PATIENT VITAL SIGNS MONITORING

JESSE OLIVER YEO ENG PING

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

JUNE 2009

Patient Vital Signs Monitoring

By

Jesse Oliver Yeo Eng Ping

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

JUNE 2009

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Patient Vital Signs Monitoring

by

Jesse Oliver Yeo Eng Ping

A project dissertation submitted to the
Electrical and Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL AND ELECTRONICS ENGINEERING)

Approved by,

(Dr. Afza Shafie)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2009

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.

JESSE OLIVER YEO ENG PING

ABSTRACT

During a disaster scene (earthquake, fire, twister etc) where it involves many victims, it is important to always keep track of the vital signs status of the victim. Vital signs mentioned were referring to body temperature, pulse rate, blood pressure, blood oxygenation level (SpO_2) and respiratory rate. Secondary injuries such as hypoxemia, hypotension, and cardiac tamponade become life-threatening if not treated immediately [6]. The objective of this project is to design a vital sign device that is able to transmit the data to a personal computer. This system could be applied in the emergency room to monitor patients. In FYP I, the scope will mainly be focusing and researching on the background of this project and the prototype design planning such as tools and components needed. The researching part will be done by interviewing medical officer, reading research paper and journal to find out what are the available ways to do the project and improve on that. Studies on the technologies available in Malaysia will also be done.

ACKNOWLEDGEMENT

I would firstly like to thank God for giving me the strength throughout these tough times and guiding me through them. Secondly, I would like to also thank Dr. Ratna and Dr, Afza for being my supervisor who willingly guide, motivates, keep track and also encourage me through this project. My project would definitely unsuccessful without them. Last but not least, I would like to thank a few friends especially Pang Kee Yong and Kanaparthy who helped me a lot in making doing this project possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background Study

During a disaster scene (earthquake, fire, twister etc) where it involves many victims, it is important to always keep track of the vital signs status of the victim. This is critical especially for those victims who are severely injured and needed constant monitoring on their vital status. Vital signs mentioned were referring to body temperature, pulse rate, blood pressure, blood oxygenation level (SpO_2) and respiratory rate.

Patients at a disaster scene can greatly benefit from technologies that can monitor their vital status continuously and track their locations until they are admitted to the hospital [2]. It is very difficult for medical officer to continuously monitor the vital signs status of victims as there are only a few medical officers available at the place of disaster but a lot of victims involve. Constant monitoring especially at that moment is important so that the medical officers can prioritize which patient they should first give attention to. It is critical that patients are correctly diagnosed, monitored, and located to ensure the preservation of the maximum number of patients [4]. Furthermore, during the waiting period for the ambulance to come, patient condition may deteriorate [6]. Secondary injuries such as hypoxemia, hypotension, and cardiac tamponade become life-threatening if not treated immediately [6].

With having a tag which can help monitoring these vital signs could dramatically improve the time-consuming process of manually recording vital signs onto hardcopy pre-hospital care reports and then converting the reports into electronic format [4] and also prioritize the attention from the medical officer.

Beside this, the admission of a large number of victims in a hospital after a mass casualty incident can easily lead to chaos and disruption of the hospital's regular organization [5].

1.2 Problem Statement

In the emergency room, it would be hard for a doctor to constantly monitor the vital sign of a patient. With a tool that can help doctor to monitor the patient's vital sign such as body temperature and heart beat constantly which could also alert doctor when the reading reaches an unwanted value. This could be a great thing to ease the doctor in monitoring their patients. Besides, by measuring these digitally, data could be stored for future references.

1.3 Objective

The main objective for this FYP is to:

- designing a vital sign device (temperature)
- make it communicate with the computer used in the emergency room to monitor patients

1.4 Scope Of The Study

The scope of the study is to design a wearable vital sign sensor which can then wirelessly transmit to a computer which acts as a receiver to monitor. It will trigger an alarm when it reaches an unwanted value (extreme high blood pressure, high or low temperature, low oxygen level in blood etc). This project also requires research regarding the temperature sensor, learning the microcontroller programming and design of the electronic circuit.

CHAPTER 2

LITERATURE REVIEW/THEORY

2.1 Temperature Sensor

For this, the initial stage of this project will be just focusing on the temperature first. After it is complete, will add in other functions. Throughout this semester, research on various type of temperature sensor had been done. The following are the results:

2.1.1 Digital Thermometer

Figure 1 Digital Thermometer

This thermometer is compact, accurate and durable large scale integration device. Temperatures can be taken under an arm or under the tongue. It is a very sensitive device and it obtains results fast. Generally, it is universally in use for the whole family, especially for children.

Features [7]:

- Electronic Thermometer is easy to read - LCD display, beeping sound let you know when measurement is completed
- Accurate - dependable accuracy +/- 0.1 °C
- Temperature range - 32 - 42 °C
- Memory function - Electronic Digital Thermometer can store the whole family's temperature data
- Body Thermometer powered by 1AG3 button cell

2.1.2 Ear Thermometer:

Figure 2: Ear thermometer

The infrared Ear thermometer is routinely monitored in clinical settings with infrared ear thermometers which measure the infrared energy emitted from the patient's eardrum in a calibrated length of time [9]. A short tube with a protective sleeve is inserted into the ear, and a shutter is opened to allow radiation from the tympanic membrane to fall on an infrared detector for a period which is typically from 0.1 to 0.3 seconds in the varieties surveyed [9]. Sensors rapidly track the heat flow generated from blood vessels to the skin's surface and convert measurement to body temperature, meeting accuracy standards. Because it is non-invasive, it is easy to use asleep or awake.

It features a large digital display, an audible beep when ready, and a memory that recalls previous temperature reading[8].

2.1.3 ETP104A

Figure 3: ETP104A temperature sensor

This is a small, simple and cheap temperature sensor. It has a long probe where temperature measurement could be very convenient and it needed only an AAA size battery to function. This ETP104A can be easily get from the nearby electronics components shop.

- Range: -20°C to 70°C
- Accuracy: +/-1.5°C
- Advantages: Small and portable

2.1.4 LM35

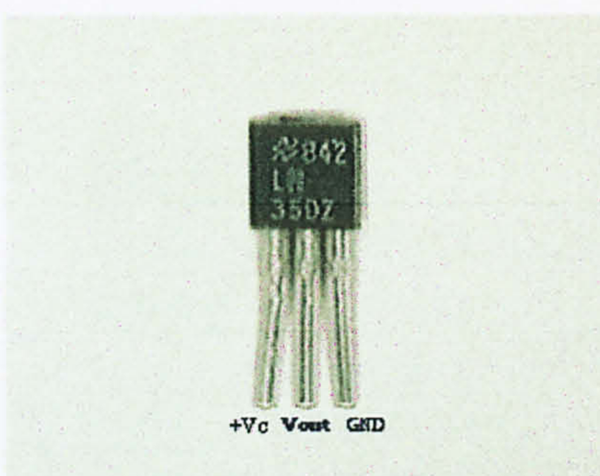


Figure 4: LM35 temperature sensor

This is a LM35 temperature sensor and is very small in size. It delivers very accurate reading and it is available in UTP lab. For more information, please refer to the appendix.

- Range: Rated for full -55°C to 150°C
- Accuracy: 0.5°C accuracy guarantee (at 25°C)
- Advantages: Operates from 4 to 30 volts, less than **60μA** current drain, low self heating (0.08°C in still air), low impedance output, 0.1Ω for 1mA load.

2.1.5 Comparison Between The Temperature Sensor

The most important criteria for choosing a temperature sensor in this project are its accuracy and its availability. Every small change in temperature means a lot in this medical world. After comparing all 4 options of the accuracy, digital and ear thermometer has the highest accuracy. As for the availability of these temperature sensors, the best option is LM35. Comparing all of them, LM35 is chosen as can provide an accuracy of +/- 0.4°C at room temperature and +/- 0.8°C over a range of 0°C to 100°C and it is easily obtain. Furthermore, it is a commonly used circuit. It is connected as shown:

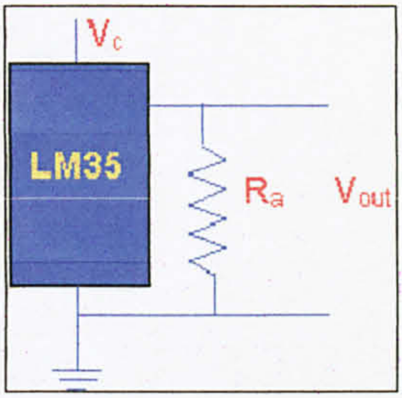


Figure 5: LM35 circuit connection

The common parameter values are:

- V_c = 4 to 30V
- 5V or 12V are typical values used
- $R_a = Vc/10^{-6}$

The output of the LM35 is in voltage. The output voltage is converted to temperature by a simple conversion factor. The sensitivity of the sensor is 10mV/°C. In addition, the output voltage varies linearly with temperature.

As we can see in the picture above, the LM35 is very small and a probe is required in order to detect a patient's body temperature. Thus, the connection is connected as below:

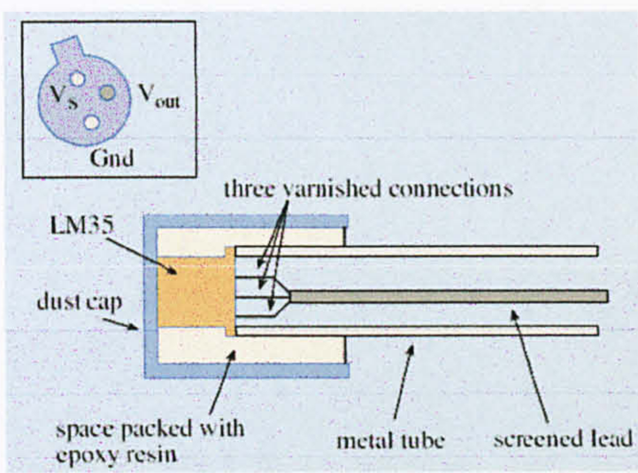


Figure 6: Cross sectional of the probe [10]

Figure 7: Probe end [10]

The end is sealed with epoxy resin which can avoid short circuit and also support the sensor. The whole probe is metal because metal can spread heat easily.

2.2 Transmitter And Receiver

TLP434 (Transmitter) and RLP434 (Receiver) is a wireless data link comprises of radio frequency (RF) module. It is ideal for remote control projects or data transfer to a remote object. The data at receiver outputs is actually the data at the transmitter inputs. The

The data transmission reliability is dependent on the external antenna which helps to reach maximum range. For an operating frequency of 433.92 MHz, a 17cm antenna is recommended for better transmission. These RF modules require no licensing since the transmitter and receiver are used in accordance with low power devices such as remote control applications. **Table 1** lists down the transmitter features while **Table 2** lists down the receiver features.

Table 1: Features of TLP434A Transmitter [3]

Features	**Specification**
Frequency	433.92MHz
Operating Range	3 – 12 Vdc
Data Rate	Up to 8000 bps (bit per second)
Dimensions	Width – 10.3mm Height – 13.33mm (Excluding Pins)
Transmission Range	Outdoor – 500ft (approximately 200m) Indoor – 200ft (approximately 60m)
Others	• Works with HT12E or similar encoder • Extremely Small and Light Weight • Low Cost (< RM 30)

Table 2: Features of RLP434A Receiver [3]

Features	Specification
Frequency	433.92MHz
Operating Range	3.3 – 6 Vdc
Data Rate	Up to 4800 bps (bit per second)
Dimensions	Width – 43.4mm Height – 11.5mm (Excluding Pins)
Transmission Range	Outdoor – 500ft (approximately 200m) Indoor – 200ft (approximately 60m)
Others	• Works with HT12D or similar decoder • Extremely Small and Light Weight • Low Cost (< RM 80)

2.3 Microcontroller

Microcontroller is use widely because it is inexpensive and works as a brain of a project. Apart from that, microcontroller is capable to store and run program. It also has the ability to perform math and logic functions, example for this project, it converts the equivalent milivolt reading from the LM35 to the PIC's ADC port and thus go through a simple maths function (temp1=500*temp/1023) to get the desired reading in Celcius. It also has memories which function to store data. Its ability of programming in a high level language programming has the advantage of simplifying debugging and modification or adaptation of the code when compared to assembly language.

2.3.1 PIC16F877A

Table 3 shows the peripheral and key features of the microcontrollers.

Table 3: Key Features of PIC16F877A [3]

Key Features	Specification
Operating Frequency	DC – 20MHz
Flash Program Memory (14-bit words)	8K
Data Memory (bytes)	368
EEPROM Data Memory	256
I/O Ports	Ports A,B,C,D,E
Timers	3
Serial Communications	MSSP, USART
Parallel Communications	PSP

2.4 Max233 and USB to Serial Converter (CB15-CT)

Max 233 is a dual driver/receiver that includes a capacitive voltage generator to supple TIA/EIA-232-F voltage levels from a single 5V supply [11]. Each receiver converts TIA/EIA-232-F inputs to 5V TTL/CMOS levels [11]. These receivers have a typical threshold of 1.3 V, a typical hysteresis of 0.5V, and can accept around 30V inputs [11]. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels [11].

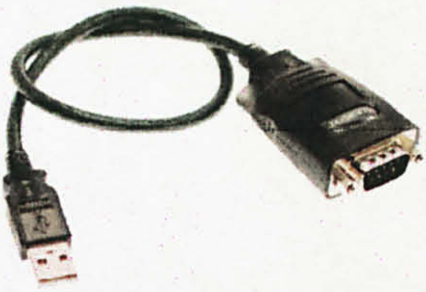


Figure 8 : USB to Serial Converter

2.5 Current Vital Signs Monitoring

There is a wearable patient sensor that communicates, over a wireless a-hoc mesh network, with patient monitoring laptops at the scene [6]. The ad-hoc mesh network, developed by the Harvard University CodeBlue project and based upon the IEEE 802.15.4 standard, has rerouting and meshing capabilities to ensure reliability in mass casualty environments [6]. They have integrated several peripheral devices with the mote, including location sensors for both indoor and outdoor use, a pulse oximeter, a blood pressure sensor, and an electronic triage tag [2]. The triage tag helps medical officer to organize the priority of attention to the patients. This prototype uses the MICAZ platform from Crossbow Technology [2] and it is powered by 2 AA batteries which can last around 5-6 days using a single chip radio.

They have this pre-hospital care software package (MICHAELS) to transmit patent information in real time to a central server for record database [2]. Besides, this wearable sensor also have location sensor. For indoor, they use location beacons to locate their patients, and outdoor, GPS. In prior to this, The patient sensors were enhanced to minimize false alarms and provide new modes of operation [6]. Functionalities were added to the base station to provide greater assistance in responders' workflows [6]. A PDA application was developed to provide a portable medium for documentation and communication [6].

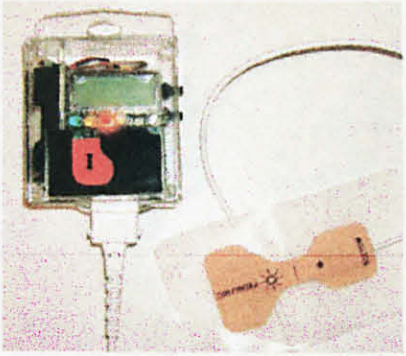


Figure 9: Electronic triage tag

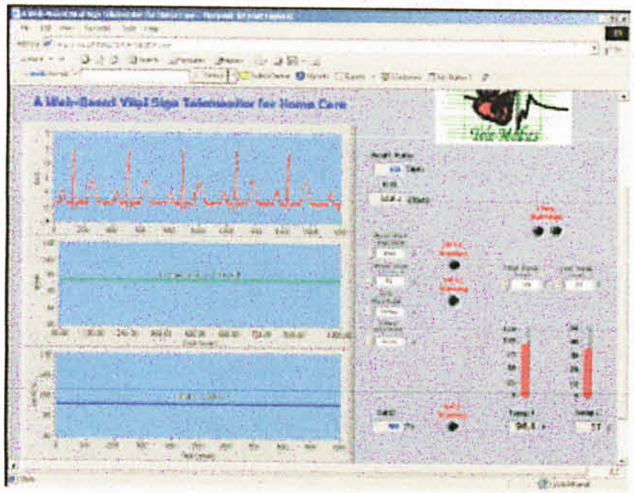


Figure 10: The graphical user interface of the Web-based vital sign tele monitor accessed from a client site [1]

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

For literature review, the main method used is study on people's journal in library and some related websites. This is to understand and know about what is available in the world now and also to get an idea on how to implement my project. Besides, consulting lab technicians available in the lab will be very helpful to make this project a success. In addition to that, these lab technicians could help out regarding the information of the availability of the components or device needed and where to get them. Conducting interview with doctor clinic or medical centre is also a way to gather useful information. The product will then be tested together with a mercury thermometer to verify the accuracy of it. It will be done several times to monitor its precision.

3.2 Flowchart

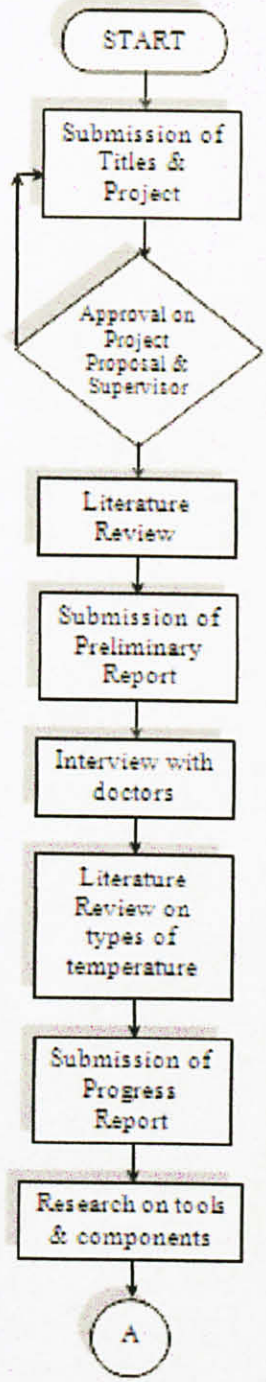


Figure 11 Flowchart for Project flow

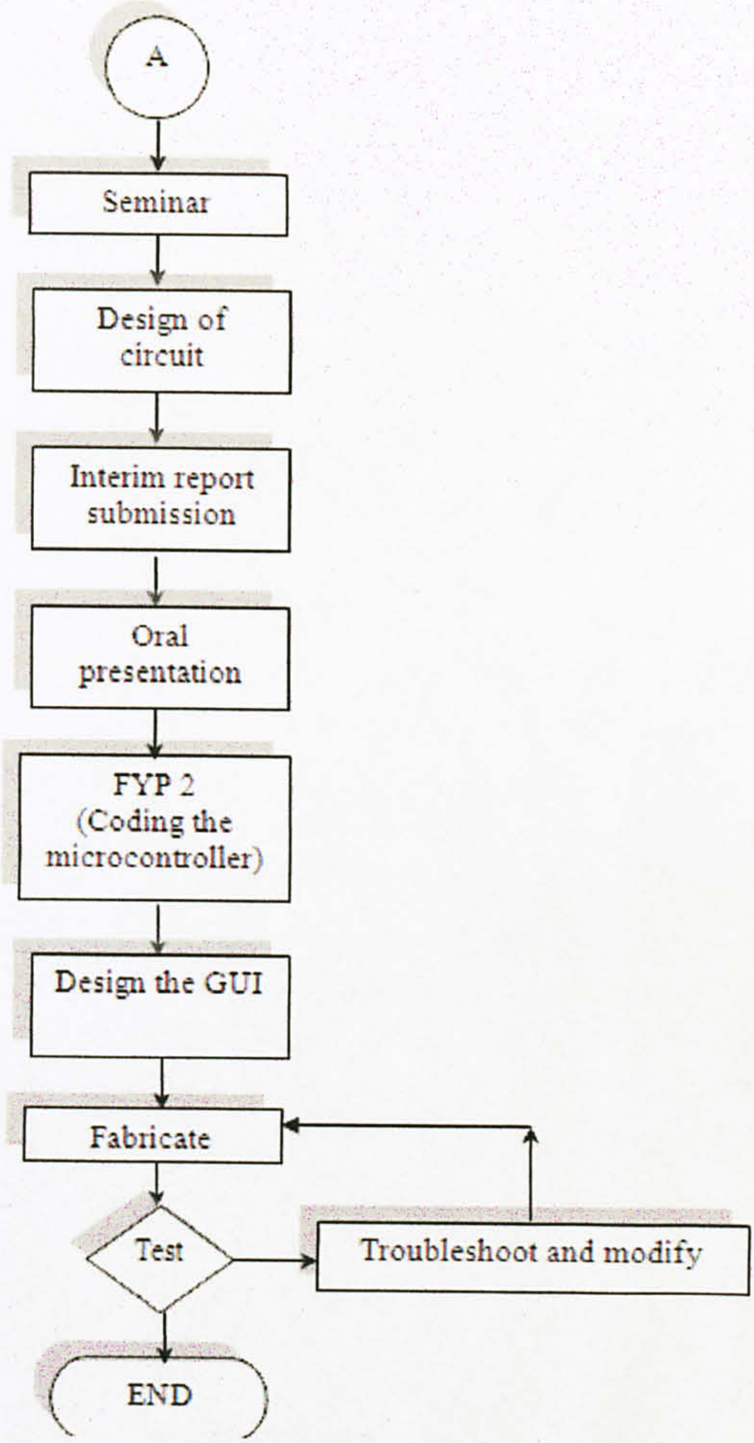


Figure 12 Flowchart for project flow

3.3 Tools

The tools needed for this project are

- PIC C Compiler : C compiler and partial assembler designed specially for PIC microcontroller development
- Visual Basic : A software to create a graphical user interface (GUI)
- Microsoft Word : A word software for completion of reports
- Epoxy resin : To stick the stick the LM35 on the probe
- Microsoft Access : To create database for saving data
- WinPic800 : To Burn the .hex file into the PIC

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Interview With Doctor

Interview had been conducted with two doctors (Dr. Gucharan from General Hospital Ipoh and Dr. Ali from UTP clinic), and both gave very similar answers. These answers are as following:

According to these doctors, the most important vital sign is blood pressure, pulse, respiratory and body temperature. The equipment use in emergency room for blood pressure is sphygmomanometer. The heart beat / pulse is connected to a machine which will indicate it. As a result of the interview, there are a few types of temperature sensor are used in hospitals in Malaysia. The most commonly use is the thermometer. The other one is like a plaster stick on the head. It will indicate some colour to show the current temperature.

Figure 13: Thermometer forehead strip

Another is the ear infrared thermometer and the digital thermometer.

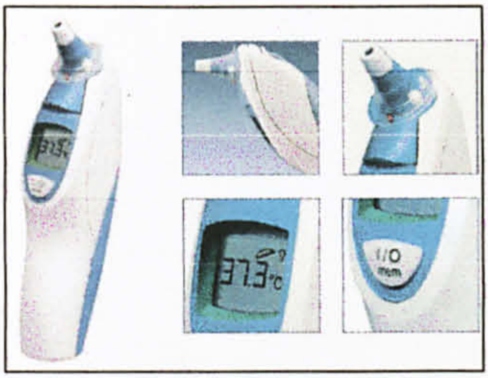


Figure 14: Ear infrared thermometer

Figure 15: Digital Thermometer

And the traditional thermometer which is the most commonly used thermometer.

Figure 16: Mercury Thermometer

A patient in the emergency room is usually monitored on his/her vital signs depending on its severity. Every 15 to 20 minutes for severe cases and every 30minutes less severe cases. According to the doctor, there aren't any vital signs monitoring device that are connected to a main computer in the hospital. So far, no computers are use in the emergency room. Monitoring is done by allowing the nurse to monitor the patient from time to time. Furthermore, only the blood pressure set and the pulse monitoring machine produce alarm in the emergency room.

4.2 Circuit and GUI

This is the schematics of the simple temperature circuit which is connected to the PC via serial port. The components are the LCD, one Micro-controller and one temperature sensor, 9V battery, oscillator, voltage regulator, MAX 232 and the serial port.

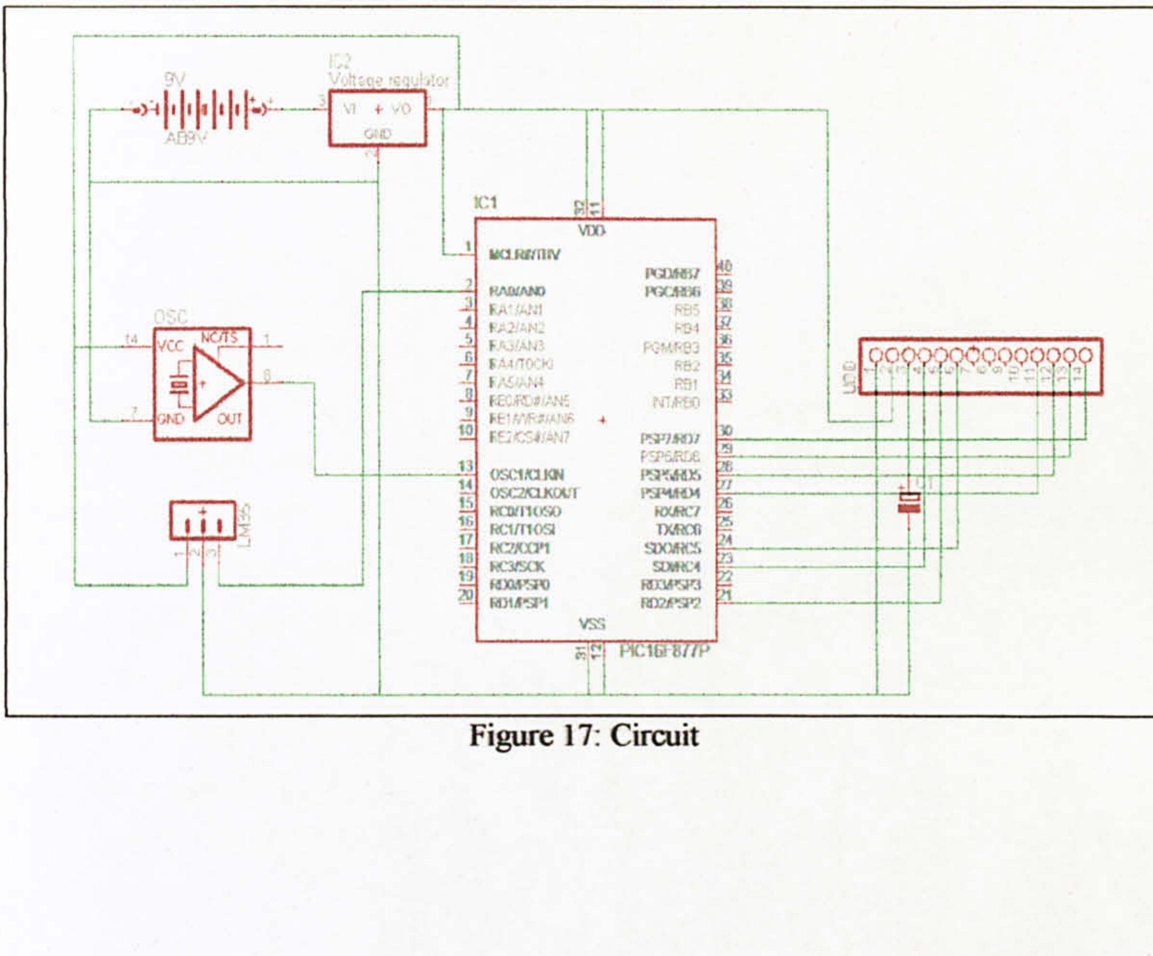


Figure 17: Circuit

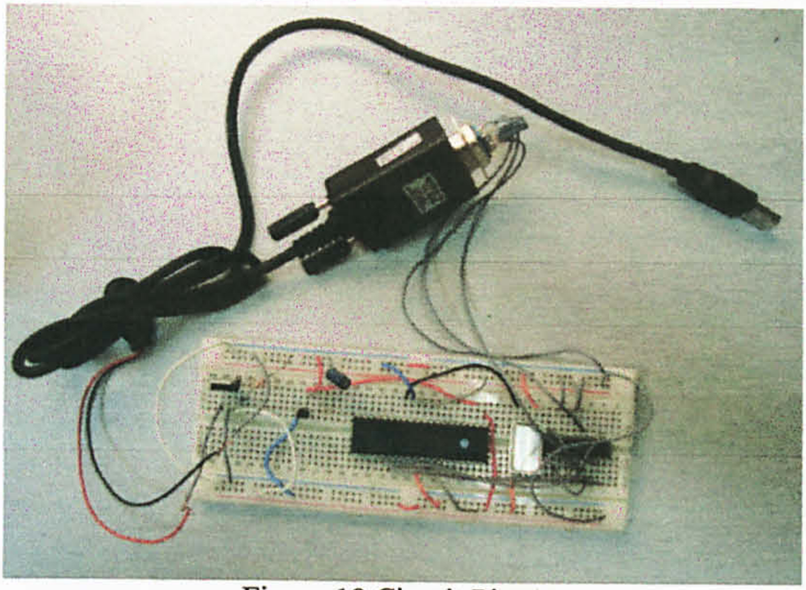


Figure 18 Circuit Picture

This circuit was tested using the build in windows software which is HyperTerminal. HyperTerminal, developed by Hilgraeve, is software that can be used to set up dial up connection to another computer, access a bulletin board service in another computer, and data transfer between two computers etc. The serial port connection to the PC is 9600 bits/second, 8 data bits, no parity, and no flow control. It reads data every 2 to 3 seconds. To ensure the accuracy of the temperature sensor, the temperature was tested with a digital thermometer side by side. The differences in readings compared to the digital thermometer was plus minus 0.3 degree Celsius. To make consistent the reading of the temperature sensor reading, a line of code to average the last 10 readings of the temperature sensor and display it out instead of displaying what it is reading currently. This could give a much better reading comparatively. As for the GUI in VB, it is as following.

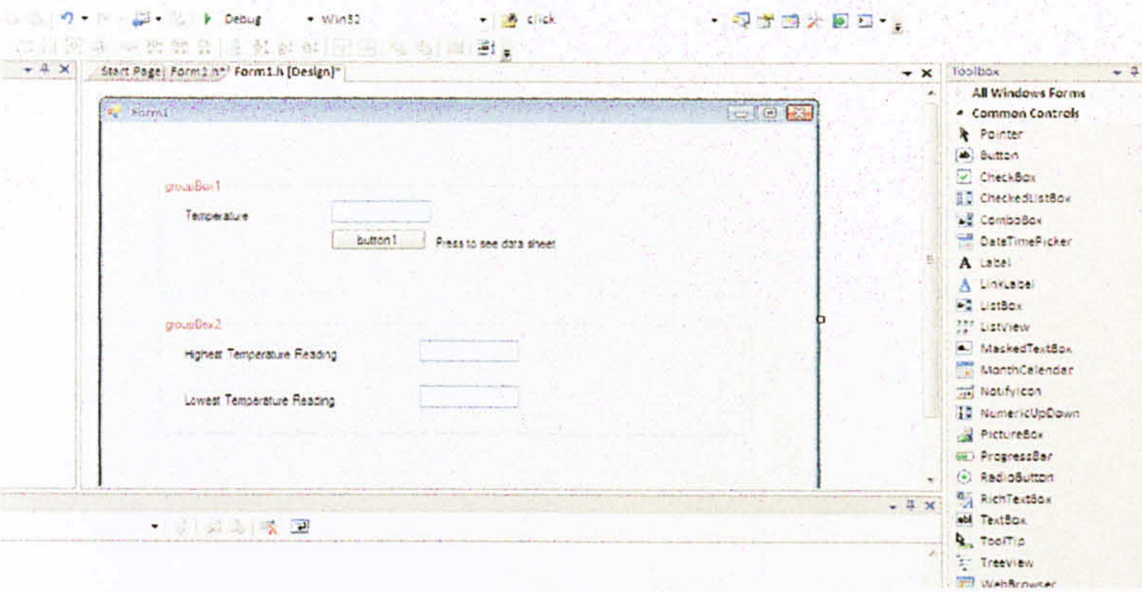
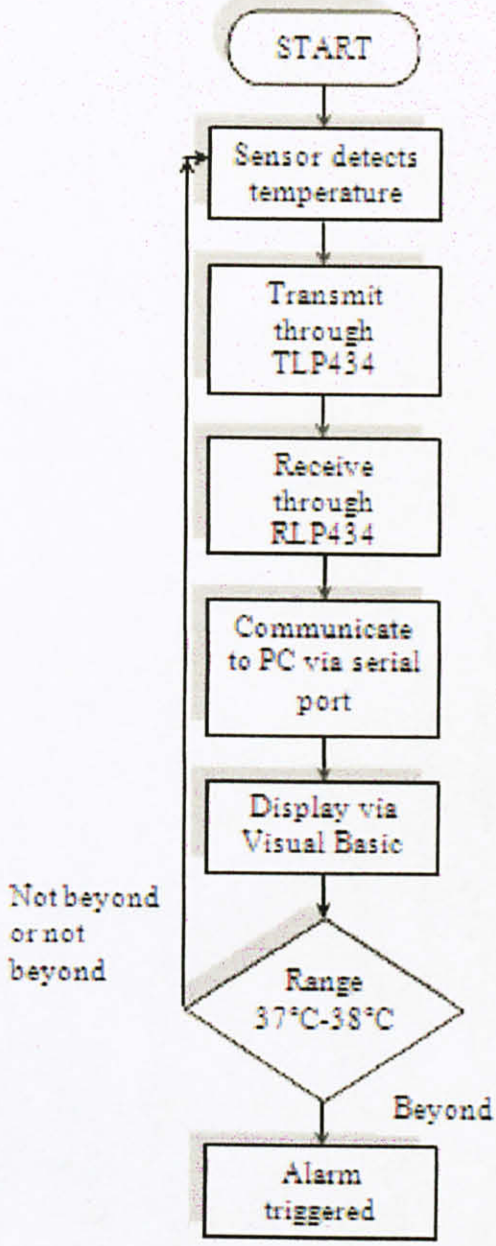


Figure 19: GUI in visual studio 2005

4.3 Flowchart

20 meters maximum



imum

Figure 20 Flowchart for circuit

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this project, the LM35 will convert the temperature signal from the patient's body temperature to voltage and process by the PIC controller which is programme to communicate it with the PC using serial communication. The reading is then interface with the user using visual basic as the GUI. This project is a very helpful tool for the doctor as it helps the doctor to prioritize the severity of each patient and thus save lives more efficiently. Besides, this project also helps to reduce the workload of the nurses to constantly manually checking the patients every now as the readings from the patients will be stored on the computer and they only need to monitor the patients through the computer.

5.2 Recommendation

Recommendation for this project is that additional features such as pulse rate, blood pressure, blood oxygenation level (SpO_2) or even integrated GPS be added to improve this project. This can further assist the doctors and nurses in monitoring the patient's vital signs and position. Besides, this project can be further improved by connecting all the devices, into a computer and prioritize which patient should come first. Besides that, this project can be modify to as small and portable as possible so that it wouldn't be a big burden for the patient to move around. On the other hand, features like helping doctor prioritizing patients according to their condition criticality could be done to improve this project.

References:

[1] Patricia Mendoza, P.G.et al. (2004). A Web-Based Vital Sign Telemonitor and Recorder for Telemedicine Applications. Proceedings of the 26th Annual International Conference of the IEEE EMBS, 2196-2199

[2] Tia Gao, D. G. et al. (2005). Vital Signs Monitoring and Patient Tracking Over a Wireless Network. *In Proceedings of the 27th Annual International Conference of the IEEE EMBS, Shanghai* .

[3] Microchip.2008. Retrieved August 14, 2008. from http://www.microchip.com DatasheetCatalog.com. Retrieved August 12, 2008 from http://www.datasheetcatalog.com

[4] Tammara Massey1, T. G. (2006). Pervasive Triage: Towards Ubiquitous, Real-time.

[5] Noordergraaf GJ et al. Computerization of patient tracking and tracing during mass casualty incidents. *The American Journal of Emergency Medicine* 2000 Sep;7(3):211-6

[6] Tia Gao and David White, A Next Generation Electronic Triage to Aid Mass Casualty Emergency Medical Response, *Proceedings of the 28th IEEE EMBS Annual International Conference, New York City*, Aug 30-Sept 3, 2006, 6501-6504

[7] Sourcing map. (2008, June 24). Retrieved September 12, 2008, from Electronics Beeper Digital Body Thermometer: Http://www.sourcingmap.com/electronic-beeper-digital-body thermometer-p-18428.html

[8] Amazon.com. Retrieved September 12, 2008, from Instant Read Digital Temple Thermometer: http://www.amazon.com/dp/B001AHXX6K?smid=A5EKKVXU1T4N9&tag=nextag-hpc-20&linkCode=asn

[9] Hyperphysics. Retrieved September 12, 2008, from Infrared Ear Thermometer: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/eartherm.html

[10] (2008). Temperature, A simple temperature probe. In D. L. Kevin Carlton, *Frontline* (pp. 28-29). Physics education.

[11] MAX232, MAX232I, DUAL EIA232 DRIVERS/RECEIVERS. (2008). Retrieved April 22, 2009, from Texas Instrument Incorporated.

APPENDIXES

Appendixes I – Source Code for the Basic Circuit

```
#include<16f877a.h>
#device adc=10
#fuses xt,noprotect,nolvp,nobrownout
#use delay(clock=4000000)
#use rs232(baud=9600, parity=N,xmit=PIN_C6,rcv=PIN_C7,stream=,bits=8)
#include <stdio.h>
//#include<lcd.c>
float temp, temp1;
unsigned int value;

void main()
{
int history[10],i;
int history_ptr = 0;
long reading;
int count=0;

setup_adc_ports(AN0);
setup_adc(adc_clock_internal);
set_adc_channel(0);

while(1)
{
delay_us(50);


//lcd_init();
reading=0;
delay_ms(1000);
history[history_ptr++] = read_adc();
if (history_ptr==10) {
history_ptr=0;
count = 10;
} else
if (count<10)
```

```
count=history_ptr;
for (i=0; i<count;i++)
reading += history[i];
reading /= count;

temp = reading;
temp1=500*temp/1023;
printf("\n \r tem:%2.1f",temp1);
delay_ms(5000);
}

}
```

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

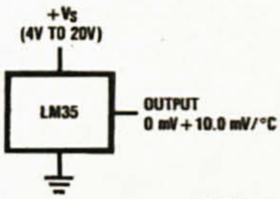
General Description

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 ±¼˚C at room temperature and ±¾˚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

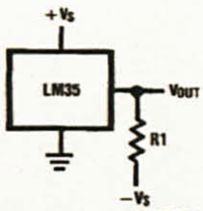
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- 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)



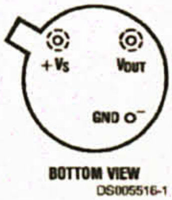
DS005516-4

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

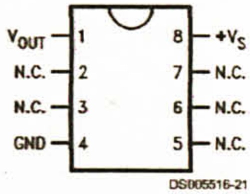
TO-46
Metal Can Package*



*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



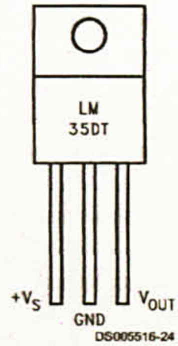
N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

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

TO-220
Plastic Package*



*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}≤T_A≤T_{MAX}	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	T_{MIN}≤T_A≤T_{MAX}	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	T_{MIN}≤T_A≤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≤V_S≤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≤V_S≤30V, +25°C	0.2	1.0		0.2	1.0		μA
	4V≤V_S≤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*.

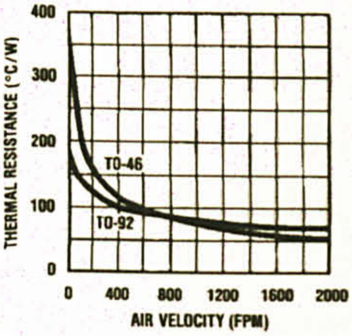
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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.

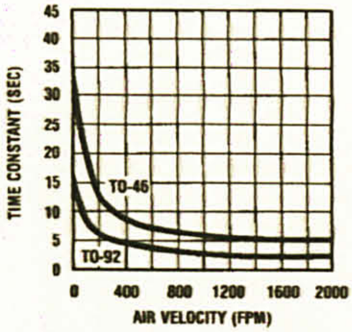
Typical Performance Characteristics

Thermal Resistance Junction to Air



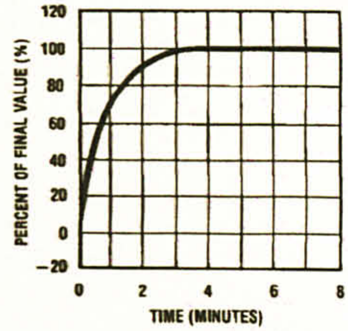
DS005516-25

Thermal Time Constant



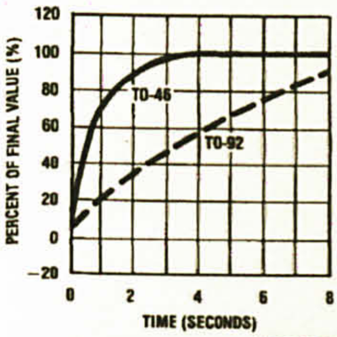
DS005516-26

Thermal Response in Still Air



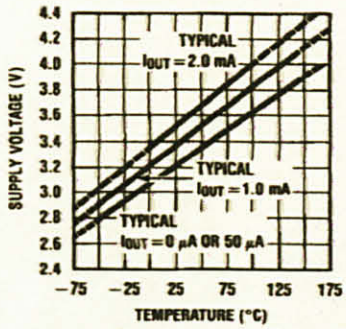
DS005516-27

Thermal Response in Stirred Oil Bath



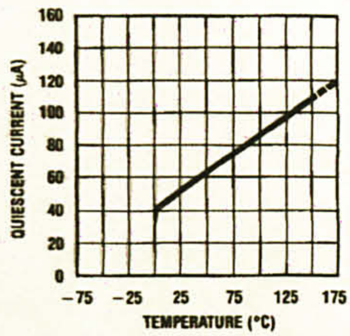
DS005516-28

Minimum Supply Voltage vs. Temperature



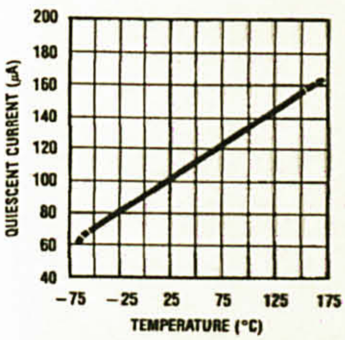
DS005516-29

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



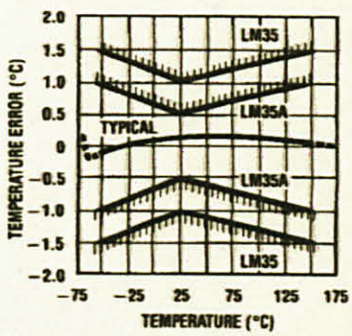
DS005516-30

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



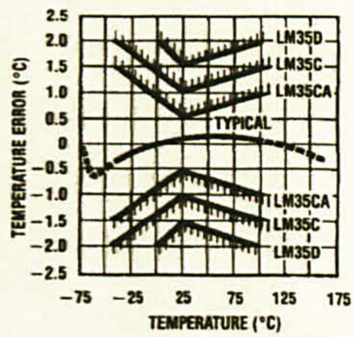
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

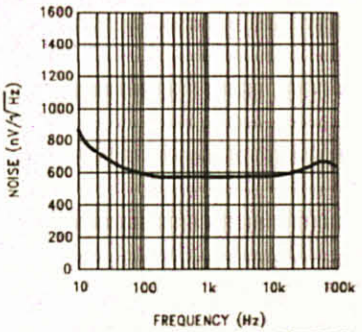
Accuracy vs. Temperature (Guaranteed)



DS005516-33

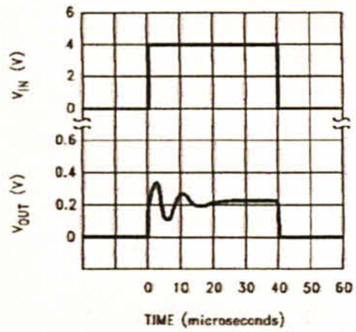
Typical Performance Characteristics (Continued)

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

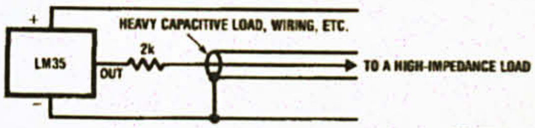


FIGURE 3. LM35 with Decoupling from Capacitive Load

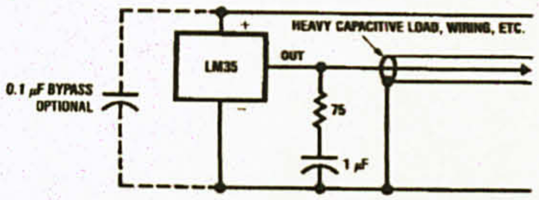


FIGURE 4. LM35 with R-C Damper

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*.

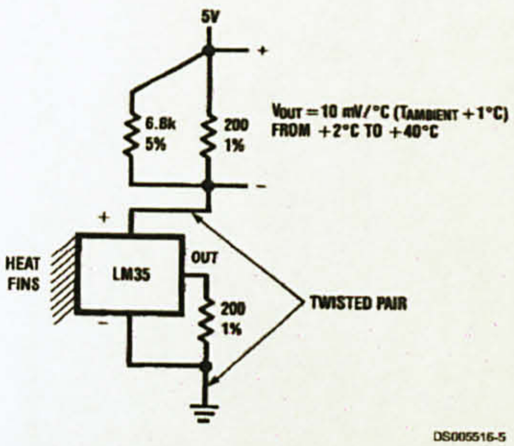


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

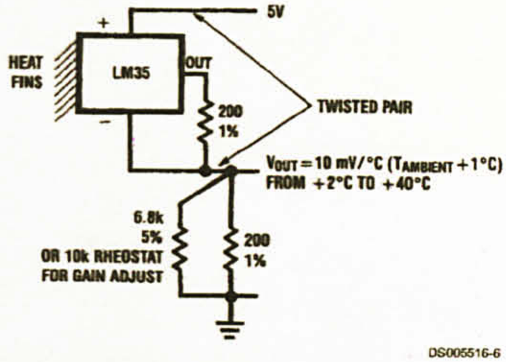


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

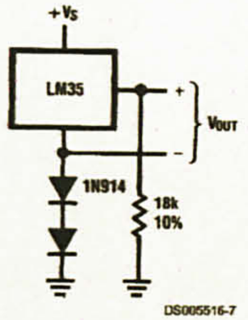


FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C

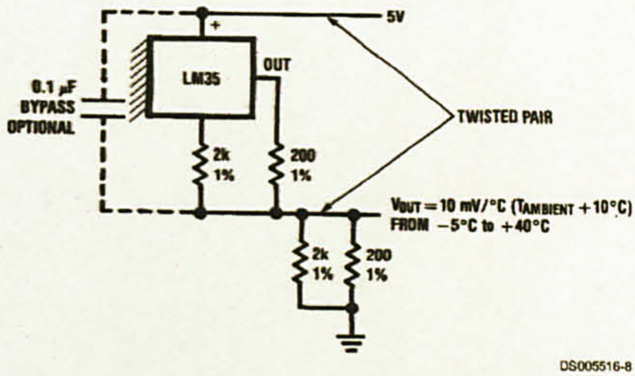


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

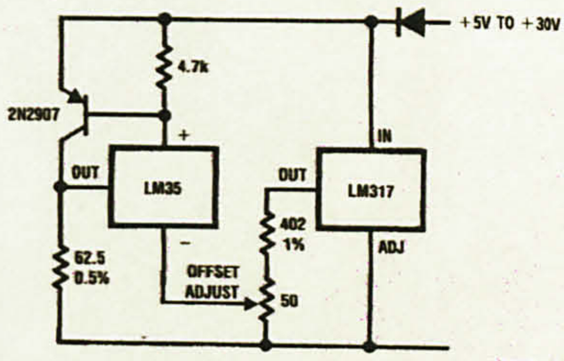


FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

Typical Applications (Continued)

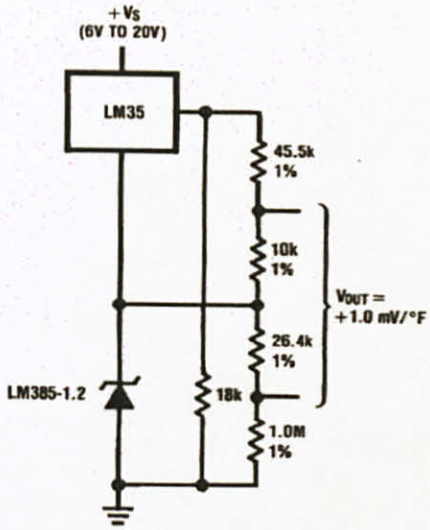


FIGURE 10. Fahrenheit Thermometer

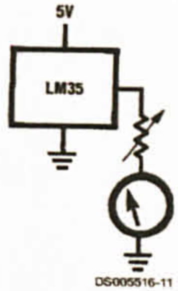


FIGURE 11. Centigrade Thermometer (Analog Meter)

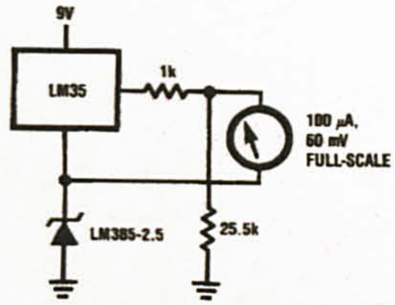


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50° to 80° Fahrenheit, for Example Shown)

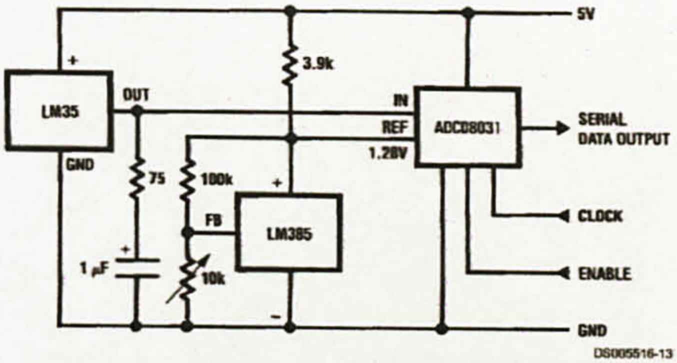


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

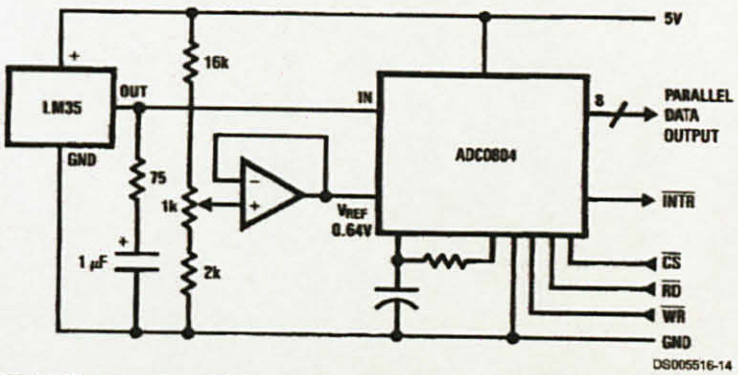
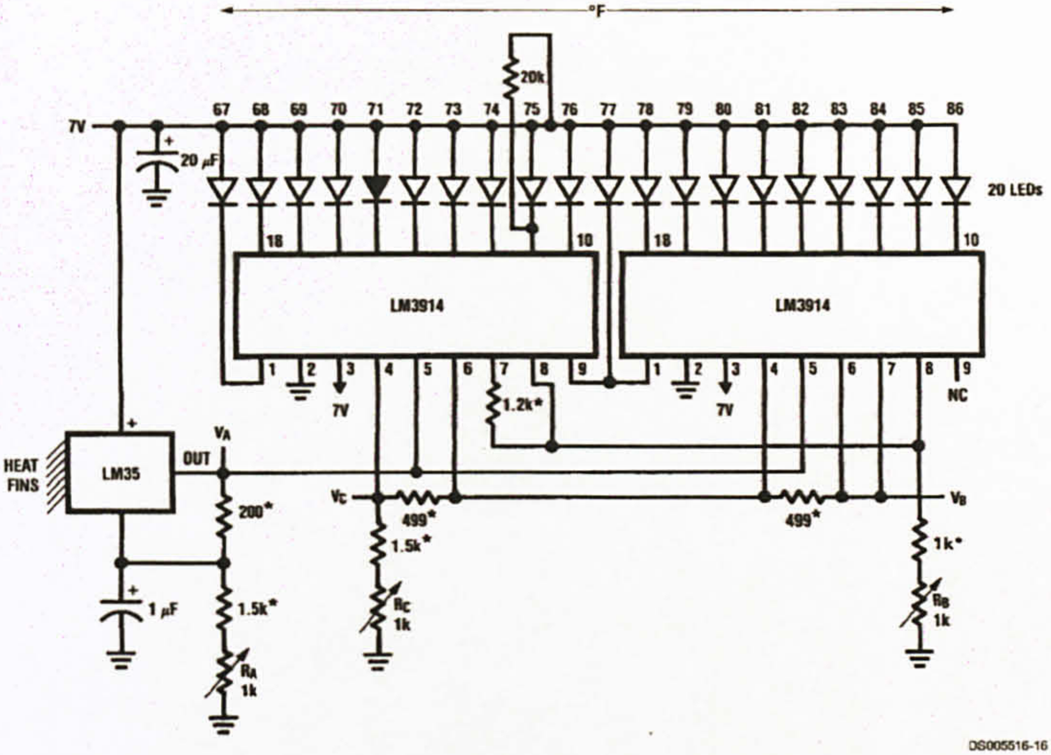


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to µP Interface) (128°C Full Scale)

Typical Applications (Continued)



*=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)

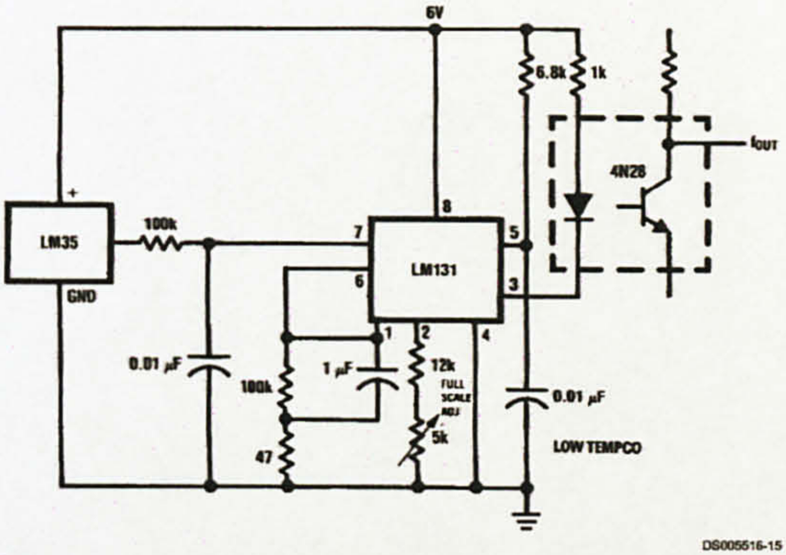
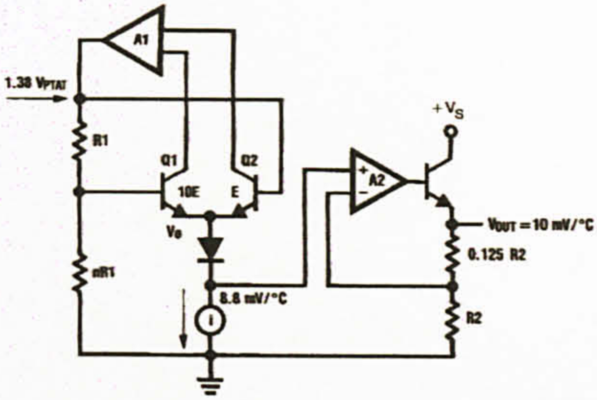


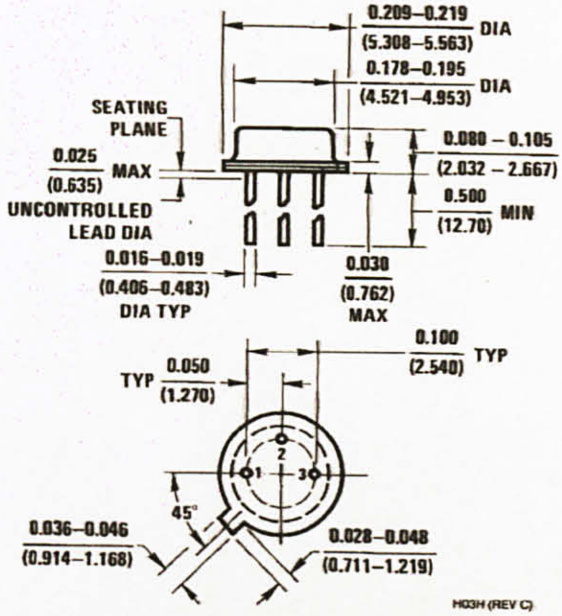
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2°C to +150°C; 20 Hz to 1500 Hz)

Block Diagram

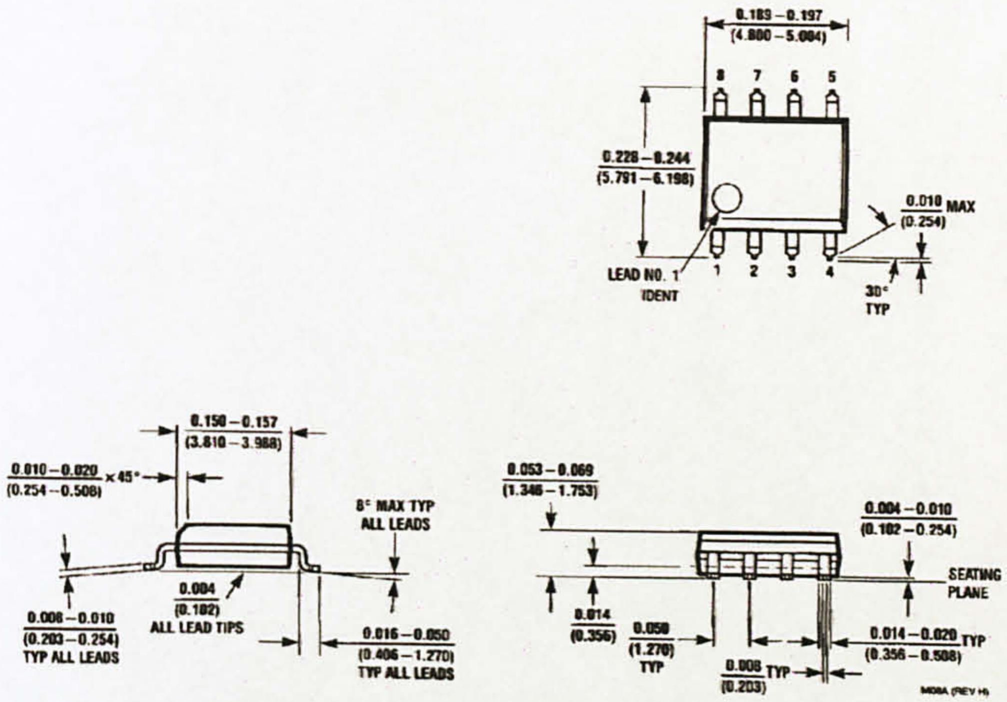


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

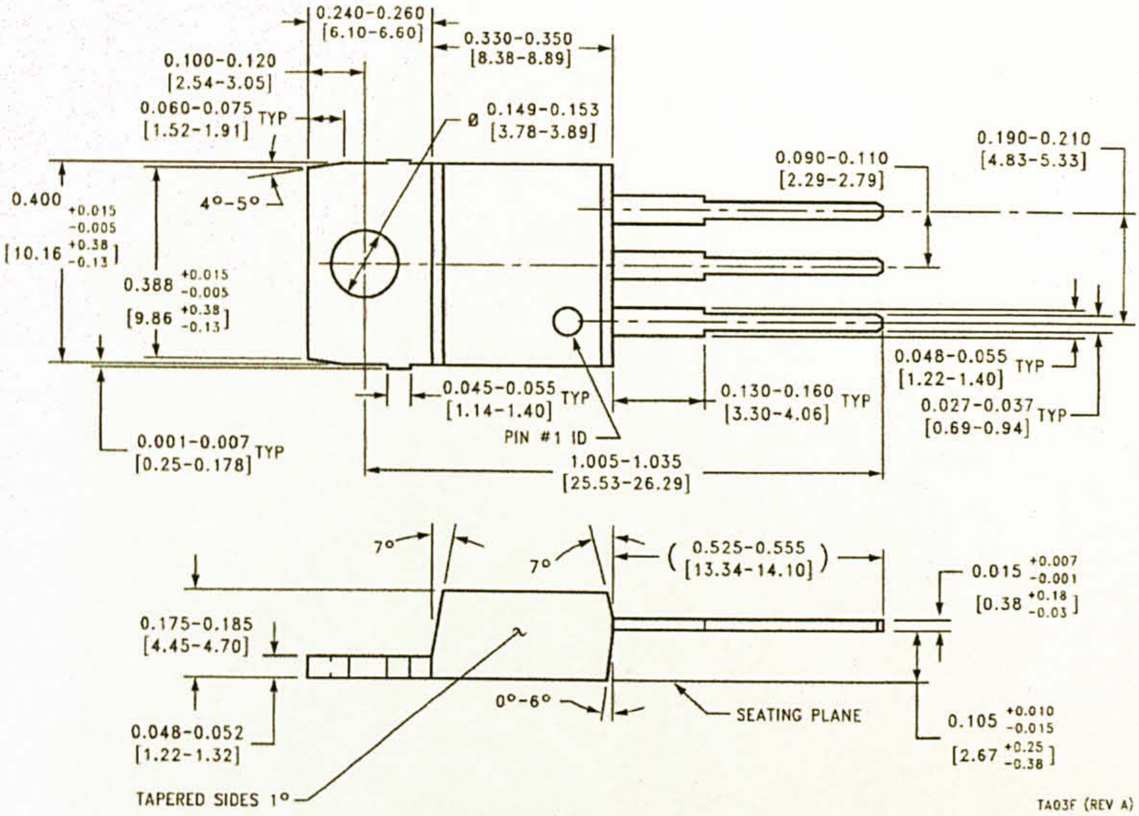


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



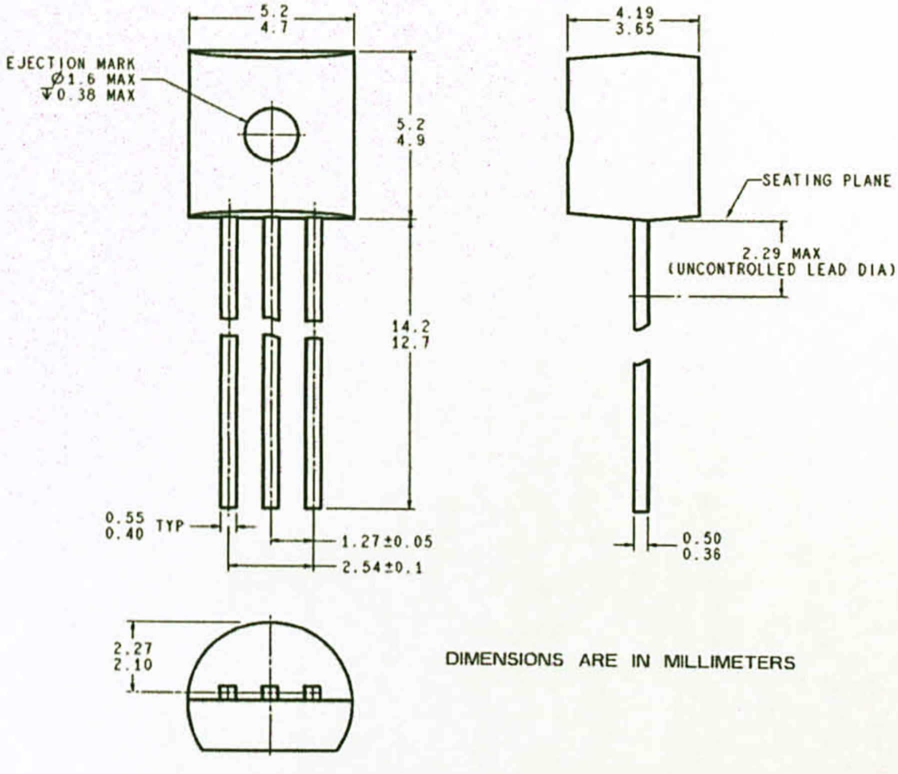
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

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.

National Semiconductor Corporation
Americas
Tel: 1-800-272-9959
Fax: 1-800-737-7018
Email: support@nsc.com
www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507