MONITOR AND CONTROL OF GREENHOUSE ENVIRONMENT

Project Report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

Aakanksha Chhabra 061001
Garima Pathak 061051
Ruchika Duggal 061154

under the Supervision of

Mr. Jitendra Mohan

May 2010

Jaypee University of Information Technology
Waknaghat, Solan - 173 234, Himachal Pradesh

Certificate

This is to certify that the project report entitled "**MONITOR AND CONTROL OF GREENHOUSE ENVIRONMENT**", submitted by Aakanksha Chhabra, Garima Pathak and Ruchika Duggal in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

Date : 18/05/10

Mr. Jitendra Mohan

(Sr. Lecturer)

It is certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

1) Aakanksha Chhabra 061001.

2) Garima Pathak 061051

3) Ruchika Duggal 061154

ACKNOWLEDGEMENT

The completion of any project brings with it a sense of satisfaction, but it is never complete without thanking those people who made it possible and whose constant support has crowned our efforts with success. One cannot even imagine the power of the force that guides us all and neither can we succeed without acknowledging it. Our deepest gratitude to Almighty God for holding our hands and guiding us throughout our lives.

I would also like to express our gratitude to **Prof. S.V. Bhooshan** Head of the Department, Electronics and Communication JUIT, Waknaghat(H.P.) for encouraging and inspiring us to carry out the project in the department lab. I would also like to thank our guide, **Mr. Jitendra Mohan** for his expert guidance, encouragement and valuable suggestions at every step. We also would like to thank all the staff members of E&C dept. for providing us with the required facilities and support towards the completion of the project.

Table of Content

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Appropriate environmental conditions are necessary for optimum plant growth, improved crop yields, and efficient use of water and other resources. Automating the data acquisition process of the soil conditions and various climatic parameters that govern plant growth allows information to be collected at high frequency with less labor requirements. The existing systems employ PC or SMS-based systems for keeping the user continuously informed of the conditions inside the greenhouse; but are unaffordable, bulky, difficult to maintain and less accepted by the technologically unskilled workers.

The objective of this project is to design a simple, easy to install, microcontroller-based circuit to monitor and record the values of temperature, humidity, soil moisture and sunlight of the natural environment that are continuously modified and controlled in order to optimize them to achieve maximum plant growth and yield. The controller used is a low power, cost efficient chip manufactured by ATMEL having 8K bytes of on-chip flash memory. It communicates with the various sensor modules in real-time in order to control the light, aeration and drainage process efficiently inside a greenhouse by actuating a cooler, fogger, dripper and lights respectively according to the necessary condition of the crops. An integrated Liquid crystal display (LCD) is also used for real time display of data acquired from the various sensors and the status of the various devices. Also, the use of easily available components reduces the manufacturing and maintenance costs. The design is quite flexible as the software can be changed any time. It can thus be tailor-made to the specific requirements of the user.

This makes the proposed system to be an economical, portable and a low maintenance solution for greenhouse applications, especially in rural areas and for small scale agriculturists.

CHAPTER 1

INTRODUCTION

We live in a world where everything can be controlled and operated automatically, but there are still a few important sectors in our country where automation has not been adopted or not been put to a full-fledged use, perhaps because of several reasons one such reason is cost. One such field is that of agriculture. Agriculture has been one of the primary occupations of man since early civilizations and even today manual interventions in farming are inevitable. Greenhouses form an important part of the agriculture and horticulture sectors in our country as they can be used to grow plants under controlled climatic conditions for optimum produce .Automating a greenhouse envisages monitoring and controlling of the climatic parameters which directly or indirectly govern the plant growth and hence their produce. Automation is process control of industrial machinery and processes, thereby replacing human operators.

1.1 Current scenario

Greenhouses in India are being deployed in the high-altitude regions where the sub-zero temperature up to -40° C makes any kind of plantation almost impossible and in arid regions where conditions for plant growth are hostile. The existing set-ups primarily are:

1.1.1 Manual set-up

This set-up involves visual inspection of the plant growth, manual irrigation of plants, turning ON and OFF the temperature controllers, manual spraying of the fertilizers and pesticides. It is time consuming, vulnerable to human error and hence less accurate and unreliable.

1.1.2 Partially automated set-up

This set-up is a combination of manual supervision and partial automation and is similar to manual set-up in most respects but it reduces the labor involved in terms of irrigating the set-up.

1.1.3 Fully- automated

This is a sophisticated set-up which is well equipped to react to most of the climatic changes occurring inside the greenhouse. It works on a feedback system which helps it to respond to the external stimuli efficiently. Although this set-up overcomes the problems caused due to human errors it is not completely automated and expensive.

1.2 Problem definition

A number of problems associated with the above mentioned systems are enumerated as below:

1. Complexity involved in monitoring climatic parameters like humidity, soil moisture, illumination, soil pH, temperature, etc which directly or indirectly govern the plant growth.

2. Investment in the automation process are high, as today's greenhouse control systems are designed for only one parameter monitoring (as per GKVK research center); to control more than one parameter simultaneously there will be a need to buy more than one system.

3. High maintenance and need for skilled technical labor. The modern proposed systems use the mobile technology as the communication schemes and wireless data acquisition systems, providing global access to the information about one's farms. But it suffers from various limitations like design complexity, inconvenient repairing and high price. Also the reliability of the system is relatively low, and when there are malfunctions in local devices, all local and tele data will be lost and hence the whole system collapses. More over

farmers in India do not work under such sophisticated environment and find no necessity of such an advanced system, and cannot afford the same.Keeping these issues in view, a microcontroller based monitoring and control system is designed to find implementation in the near future that will help Indian farmers.

1.3 Proposed model for automation of greenhouse

The proposed system is an embedded system which will closely monitor and control the microclimatic parameters of a greenhouse on a regular basis round the clock for cultivation of crops or specific plant species which could maximize their production over the whole crop growth season and to eliminate the difficulties involved in the system by reducing human intervention to the best possible extent. The system comprises of sensors, Analog to Digital Converter, microcontroller and actuators.

When any of the above mentioned climatic parameters cross a safety threshold which has to be maintained to protect the crops, the sensors sense the change and the microcontroller reads this from the data at its input ports after being converted to a digital form by the ADC. The microcontroller then performs the needed actions by employing relays until the strayed-out parameter has been brought back to its optimum level. Since a microcontroller is used as the heart of the system, it makes the set-up low-cost and effective nevertheless. As the system also employs an LCD display for continuously alerting the user about the condition inside the greenhouse, the entire set-up becomes user friendly.

Thus, this system eliminates the drawbacks of the existing set-ups mentioned in the previous section and is designed as an easy to maintain, flexible and low cost solution.

CHAPTER 2

SYSTEM MODEL

2.1 Basic model of the system

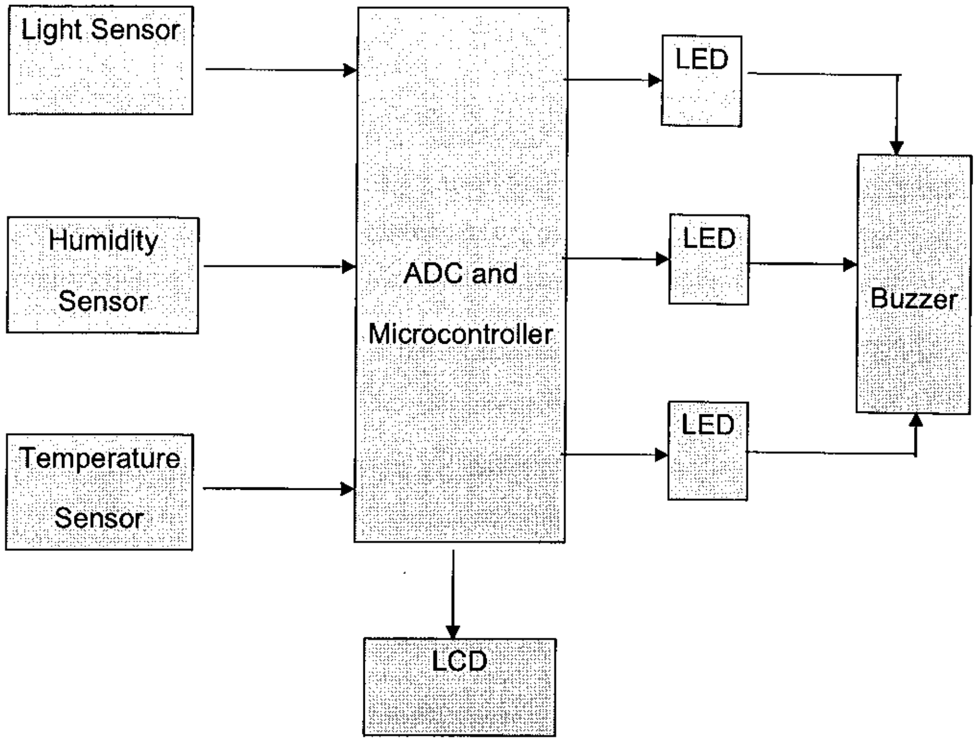


Fig 2.1 Basic Model of System

2.2 Parts of the system

- Sensors

  Temperature sensor (LM35)

  Humidity sensor (HIH4000)

  Light sensor (LDR)
- Microcontroller (ATMEGA 8535)
- Liquid Crystal Display (JHD162A)
- LED's
- Buzzer

2.3Working of the system

1. In a greenhouse important parameters that are required to be measured are :-

- Temperature inside the greenhouse
- Humidity in air
- Intensity of light present inside the greenhouse

These parameters directly effect the growth of plants, thus they should be controlled. The proposed system consists of three sensors (light sensor, humidity sensor, temperature sensor) which will measure their respective parameters.

2. These values are passed to the microcontroller connected to them, separate ADC is not required as the microcontroller(ATMEGA 8535)has inbuilt ADC.
3. LCD is connected to the microcontroller which shows the respective readings taken by sensor and converted to digital by microcontroller.
4. Three LED's are connected for three different types of readings. A threshold is set for all three readings, if the value exceeds the threshold then LED glows.
5. Since some kind of alarm is needed to indicate to the user that threshold has been crossed so a buzzer can be connected to the LED. Whenever LED glows current passes through the buzzer circuitry also and it beeps.
6. Instead of LED the output terminal of microcontroller can be connected to the relays which convert signal into mechanical form. This can further be connected to fans which will decrease the temperature level in case temperature crosses the threshold. If intensity of light crosses the threshold then some kind of arrangement should be made to decrease the light intensity etc.

CHAPTER 3

HARDWARE DESCRIPTION OF THE SYSTEM

3.1 Light sensor

Light Sensors are Photocells that allow you to detect light. They are small, inexpensive, low-power, easy to use and don't wear out. For that reason they often appear in toys, gadgets and appliances. They are often referred to as CdS cells (they are made of Cadmium-Sulfide), light-dependent resistors (LDR), and photoresistors.

Photocells are basically a resistor that changes its resistive value (in ohms Ω) depending on how much light is shining onto the squiggly face. They are very low cost, easy to get in many sizes and specifications, but are very inaccurate. Each photocell sensor will act a little differently than the other, even if they are from the same batch. The variations can be really large, 50% or higher! For this reason, they shouldn't be used to try to determine precise light levels in lux or millicandela.

3.1.1 Features

- **Size:** Round, 5mm (0.2") diameter. (Other photocells can get up to 12mm/0.4" diameter!)
- **Price:** Rs 50
- **Resistance range:** 200KΩ (dark) to 10KΩ (10 lux brightness)
- **Sensitivity range:** CdS cells respond to light between 400nm (violet) and 600nm (orange) wavelengths, peaking at about 520nm (green).
- **Power supply:** pretty much anything up to 100V, uses less than 1mA of current on average (depends on power supply voltage)

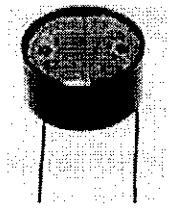


Fig-3.1 Light Dependent Resistor

How to measure light using a photocell : a photocell's resistance changes as the face is exposed to more light. When its dark, the sensor looks like a large resistor up to 10MΩ, as the light level increases, the resistance goes down. This graph indicates approximately the resistance of the sensor at different light levels.

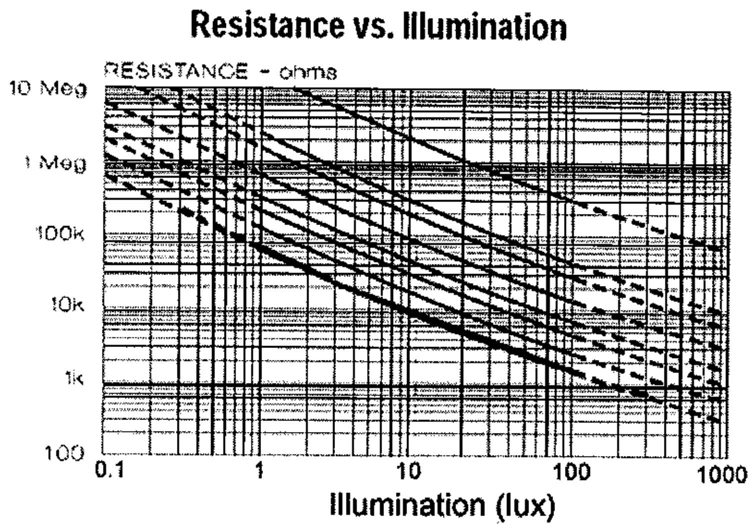


Fig3.2 Graph of resistance vs. illumination

Note that the graph is not linear, its a log-log graph. Photocells, particularly the common CdS cells are not sensitive to all light. In particular they tend to be sensitive to light between 700nm (red) and 500nm (green) light. Basically, blue light won't be nearly as effective at triggering the sensor as green/yellow light.

3.1.2 What is LUX?

Most datasheets use lux to indicate the resistance at certain light levels. Its not a method we tend to use to describe brightness so its tough to gauge.

Table 3.1

Illuminance	Example
0.002 lux	Moonless clear night sky
0.2 lux	Design minimum for emergency lighting (AS2293).
0.27 - 1 lux	Full moon on a clear night
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Very dark overcast day
300 - 500 lux	Sunrise or sunset on a clear day. Well-lit office area.
1,000 lux	Overcast day; typical TV studio lighting
10,000–25,000 lux	Full daylight (not direct sun)
32,000–130,000 lux	Direct sunlight

3.1.3 Functional description

a) Testing light sensor

The easiest way to determine how your photocell works is to connect a multimeter in resistance-measurement mode to the two leads and see how the resistance changes when shading the sensor with your hand, turning off lights, etc. Because the resistance changes a lot and ranges between 1MΩ and 1KΩ .

b) Connecting light sensor

Because photocells are basically resistors, they are non-polarized. That means one can connect them up 'either way' and they'll work just fine. Photocells are pretty hardy, we can easily solder to them, clip the leads, plug them into breadboards, use alligator clips, etc. The only care you should take is to avoid bending the leads right at the epoxied sensor, as they could break off if flexed too often.

c) Analog voltage reading method

The easiest way to measure a resistive sensor is to connect one end to Power and the other to a pull-down resistor to ground. Then the point between the fixed pulldown resistor and the variable photocell resistor is connected to the analog input of a microcontroller.

For this example showing it with a 5V supply. In this configuration the analog voltage reading ranges from 0V (ground) to about 5V (or about the same as the power supply voltage).The way this works is that as the resistance of the photocell decreases, the total resistance of the photocell and the pulldown resistor decreases from over 600KΩ to 10KΩ. That means that the current flowing through both resistors increases which in turn causes the voltage across the fixed 10KΩ resistor to increase.

Ambient light like...	Ambient light (lux)	Photocell resistance (Ω)	LDR + R (Ω)	Current thru LDR +R	Voltage across R
Dim hallway	0.1 lux	600KΩ	610 KΩ	0.008 mA	0.1 V
Moonlit night	1 lux	70 KΩ	80 KΩ	0.07 mA	0.6 V
Dark room	10 lux	10 KΩ	20 KΩ	0.25 mA	2.5 V
Dark overcast day / Bright room	100 lux	1.5 KΩ	11.5 KΩ	0.43 mA	4.3 V
Overcast day	1000 lux	300 Ω	10.03 KΩ	0.5 mA	5V

Table 3.2

This table indicates the approximate analog voltage based on the sensor light/resistance w/a 5 V supply and 10 kΩ pulldown resistor.

If you're planning to have the sensor in a bright area and use a 10 kΩ pulldown, it will quickly saturate. That means that it will hit the 'ceiling' of 5V and not be able to differentiate between kind of bright and really bright. In that case, you should replace the 10KΩ pulldown with a 1KΩ pulldown. In that case, it will not be able to detect dark level differences as well but it will be able to detect bright light differences better.

Note that our method does not provide linear voltage with respect to brightness! Also, each sensor will be different. As the light level increases, the analog voltage goes up even though the resistance goes down:

$$V_o = V_{cc} \left(R / (R + \text{Photocell}) \right)$$

That is, the voltage is proportional to the inverse of the photocell resistance which is, in turn, inversely proportional to light levels.

3.2 Humidity sensor

The humidity sensor HIH4000, manufactured by Honeywell is used for sensing the humidity. It delivers instrumentation quality RH (Relative Humidity) sensing performance in a low cost, solder able SIP (Single In-line Package). Relative humidity is a measure, in percentage, of the vapour in the air compared to the total amount of vapour that could be held in the air at a given temperature.

Fig 3.3 Humidity sensor HIH 4000

3.2.1 Features

- Linear voltage output vs. %RH
- Laser trimmed interchangeability
- Low power design
- High accuracy
- Fast response time
- Chemically resistant
- The RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element's multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals.

3.2.2 Functional description

- The sensor develops a linear voltage vs. RH output that is ratiometric to the supply voltage. That is, when the supply voltage varies, the sensor output voltage follows in the same proportion. It can operate over a 4-5.8 supply voltage range. At 5V supply voltage, and room temperature, the output voltage ranges from 0.8 to 3.9V as the humidity varies from 0% to 100% (noncondensing).

• The humidity sensor functions with a resolution of up to 0.5% of relative humidity (RH).

• With a typical current draw of only 200 μA, the HIH-4000 Series is ideally suited low drain, battery operated systems.

• The change in the RH of the surroundings causes an equivalent change in the voltage output. The output is an analog voltage proportional to the supply voltage.Consequently, converting it to relative humidity (RH) requires that both the supply and sensor output voltages be taken into account according to the formula:

$$RH = ((Vout / Vsupply) - 0.16) / 0.0062, \text{ typical at } 25°C$$

• This voltage is converted to the digital form by the ADC and then sent as input to the microcontroller which reads the data.

3.3Temperature sensor

An analog temperature sensor is a chip that tells you what the ambient temperature is. These sensors use a solid-state technique to determine the temperature. This means that they do not use mercury (like old thermometers),bimetallic strip (like in some home thermometers or stoves), nor do they use thermistors (temperature sensitive resistors). Instead, they use the fact as temperature increases, the voltage across a diode increases at a known rate. (Technically, this is actually the voltage drop between the base and emitter - the Vbe - of a transistor. By precisely amplifying the voltage change, it is easy to generate an analog signal that is directly proportional to temperature. There have been some improvements on the technique but, essentially that is how temperature is measured. Because these sensors have no moving parts, they are precise, never wear out, don't need calibration, work under many environmental conditions, and are consistent between sensors and readings. Moreover they are very inexpensive and quite easy to use.

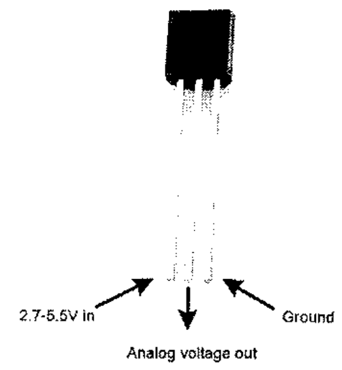


Fig 3.4

3.3.1 Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteed (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 ±1⁄4°C typical

3.3.2 Functional Description

- The sensor has a sensitivity of 10mV / ^{o}C.
- The output of LM35 is amplified using a LM324 single power supply (+5V) op-amp.
- The op-amp is designed to have a gain of 5.
- The circuitry measures temperatures with a resolution of up to 0.5 degree Celsius.
- The output voltage is converted to temperature by a simple conversion factor. The general equation used to convert output voltage to temperature is:

$$\text{Temperature } (^{o}C) = (V_{out} * 100) / 5\ ^{o}C$$

So if V_{out} is 5V, then, Temperature = 100 ^{o}C

- The output voltage varies linearly with temperature.

Using the LM 35 is easy, simply connect the left pin to power (2.7-5.5V) and the right pin to ground. Then the middle pin will have an analog voltage that is directly proportional (linear) to the temperature. The analog voltage is independant of the power supply. To convert the voltage to temperature, simply use the basic formula:

Temp in °C = [(Vout in mV) - 500] / 10

So for example, if the voltage out is 1V that means that the temperature is ((1000 mV - 500) / 10) = 50 °C

If you're using a LM35 or similar, use line 'a' in the image above and the formula:
Temp in °C = (Vout in mV) / 10

Testing your temperature sensor

Testing these sensors is pretty easy but you'll need a battery pack or power supply.

Connect a 2.7-5.5V power supply (2-4 AA batteries work fantastic) so that ground is connected to pin 3 (right pin), and power is connected to pin 1 (left pin)

Then connect your multimeter in DC voltage mode to ground and the remaining pin 2 (middle). If you've got a TMP36 and its about room temperature (25°C), the voltage should be about 0.75V. Note that if you're using a LM35, the voltage will be 0.25V.These sensors have little chips in them and while they're not that delicate, they do need to be handled properly. Be careful of static electricity when handling them and make sure the power supply is connected up correctly and is between 2.7 and 5.5V DC - so don't try to use a 9V battery!They come in a "TO-92" package which means the chip is housed in a plastic hemi-cylinder with three legs. The legs can be bent easily to allow the sensor to be plugged into a breadboard. You can also solder to the pins to connect long wires.

Reading the analog temperature data

Unlike the FSR or photocell sensors we have looked at, the TMP36 and friends doesn't act like a resistor. Because of that, there is really only one way to read the temperature value from the sensor, and that is plugging the output pin directly into an Analog (ADC) input.

Remember that you can use anywhere between 2.7V and 5.5V as the power supply. For this example I'm showing it with a 5V supply but note that you can use this with a 3.3v supply just as easily. No matter what supply you use, the analog voltage reading will range from about 0V (ground) to about 1.75V.

If you're using a 5V Arduino, and connecting the sensor directly into an Analog pin, you can use these formulas to turn the 10-bit analog reading into a temperature:

Voltage at pin in milliVolts = (reading from ADC) * (5000/1024)
This formula converts the number 0-1023 from the ADC into 0-5000mV (= 5V)

If you're using a 3.3V Arduino, you'll want to use this:

Voltage at pin in milliVolts = (reading from ADC) * (3300/1024)
This formula converts the number 0-1023 from the ADC into 0-3300mV (= 3.3V)

Then, to convert millivolts into temperature, use this formula:

Centigrade temperature = [(analog voltage in mV) – 500

3.4 ATMEGA 8535

It is AVR Microcontroller with 8K bytes in system programmable flash.

3.4.1 Features

1) High-performance, Low-power AVR® 8-bit Microcontroller

2) Advanced RISC Architecture

- 130 Powerful Instructions – Most Single Clock Cycle Execution
- 32 x 8 General Purpose Working Register

- Fully Static Operation
- Up to 16 MIPS Throughput at 16 MHz
- On-chip 2-cycle Multiplier

3)Non-volatile Program and Data Memories

- 8K Bytes of In-System Self-Programmable Flash
- Endurance: 10,000 Write/Erase Cycles
- Optional Boot Code Section with Independent Lock Bits
- In-System Programming by On-chip Boot Program
- True Read-While-Write Operation
- 512 Bytes EEPROM
- Endurance: 100,000 Write/Erase Cycles
- 512 Bytes Internal SRAM
- Programming Lock for Software Security

4)Peripheral Features

- Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
- One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
- Real Time Counter with Separate Oscillator
- Four PWM Channels
- 8-channel, 10-bit ADC
- 8 Single-ended Channels
- 7 Differential Channels for TQFP Package Only
- 2 Differential Channels with Programmable Gain at 1x, 10x, or 200x for TQFP Package Only
- Byte-oriented Two-wire Serial Interface
- Programmable Serial USART
- Master/Slave SPI Serial Interface

- Programmable Watchdog Timer with Separate On-chip Oscillator
- On-chip Analog Comparator

5)Special Microcontroller Features

- Power-on Reset and Programmable Brown-out Detection
- Internal Calibrated RC Oscillator
- External and Internal Interrupt Sources
- Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby

6)I/O and Packages

- 32 Programmable I/O Lines
- 40-pin PDIP, 44-lead TQFP, 44-lead PLCC, and 44-pad QFN/MLF

7)Operating Voltages

- 2.7 - 5.5V for ATmega8535L
- 4.5 - 5.5V for ATmega8535

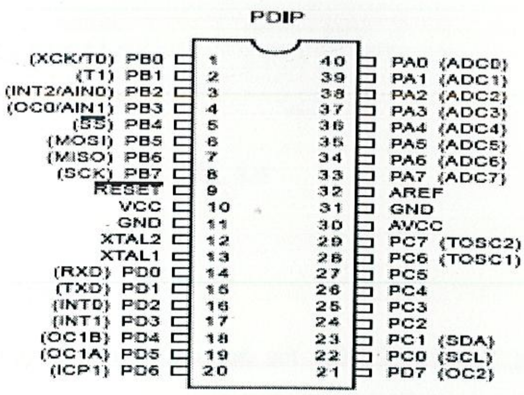


Fig 3.5

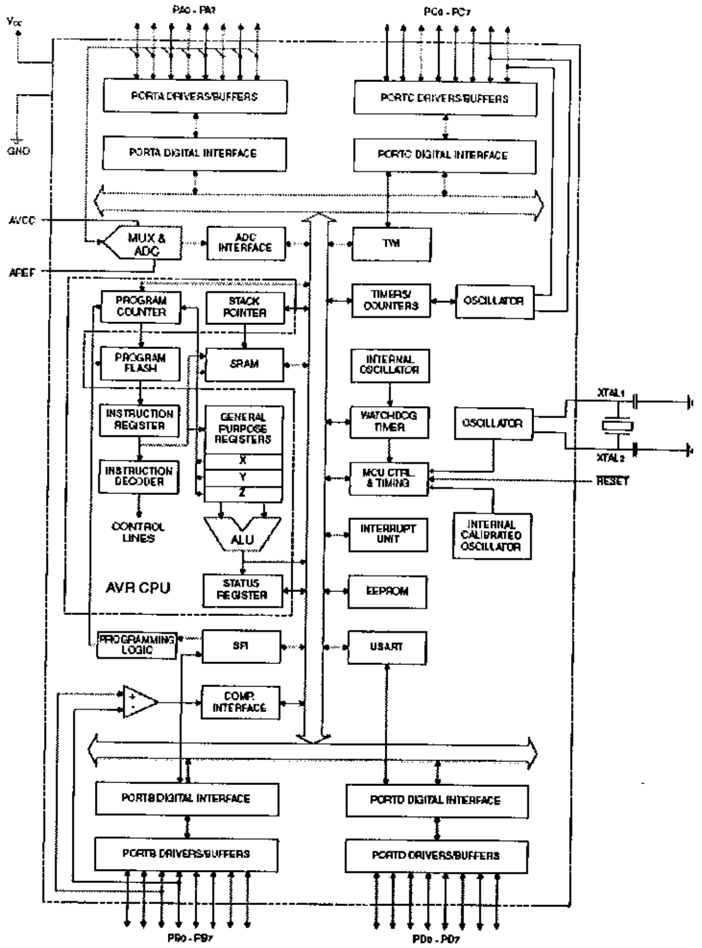


Fig. 3.6

3.4.2 Block Diagram of 8535

The AVR core combines a rich instruction set with 32 general purpose working registers. All 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.The ATmega8535 provides the following features: 8K bytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes EEPROM, 512 bytes SRAM, 32 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain in TQFP package, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM,Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or Hardware Reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the asynchronous timer continue to run. The device is manufactured using Atmel's high density nonvolatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega8535 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The ATmega8535 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, In-Circuit Emulators, and evaluation kits.

3.4.3 Pin description

1)**VCC** - Digital supply voltage.

2)**GND** - Ground.

3)**Port A (PA7..PA0)** - Port A serves as the analog inputs to the A/D Converter. Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.

4)**Port B (PB7..PB0)** - Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running. Port B also serves the functions of various special features of the ATmega8535 as listed on page 60.

5)**Port C (PC7..PC0)** - Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will sourcecurrent if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

6)**Port D (PD7..PD0)** - Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.Port D also serves the functions of various special features.

7)**RESET** - Reset input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. Shorter pulses are not guaranteed to generate a reset.

8)**XTAL1** - Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

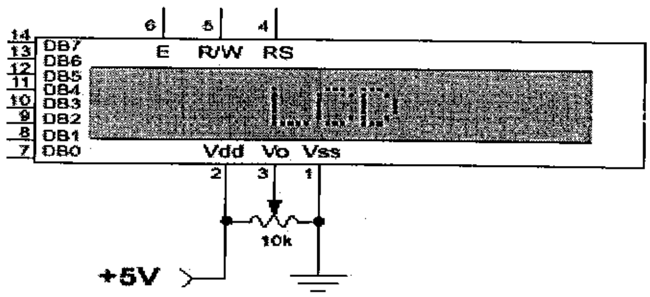
9)**XTAL2** - Output from the inverting Oscillator amplifier.

10)**AVCC** - AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to VCC, even if the ADC is not used. If the ADC is used, it should be connected to VCC through a low-pass filter.

11)**AREF** - AREF is the analog reference pin for the A/D Converter.

3.5 Display unit

A Liquid crystal display is used to indicate the present status of parameters and the respective AC devises (simulated using bulbs). The information is displayed in two modes which can be selected using a push button switch which toggles between the modes. Any display can be interfaced to the system with respective changes in driver circuitry and code. A liquid crystal display (LCD) is a thin, flat display device made up of any number of color or monochrome pixels arrayed in front of a light source or reflector. Each pixel consists of a column of liquid crystal molecules suspended between two transparent electrodes, and two polarizing filters, the axes of polarity of which are perpendicular to each other. Without the liquid crystals between them, light passing through one would be blocked by the other. The liquid crystal twists the polarization of light entering one filter to allow it to pass through the other.In this project we are using LCD JHD162A.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VSS	Vcc	VEE	RS	R/W	E	DB0	DB1	DB2	DB3	DB4	DB5	DB6	DB7	LED+	LED-

Fig 3.7 Pin Description of 2*16 LCD

3.5.1 Signals to the LCD

The LCD also requires 3 control lines from the microcontroller:

1) Enable (E)

This line allows access to the display through R/W and RS lines. When this line is low, the LCD is disabled and ignores signals from R/W and RS. When (E) line is high, the LCD checks the state of the two control lines and responds accordingly.

2) Read/Write (R/W)

This line determines the direction of data between the LCD and microcontroller. When it is low, data is written to the LCD. When it is high, data is read from the LCD.

3) Register select (RS)

With the help of this line, the LCD interprets the type of data on data lines. When it is low, an instruction is being written to the LCD. When it is high, a character is being written to the LCD.

3.5.2 Logic status on control lines

•E - 0 Access to LCD disabled

- 1 Access to LCD enabled

•R/W - 0 Writing data to LCD

- 1 Reading data from LCD

•RS - 0 Instruction

- 1 Character

3.5.3 Writing and reading data from LCD

Writing data to the LCD is done in several steps:

1) Set R/W bit to low

2) Set RS bit to logic 0 or 1 (instruction or character)

3) Set data to data lines (if it is writing)

4) Set E line to high

5) Set E line to low

Read data from data lines (if it is reading):

1) Set R/W bit to high

2) Set RS bit to logic 0 or 1 (instruction or character)

3) Set data to data lines (if it is writing)

4) Set E line to high

5) Set E line to low

3.6 Alarm circuitry

3.6.1 Buzzer:

A **buzzer** or **beeper** is a signaling device, usually electronic, typically used in automobiles, household appliances such as a microwave oven.

Fig. 3.8 Electrical symbol of a buzzer

It is connected to the control unit through the transistor that acts as an electronic switch for it. When the switch forms a closed path to the buzzer, it sounds a warning in the form of a continuous or intermittent buzzing or beeping sound.The transistor acts as a normal controlled by the base connection. It switches ON when a positive voltage from the control unit is applied to the base. If the positive voltage is less than 0.6V, the transistor switches OFF. No current flows through the buzzer in this case and it will not buzz. As can be seen in the buzzer circuitry given below, a protection resistor of 10k ohm is used in order to protect the transistor from being damaged in case of excessive current flow. In our system, the buzzer is designed to give a small beep whenever one of the devices such as a cooler or a bulb turns on in order to alert the user.

3.7 Power supply connection

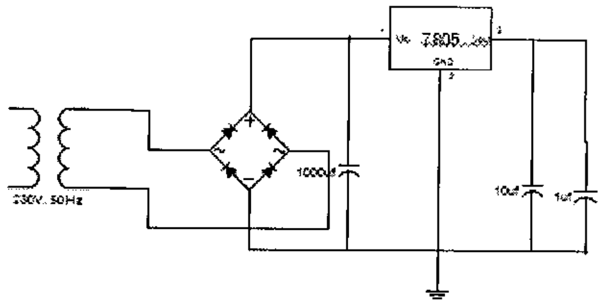


Fig 3.9

The power supply section consists of step down transformers of 230V primary to 9V and 12V secondare voltages for the +5V and +12V power supplies respectively. The stepped down voltage is then rectified by 4 1N4007 diodes. The high value of capacitor 1000 μF charges at a slow rate as the time constant is low, and once the capacitor charges there is no resistor for capacitor to discharge. This gives a constant value of DC. IC 7805 is used for regulated supply of +5 volts and IC 7812 is used to provide a regulated supply of +12 volts in order to prevent the circuit ahead from any fluctuations. The filter capacitors connected after this IC filters the high frequency spikes. These capacitors are connected in parallel with supply and common so that spikes filter to the common. These give stability to the power supply circuit. As can be seen from the above circuit diagrams, the rectified voltage from the 4 diodes is given to pin 1 of the respective regulators. Pin 2 of the regulators is connected to ground and pin 3 to V_{CC}. With adequate heat sinking the regulator can deliver 1A output current. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

3.8 LED

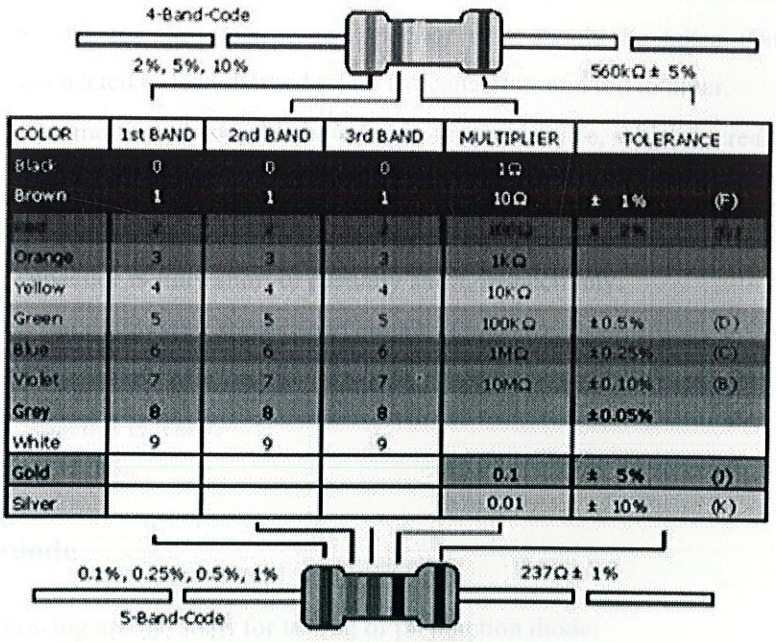
A **light-emitting diode (LED)** is a semiconductor light source. LEDs are used as indicator lamps in many devices, and are increasingly used for lighting.Introduced as a practical electronic component in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet and infrared wavelengths, with very high brightness.The LED is based on the semiconductor diode. When a diode is forward biased (switched on), electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor. An LED is usually small in area (less than 1 mm^2), and integrated optical components are used to shape its radiation pattern and assist in reflection LEDs present many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliability. However, they are relatively expensive and require more precise current and heat management than traditional light sources. Current LED products for general lighting are more expensive to buy than fluorescent lamp sources of comparable output.

CHAPTER 4

COMPONENT TESTING

4.1 Resistors

Resistors can easily tested using multimeter in resistance range. The idea is to measure the resistance of the resistor and compare this measured value with colour coded value.If the measured value matches the colour coded value, resistor is OK, and otherwise it is not. The steps involved in measurement of resistance are as follows.



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Fig 4.1 Measuring resistance value

- Switch on the multimeter and point selector switch in ohm section.
- Connect leads to V/ohm and COM sockets.
- Select the lowest range in ohm section with selector switch

- Connect tips of leads to both leads of the resistor
- If resistance of the resistor is in the selected range, then the resistance value will be displayed, switch the selector switch to next higher value and repeat till value is displayed.
- For an open resistor, over range will be displayed in even the highest selected range.
- The range can also be directly selected depending on the colour code value.

4.2 Capacitor

A capacitor can be tested using a multimeter by measuring its resistance and also, by measuring their voltages after charging. Following are the steps for testing

- Set the multimeter to highest resistance range using the selector switch.
- Connect the probe tips to capacitor leads. Any lead can be connected to any lead except for the electrolytic capacitor care should be taken that black lead is connected to lead marked (-) on the capacitor, and red to other.
- The multimeter should show increasing resistance, which increases ultimately to attain over range for a good capacitor. On analog multimeter.
- If multimeter shows zero or low resistance which is not increasing then the capacitor is fully short or partially short, respectively.
- If the multimeter shows open circuit, it means capacitor is open.
- If resistance of capacitor increases, but not attain 'over- range' that means the capacitor is leaky.

4.3 Diode

Following are the steps for testing of pn junction diode:

- Select the lowest resistance range in the multimeter.Connect the leads to V/ohm and COM sockets.Red to V/ohm and black to COM.
- Connect red lead to 'p' side of diode and black lead to 'n' side. The multimeter should show a low resistance. This resistance can vary from tens of ohms to few hundreds of ohms depending on the voltage in the leads. This resistance will be further less for germanium diode.

- Now connect red lead to 'n' side and black lead to 'p' side. The diode gets reverse biased. It should show open circuit even in highest range.
- If diode shows low resistance in both directions, it is short and if it shows open in both directions, it is open. If forward bias resistance is low and reverse bias resistance is quite less that means diode is faulty.
- Some digital multimeters have diode checking facility in them, which is marked with the help of symbol of diode on multimeter. If multimeter is switched to this position, then multimeter should show 0.5V to 0.8V in forward bias and open in reverse bias. In this position the multimeter reads the voltage drop across the diode. The variation from 0.5V to 0.8V is due to variation in voltages in leads. The diode resistance is actually voltage dependent, because it is non ohmic device.

4.4 LED

The testing procedure for testing a LED is as follows:-

- Select the lowest resistance range of multimeter
- Connect red lead of the multimeter to anode of the LED and black lead to cathode (shorter lead) so as to forward bias the LED.
- The multimeter should read low resistance.This resistance will be higher than that of regular diode.If multimeter is showing open then switch to next higher range. This is because the voltage in multimeter leads may not be enough to forward bias the LED.At higher range this voltage increases, and diode gets forward biased. When this happens, the diode starts glowing.
- Now reverse bias the diode by connecting red lead to cathode and black lead to anode.The multimeter should show open at all ranges.
- If multimeter has diode testing facility, then, during forward biasing, a good LED should show a forward voltage drop ranging from 1.5 volt to 3 volts.

CONCLUSION

A step-by-step approach in designing the microcontroller based system for measurement and control of the four essential parameters for plant growth, i.e. temperature, humidity, soil moisture, and light intensity, has been followed. The results obtained from the measurement have shown that the system performance is quite reliable and accurate.

The system has successfully overcome quite a few shortcomings of the existing systems by reducing the power consumption, maintenance and complexity, at the same time providing a flexible and precise form of maintaining the environment.

The continuously decreasing costs of hardware and software, the wider acceptance of electronic systems in agriculture, and an emerging agricultural control system industry in several areas of agricultural production, will result in reliable control systems that will address several aspects of quality and quantity of production. Further improvements will be made as less expensive and more reliable sensors are developed for use in agricultural production. Although the enhancements mentioned in the previous chapter may seem far in the future, the required technology and components are available, many such systems have been independently developed, or are at least tested at a prototype level. Also, integration of allthese technologies is not a daunting task and can be successfull carried out.

APPENDIX

```
; ************************************************************ *
; *          This program uses channels 0  to 7 ADC of Mega8535

; *  It reads the ADC. The Channel can be selected by sending Channel number.
; * 8535 receives the Channel no. and outputs the five digit ADC value
; *  on RS232 port for reading by a PC's XTALK program or a VB project.
;
; ************************************************************
;
; Hardware requirements:   8535 Mega board with LCD display and MAX232.
;
; Software features:  It is possible to read the ADC value and also
;          transmit to the PC for data logging.
.NOLIST
.INCLUDE "m8535def.inc"
;device =ATMega8535
.LIST
;
; Constants
;
.EQU xyz = 12345
; Constants for Sio properties
.EQU   fq=1000000;  clock frequency of m8535 with internal oscillator
.EQU   baud=4800; Baudrate for SIO communication
```

```
.EQU   bddiv=(fq/(16*baud))-1; Baudrate divider
;
; Used registers
;
.DEF rmpr = R16
.DEF temp = R14
.DEF result=R12
.DEF mpr =R16
; Code starts here
;
.CSEG
.ORG $0000
; Reset- and Interrupt-vectors
rjmp Start ; Reset-vector
.org $000b
rjmp USART_RXC
; Various subroutines
.org $0100
InitSio:
LDI   rmpr,bddiv ; Init baud generator
OUT   UBRRL,rmpr ; set divider in UART baud rate register
ldi rmpr, 0
out   ubrrh,rmpr
LDI   rmpr,(1<<Rxen)|(1<<Txen)|(1<<RXCIE)
; Enable TX and RX,
out  UCsRB,rmpr
LDI   ZL,0 ; Wait some time
```

```
LDI   ZH,0
InitSio1:
SBIW   ZL,1
BRNE   InitSio1
ldi r16,(1<<Ursel)|(1<<USBS)|(3<<UCSZ0)
;   ldi r16,10000110b
out ucsrc,r16
RET
USART_RXC:  push r16
in R16,udr
andi R16,07
mov r1,r16
ori r16,$c0
out admux,r16
;   pop r16
;   reti
ldi r16,$43
rcall tout      ; intimate new channel to host
ldi r16,$48
rcall tout
mov r16,r1
ori r16,$30
rcall tout
pop r16
reti
; *************** End of interrupt service routines ***********
cmd: cbi portc,2
```

```
cbi portc,3
cbi portc,4
out portb,r16
sbi portc,4
nop
nop
nop
nop
nop
nop
nop
nop
nop
cbi portc,4
rcall delay1
rcall delay1
rcall delay1
ret
lcdwr:  cbi portc,2
cbi portc,3
cbi portc,4
sbi portc,2
out portb,r16
sbi portc,4
nop
nop
nop
```

```
nop
nop
nop
nop
nop
nop
cbi portc,4
rcall delay1
ret
init_lcd:
ldi R16,$38
rcall cmd
rcall delay1
rcall delay1
ldi R16,$0e
rcall cmd
    rcall delay1
    ldi R16,6
    rcall cmd
    ldi r16,1
    rcall cmd
    rcall delay2
  ret
tout:
sbis UcSRa,UDRE ;TX COMPLETE check
  RJMP tout
  OUT UDR,R16
```

```
ret
delay1: push r16
        clr result
loop22:  ldi R16,$f0
loop2:  inc R16
        brne loop2
        inc result
        brne loop22
        pop r16
        ret
delay2: push r16
        clr result
loop221:  ldi R16,$f0
loop21:  inc R16
        brne loop21
        inc result
        brne loop221
        pop r16
        ret
delay:      clr result
ld:     inc result
        brne ld
        ret
lcddisp: push r16
        ldi r16,128 ;cursor to left end
        rcall cmd
        pop r16
```

```
rcall delay1
rcall delay1
rcall binbcd
mov r16,r15
andi r16,0x0f
ori r16,0x30
rcall tout
rcall lcdwr      ; 1
mov r16,r14
andi r16,0b11110000
ror r16
ror r16
ror r16
ror r16
ori r16,0x30
rcall tout
rcall lcdwr      ;2
mov r16,r14
andi r16,0x0f
ori r16,0x30
rcall tout
rcall lcdwr      ;3
mov r16,r13
andi r16,0b11110000
ror r16
ror   r16
ror   r16
```

```
ror     r16
ori r16,0x30
rcall tout
rcall lcdwr    ;4
mov r16,r13
andi r16,0x0f
ori r16,0x30
rcall tout
rcall  lcdwr    ;5
ldi r16,$0a
rcall tout
ldi r16,$0d
rcall tout
ret
binbcd:;*
;* "bin2BCD16" - 16-bit Binary to BCD conversion
;* This subroutine converts a 16-bit number (fbinH:fbinL) to a 5-digit
;* packed BCD number represented by 3 bytes (tBCD2:tBCD1:tBCD0).
;* MSD of the 5-digit number is placed in the lowermost nibble of tBCD2.
;* Number of words    :25
;* Number of cycles   :751/768 (Min/Max)
;* Low registers used :3 (tBCD0,tBCD1,tBCD2)
;* High registers used  :4(fbinL,fbinH,cnt16a,tmp16a)
;* Pointers used          :Z
;*
;***************************************************************************
```

```
;***** Subroutine Register Variables
.equ    AtBCD0      =13         ;address of tBCD0
.equ    AtBCD2      =15         ;address of tBCD1
.def    tBCD0=r13           ;BCD value digits 1 and 0
.def    tBCD1=r14           ;BCD value digits 3 and 2
.def    tBCD2=r15           ;BCD value digit 4
.def    fbinL   =r16        ;binary value Low byte
.def    fbinH   =r17        ;binary value High byte
.def    cnt16a =r18         ;loop counter
.def    tmp16a      =r19        ;temporary value
;***** Code
bin2BCD16:
        ldi     cnt16a,16       ;Init loop counter
        clr     tBCD2           ;clear result (3 bytes)
        clr     tBCD1
        clr     tBCD0
        clr     ZH              ;clear ZH (not needed for AT90Sxx0x)
bBCDx_1:lsl     fbinL;shift input value         35
        rol     fbinH           ;through all bytes
        rol     tBCD0           ;
        rol     tBCD1
        rol     tBCD2
        dec     cnt16a          ;decrement loop counter
        brne    bBCDx_2             ;if counter not zero
        ret                     ;   return
bBCDx_2:ldi     r30,AtBCD2+1        ;Z points to result MSB + 1
bBCDx_3:
```

```
        ld      tmp16a,-Z       ;get (Z) with pre-decrement
;---------------------------------------------------------------
;For AT90Sxx0x, substitute the above line with:
;
;       dec     ZL
;       ld      tmp16a,Z
;
;---------------------------------------------------------------
        subi    tmp16a,-$03     ;add 0x03
        sbrc    tmp16a,3        ;if bit 3 not clear
        st      Z,tmp16a        ;       store back
        ld      tmp16a,Z        ;get (Z)
        subi    tmp16a,-$30     ;add 0x30
        sbrc    tmp16a,7        ;if bit 7 not clear
        st      Z,tmp16a        ;       store back
        cpi     ZL,AtBCD0       ;done all three?
        brne    bBCDx_3;loop again if not
        rjmp    bBCDx_1
; *************** End of the subroutine section ***************
;
; ****************** Main program ***************************
;
; Main program routine starts here
;
Start:  ldi     R16,low(RAMEND)         ; Load low byte address of end of RAM
into register R16
        out     SPL,R16                 ; Initialize stack pointer to end of
internal RAM
```

```
        ldi     R16,high(RAMEND) ; Load high byte address of end of RAM into
register R16

        out     SPH, R16                ; Initialize high byte of stack pointer to end of
internal RAM

;       ldi rmpr,0b00000001     ;TIMER 0 INTERRUPT ENABLE

;       out TIMSK,rmpr

;       ldi rmpr,05             ; So, we get once 1x10^6/1024=1000 Hz

;       out TCCR0,rmpr          ;prescalar 1024

                ;so that timer interrupt occurs at 1KHz rate

        ldi  r16,$c0     ; c0 for int. ref, e0 with adch alone used.

        out admux,r16  ; channel 0 is selected

        ldi r16,0b11000101    ;    prescale /32 (1x32=33 usec)

   ;adc enable,adc start,adc freerun,adcflag,adcno int, adcprescale/32

        out adcsra,r16

        ldi r16,0

out sfior,r16 ; write 0-0-0 to bits d7-d5 for free run adc (ATMEGA)

here1:   in r16,adcsra ;    sbi adcsr,6

        andi r16,0b01000000

        breq here1  ;value got

      ldi R16,255

       out ddrb,R16   ; port b is all bits output

       out ddrc,R16   ; so is port c

       ldi r16,0

       out ddra,r16         ;port a input

init:

       rcall initsio

      sei                               ;enable global interrupt
                ; Enable global interrupts
```

```
LCD:
        rcall init_lcd
lcd1:       ldi R16,$80
        rcall cmd
        rcall delay1
        rcall delay1
        rcall delay1
        rcall delay1
here3:      in r16,adcsra ;    sbi adcsr,6
         andi r16,0b01000000
         brne here3  ;value got
  in  r16,adcl
   IN R17,adch
   push r16
  ;restart adc
   ldi r16,0b11000101 ;prescale /32 (1x32=32 usec)
           ;adc enable,adc start,adc freerun,adcflag,adcno int, adcprescale/32
   out adcsra,r16
  pop r16
   rcall lcddisp
   ;in r16, udr  ; IF this is put, we always get CH2 only 2 only
;    sbis ucsra,rxc    ;if the last byte transmitted remains, then
                ;that is considered as a received byte?
rjmp lcd1
in r16,udr
andi r16,07
 mov r14,r16
```

```
ori r16,$c0
out admux,r16
ldi r16,$43
rcall tout      ; intimate new channel to host
ldi r16,$48
rcall tout
mov r16,r14
ori r16,$30
rcall tout
rjmp lcd1□
```

BIBLIOGRAPHY

[1]Electronic Devices And Circuits , J.B. GUPTA

[2]Programming For Embedded Systems , Dreamtech, Wiley

[3]www.atmel.com

[4]www.alldatasheet.com

[5]www.electronics4u.com

[6]http://www.facstaff.bucknell.edu/mastascu/elessonshtml/StartEE.html

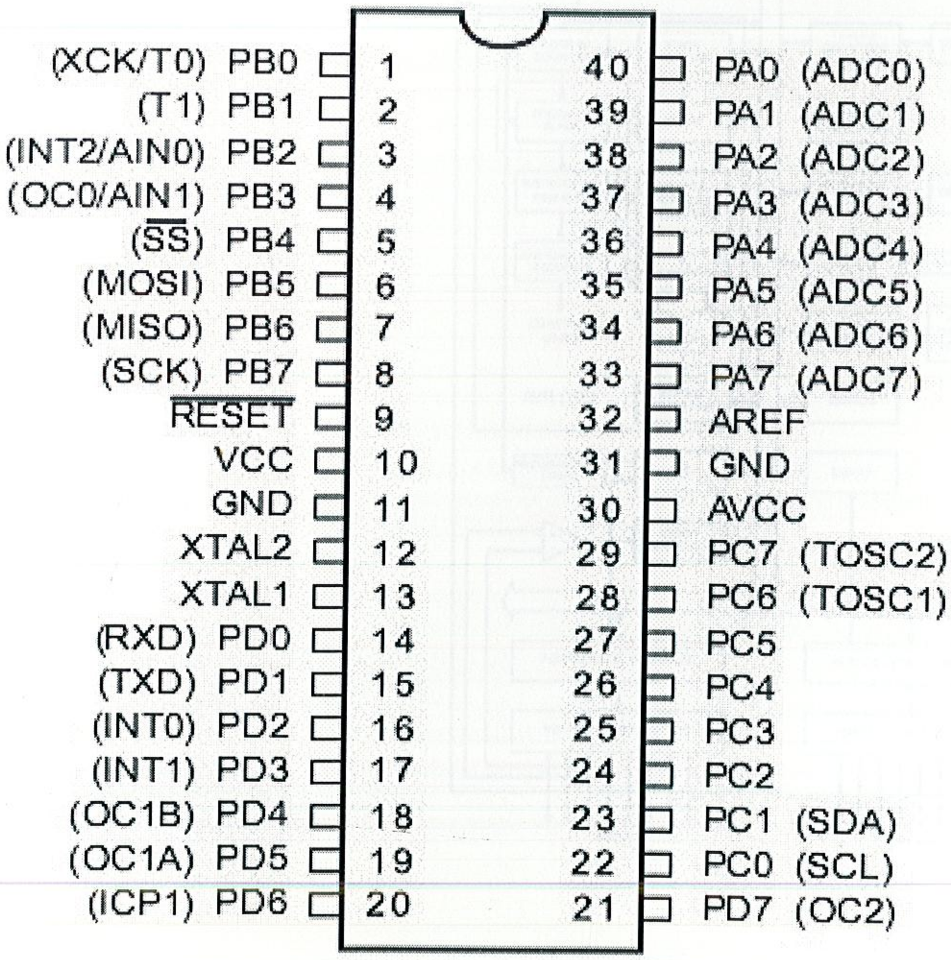
[7]http://www.google.com

[8] http://www.ladyada.net/

[9] Muhammad Ali Mazidi, Janice Gillispie Mazidi, Rolin D. Mc Kinlay , *The 8051 Microcontroller & Embedded Systems*, Pearson Education Inc. 2nd Edition, 2008.

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 130 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- Nonvolatile Program and Data Memories
  - 8K Bytes of In-System Self-Programmable Flash
    Endurance: 10,000 Write/Erase Cycles
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - 512 Bytes EEPROM
    Endurance: 100,000 Write/Erase Cycles
  - 512 Bytes Internal SRAM
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    8 Single-ended Channels
    7 Differential Channels for TQFP Package Only
    2 Differential Channels with Programmable Gain at 1x, 10x, or 200x for TQFP Package Only
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, 44-lead PLCC, and 44-pad QFN/MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega8535L
  - 4.5 - 5.5V for ATmega8535
- Speed Grades
  - 0 - 8 MHz for ATmega8535L
  - 0 - 16 MHz for ATmega8535



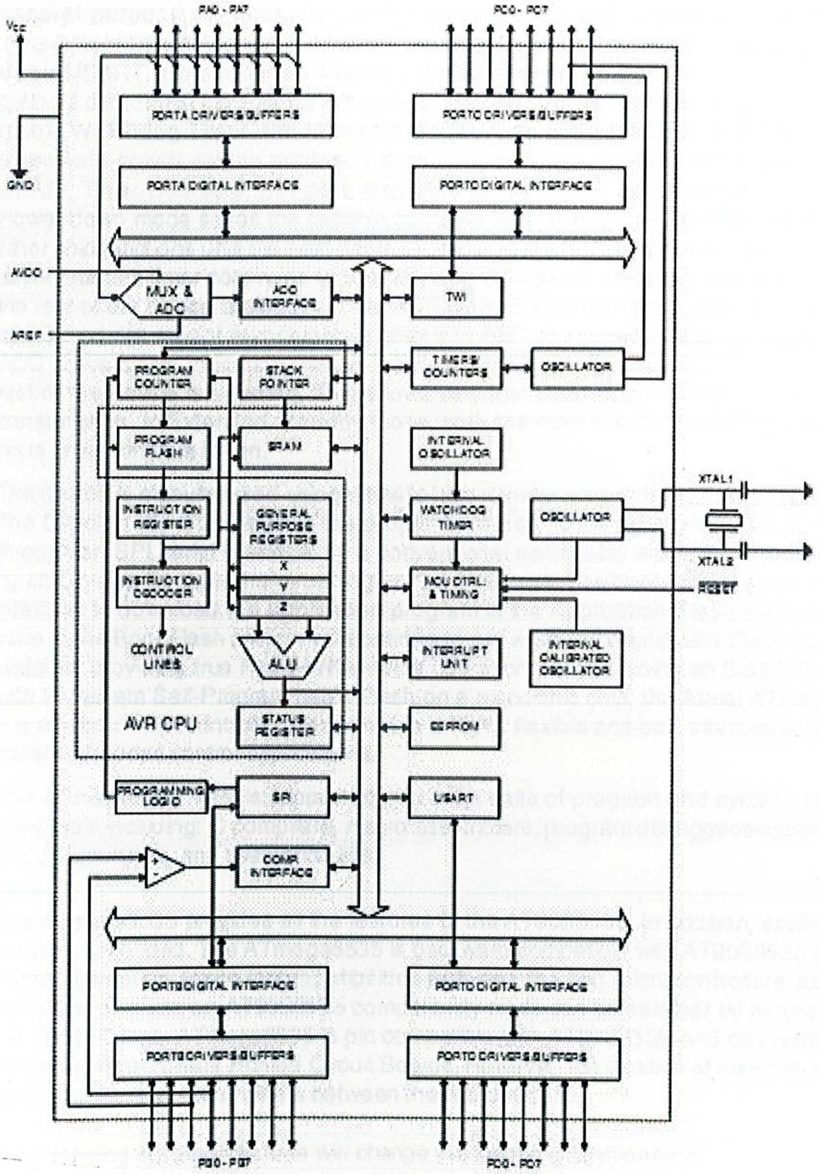
(XCK/T0) PB0 1
(T1) PB1 2
(INT2/AIN0) PB2 3
(OC0/AIN1) PB3 4
(SS) PB4 5
(MOSI) PB5 6
(MISO) PB6 7
(SCK) PB7 8
RESET 9
VCC 10
GND 11
XTAL2 12
XTAL1 13
(RXD) PD0 14
(TXD) PD1 15
(INT0) PD2 16
(INT1) PD3 17
(OC1B) PD4 18
(OC1A) PD5 19
(ICP1) PD6 20
40 PA0 (ADC0)
39 PA1 (ADC1)
38 PA2 (ADC2)
37 PA3 (ADC3)
36 PA4 (ADC4)
35 PA5 (ADC5)
34 PA6 (ADC6)
33 PA7 (ADC7)
32 AREF
31 GND
30 AVCC
29 PC7 (TOSC2)
28 PC6 (TOSC1)
27 PC5
26 PC4
25 PC3
24 PC2
23 PC1 (SDA)
22 PC0 (SCL)
21 PD7 (OC2)

Overview

The ATmega8535 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing instructions in a single clock cycle, the ATmega8535 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

Block Diagram

Figure 2. Block Diagram



The AVR core combines a rich instruction set with 32 general purpose working registers. All 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega8535 provides the following features: 8K bytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes EEPROM, 512 bytes SRAM, 32 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain in TQFP package, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or Hardware Reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the asynchronous timer continue to run.

The device is manufactured using Atmel's high density nonvolatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega8535 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The ATmega8535 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, In-Circuit Emulators, and evaluation kits.

AT90S8535 Compatibility

The ATmega8535 provides all the features of the AT90S8535. In addition, several new features are added. The ATmega8535 is backward compatible with AT90S8535 in most cases. However, some incompatibilities between the two microcontrollers exist. To solve this problem, an AT90S8535 compatibility mode can be selected by programming the S8535C fuse. ATmega8535 is pin compatible with AT90S8535, and can replace the AT90S8535 on current Printed Circuit Boards. However, the location of fuse bits and the electrical characteristics differs between the two devices.

AT90S8535 Compatibility Mode

Programming the S8535C fuse will change the following functionality:

- The timed sequence for changing the Watchdog Time-out period is disabled. See "Timed Sequences for Changing the Configuration of the Watchdog Timer" on page 45 for details.
- The double buffering of the USART Receive Register is disabled. See "AVR USART vs. AVR UART – Compatibility" on page 146 for details.

Pin Descriptions

V_{CC} Digital supply voltage.

GND Ground.

Port A (PA7..PA0) Port A serves as the analog inputs to the A/D Converter.

Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B (PB7..PB0) Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B also serves the functions of various special features of the ATmega8535 as listed on page 60.

Port C (PC7..PC0) Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D (PD7..PD0) Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega8535 as listed on page 64.

$\overline{\text{RESET}}$ Reset input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 37. Shorter pulses are not guaranteed to generate a reset.

XTAL1 Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2 Output from the inverting Oscillator amplifier.

AVCC AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to V_{CC}, even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter.

AREF AREF is the analog reference pin for the A/D Converter.

Honeywell

Representative photograph, actual product appearance may vary.

Due to regional agency approval requirements, some products may not be available in your area. Please contact your regional Honeywell office regarding your product of choice.

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Features

- Molded thermoset plastic housing with cover
- Linear voltage output vs %RH
- Laser trimmed interchangeability
- Low power design
- High accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

Typical Applications

- Refrigeration
- Drying
- Meteorology
- Battery-powered systems
- OEM assemblies

Description

The HIH-4000 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users. Direct input to a controller or other device is made possible by this sensor's linear voltage output. With a typical current draw of only 200 µA, the HIH-4000 Series is ideally suited for low drain, battery operated systems. Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4000 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a low cost, solderable SIP (Single In-line Package). Available in two lead spacing configurations, the RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element's multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals.

Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

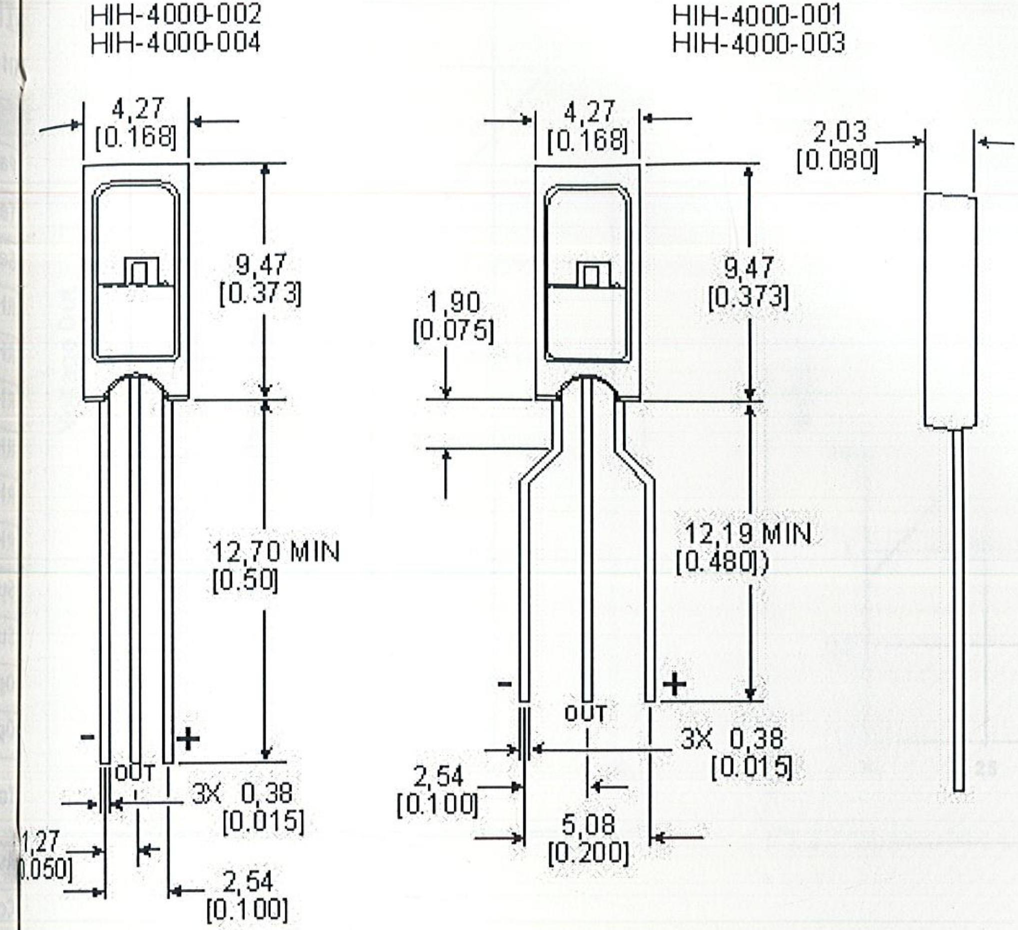
Product Specifications	
Package Style	Solderable SIP
Termination Details	2,54 mm [0.100 in] Lead Pitch
Series Name	HIH-4000 Series
RH Accuracy	± 3.5% RH, 0-100 % RH non-condensing, 25 °C, 5 Vdc supply
RH Interchangeability	± 5% RH, 0-60% RH; ± 8% @ 60-100% RH Typical
RH Hysteresis	± 3% of RH Span Maximum
RH Repeatability	± 0.5% RH
RH response time, 1/e	15 s in slowly moving air @ 25 °C
RH Stability	± 0.2% RH Typical at 50% RH in 1 Year
Supply Voltage	4.0 Vdc to 5.8 Vdc
Supply Current	500 μA Max.
Operating Humidity Range	0 to 100% RH, non-condensing
Operating Temperature Range	-40 °C to 85 °C (-40 °F to 185 °F)
Temperature Compensation	True RH = Sensor RH/(1.0305+0.000044T-0.0000011T^2) T in °C (True RH = Sensor RH/(0.9237-0.0041T+0.000040T^2) T in °C)
Availability	Global
Comment	Light sensitive, shield from bright light.
UNSPSC Code	411121
UNSPSC Commodity	411121 Transducers

Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Mounting Dimensions
For Reference Only [mm/in]

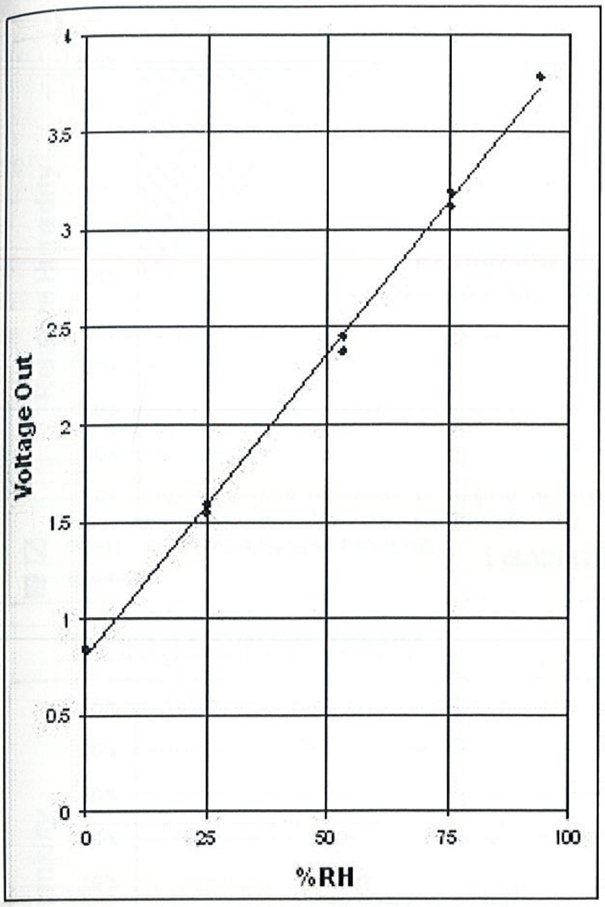


Honeywell

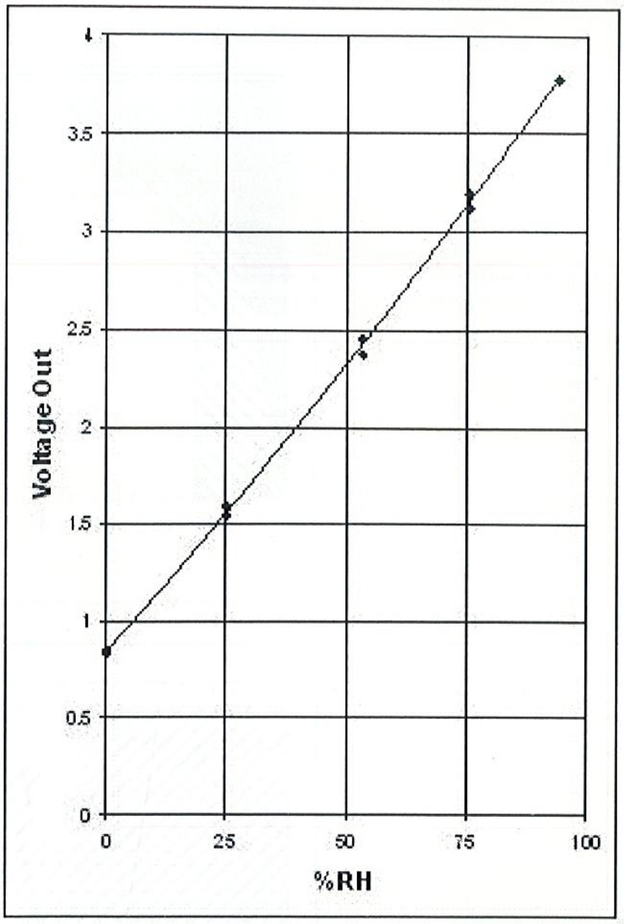
HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

TYPICAL BEST FIT STRAIGHT LINE



TYPICAL 2nd ORDER CURVE FIT

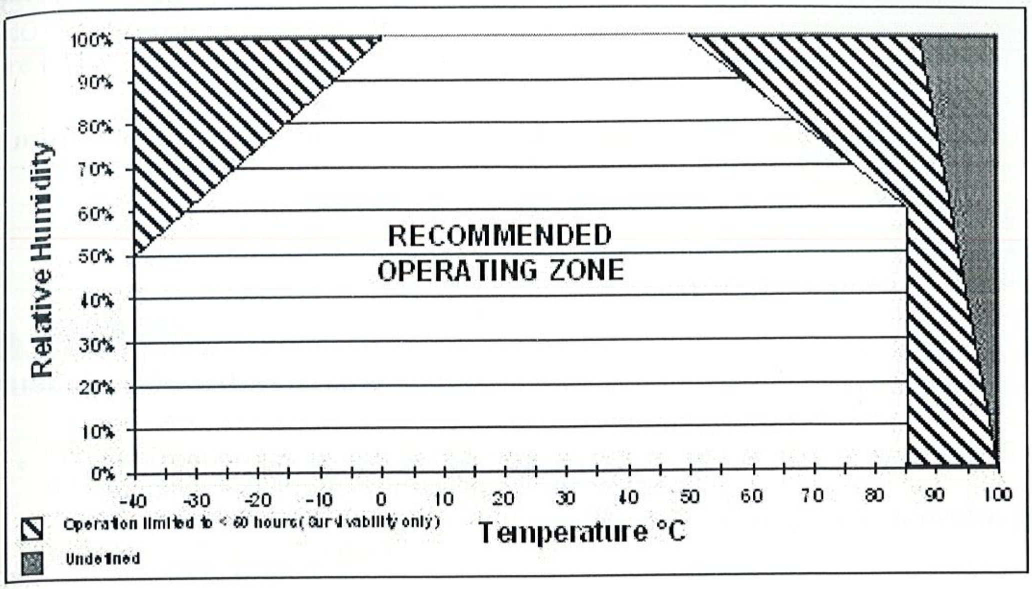


Honeywell

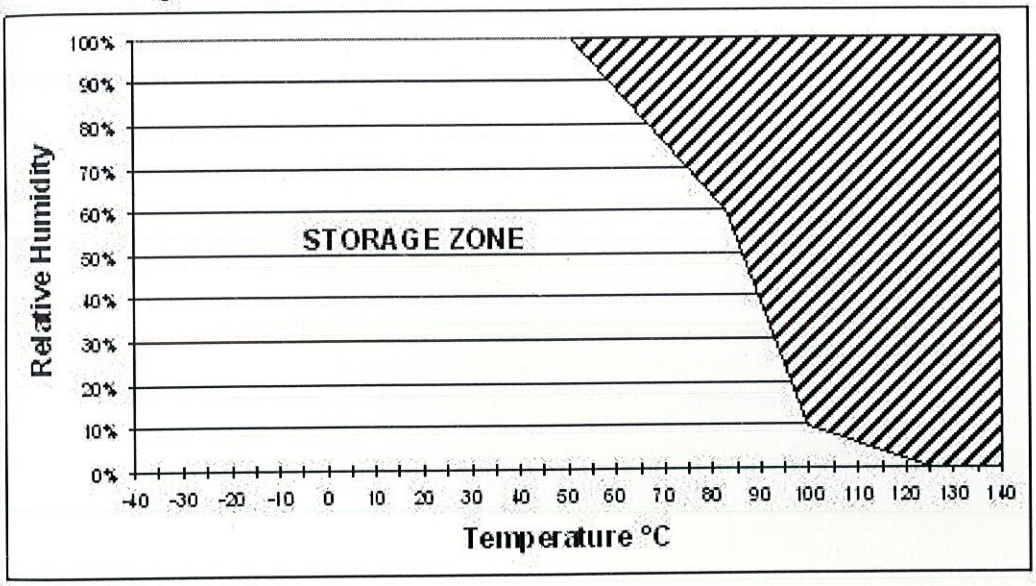
HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

Recommended Operating Conditions



Storage Environment



Honeywell

HIH-4000-001

HIH-4000 Series Integrated Circuity Humidity Sensor, 2,54 mm (0.100 in) Lead Pitch SIP

⚠ WARNING

PERSONAL INJURY

DO NOT USE these products as safety or emergency stop devices, or in any other application where failure of the product could result in personal injury.

Failure to comply with these instructions could result in death or serious injury.

⚠ WARNING

MISUSE OF DOCUMENTATION

- The information presented in this product sheet (or catalog) is for reference only. DO NOT USE this document as product installation information.
- Complete installation, operation and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

JHD162A SERIES

CHARACTERISTICS:

DISPLAY CONTENT: 16 CHAR x 2ROW

CHAR. DOTS: 5 x 8

DRIVING MODE: 1/16D

AVAILABLE TYPES:

TN, STN(YELLOW GREEN、GREY、B/W)

REFLECTIVE、WITH EL OR LED BACKLIGHT

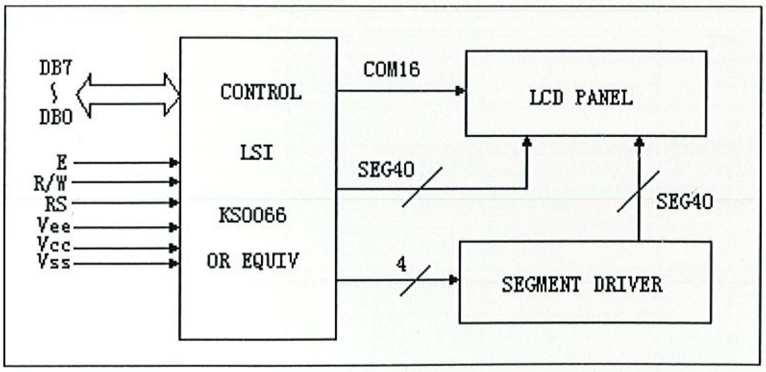
EL/100VAC, 400HZ

LED/4.2VDC

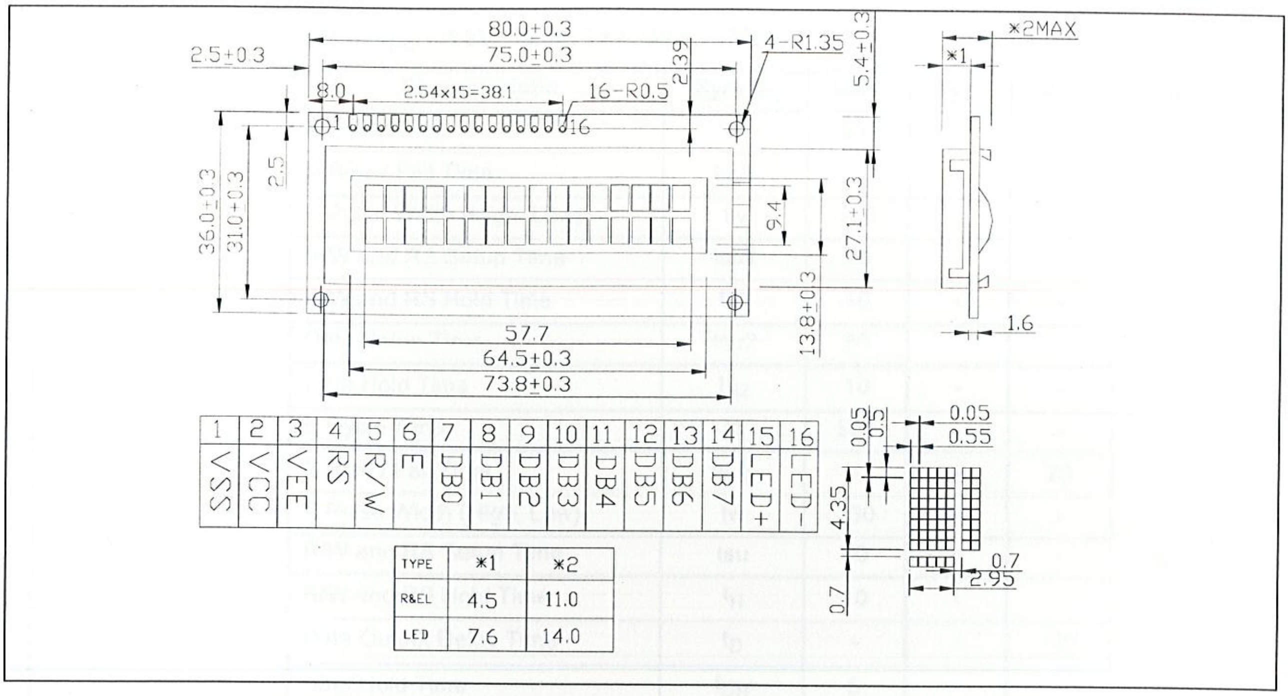
PARAMETER (V_{DD}=5.0V±10%, V_{SS}=0V, T_a=25℃)

Parameter	Symbol	Testing Criteria	Standard Values Min.	Typ.	Max	Unit
Supply voltage	V_{DD}-V_{SS}	-	4.5	5.0	5.5	V
Input high voltage	V_{IH}	-	2.2	-	V_{DD}	V
Input low voltage	V_{IL}	-	-0.3	-	0.6	V
Output high voltage	V_{OH}	$-I_{OH}$=02mA	2.4	-	-	V
Output low voltage	V_{OL}	I_{OL}=1.2mA	-	-	0.4	V
Operating voltage	I_{DD}	V_{DD}=5.0V	-	1.5	3.0	mA

APPLICATION CIRCUIT



DIMENSIONS/DISPLAY CONTENT



PIN CONFIGURATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VSS	VCC	VEE	RS	R/W	E	DB0	DB1	DB2	DB3	DB4	DB5	DB6	DB7	LED+	LED-

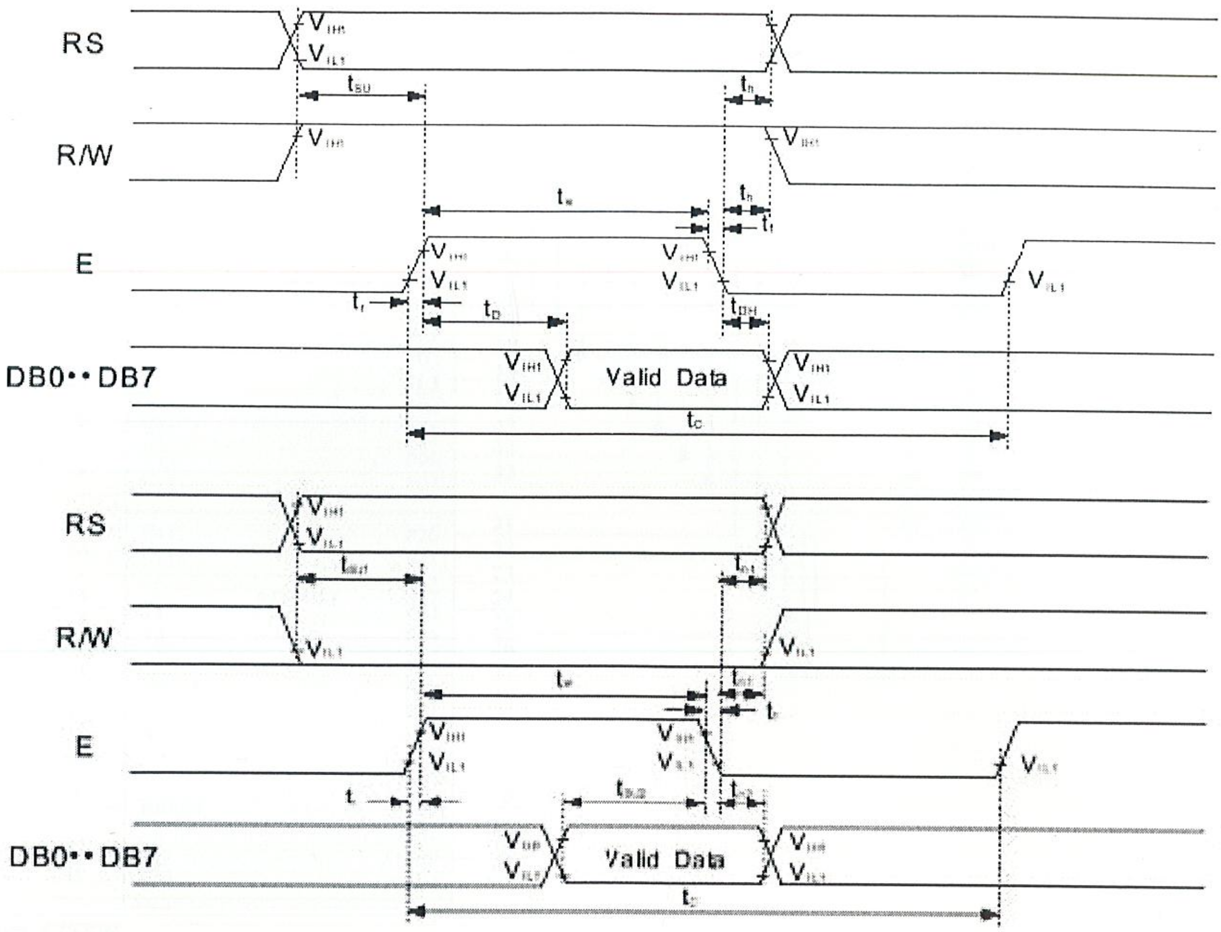
AC Characteristics Read Mode Timing Diagram

Table 12. AC Characteristics (V_{DD} = 4.5V ~ 5.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu1	40	-	-	
	R/W and RS Hold Time	t_{H1}	10	-	-	
	Data Setup Time	tsu2	80	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu	40	-	-	
	R/W and RS Hold Time	t_H	10	-	-	
	Data Output Delay Time	t_D	-	-	120	
	Data Hold Time	t_{DH}	5	-	-	

Table 13. AC Characteristics (V_{DD} =2.7V ~ 4.5V, Ta = -30 ~ +85°C)

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	$t_R$$t_F$	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu1	60	-	-	
	R/W and RS Hold Time	t_{H1}	20	-	-	
	Data Setup Time	tsu2	195	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	1000	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	25	
	E Pulse Width (High, Low)	tw	450	-	-	
	R/W and RS Setup Time	tsu	60	-	-	
	R/W and RS Hold Time	t_H	20	-	-	
	Data Output Delay Time	t_D	-	-	360	
	Data Hold Time	t_{DH}	5	-	-	

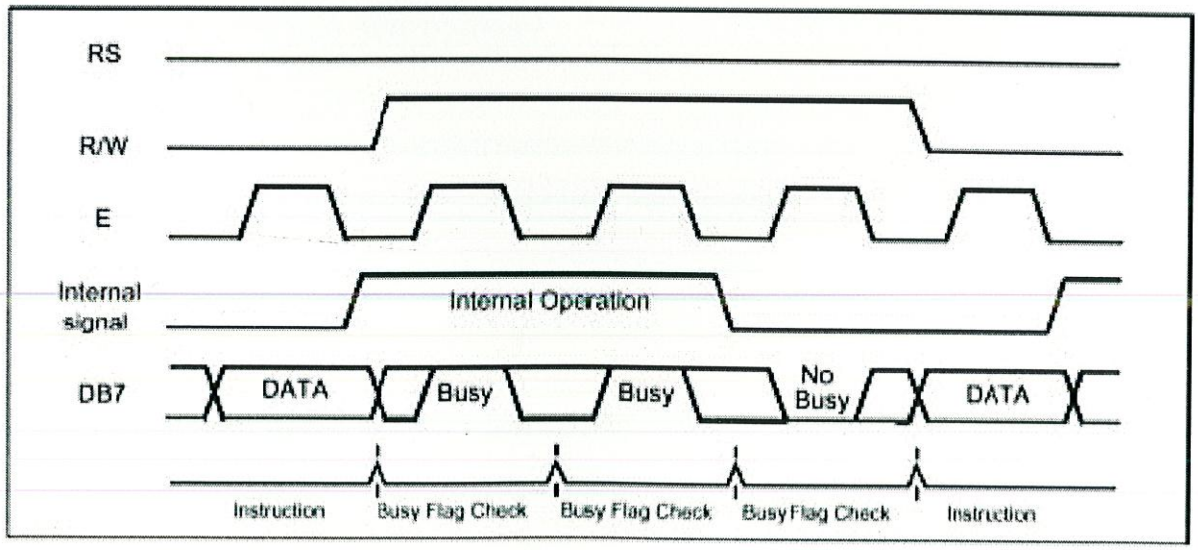


Write Mode Timing Diagram

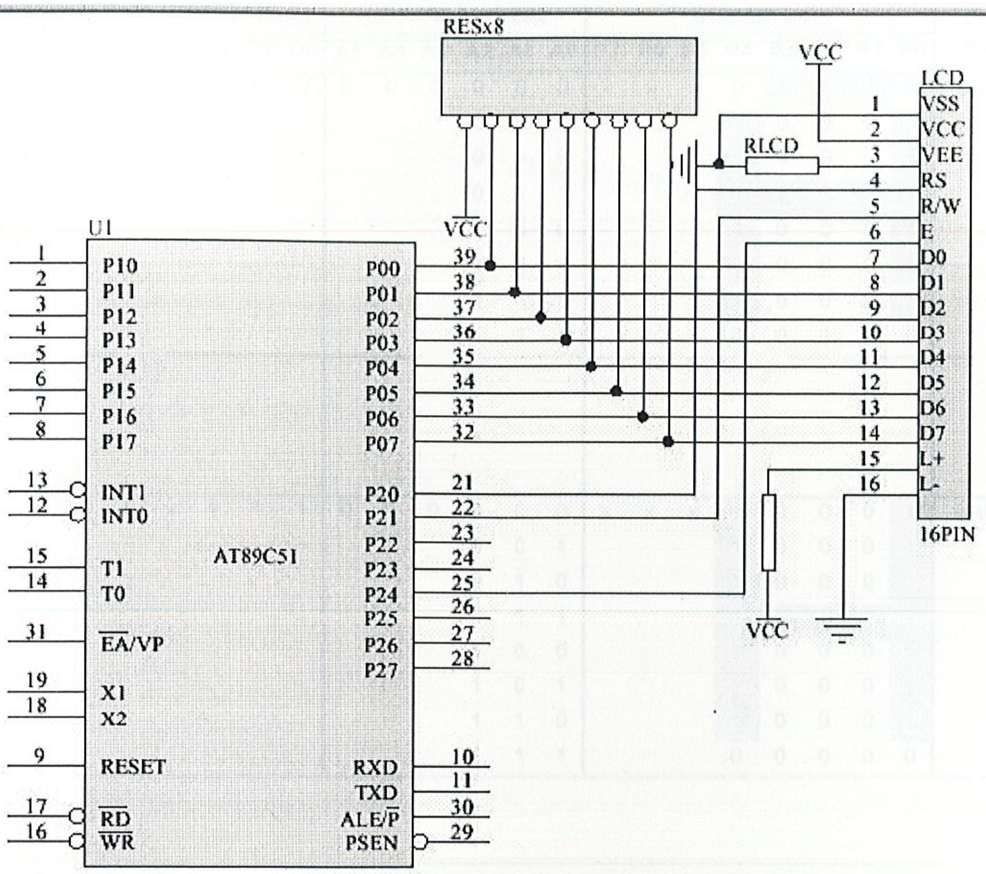
Timing

1) Interface with 8-bit MPU

When interfacing data length are 8-bit, transfer is performed at a time through 8 ports, from DB0 to DB7. Example of timing sequence is shown below.



Connection



CGROM

Table 5. Relationship between Character Code (DDRAM) and Character Pattern (CGRAM)

Character Code (DDRAM data)								CGRAM Address						CGRAM Data								Pattern number
D7	D6	D5	D4	D3	D2	D1	D0	A5	A4	A3	A2	A1	A0	P7	P6	P5	P4	P3	P2	P1	P0	
0	0	0	0	×	0	0	0	0	0	0	0	0	0	×	×	×	0	1	1	1	0	pattern 1
											0	0	1				1	0	0	0	1	
											0	1	0				1	0	0	0	1	
			⋮						⋮		0	1	1		⋮		1	1	1	1	1	
											1	0	0				1	0	0	0	1	
											1	0	1				1	0	0	0	1	
											1	1	0				1	0	0	0	1	
											1	1	1				0	0	0	0	0	
			⋮								⋮							⋮				⋮
0	0	0	0	×	1	1	1	0	0	0	0	0	0	×	×	×	1	0	0	0	1	pattern 8
											0	0	1				1	0	0	0	1	
											0	1	0				1	0	0	0	1	
			⋮						⋮		0	1	1		⋮		1	1	1	1	1	
											1	0	0				1	0	0	0	1	
											1	0	1				1	0	0	0	1	
											1	1	0				1	0	0	0	1	
											1	1	1				0	0	0	0	0	

Example

```
#include <reg51.h>
#include <intrins.h>
sbit dc=0xa0;          /*P2.0  LCD 的 RS   21*/
sbit rw=0xa1;          /*P2.1  LCD 的R/W 22*/
sbit cs=0xa4;          /*P2.4  LCD 的 E    25*/
sfr  lcdbus=0x80;     /*p0LCD 数据 D0=P0.0*/
unsigned int sys10mscounter;
unsigned char syslimitcounter;
char path1[8]={0x00,0x1f,0x00,0x1f,0x00,0x1f,0x00,0x1f};/*自定义符号    横1*/
char path2[8]={0x1f,0x00,0x1f,0x00,0x1f,0x00,0x1f,0x00};/*自定义符号    横2*/
char pats1[8]={0x15,0x15,0x15,0x15,0x15,0x15,0x15,0x15};/*自定义符号    竖1*/
char pats2[8]={0x0a,0x0a,0x0a,0x0a,0x0a,0x0a,0x0a,0x0a};/*自定义符号    竖2*/
void soft_nop(){}
void soft_10ms()/***********12MHZ  提供10MS  软件延时************/
{     register int i;
for(i=0;i<711;i++);
```

```
}
void soft_20ms()/***********12MHZ 提供20MS 软件延时************/
{     soft_10ms();
soft_10ms();
}
void hard_10ms(unsigned int delaytime) /*基于10MS 的硬件延时*/
{     sys10mscounter=delaytime;
while(sys10mscounter);
}
unsigned char data lcdcounter;
bit lcdusing1,lcdusing2;
bit lcd_checkbusy()/*检查LCD 忙*/
{     register lcdstate;
      dc=0;                     /*dc=1为数据,=0 为命令.*/
      rw=1;                     /*rw=1为读,=0 为写.*/
      cs=1;                     /*cs=1选通.*/
soft_nop();
lcdstate=lcdbus;
cs=0;
return((bit)(lcdstate&0x80));
}
void lcd_wrcmd(unsigned char lcdcmd) /*写LCD 命令*/
{     lcdusing1=1;
while(lcd_checkbusy());
lcdbus=lcdcmd;
        dc=0;           /*dc=1为数据,=0 为命令.*/
        rw=0;           /*rw=1为读,=0 为写.*/
        cs=1;           /*cs=1选通.*/
soft_nop();

     cs=0;
     lcdbus=0xff;
     lcdusing1=0;

}
            void lcd_moveto(char position) /*移动光标到指定位.0-79*/
            { register cmd=0x80;

       lcdcounter=position;
            if (position > 59)
            position += 0x18;
            else
```

```
        {   if (position > 39)position -= 0x14;
             else
             {                    if (position > 19)position += 0x2c;
             }
        }

    cmd=cmd|position;
    lcd_wrcmd(cmd); } void lcd_wrdata(char lcddata) /*在当前显示位置显示数据*/ { char i;
    lcdusing2=1;
    while(lcd_checkbusy());
    if(lcdcounter==20){

        lcd_moveto(20);
        while(lcd_checkbusy());
        }

    if(lcdcounter==40){
        lcd_moveto(40);
        while(lcd_checkbusy());
        }

    if(lcdcounter==60){
        lcd_moveto(60);
        while(lcd_checkbusy());
        }

    if(lcdcounter==80){
        lcd_moveto(0);
        while(lcd_checkbusy());
        lcdcounter=0;
        } /*为通用而如此*/

    lcdcounter++;
    lcdbus=lcddata;
    dc=1; /*dc=1为数据,=0 为命令.*/
    rw=0; /*rw=1为读,=0 为写.*/
    cs=1; /*cs=1选通.*/
    soft_nop();
    cs=0;

    lcdbus=0xff;
    lcdusing2=0; } void lcd_string(char *strpoint) /*在当前显示位置显示LCD 字符串*/
{ register i=0;
    while(strpoint[i]!=0){
```

```
            lcd_wrdata(strpoint[i]);
            i++;
            }

} void lcd_init()/*初始化*/

{   lcd_wrcmd(0x38);        /*设置8 位格式,2 行,5*7*/
    lcd_wrcmd(0x0c);        /*整体显示,关光标,不闪烁*/
    lcd_wrcmd(0x06);        /*设定输入方式,增量不移位*/
    lcd_wrcmd(0x01);        /*清除显示*/
    lcdcounter=0;
}

void lcd_cls()/*清除显示*/ { lcd_wrcmd(0x01);
     lcdcounter=0; } void timer0(void) interrupt 1 /*T0 中断*/ { TH0=0xd8; /*12M,10ms*/
     TL0=0xf6;
     TR0=1;
     if(sys10mscounter!=0)sys10mscounter--; /*定时器10ms*/
     if(syslimitcounter!=0)syslimitcounter--; /*定时器10ms*/

}
             main()
             {
             unsigned char j;
             IE=0;P0=0xff;P1=0xff;P2=0xff;P3=0xff; /*初始化T*/
             lcd_init();soft_20ms();
             TMOD=0x51;
             TH0=0xd8; /*12M,10ms*/
             TL0=0xf6;
             TR0=1;ET0=1;EA=1;

     while(1)
     {
     /*全黑横一横二竖一竖二U Q ABCD... */
     lcd_init(); /*全黑*/
     for(j=0;j<80;j++){lcd_wrdata(0xff);}
     hard_10ms(50);
     lcd_init(); /*横一可参考自行设计符号*/
     lcd_wrcmd(0x40);
     for(j=0;j<8;j++)lcd_wrdata(path1[j]);

     for(j=0;j<100;j++)lcd_wrdata(0);
     hard_10ms(50);
     lcd_init(); /*横二*/
```

```
        lcd_wrcmd(0x40);
        for(j=0;j<8;j++)lcd_wrdata(path2[j]);
        for(j=0;j<100;j++)lcd_wrdata(0);
        hard_10ms(50);
        lcd_init(); /*竖一*/
        lcd_wrcmd(0x40);
        for(j=0;j<8;j++)lcd_wrdata(pats1[j]);
        for(j=0;j<100;j++)lcd_wrdata(0);
        hard_10ms(50);
        lcd_init(); /*竖二*/
        lcd_wrcmd(0x40);
        for(j=0;j<8;j++)lcd_wrdata(pats2[j]);
        for(j=0;j<100;j++)lcd_wrdata(0);
        hard_10ms(50);
        lcd_init();
        lcd_string("UUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUU
        UUUUUUUUUUUUUUUUUUUUUUUU

    UUUUU"); hard_10ms(50); lcd_init();
        lcd_string("QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
        QQQQQQQQQQQQQQQQQQQQQQQQ
    QQQQQ"); hard_10ms(50); lcd_init();
        lcd_string("ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789abcdefghijklmnopqrstuvwx
        yz0123456789+-!
    #$%&?"); hard_10ms(50); }
    }
```

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

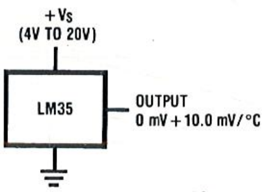
General Description

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

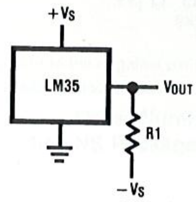
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
-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

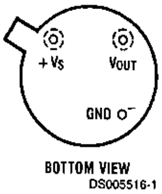
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

 DS005516

Connection Diagrams

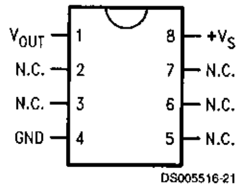
TO-46
Metal Can Package*



*Case is connected to negative pin (GND)

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

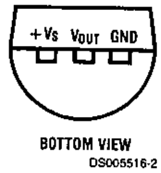
SO-8
Small Outline Molded Package



N.C. = No Connection

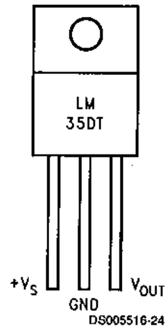
Top View
Order Number LM35DM
See NS Package Number M08A

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)	$T_{MIN} \leq T_A \leq T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	˚C
Sensor Gain (Average Slope)	$T_{MIN} \leq T_A \leq T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/˚C
Load Regulation (Note 3) $0 \leq I_L \leq 1$ mA	T_A=+25˚C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN} \leq T_A \leq T_{MAX}$	**±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
	$4V \leq V_S \leq 30V$	**±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)	$4V \leq V_S \leq 30V$, +25˚C	0.2	2.0		0.2	2.0		μA
	$4V \leq V_S \leq 30V$	**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: $-55˚C \leq T_J \leq +150˚C$ for the LM35 and LM35A; $-40˚ \leq T_J \leq +110˚C$ for the LM35C and LM35CA; and $0˚ \leq T_J \leq +100˚C$ 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*.

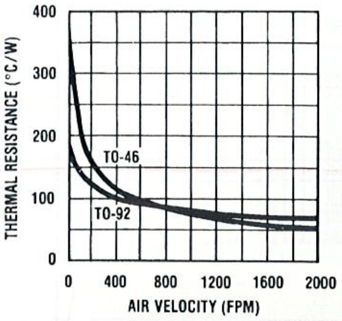
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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.

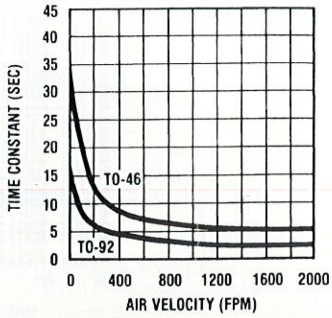
Typical Performance Characteristics

Thermal Resistance Junction to Air



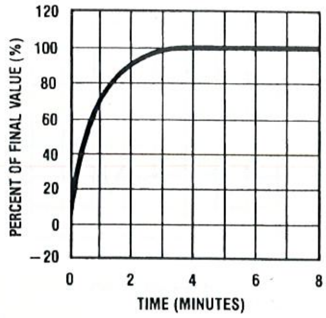
DS005516-25

Thermal Time Constant



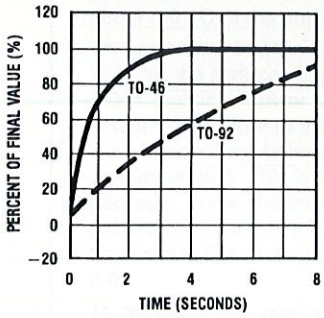
DS005516-26

Thermal Response in Still Air



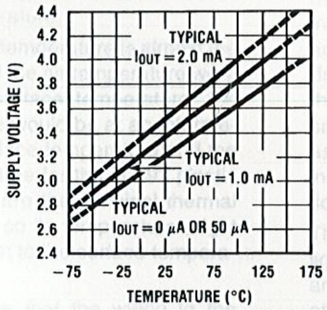
DS005516-27

Thermal Response in Stirred Oil Bath



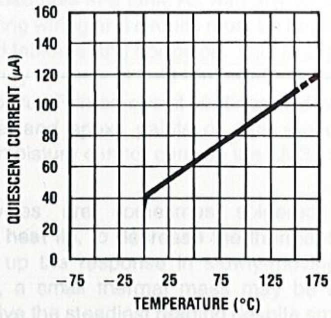
DS005516-28

Minimum Supply Voltage vs. Temperature



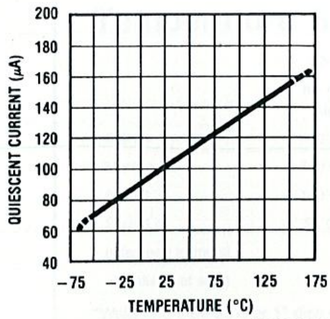
DS005516-29

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



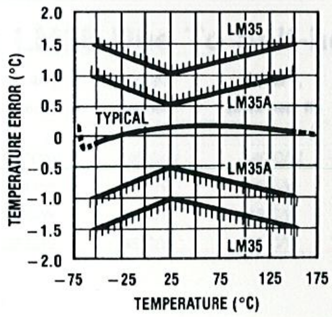
DS005516-30

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



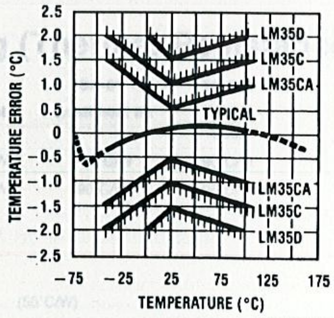
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

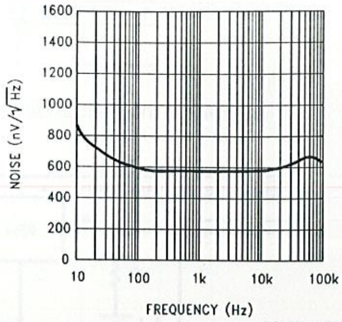
Accuracy vs. Temperature (Guaranteed)



DS005516-33

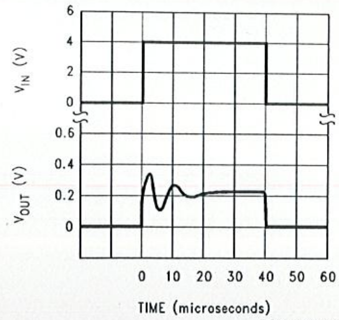
Typical Performance Characteristics (Continued)

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.

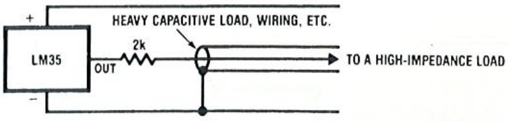
Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	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.

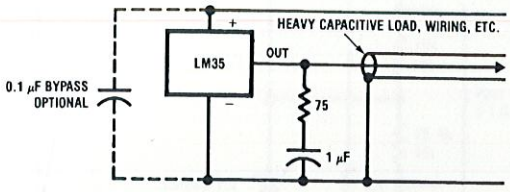
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications



DS005516-19

FIGURE 3. LM35 with Decoupling from Capacitive Load



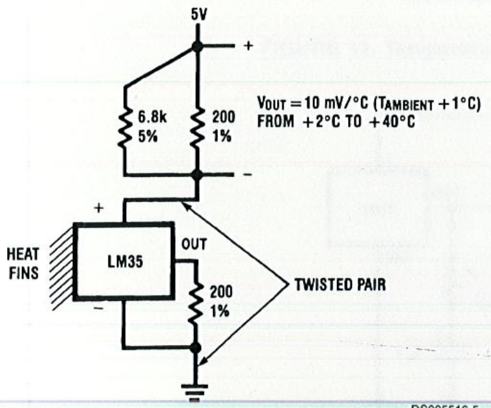
DS005516-20

FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

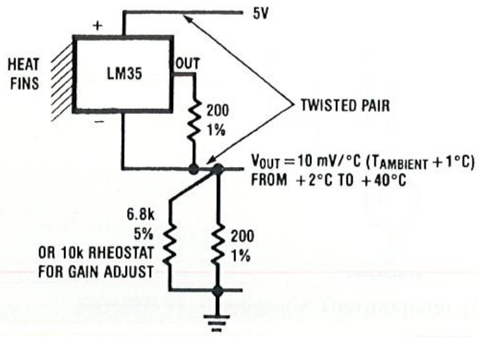
Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance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



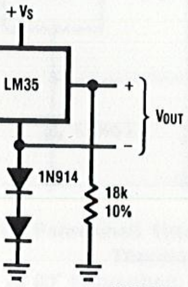
DS005516-5

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



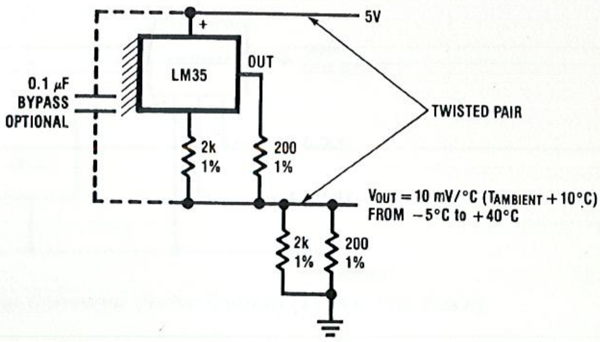
DS005516-6

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



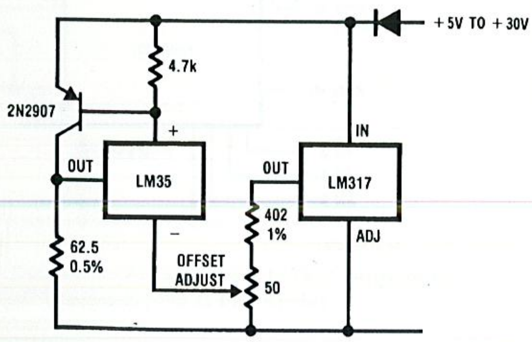
DS005516-7

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



DS005516-8

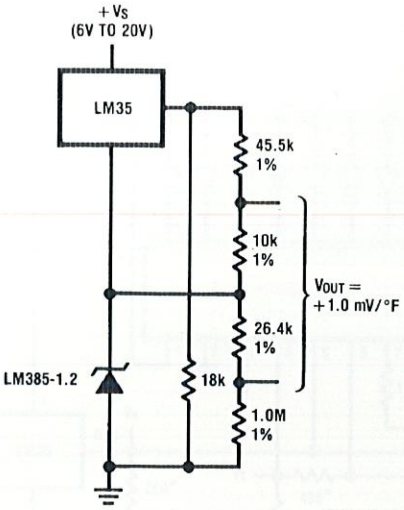
FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



DS005516-9

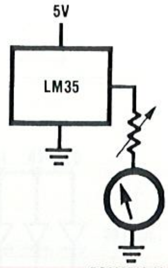
FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

Typical Applications (Continued)



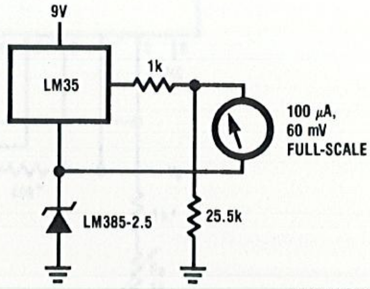
DS005516-10

FIGURE 10. Fahrenheit Thermometer



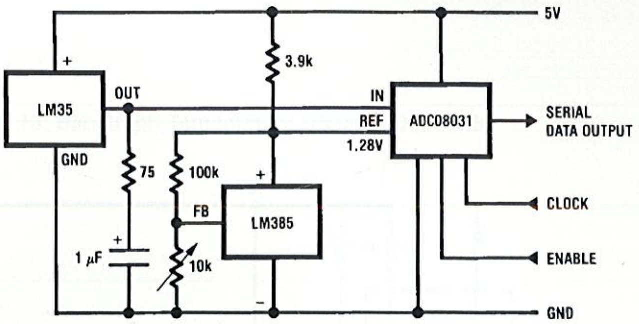
DS005516-11

FIGURE 11. Centigrade Thermometer (Analog Meter)



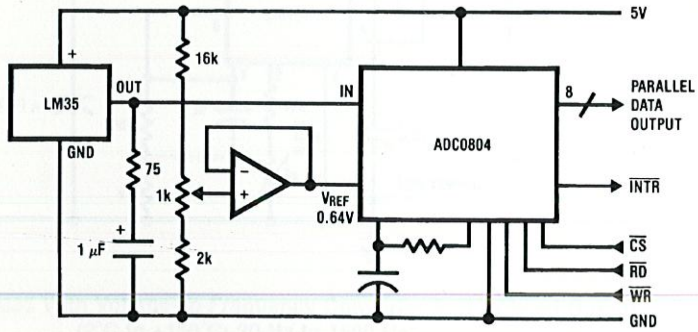
DS005516-12

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



DS005516-13

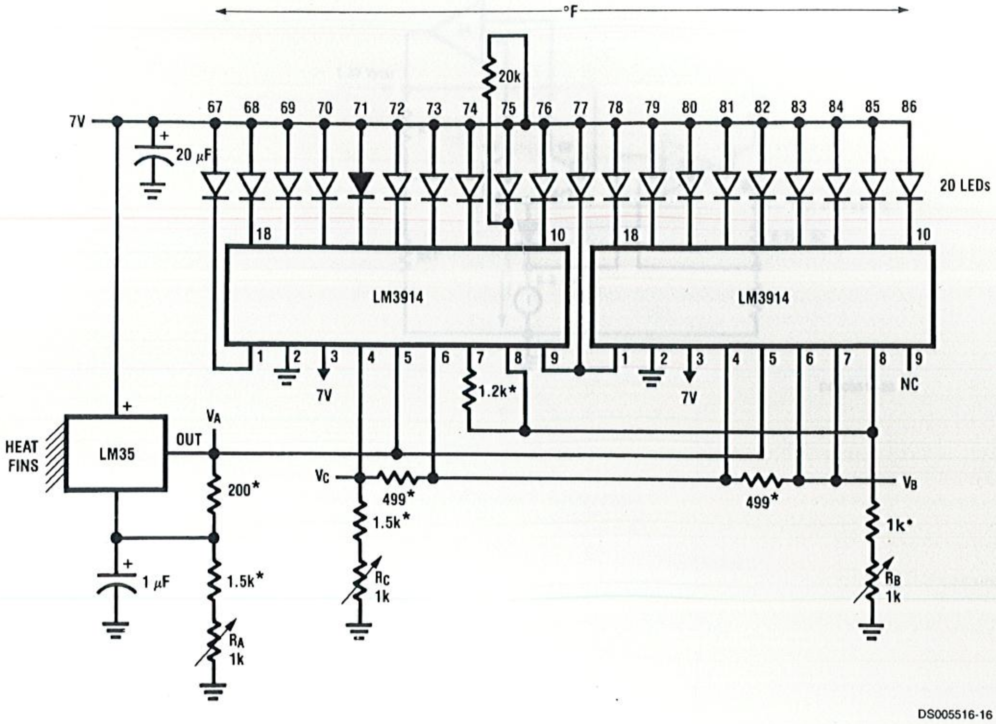
FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)



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)



*=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)

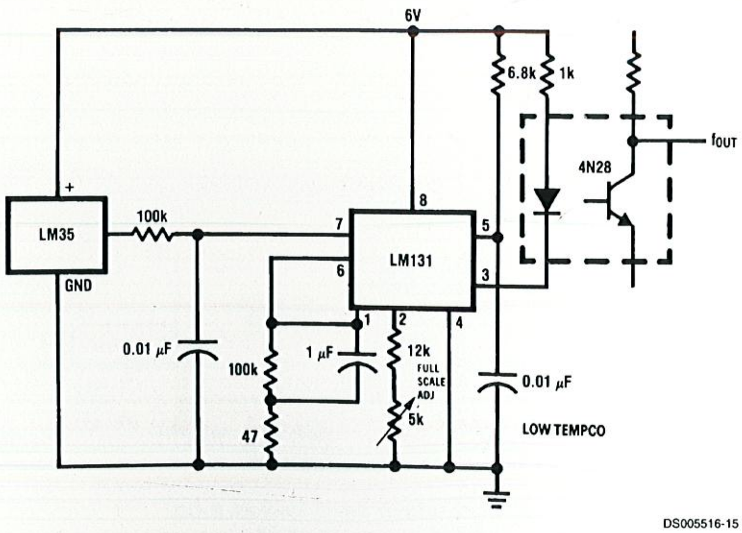
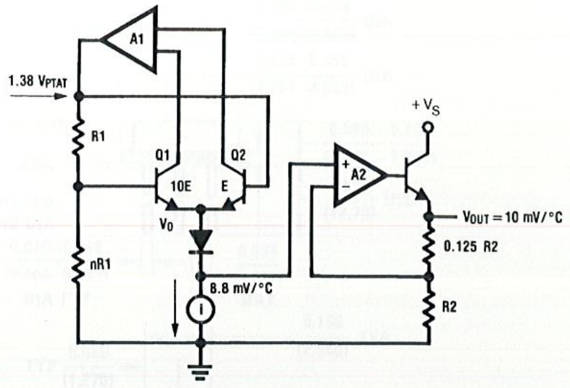


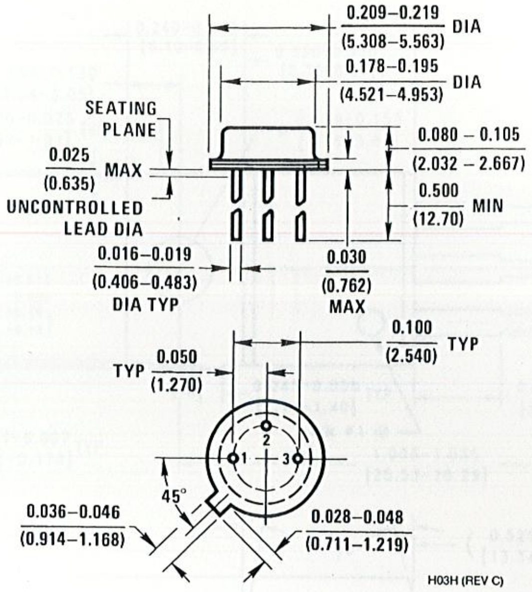
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2°C to +150°C; 20 Hz to 1500 Hz)

Block Diagram

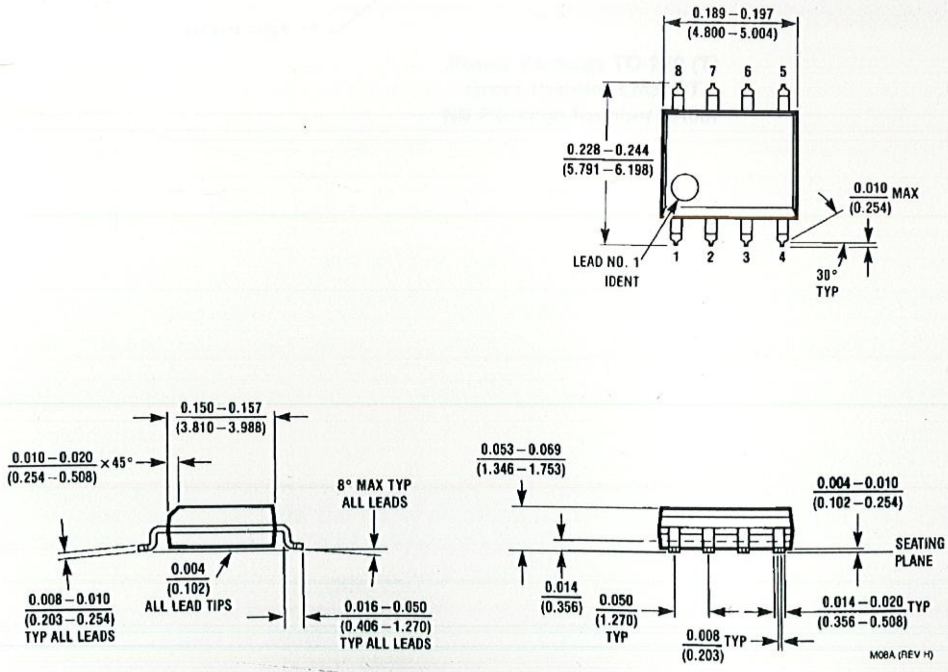


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

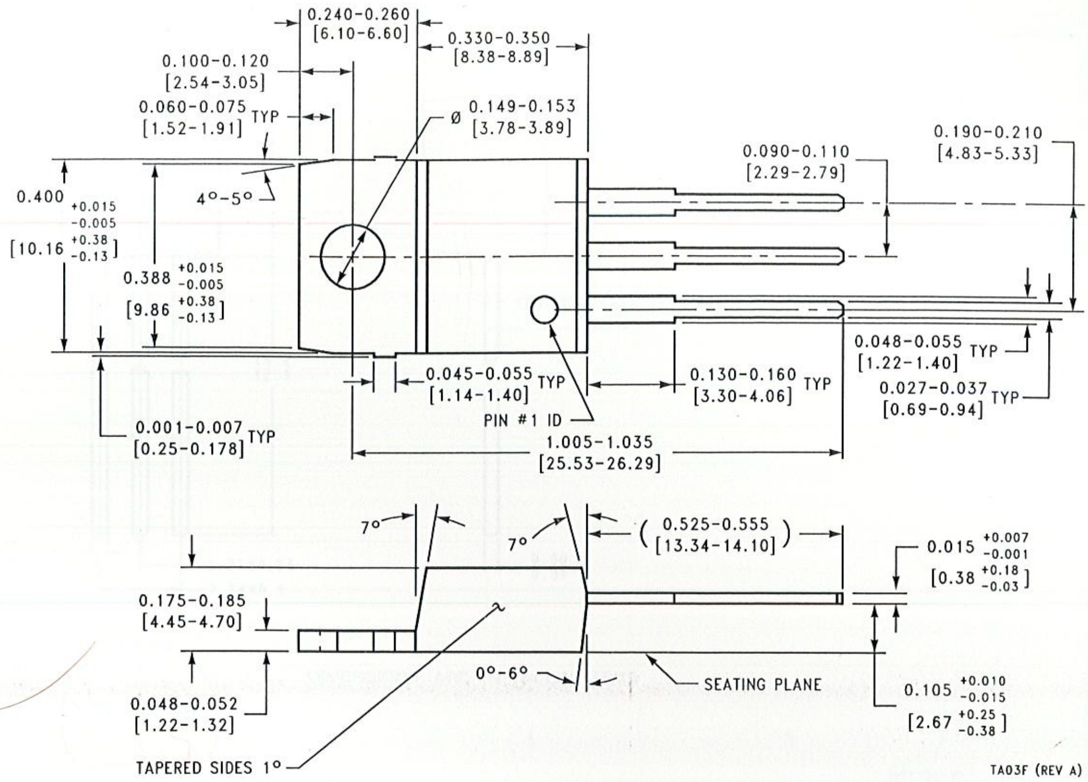


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



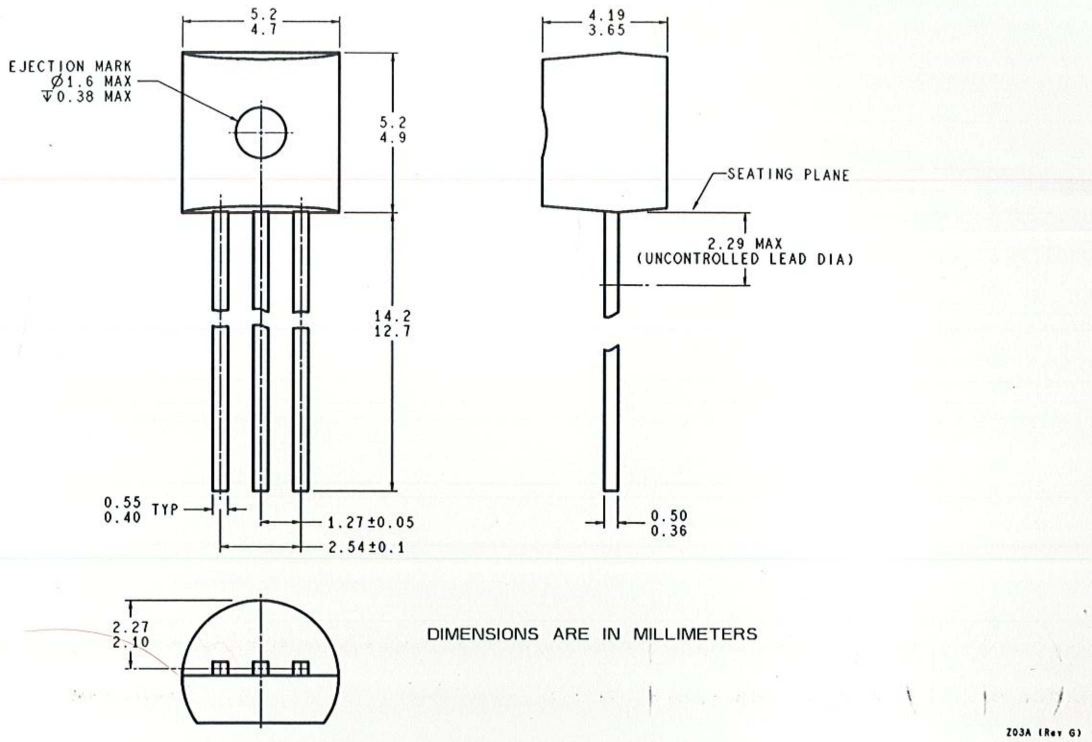
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

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