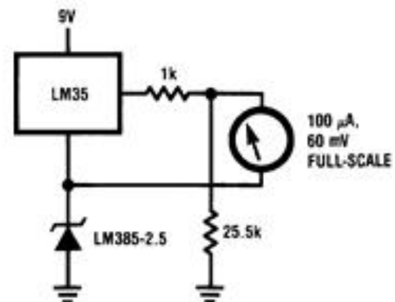
DS005516-10

FIGURE 10. Fahrenheit Thermometer



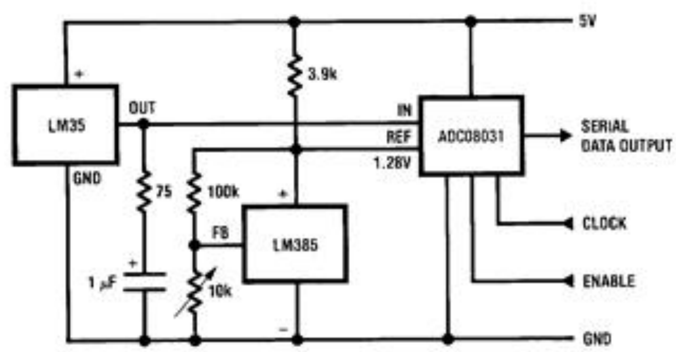
DS005516-11

FIGURE 11. Centigrade Thermometer (Analog Meter)



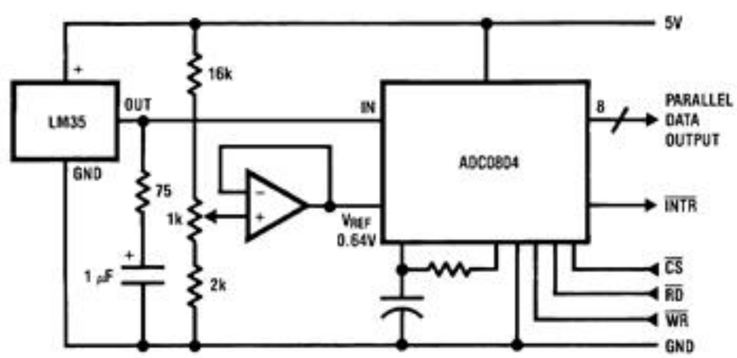
DS005516-12

FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50˚ to 80˚ Fahrenheit, for Example Shown)



DS005516-13

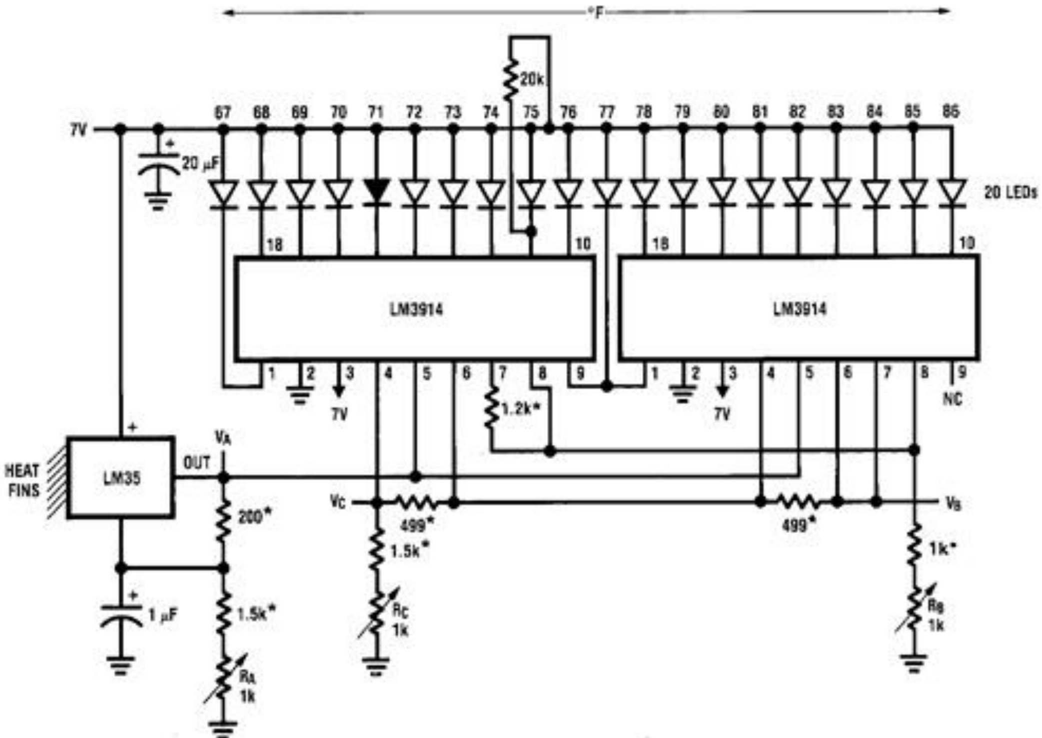
FIGURE 13. Temperature To Digital Converter (Serial Output) (+128˚C Full Scale)



DS005516-14

FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to µP Interface) (128˚C Full Scale)

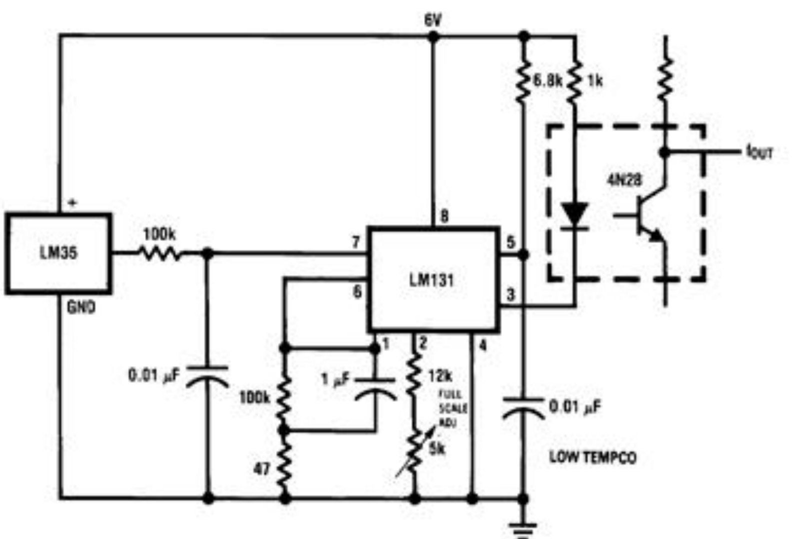
Typical Applications (Continued)



DS005516-16

*=1% or 2% film resistor
Trim R_B for V_B=3.075V
Trim R_C for V_C=1.955V
Trim R_A for V_A=0.075V + 100mV/˚C x $T_{ambient}$
Example, V_A=2.275V at 22˚C

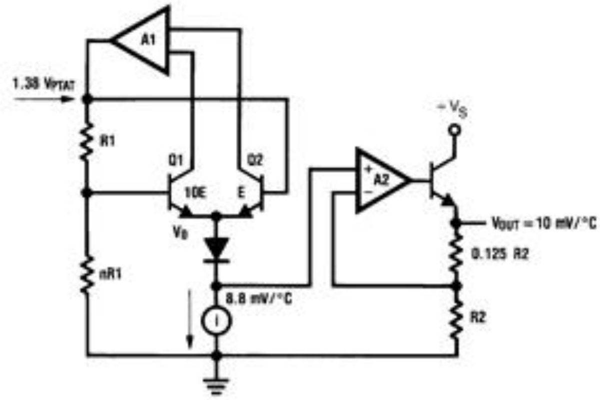
FIGURE 15. Bar-Graph Temperature Display (Dot Mode)



DS005516-15

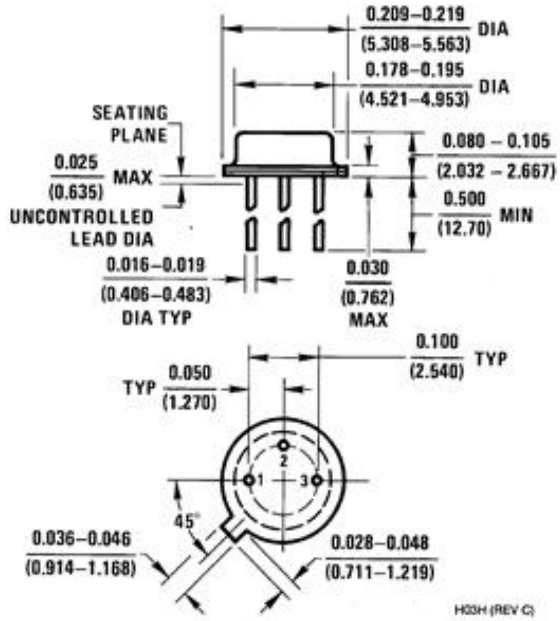
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2˚C to +150˚C; 20 Hz to 1500 Hz)

Block Diagram

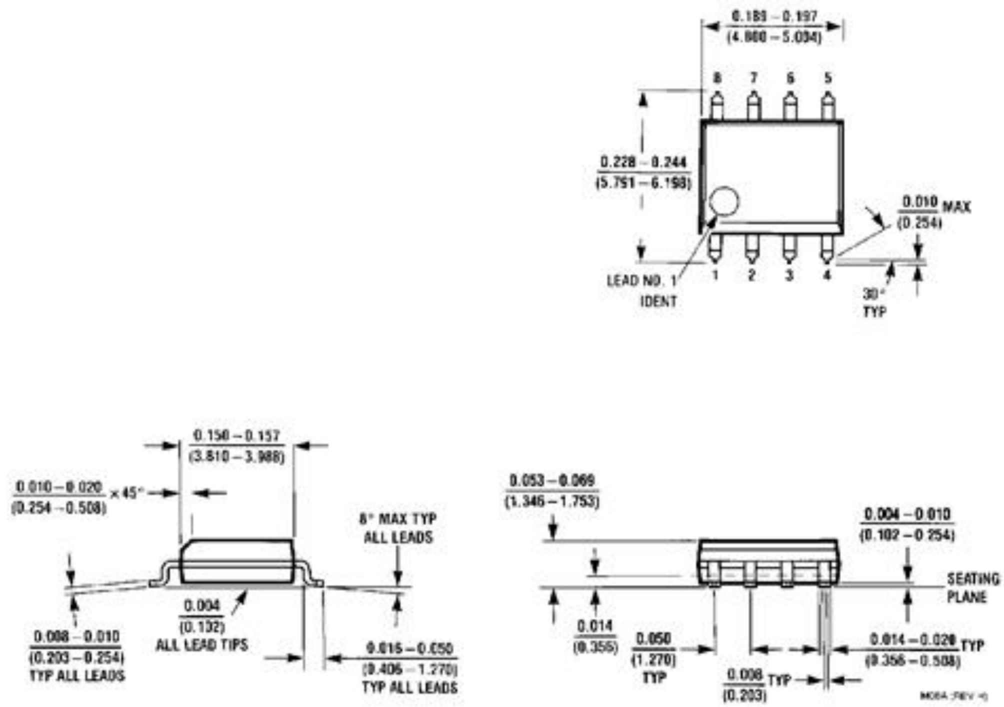


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

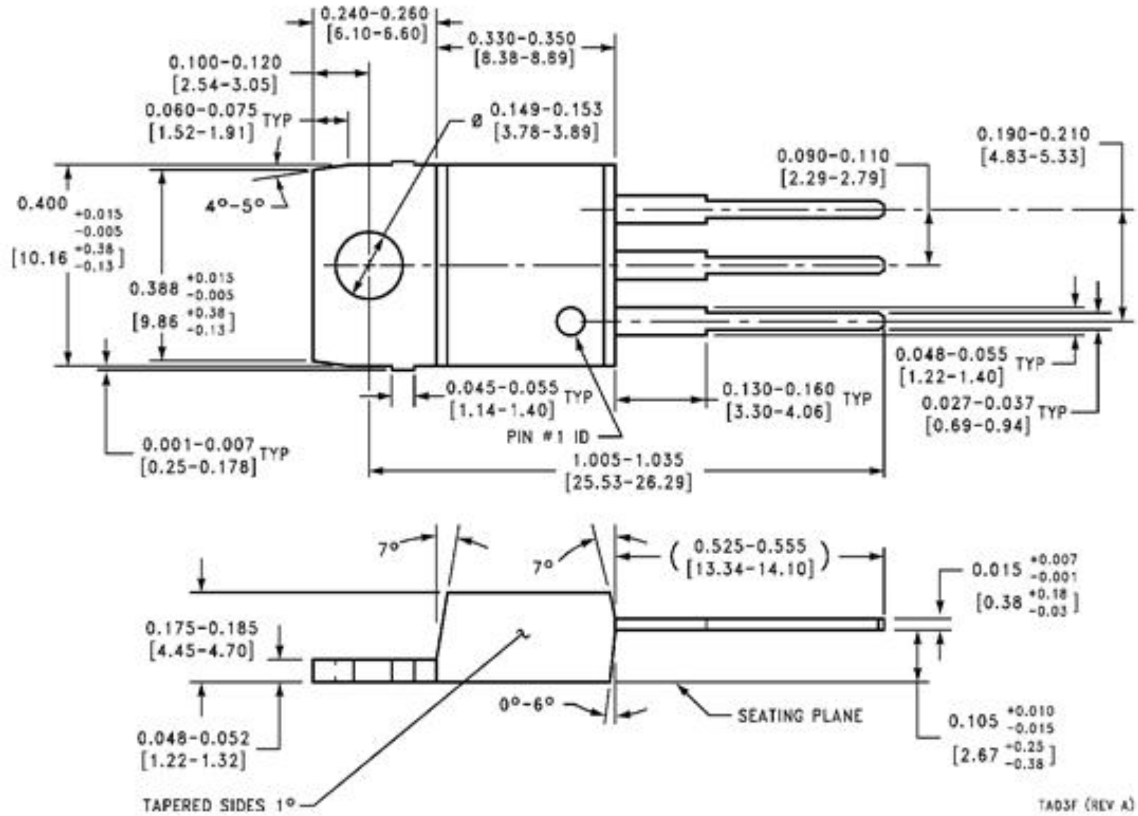


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



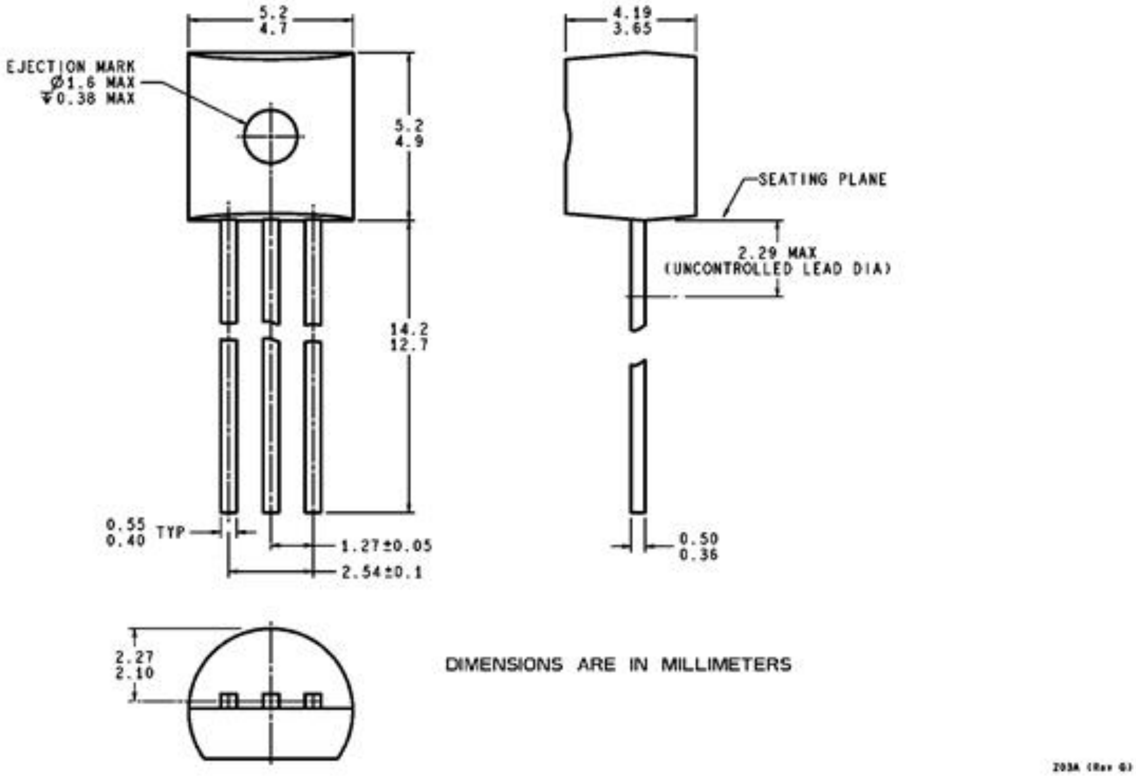
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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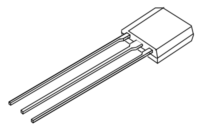
BIPOLAR LATCH TYPE HALL-EFFECT FOR HIGH-TEMPERARURE OPERATION



1

SIP -3

*Pb-free plating product number: U18L

DESCRIPTION

U18 is a semiconductor integrated circuit utilizing the Hall effect. It has been so designed as to operate in the alternating magnetic field especially at low supply voltage and operation over extended temperature ranges to +125℃ .This Hall IC is suitable for application to various kinds of sensors, contact less switches, and the like.

FEATURES

* Wide supply voltage range of 2.5V to 20V
* Wide temperature operation range of -20 ℃ ~+125℃
* Alternating magnetic field operation
* TTL and MOS IC are directly drivable by the output
* The life is semipermanent because it employs contact less parts * SIP-3 package

APPLICATION

* Speed sensor
* Position sensor
* Rotation sensor
* Contact-less sensor
* Motor control
* Built-in protection diode

ORDERING INFORMATION

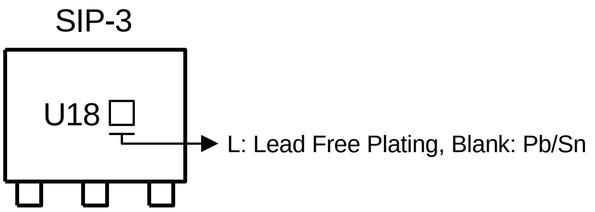
Order Number		Package	Pin Assignment			Packing
Normal	Lead Free Plating		1	2	3	
U18-G03-D-K	U18L-G03-D-K	SIP-3	I	G	O	Bulk

Note: Pin Assignment: I:V_{CC} O:V_{OUT} G:GND

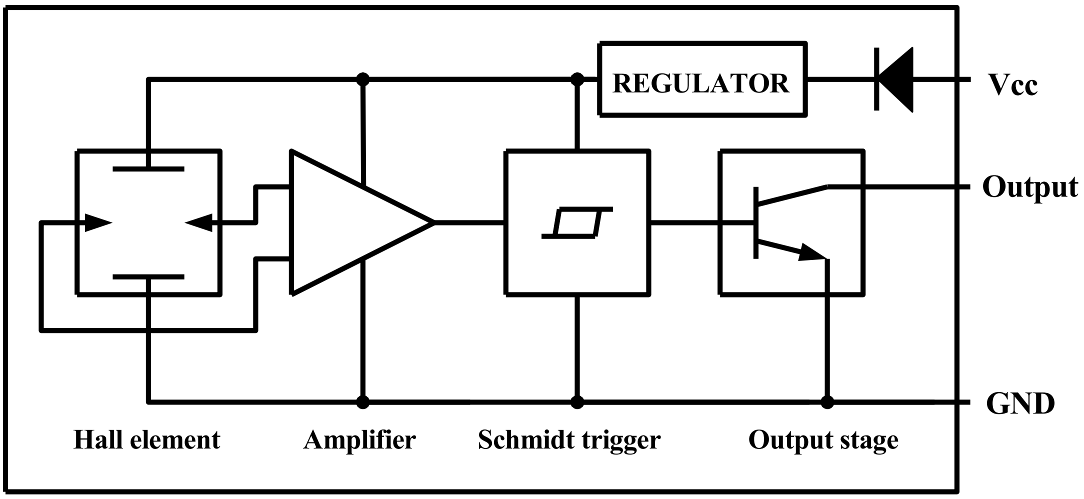
U18L-G03-D-K

(1)Packing Type	(1) K: Bulk
(2)Pin Assignment	(2) refer to Pin Assignment
(3)Package Type	(3) G03: SIP-3
(4)Lead Plating	(4) L: Lead Free Plating, Blank: Pb/Sn

MARKING INFORMATION



BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

PARAMETER	SYMBOL	RATING	UNIT
Supply Voltage	V_{CC}	2.5V ~ 20V	V
Supply Current	I_{CC}	10	mA
Circuit Current	I_{OUT}	20	mA
Power Dissipation	P_D	400	mW
Operating Temperature	T_{OPR}	-20~+125	℃
Storage Temperature	T_{STG}	-40~+150	℃

Note 1. Absolute maximum ratings are those values beyond which the device could be permanently damaged. Absolute maximum ratings are stress ratings only and functional device operation is not implied.

2. The device is guaranteed to meet performance specification within 0℃~+70℃ operating temperature range and assured by design from -20℃~+125℃.

ELECTRICAL CHARACTERISTICS (Ta=25℃)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
Low-Level Output Voltage	V_{OL}	V_{CC}=16V,I_{OUT}=12mA,B=30mT			0.7	V
		V_{CC}=3.6V,I_{OUT}=12mA,B=30mT			0.7	V
Output Leakage Current	$I_{O(LEAK)}$	V_{CC}=16V,B=-30mT		1	10	µA
Output Short Circuit Current	-Ios	V_{CC}=16V,V_{OUT}=0V,B=-30mT		0.8		mA
Supply Current	I_{CC}	V_{CC}=16V			6	mA
		V_{CC}=3.6V			5.5	mA
MAGNETIC CHARACTERISTICS						
Operate Point	B_{OP}	At Ta = +25℃			5	mT
Release Point	B_{RP}	At Ta = +25℃			-5	**mT**
Hysteresis	B_{HYS}	At Ta = +25℃			5.5	mT

Note 1.B_{OP} = operate point (output turns ON); B_{RP} = release point (output turns OFF); B_{HYS} = hysteresis (B_{OP} -B_{RP}).As used here, negative flux densities are defined as less than zero (algebraic convention). Typical values are at Ta = +25℃ and V_{CC} = 12V.

2.1mT=10 gauss

„ **PACKAGE INFORMATION**

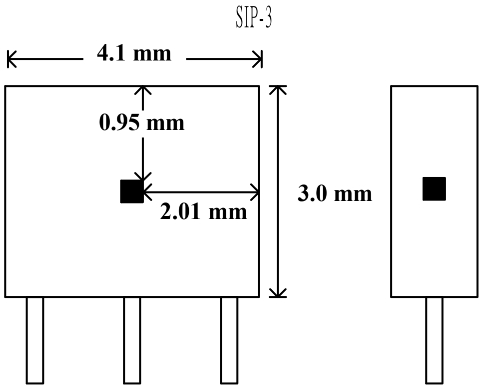


Fig. 1 SENSOR LOCATIONS

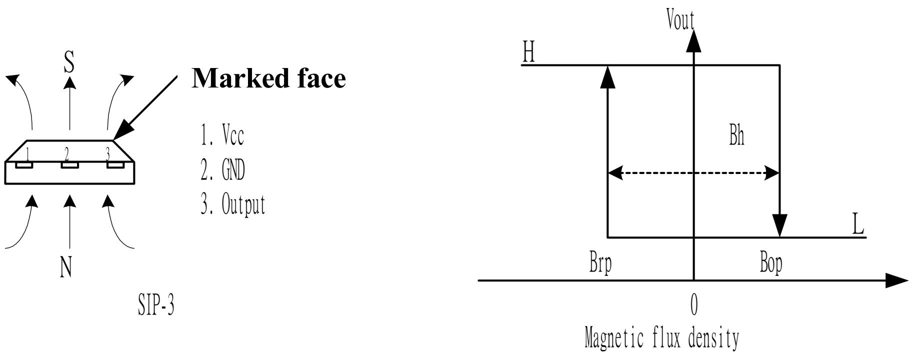
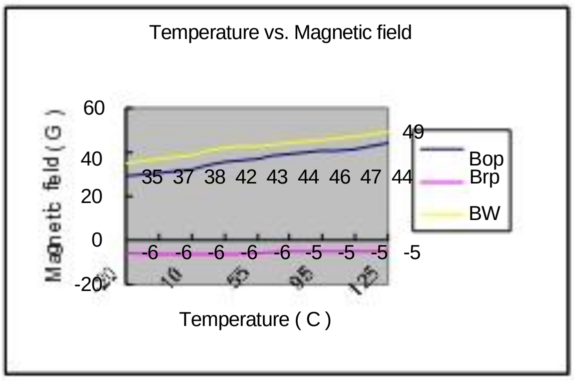
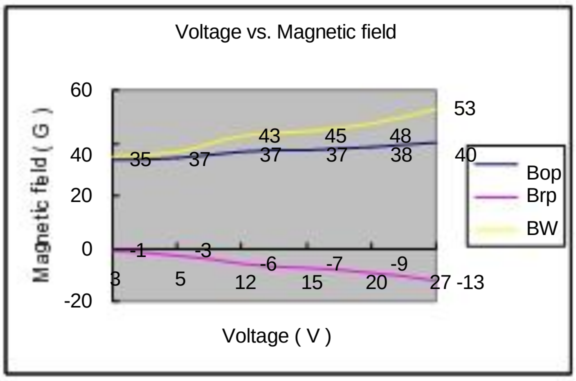
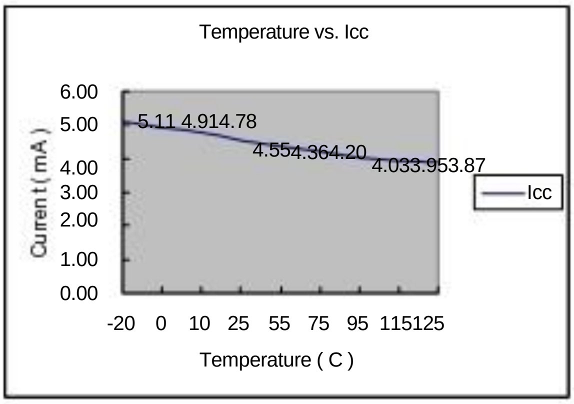


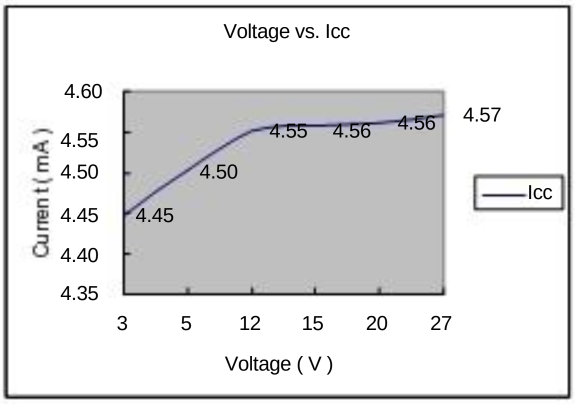
Fig. 2 APPLYING DIRECTION OF MAGNETIC FLUX

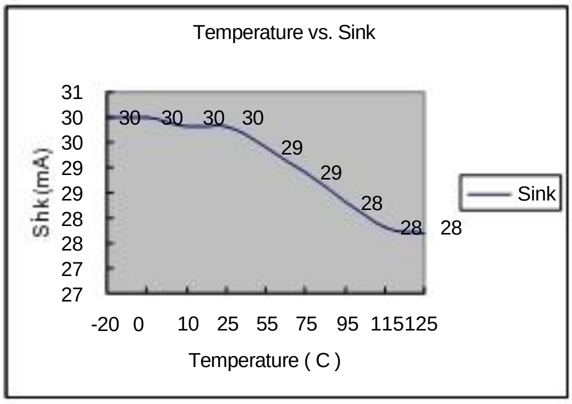
„ TYPICAL CHARACTERISTICS

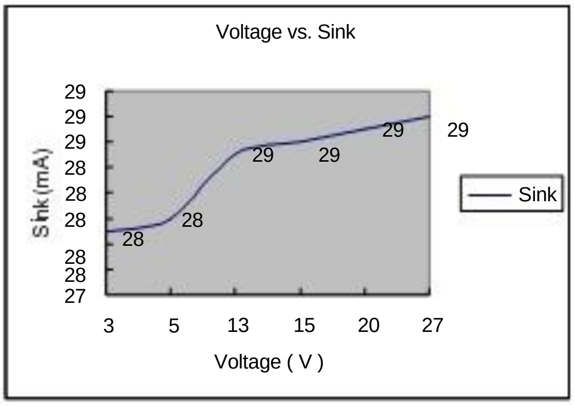












TYPICAL CHARACTERISTICS(Cont.)