TPC TEMPERATURE

The TPC is equipped with a system of 120 thermocouple devices used to measure the temperature of the end wheels, FEE and RDO cooling manifolds. The system was initially installed by Wayne Betts and Mike Anderson in 1999-2000. The main purpose of the system was to look for temperature gradients across the end wheels, and most important, to look for hot spots on the cooling manifolds. Since the manifolds are Aluminum there is a danger that cooling water with a low pH could cause corrosion and clog the manifolds. So far we have not seen evidence of this.

The original readout of this system was by a PC on the platform, but in 2003 the PC was replaced by a stand alone readout box based on a microprocessor. This new system was designed and installed by Peter Kravtsov, who also did the gas system readout PC.

HARDWARE

The small readout box is kept inside Rack 2A4 at the bottom (this is where the cables from the thermocouples terminate. The box is powered by an AC/DC converter and has a small LCD display which shows the sensor number and temperature. The box is readout via an RS232 serial cable, which goes to the transition module for a VME processor in rack 2A7. The processor is in the non-CANBUS crate that was added last year. The processor is on port 9012 of the terminal server, and also reads out the status of the TPC AB interlock system. Since this crate is not on the CANBUS chain one can only reboot the processor by logging in, or by using the remote power switch to cycle power.

The readout display of the 120 temperatures is accessible from the TPC top level GUI. Click on “TPC TEMPERTURE” and the temperature GUI will come up:

tpc_temp.adl

	Inner			Outer		
	Wheel	FEE	RDO	Wheel	FEE	RDO
1	73.5	74.2	73.9	73.2	73.2	72.8
2		73.0	73.1		73.1	61.5
3	74.0	73.3	73.1	73.1	74.2	73.1
4		70.1	73.6		75.1	73.4
5	63.4	47.8	47.6	72.7	74.1	73.0
6		75.3	72.8		73.1	74.2
7	74.1	72.8	73.1	72.8	72.9	74.2
8		74.0	72.8		73.1	72.8
9	73.7	73.2	72.9	73.3	75.0	72.1
10		75.1	73.7		74.1	73.9
11	73.9	72.7	73.1	74.2	75.1	73.3
12		74.2	75.0		73.2	72.9
13	73.6	73.1	72.9	73.1	73.1	73.1
14		73.4	72.9		72.8	72.9
15	73.8	72.9	72.9	71.1	73.4	73.0
16		73.2	75.1		68.2	73.2
17	73.8	73.3	72.8	71.1	73.4	72.9
18		74.1	75.0		75.0	74.2
19	74.0	73.0	74.2	73.5	73.3	73.3
20		73.2	73.1		72.9	73.7
21	73.5	72.9	72.7	72.8	72.8	72.8
22		74.0	73.0		73.4	75.1
23	73.8	75.0	73.0	74.1	73.4	73.0
24		72.8	72.9		75.1	71.9

Average: 72.8

Since the TPC cooling water is regulated at ~ 74 deg F most of the sensors should be near this value. Note the readings for inner 5 are clearly incorrect – they have been this way since the new readout system was installed.

In the early RHIC runs we used to see a ~ 2 degree F rise in the FEE and RDO manifold temperatures when the FEEs were powered on. We then added more plates to the TPC water skid heat exchanger and we no longer see this rise. Note that TPC water exchanges heat with the STAR modified chilled water system, which is usually kept at ~ 62 degrees F. However, for running during hot weather, MCW is sometimes raised to 65 or 66, to avoid condensation in the hall. For those times one should watch the TPC temperature for any rise.

These temperatures are archived by the Slow Controls archiver and are also input into the TPC alarm handler.

There are two manuals which document this system:

1. "STAR TPC Temperature Monitoring System" by Betts, Anderson and Wieman describes the sensors and their placement.

2. "Temperature Monitor Manual" by Kravtsov which describes the readout box.

The thermocouples are glued in place and the cable that attaches to each one is not robust. We usually check these connections before each run, especially if there has been extensive work at the TPC endcaps.

STAR TPC Temperature Monitoring System

Wayne Betts (BNL), Mike Anderson (UC-Davis), Howard Wieman (LBNL)

Introduction

We have installed a temperature measurement system on the TPC in order to diagnose cooling (or heating) problems before any damage is done to the TPC electronics (or in extreme cases, damage to the TPC itself). A total of one hundred twenty temperature sensors are on the East and West sector mounting wheels and on the FEE and RDO cooling manifolds. These sensors are readout using an A/D card in a PC and the results (including periodic historical readings) are available on the WWW. The temperature measurements are also placed on a shared disk accessible by Slow Controls for storage in the data stream and the possibility of setting alarms.

Locations

The sector mounting wheels at the two ends of the TPC each have twelve temperature sensors. Each side has six located near the inner radius (referred to as the 'Inner Wheel') and six more located on the boundary between the inner and the outer sectors (referred to as the 'Outer Wheel'). See the picture below for the locations and numbering.

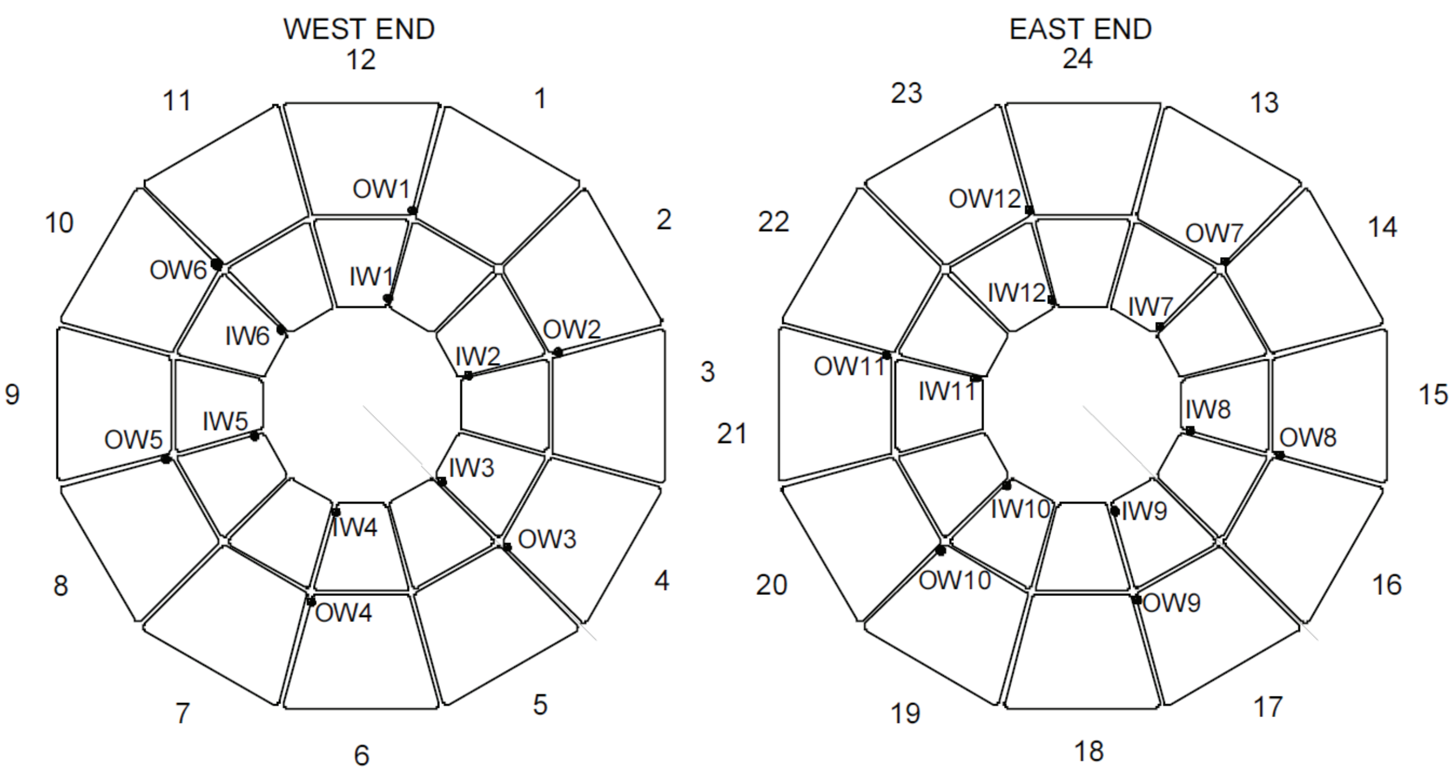


Figure 1. Mounting wheel temperature locations. Each end of the TPC has twelve temperature sensors in the locations shown in the figure.

Each FEE and RDO manifold has one sensor. The sensor locations were chosen to try to diagnose potential cooling (or heating) problems before they become serious. They have been placed in the region most likely to have reduced water flow in the event of particulate buildup in the manifolds (which unfortunately is usually not the same region in which any trapped air is likely to impede flow). The manifolds have water input and output on opposite sides. The sensors are placed on the same side of the manifold as the water exhaust but at the 'dead' end of that side. Figure 2 illustrates a typical layout.

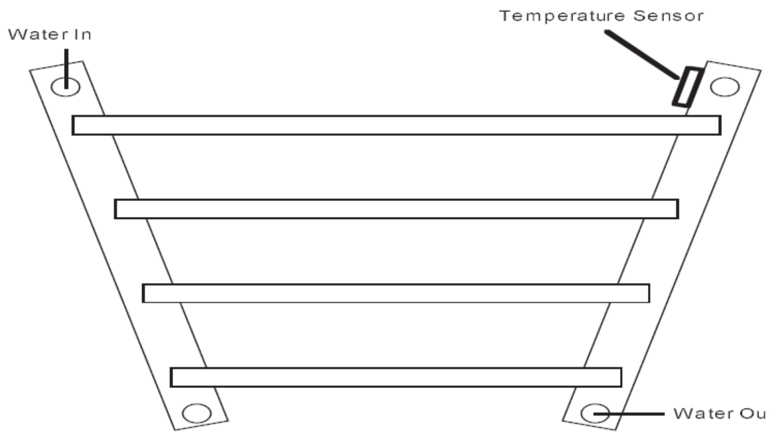


Figure 2. Temperature sensor locations on the TPC electronics manifolds. The sensors are positioned on the same side of the manifold as the water output, but on the far end. The brass mounting base (described later) is epoxied onto the water manifold.

Sensor Description and Readout System

The measurement system uses National Semiconductor LM34CAZ integrated circuit temperature sensors[1] in the circuit shown in Figure 3. The LM34, resistor and capacitor are all captured in an epoxy cast on a ⅛" thick brass 'sled' about 1½"x ⅝". One end of the sled is bent upwards at about 40° to allow for easy removal once it is epoxied to the manifold.

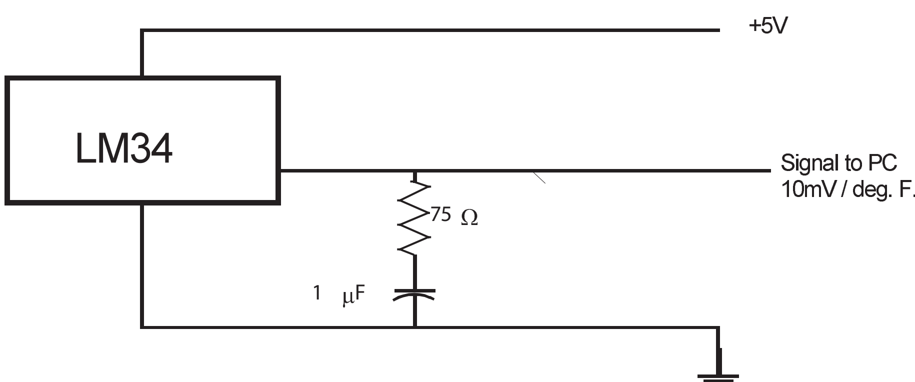


Figure 3. The circuit with an R-C damper used to measure the temperatures.

[1] More information on this device can be found at http://www.national.com/pf/LM/LM34.html

The low voltage, ground and temperature signal are carried on ribbon cables running between the endcaps and an interface box in Rack 2A4 on the South Platform. Five volts is supplied by a standard wall outlet transformer, which plugs directly into the interface box. The interface box has twenty-four DB-9 connectors, each of which serves five sensors (one pin for each signal plus a common ground and +5V). The 120 signal pins on the DB-9 connectors are connected inside the interface box to four DB-37 connectors, which in turn are cabled to the four computer A/D cards. The exact pin mapping is included in Attachment 1 in case there is need for troubleshooting or upgrades in the future.

The A/D cards are NuDAQ ACL-8113 units[2], each with 32 isolated 12-bit channels. The PC is a Pentium 90 running Microsoft Windows NT 4.0 (w/ Service Pack 5 as of this writing) which also sits on the second floor of the South Platform. Since physical access to this computer is subject to RHIC access controls, a remote desktop can be obtained using a VNC Viewer (requires the password). The readout is done by a C++ program that runs continuously and writes out the results to files. Several files hold information from the most recent measurements, and a history file holds a periodic sample of measurements indefinitely. Additionally, the C++ code invokes a Perl program that generates a new Temperature Homepage (described below) for each new set of temperatures. Routine access to the measurements is performed through the WWW in a manner described later. Several parameters of the readout code can be set at start time, such as the frequency of measurements (typically once per minute), how often to write an event to the history file (every 57 events, which is approximately one hour) and what temperature range should be considered normal (typically 68-78ºF). If any temperature is found to be outside of the specified range, a special event is written to the history file and the web page display clearly shows the out-of-bounds condition. At this time however, there are no automatic actions taken when an out-of-bounds temperature is detected other than updating the Web display. In the near term, it is expected that the temperature homepage will be checked sufficiently often to avoid any serious problems. At some point in the future, Slow Controls will include automatic monitoring of the temperatures and generate alerts when necessary.

WWW Display Setup

The TPC Temperature Homepage is accessed at http://tpctemp.star.bnl.gov/. This page displays the most recent measurements, including the highest and lowest temperature, the overall average temperature and the time the measurements were made. Temperature values that fall outside the acceptable range are displayed in bold and color coded (red for high temperatures, blue for cold temperatures). Special events are recorded whenever the temperature service is started, or when a temperature crosses the normal temperature limits. The most recent special event is displayed by clicking on the appropriately labeled button. Additionally, the six most recent special events can be accessed by name as 'AlertX.txt' where X=1,2,3,4,5 or 6 (one being the most recent). Below the textual information, each of the six sensor location types (such as Inner Wheel or Outer FEE Manifold) has a graph with the most recent measurement from each sensor. These graphs display out-of-bound temperatures in different colors as well. This front page updates itself automatically, if the browser is sufficiently modern. It has been shown to work with MS Internet Explorer 4 and 5 and with Netscape Communicator 4.6 on PCs with Windows. Several Unix systems with various versions of Netscape Navigator 4.xx have been shown to have problems updating the graphs. This appears to be a Navigator feature/bug, for which there may be no solution.

The user can click any of the six graphs in the vicinity of a point (or somewhere in a vertical region around a point) to request a generic history graph for that sensor (50 events starting with the most recent). Alternatively, the user can fill out a form near the bottom of the page to request a history graph. (Hopefully the available parameters are self-explanatory on the web page.) When either method is used to select a history graph, another Perl script (with a CGI interaction to pass the parameters) generates the desired GIF image, displays it in a new window and returns the main browser window back to the Temperature Homepage. This makes it possible to have multiple history graphs open at once, while still looking at the main page. Each history graph is also color-coded and marks special events. The individual history graphs attempt to update themselves every ten minutes. Under normal circumstances, the history file is only updated once an hour, but the history can be updated more frequently in the case of a special event (as defined previously). To prevent historical graphs from clogging the server's disk space, a separate Perl script is automatically started that deletes any GIF images that are more than 2 hours old.

[2] More information on this device can be found at http://www.web-tronics.com/webtronics/32se12bitisa.html

Attachment 1. Cable and Interface Descriptions

Sensor Location	DB-9 Location (Connector Number - Pin Number)	DB-37 Location (Connector Number - Pin Number - ACL9113 Analog Input Number)
Inner Wheel 1 (Sectors 12&1)	1-3	I - 3 - 4
IW2 (S. 2&3)	3-3	I - 13 - 20
IW3 (S. 4&5)	5-3	I - 23 - 7
IW4 (S. 6&7)	7-3	II - 3 - 4
IW5 (S. 8&9)	9-3	II - 13 - 20
IW6 (S. 10&11)	11-3	II - 23 - 7
IW7 (S. 13&14)	13-3	III - 3 - 4
IW8 (S. 15&16)	15-3	III - 13 - 20
IW9 (S. 17&18)	17-3	III - 23 - 7
IW10 (S. 19&20)	19-3	IV - 3 - 4
IW11 (S. 21&22)	21-3	IV - 13 - 20
IW12 (S. 23&24)	23-3	IV - 23 - 7
Outer Wheel 1 (Sectors 12&1)	2-3	I - 8 - 14
OW2 (S. 2&3)	4-3	I - 35 - 27
OW3 (S. 4&5)	6-3	I - 33 - 23
OW4 (S. 6&7)	8-3	II - 8 - 14
OW5 (S. 8&9)	10-3	II - 35 - 27
OW6 (S. 10&11)	12-3	II - 33 - 23
OW7 (S. 13&14)	14-3	III - 8 - 14
OW8 (S. 15&16)	16-3	III - 35 - 27
OW9 (S. 17&18)	18-3	III - 33 - 23
OW10 (S. 19&20)	20-3	IV - 8 - 14
OW11 (S. 21&22)	22-3	IV - 36 - 29
OW12 (S. 23&24)	24-3	IV - 34 - 25
Inner Sector 1 RDO	1-5	I - 5 - 8
IR2	3-1	I - 11 - 16
IR3	3-5	I - 15 - 24
IR4	5-1	I - 21 - 3
IR5	5-5	I - 25 - 11
IR6	7-1	II - 1 - 0
IR7	7-5	II - 5 - 8
IR8	9-1	II - 11 - 16
IR9	9-5	II - 15 - 24
IR10	11-1	II - 21 - 3
IR11	11-5	II - 25 - 11
IR12	1-1	I - 1 - 0
IR13	13-1	III - 1 - 0
IR14	13-5	III - 5 - 8
IR15	15-1	III - 11 - 16
IR16	15-5	III - 15 - 24
IR17	17-1	III - 21 - 3

IR18	17-5	III - 25 - 11
IR19	19-1	IV - 1 - 0
IR20	19-5	IV - 5 - 8
IR21	21-1	IV - 11 - 16
IR22	21-5	IV - 15 - 24
IR23	23-1	IV - 21 - 3
IR24	23-5	IV - 25 - 11
Outer Sector 1 RDO	2-5	I - 32 - 21
OR2	4-1	I - 16 - 26
OR3	4-5	I - 20 - 1
OR4	6-1	I - 26 - 13
OR5	6-5	I - 30 - 17
OR6	8-1	II - 6 - 10
OR7	8-5	II - 32 - 21
OR8	10-1	II - 16 - 26
OR9	10-5	II - 20 - 1
OR10	12-1	II - 26 - 13
OR11	12-5	II - 30 - 17
OR12	2-1	I - 6 - 10
OR13	14-1	III - 6 - 10
OR14	14-5	III - 32 - 21
OR15	16-1	III - 16 - 26
OR16	16-5	III - 20 - 1
OR17	18-1	III - 26 - 13
OR18	18-5	III - 30 - 17
OR19	20-1	IV - 6 - 10
OR20	20-5	IV - 33 - 23
OR21	22-1	IV - 16 - 26
OR22	22-5	IV - 20 - 1
OR23	24-1	IV - 26 - 13
OR24	24-5	IV - 30 - 17
Inner Sector 1 FEE	1-4	I - 4 - 6
IF2	3-2	I - 18 - 30
IF3	3-4	I - 14 - 22
IF4	5-2	I - 22 - 5
IF5	5-4	I - 24 - 9
IF6	7-2	II - 2 - 2
IF7	7-4	II - 4 - 6
IF8	9-2	II - 12 - 18
IF9	9-4	II - 14 - 22
IF10	11-2	II - 22 - 5
IF11	11-4	II - 24 - 9
IF12	1-2	I - 2 - 2
IF13	13-2	III - 2 - 2
IF14	13-4	III - 4 - 6
IF15	15-2	III - 12 - 18
IF16	15-4	III - 14 - 22
IF17	17-2	III - 22 - 5
IF18	17-4	III - 24 - 9
IF19	19-2	IV - 2 - 2
IF20	19-4	IV - 4 - 6
IF21	21-2	IV - 12 - 18

IF22	21-4	IV - 14 - 22
IF23	23-2	IV - 22 - 5
IF24	23-4	IV - 24 - 9
Outer Sector 1 FEE	2-4	I - 31 - 19
OF2	4-2	I - 17 - 28
OF3	4-4	I - 36 - 29
OF4	6-2	I - 27 - 15
OF5	6-4	I - 34 - 25
OF6	8-2	II - 7 - 12
OF7	8-4	II - 31 - 19
OF8	10-2	II - 17 - 28
OF9	10-4	II - 36 - 29
OF10	12-2	II - 27 - 15
OF11	12-4	II - 34 - 25
OF12	2-2	I - 7 - 12
OF13	14-2	III - 7 - 12
OF14	14-4	III - 31 - 19
OF15	16-2	III - 17 - 28
OF16	16-4	III - 36 - 29
OF17	18-2	III - 27 - 15
OF18	18-4	III - 34 - 25
OF19	20-2	IV - 7 - 12
OF20	20-4	IV - 31 - 19
OF21	22-2	IV - 17 - 28
OF22	22-4	IV - 37 - 31
OF23	24-2	IV - 27 - 15
OF24	24-4	IV - 18 - 30

The wire colors connected to the sensors outside of the interface box are described below (some colors are repeated):

Pin/Sensor Number	Signal Color	Ground Color	+5V Color
1	Green	Yellow	Orange
2	Red	Black	Brown
3	Violet	Gray	White
4	Blue	Yellow	Green
5	Orange	Red	Brown

Inside the interface box, the DB-9 pins are connected to the DB-37 in the following colors:

Pin Number	Wire Color
1	Red
2	Orange
3	Yellow
4	Green
5	Blue

For the DB-9 connectors, pin 6 connects to +5V (white wire) and pin 9 is for ground (black wire).

Temperature monitor

Manual

Brookhaven National Laboratory
Version 1.0

By Peter Kravtsov (E-mail: PAKravtsov@lbl.gov)

This document location: http://www-rnc.lbl.gov/~pkravt/pdf/tm_manual.pdf

August 2003

Introduction

STAR TPC detector is equipped by 120 temperature sensors placed on the East and West sector mounting wheels and on the FEE and RDO cooling manifolds. Temperature monitor (Fig. 1) is intended for reading out these sensors and provide temperature information for the slow control. These sensors are grouped by location into six groups: Inner Wheel, Outer Wheel, Inner Sector RDO, Outer Sector RDO, Inner Sector FEE, Outer Sector FEE.

Fig. 1. Temperature monitor.

The device is based on the Atmel AT89S8252 (Fig. 2) microcontroller running at 22.1184 MHz clock frequency. It has 8Kb static RAM to keep the temperature values and all data. There is also internal 2Kb EEPROM in the CPU which is used for keeping sensor names and numbers. Analog signals from the National Semiconductors LM34 sensors go through eight 16-channel multiplexers [MPC506] and instrumentation amplifier [AD711] to 16-bit ADC [ADS7813].

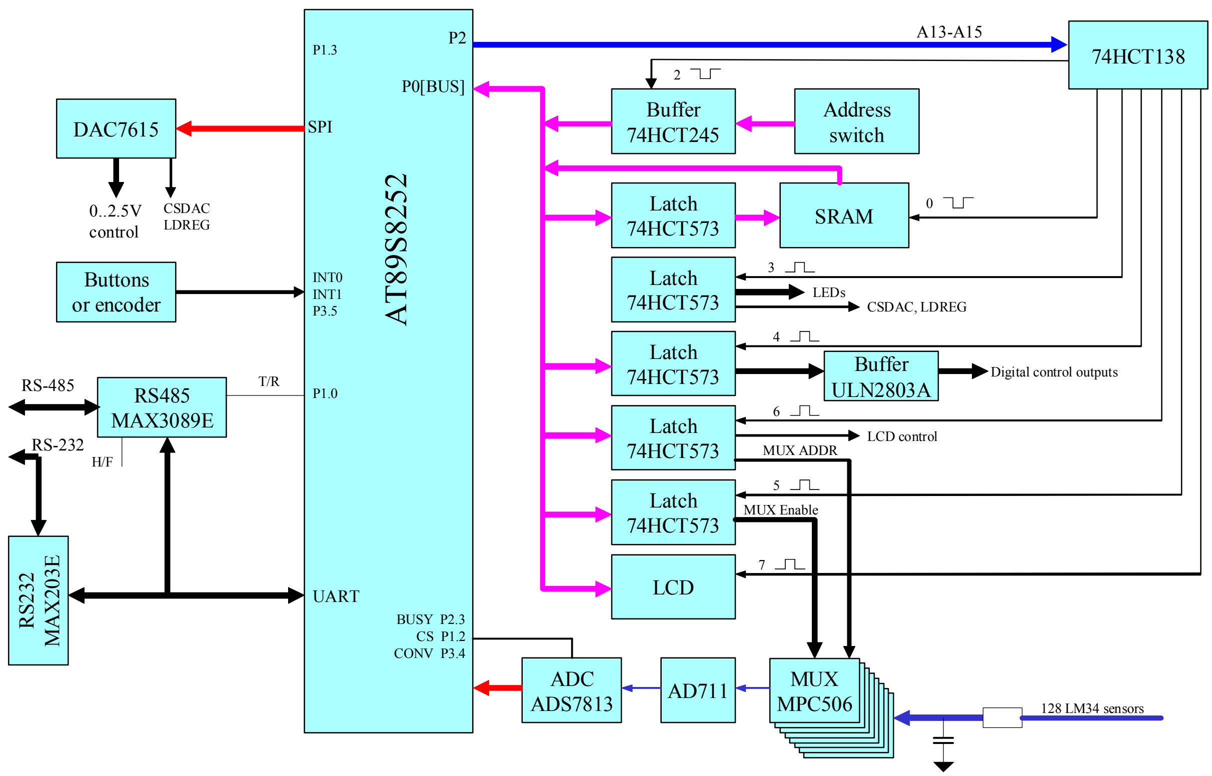


Fig. 2. Temperature monitor function diagram.

All signal lines have RC filters before the multiplexers to avoid long line noise. CPU has internal watch-dog, which attends to controller program faults and resets CPU as fast as in 0.5 s in this case.

Temperature monitor can be connected to PC via standard RS-232 or RS-485 port. Besides, the device is equipped by LCD indicator to display sensors temperature, control buttons, 8+6 open collector digital outputs that can be used in alarms handling procedure. There is a possibility to connect any ±10V sensors to this device. ADC is normally working in 0÷4V range, but this could be changed to 0÷10V or to ±10V range. In spite of single +5V power, multiplexers and amplifiers are powered by ±15V via DC-DC converter [DCP020515D] and can be used for the signals of ±10V range.

Thus input/output features of temperature monitor are the following:

- 128 analog inputs (16-bit, 0÷4V or 0÷10V or ±10V, optional averaging);
- 14 digital outputs (open collector, 500mA maximum current);
- 4 optional analog outputs (12-bit, 0÷2.5V).

There are 26 connectors (9 pin female DSUB marked X1-X26) at the top of temperature monitor to connect all sensors. Each connector has pin 6 connected to +5V for sensors power and pin 9 connected to ground. Pins 1÷5 are used for sensor signals. One additional connector (9 pin male DSUB) connected to 8 digital outputs. Pin 5 of this connector is connected to ground.

Controller software

Controller software is written in C language. It provides reading of 128 sensors with programmed averaging by 1-255 samples, handles communication with the host computer. One of the temperature values is displayed on the LCD. Two buttons are used to scroll the sensors: one selects sensors group (Inner Wheel, Outer Wheel, Inner Sector RDO, Outer Sector RDO, Inner Sector FEE, Outer Sector FEE, Extra 8 sensors) while second one scrolls the sensors of selected group. Sensor names and numbers could be programmed from the host computer and written to the CPU EEPROM.

Optionally controller software also checks all sensors for alarm limits and generates alarm signals.

Serial protocol

Communication protocol consists of two main commands: read memory byte and write memory byte. It could contain also some special commands which are specially described for every device. Protocol is based on 5-byte binary packets exchange. The device sends 5-byte answer for every 5-byte command, if device address field in this command is correct.

Command structure is following:

Byte	Description
1	6-bit device address. Should be equal to device address set on the dip switch inside the device or packet will be ignored otherwise. Two most significant bits are ignored.
2	Bit 7 – read/write bit. Bit 7 = 1 corresponds to write command and bit 7 = 0 – read command. Bit 6 – special command flag. If bit 6 = 1, packet contains special command. Bits 5÷0 – high bits of 14-bits address field.
3	Low byte of 14-bits address field.
4	Data byte.
5	XOR-sum of first 4 bytes. B5=B1^B2^B3^B4. If it is not correct XOR-sum, packet is ignored.

Examples:

1. Host computer wants to read byte at address 0x345 from the device with address 0x02. Device memory contains 0xAA at this address.

```
host request  : 0x02 0x03 0x45 0x00 0x44
device answer : 0x02 0x03 0x45 0xAA 0xEE
```

2. Host computer wants to write byte 0x55 at address 0x1543 to the device with address 0x08 (Note that read/write bit is cleared in the answer).

```
host request  : 0x08 0x95 0x43 0x55 0x8B
device answer : 0x08 0x15 0x43 0x55 0x0B
```

Communication speed could be selected from 9.6, 19.2, 57.6 or 115.2 Kbit/s by dip switch inside the device (see table below). Usually read or write access to the device memory using this protocol takes not more than 2ms for every byte at 115.2 Kbit/s. Memory map is of course different for every device and is specially described as well as additional commands. Byte ordering is little endian, high byte has low address.

Configuration switch description:

Switch position	Description (0=OFF, 1=ON)
1-6	6-bit device address in binary format. Least significant bit is selected by switch position 1. Valid range is 1÷63.
7-8	Communication speed: 00 – 9600 bit/s 01 – 19200 bit/s 10 – 57600 bit/s 11 – 115200 bit/s

Temperature monitor accepts one special command, with byte 2 = 0x41. In response to this command it sends all temperatures as word[128] array and one byte of XOR-sum in the end (257 bytes totally). This command is fastest way to get all temperatures from the device. At 115200 bit/s communication speed it takes about 30ms, while reading by one memory byte takes about 400ms.

Memory map

Address	Length	Type	Name	Description
0x0000	2	word	WDCount	Watch-dog resets counter. Should be 0 or small value and not increase. This counter resets to 0 at every “cold” start, i.e. power-on procedure and increases at every watch-dog CPU reset.
0x0007	1	byte	AVGCount	Number of samples to average. No averaging occurs if = 0. Default value is 8.
0x0008	1	byte	ADCchan	ADC channel number. Device will measure only this channel (0÷127) or all 128 channels if ADCchan>127.
0x0009	1	byte	DOUTByte	Digital outputs control byte.
0x000F	1	Byte	ID	Device ID = 0xA1. It is NOT device address.
0x0010	256	Word	ADCval[128]	Sensor values in 2-byte integer form. Temperature should be calculated by the formula: T [F] = ADCval / 0xFFFF * 400
0x04FE	1	Byte	UpdateNums	Control byte for updating sensor numbers in EEPROM. If UpdateNums=1, CPU will write sensor numbers from RAM to internal EEPROM. CPU reads numbers from EEPROM to RAM in startup procedure.

0x04FF	1	Byte	UpdateNames	Control byte for updating sensor names in EEPROM. If UpdateNames=1, CPU will write sensor names from RAM to internal EEPROM, where they will be kept until next power-on procedure. This takes about 1.5 seconds. CPU reads names from EEPROM to RAM in startup procedure.
0x0500	512	Char	Names[128][4]	4-byte sensor names for LCD display.
0x0700	168	Byte	snum[7][24]	Sensor numbers for 7 groups and 24 sensors in each group. Group names are kept in Flash memory and could not be changed.

PC software

Temperature monitor control software for the host PC was developed for Windows platform. Using this software, one could see all 128 temperature values (Fig. 2) either by sensor names or by connector and pin numbers. It also makes it possible to change sensor names and numbers in the device EEPROM (Fig. 3). Number of samples to average also could be changed by user. Note that this number will reset to 8 in device power-up procedure.

The software reads sensor values using byte memory access or buffer command (this can be changed in the setup window). All sensor values could be saved in history file for future analysis.

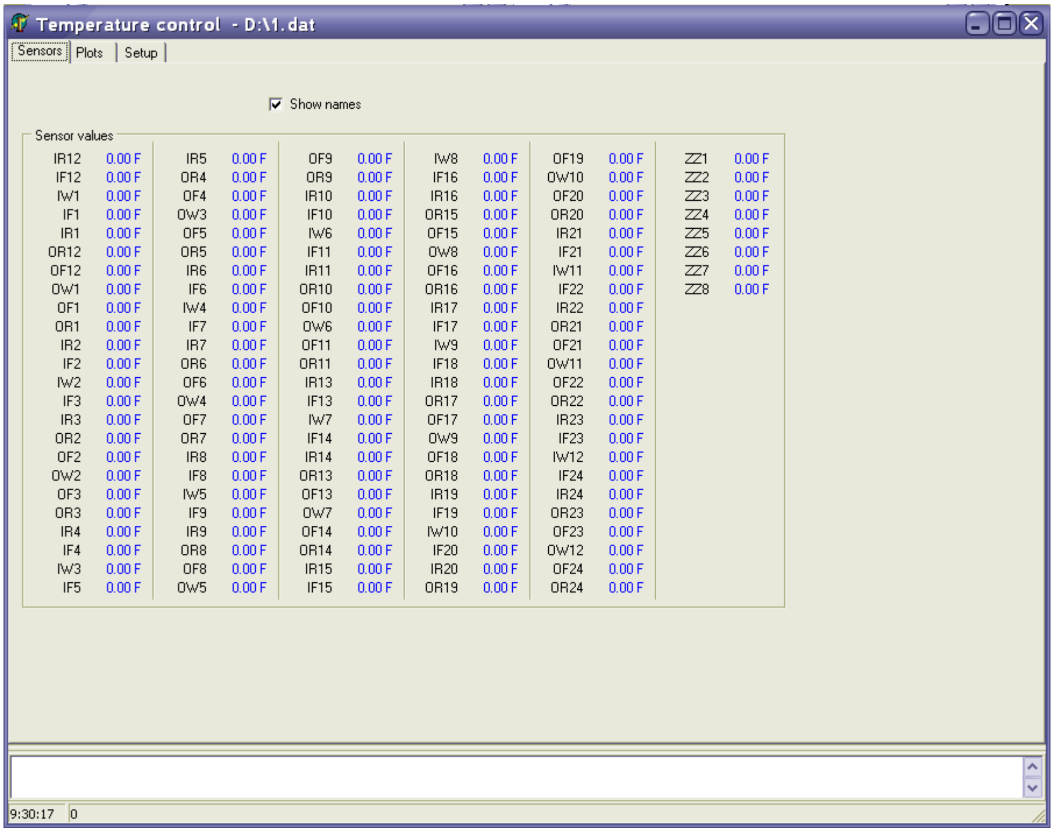


Fig. 2. Sensors display.

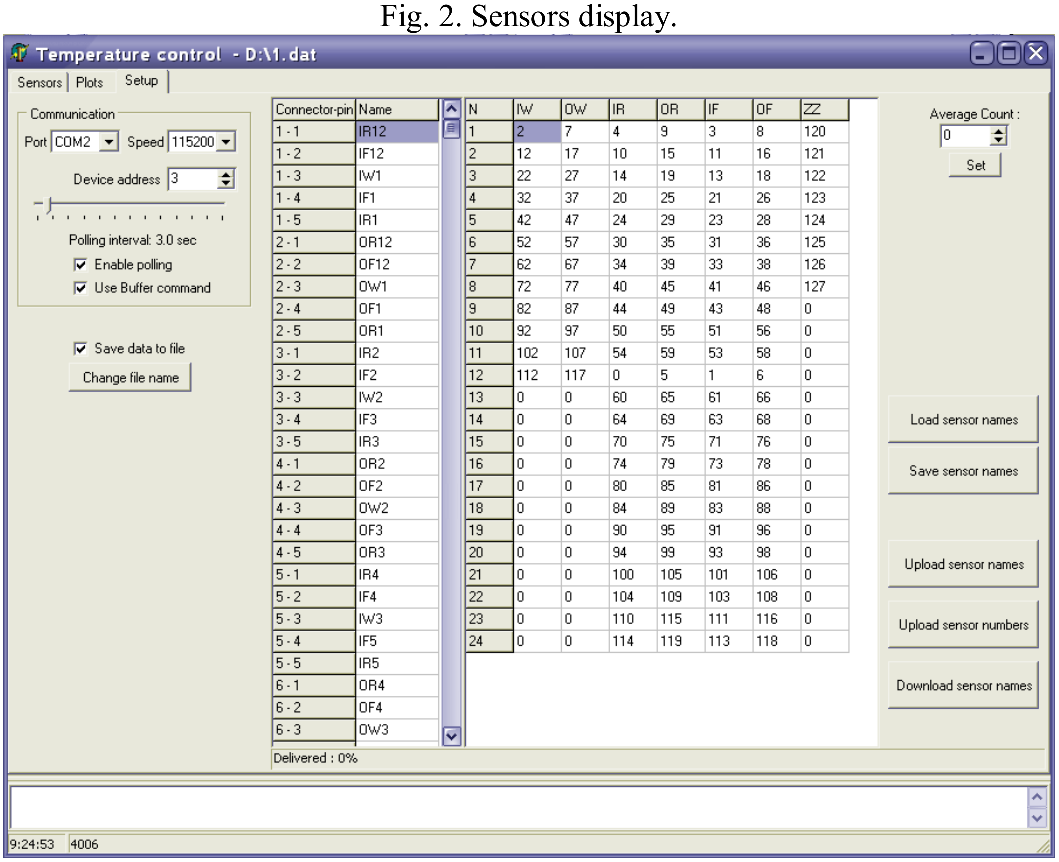


Fig. 3. Configuration window.

National Semiconductor

November 2000

LM34
Precision Fahrenheit Temperature Sensors

General Description

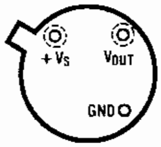
The LM34 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Fahrenheit temperature. The LM34 thus has an advantage over linear temperature sensors calibrated in degrees Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Fahrenheit scaling. The LM34 does not require any external calibration or trimming to provide typical accuracies of ±½˚F at room temperature and ±1½˚F over a full −50 to +300˚F temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM34'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 75 µA from its supply, it has very low self-heating, less than 0.2˚F in still air. The LM34 is rated to operate over a −50˚ to +300˚F temperature range, while the LM34C is rated for a −40˚ to +230˚F range (0˚F with improved accuracy). The LM34 series is available packaged in hermetic TO-46 transistor packages, while the LM34C, LM34CA and LM34D are also available in the plastic TO-92 transistor package. The LM34D is also available in an 8-lead surface mount small outline package. The LM34 is a complement to the LM35 (Centigrade) temperature sensor.

Features

- Calibrated directly in degrees Fahrenheit
- Linear +10.0 mV/˚F scale factor
- 1.0˚F accuracy guaranteed (at +77˚F)
- Rated for full -50˚ to +300˚F range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 5 to 30 volts
- Less than 90 µA current drain
- Low self-heating, 0.18˚F in still air
- Nonlinearity only ±0.5˚F typical
- Low-impedance output, 0.4Ω for 1 mA load

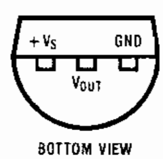
Connection Diagrams

TO-46
Metal Can Package
(Note 1)



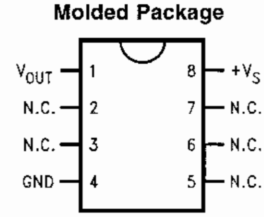
Order Numbers LM34H, LM34AH, LM34CH, LM34CAH or LM34DH
See NS Package Number H03H

TO-92
Plastic Package



Order Number LM34CZ, LM34CAZ or LM34DZ
See NS Package Number Z03A

SO-8
Small Outline
Molded Package



N.C. = No Connection

Top View
Order Number LM34DM
See NS Package Number M08A

Note 1: Case is connected to negative pin (GND).

Typical Applications

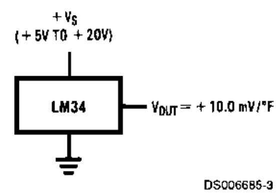


FIGURE 1. Basic Fahrenheit Temperature Sensor (+5˚ to +300˚F)

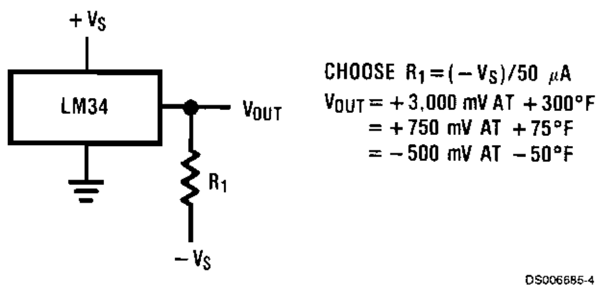


FIGURE 2. Full-Range Fahrenheit Temperature Sensor

Absolute Maximum Ratings (Note 11)

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 Temperature,	
TO-46 Package	−76˚F to +356˚F
TO-92 Package	−76˚F to +300˚F
SO-8 Package	−65˚C to +150˚C
ESD Susceptibility (Note 12)	800V
Lead Temp.	
TO-46 Package	
(Soldering, 10 seconds)	+300˚C
TO-92 Package	
(Soldering, 10 seconds)	+260˚C
SO Package (Note 13)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
Specified Operating Temp. Range (Note 3)	
	T_{MIN} to T_{MAX}
LM34, LM34A	−50˚F to +300˚F
LM34C, LM34CA	−40˚F to +230˚F
LM34D	+32˚F to +212˚F

DC Electrical Characteristics (Notes 2, 7)

Parameter	Conditions	LM34A			LM34CA			Units (Max)
		Typical	Tested Limit (Note 5)	Design Limit (Note 6)	Typical	Tested Limit (Note 5)	Design Limit (Note 6)	
Accuracy (Note 8)	T_A = +77˚F	±0.4	±1.0		±0.4	±1.0		˚F
	T_A = 0˚F	±0.6			±0.6		±2.0	˚F
	$T_A = T_{MAX}$	±0.8	±2.0		±0.8	±2.0		˚F
	$T_A = T_{MIN}$	±0.8	±2.0		±0.8		±3.0	˚F
Nonlinearity (Note 9)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.35**		**±0.7**	**±0.30**		**±0.6**	˚F
Sensor Gain	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9,**		**+10.0**		**+9.9,**	mV/˚F, min
(Average Slope)			**+10.1**				**+10.1**	mV/˚F, max
Load Regulation	T_A = +77˚F	±0.4	±1.0		±0.4	±1.0		mV/mA
(Note 4)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
	$0 \le I_L \le 1$ mA							
Line Regulation	T_A = +77˚F	±0.01	±0.05		±0.01	±0.05		mV/V
(Note 4)	$5V \le V_S \le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current	V_S = +5V, +77˚F	75	90		75	90		µA
(Note 10)	V_S = +5V	**131**		**160**	**116**		**139**	µA
	V_S = +30V, +77˚F	76	92		76	92		µA
	V_S = +30V	**132**		**163**	**117**		**142**	µA
Change of Quiescent	$4V \le V_S \le 30V$, +77˚F	+0.5	2.0		0.5	2.0		µA
Current (Note 4)	$5V \le V_S \le 30V$	**+1.0**		**3.0**	**1.0**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.30**		**+0.5**	**+0.30**		**+0.5**	µA/˚F
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L = 0	+3.0		+5.0	+3.0		+5.0	˚F
Long-Term Stability	$T_j = T_{MAX}$ for 1000 hours	±0.16			±0.16			˚F

Note 2: Unless otherwise noted, these specifications apply: $-50˚F \le T_j \le +300˚F$ for the LM34 and LM34A; $-40˚F \le T_j \le +230˚F$ for the LM34C and LM34CA; and $+32˚F \le T_j \le +212˚F$ for the LM34D. V_S = +5 Vdc and I_{LOAD} = 50 µA in the circuit of *Figure 2*; +6 Vdc for LM34 and LM34A for $230˚F \le T_j \le 300˚F$. These specifications also apply from +5˚F to T_{MAX} in the circuit of *Figure 1*.

Note 3: Thermal resistance of the TO-46 package is 720˚F/W junction to ambient and 43˚F/W junction to case. Thermal resistance of the TO-92 package is 324˚F/W junction to ambient. Thermal resistance of the small outline molded package is 400˚F/W junction to ambient. For additional thermal resistance information see table in the Typical Applications section.

Note 4: 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 5: Tested limits are guaranteed and 100% tested in production.

Note 6: 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 7: Specification in **BOLDFACE TYPE** apply over the full rated temperature range.

DC Electrical Characteristics (Notes 2, 7) (Continued)

Note 8: Accuracy is defined as the error between the output voltage and 10 mV/°F times the device's case temperature at specified conditions of voltage, current, and temperature (expressed in °F).

Note 9: 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 10: Quiescent current is defined in the circuit of *Figure 1*.

Note 11: 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 (Note 2).

Note 12: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

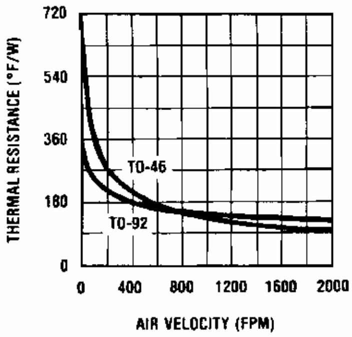
Note 13: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

DC Electrical Characteristics (Notes 2, 7)

Parameter	Conditions	LM34			LM34C, LM34D			Units (Max)
		Typical	Tested Limit (Note 5)	Design Limit (Note 6)	Typical	Tested Limit (Note 5)	Design Limit (Note 6)	
Accuracy, LM34, LM34C (Note 8)	$T_A = +77°F$	±0.8	±2.0		±0.8	±2.0		°F
	$T_A = 0°F$	±1.0			±1.0		±3.0	°F
	$T_A = T_{MAX}$	±1.6	±3.0		±1.6		±3.0	°F
	$T_A = T_{MIN}$	±1.6		±3.0	±1.6		±4.0	°F
Accuracy, LM34D (Note 8)	$T_A = +77°F$				±1.2	±3.0		°F
	$T_A = T_{MAX}$				±1.8		±4.0	°F
	$T_A = T_{MIN}$				±1.8		±4.0	°F
Nonlinearity (Note 9)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.6**		**±1.0**	**±0.4**		**±1.0**	°F
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.8,**		**+10.0**		**+9.8,**	mV/°F, min
			+10.2				**+10.2**	mV/°F, max
Load Regulation (Note 4)	$T_A = +77°F$	±0.4	±2.5		±0.4	±2.5		mV/mA
	$T_{MIN} \le T_A \le +150°F$	**±0.5**		**±6.0**	**±0.5**		**±6.0**	mV/mA
	$0 \le I_L \le 1$ mA							
Line Regulation (Note 4)	$T_A = +77°F$	±0.01	±0.1		±0.01	±0.1		mV/V
	$5V \le V_S \le 30V$	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 10)	$V_S = +5V$, +77°F	75	100		75	100		μA
	$V_S = +5V$	**131**		**176**	**116**		**154**	μA
	$V_S = +30V$, +77°F	76	103		76	103		μA
	$V_S = +30V$	**132**		**181**	**117**		**159**	μA
Change of Quiescent Current (Note 4)	$4V \le V_S \le 30V$, +77°F	+0.5	3.0		0.5	3.0		μA
	$5V \le V_S \le 30V$	**+1.0**		**5.0**	**1.0**		**5.0**	μA
Temperature Coefficient of Quiescent Current		**+0.30**		**+0.7**	**+0.30**		**+0.7**	μA/°F
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L = 0$	+3.0		+5.0	+3.0		+5.0	°F
Long-Term Stability	$T_j = T_{MAX}$ for 1000 hours	±0.16			±0.16			°F

Typical Performance Characteristics

Thermal Resistance Junction to Air



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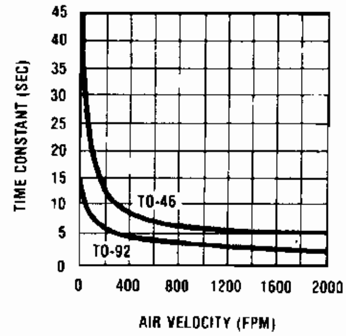
Thermal Time Constant



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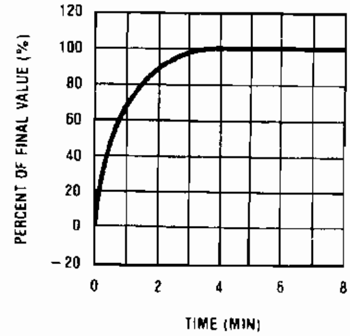
Thermal Response in Still Air



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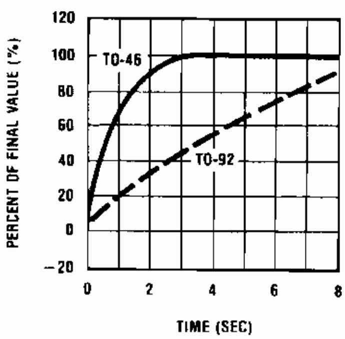
Thermal Response in Stirred Oil Bath



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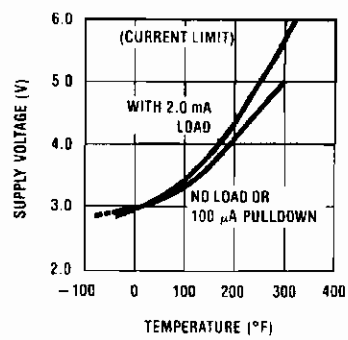
Minimum Supply Voltage vs. Temperature



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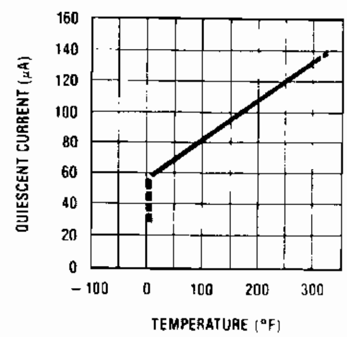
Quiescent Current vs. Temperature (In Circuit of *Figure 1*)



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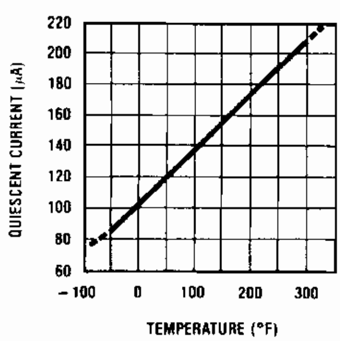
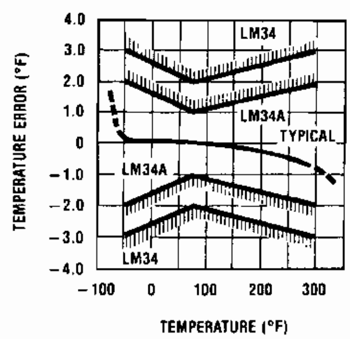
Quiescent Current vs. Temperature (In Circuit of *Figure 2*; $-V_S = -5V$, R1 = 100k)



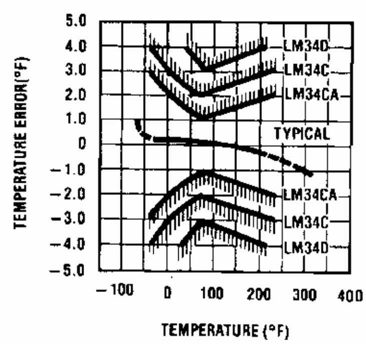
DS006685-28

Accuracy vs. Temperature (Guaranteed)



DS006685-29

Accuracy vs. Temperature (Guaranteed)



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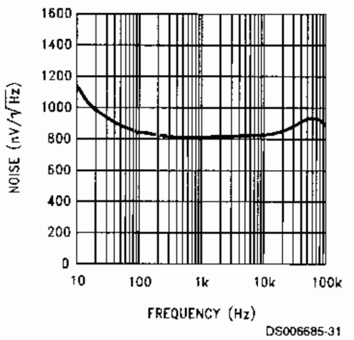
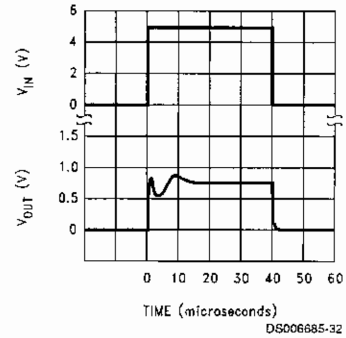
Typical Performance Characteristics (Continued)

Noise Voltage



Start-Up Response

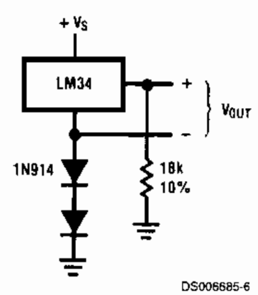


Typical Applications

The LM34 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 0.02˚F 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 LM34 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 LM34, 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 LM34 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 LM34 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 LM34 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 LM34 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.

Capacitive Loads

Like most micropower circuits, the LM34 has a limited ability to drive heavy capacitive loads. The LM34 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 LM34 is applied with a 499Ω load resistor (as shown), 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's 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 the following circuits.

Typical Applications

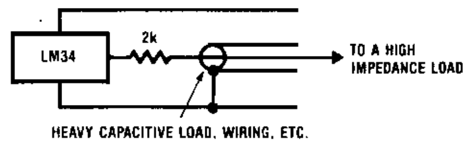


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FIGURE 3. LM34 with Decoupling from Capacitive Load

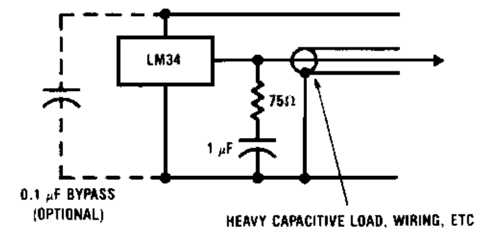

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FIGURE 4. LM34 with R-C Damper

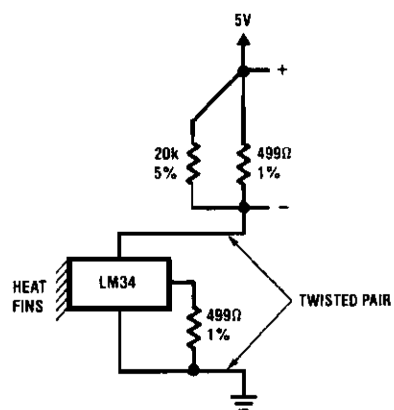
Temperature Rise of LM34 Due to Self-Heating (Thermal Resistance)

Conditions	TO-46, No Heat Sink	TO-46, Small Heat Fin (Note 14)	TO-92, No Heat Sink	TO-92, Small Heat Fin (Note 15)	SO-8 No Heat Sink	SO-8 Small Heat Fin (Note 15)
Still air	720°F/W	180°F/W	324°F/W	252°F/W	400°F/W	200°F/W
Moving air	180°F/W	72°F/W	162°F/W	126°F/W	190°F/W	160°F/W
Still oil	180°F/W	72°F/W	162°F/W	126°F/W		
Stirred oil	90°F/W	54°F/W	81°F/W	72°F/W		
(Clamped to metal, infinite heat sink)	(43°F/W)				(95°F/W)	

Note 14: Wakefield type 201 or 1" disc of 0.020" sheet brass, soldered to case, or similar.

Note 15: TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz copper foil, or similar.

Two-Wire Remote Temperature Sensor (Grounded Sensor)



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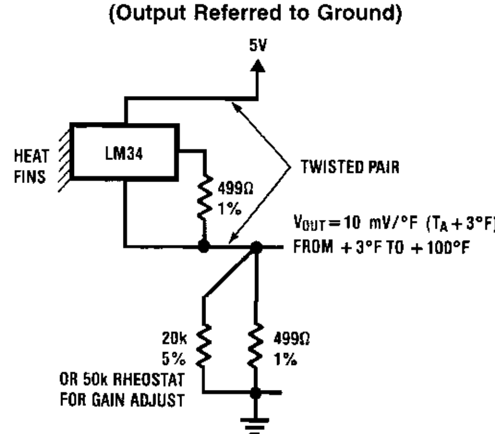
V_{OUT} = 10mV/°F (T_A+3°F)
FROM +3°F TO + 100°F

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



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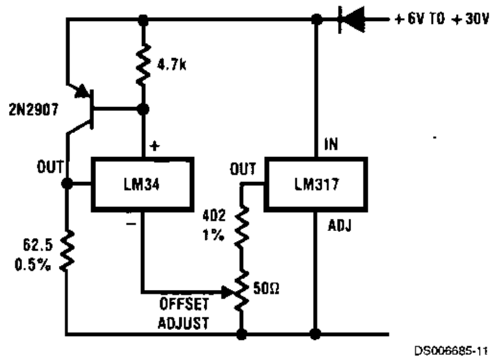
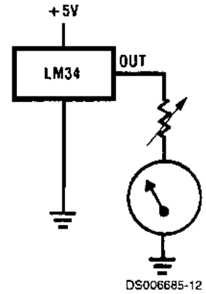
Typical Applications (Continued)

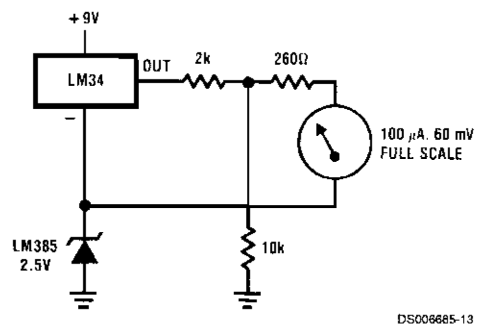
4-to-20 mA Current Source (0 to +100˚F)



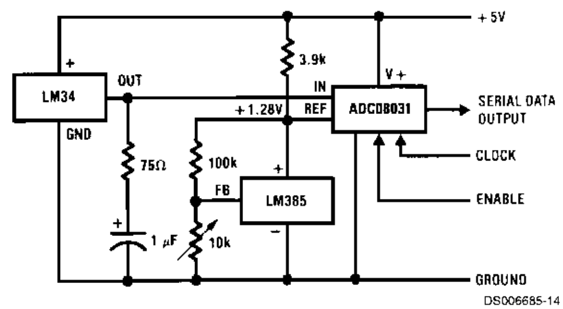
Fahrenheit Thermometer (Analog Meter)



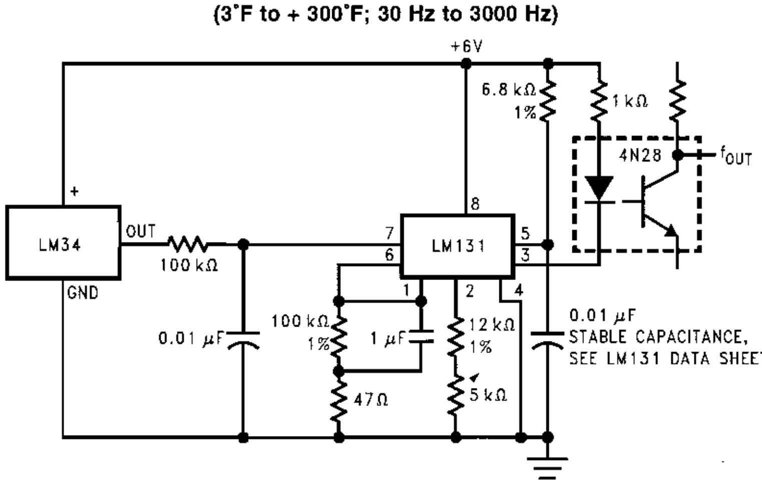
Expanded Scale Thermometer (50˚ to 80˚ Fahrenheit, for Example Shown)



Temperature-to-Digital Converter (Serial Output, +128˚F Full Scale)

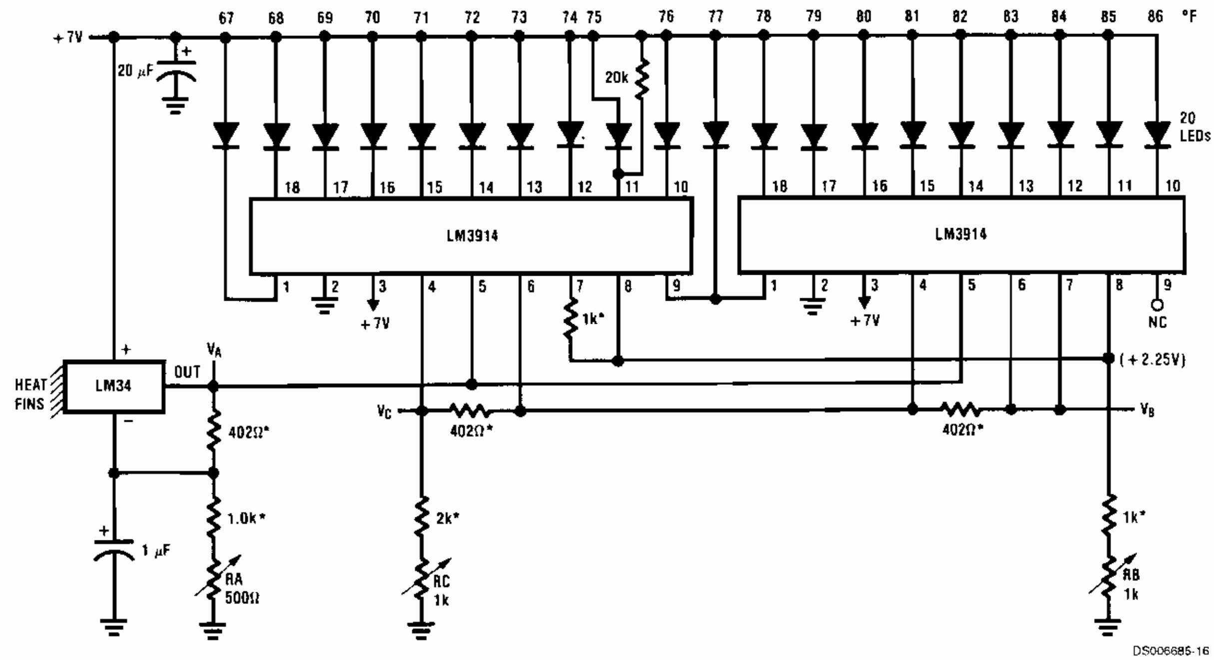


LM34 with Voltage-to-Frequency Converter and Isolated Output (3˚F to + 300˚F; 30 Hz to 3000 Hz)



Typical Applications (Continued)

Bar-Graph Temperature Display (Dot Mode)



* = 1% or 2% film resistor

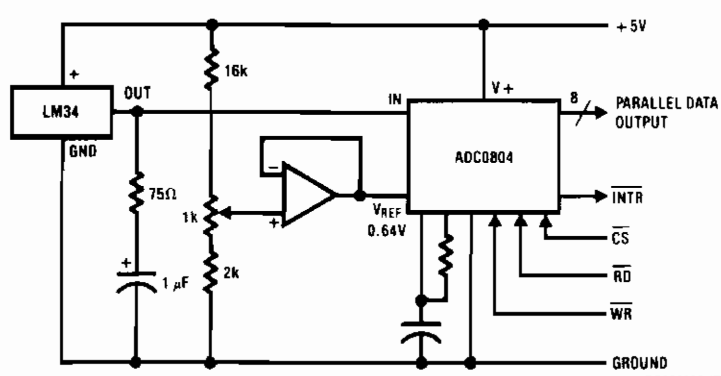
— Trim R_B for V_B = 3.525V

— Trim R_C for V_C = 2.725V

— Trim R_A for V_A = 0.085V + 40 mV/°F x $T_{AMBIENT}$

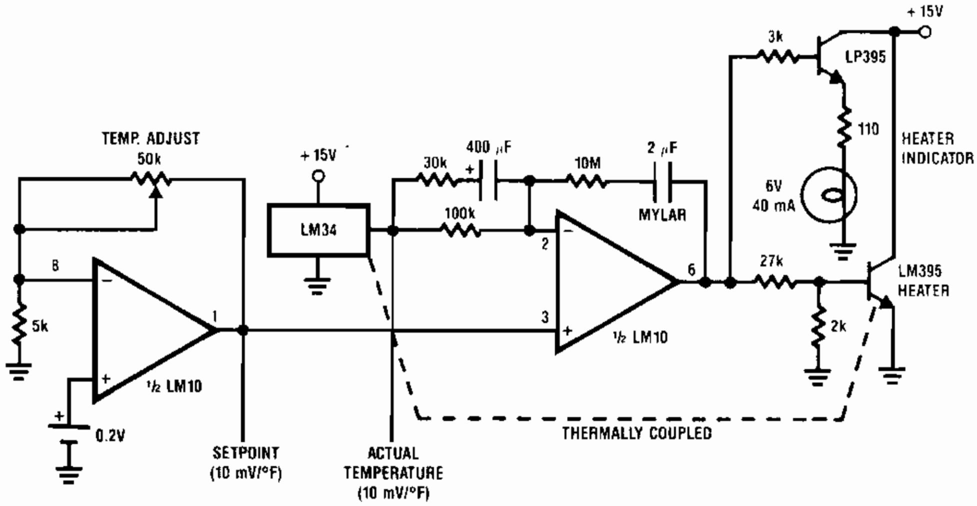
— Example, V_A = 3.285V at 80°F

Temperature-to-Digital Converter (Parallel TRI-STATE® Outputs for Standard Data Bus to µP Interface, 128 °F Full Scale)



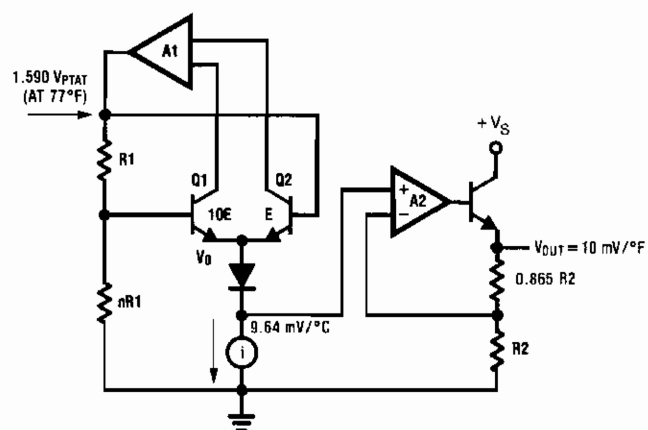
Typical Applications (Continued)

Temperature Controller



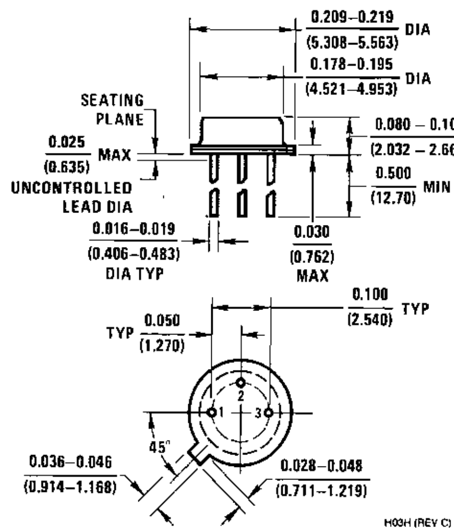
DS006685-18

Block Diagram

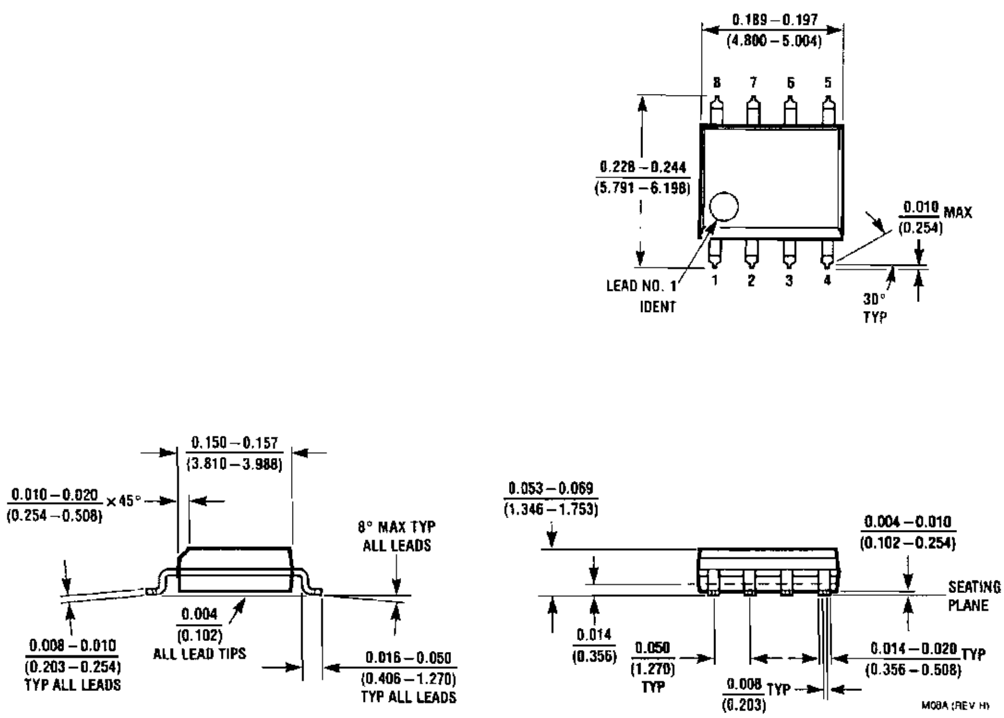


DS006685-19

Physical Dimensions inches (millimeters) unless otherwise noted

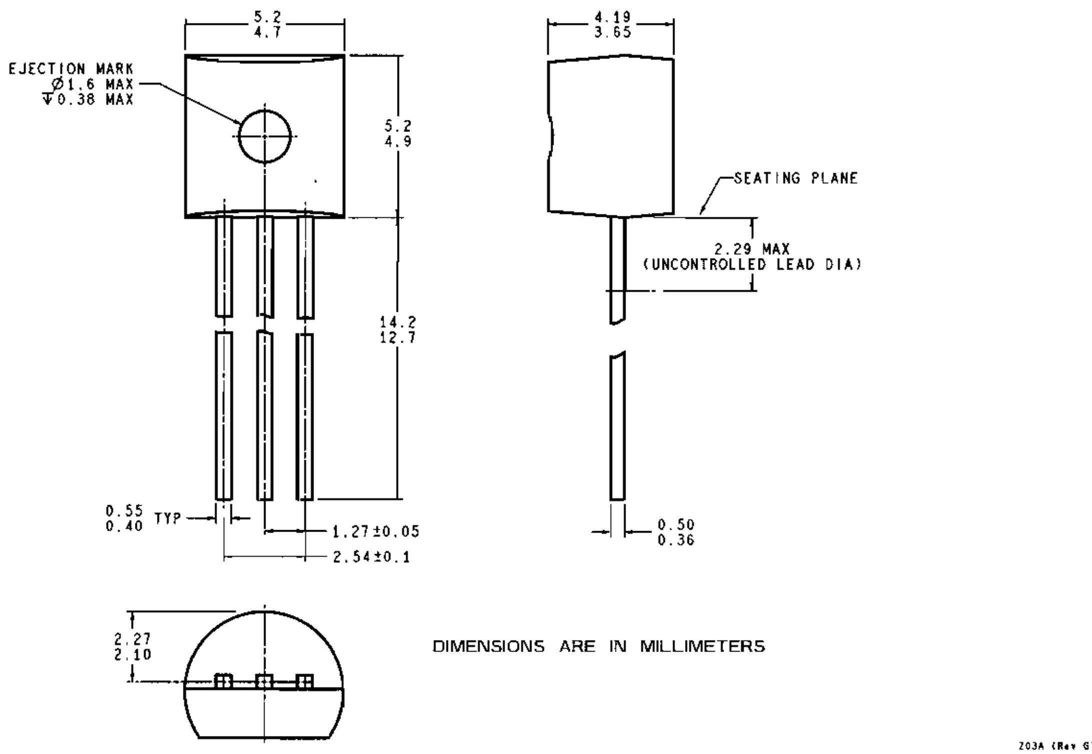


Order Number LM34H, LM34AH, LM34CH, LM34CAH or LM34DH
NS Package H03H



Order Number LM34DM
NS Package Number M08A

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



Order Number LM34CZ, LM34CAZ or LM34DZ
NS Package Z03A

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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