National Semiconductor

December 1994

# LM35/LM35A/LM35C/LM35CA/LM35D Precision Centigrade Temperature Sensors

## General Description

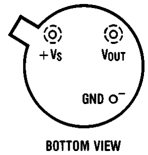
The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant 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-202 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

## Connection Diagrams

**TO-46**
**Metal Can Package***

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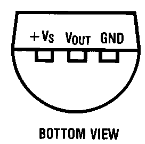
*Case is connected to negative pin (GND)

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

**TO-92**
**Plastic Package**

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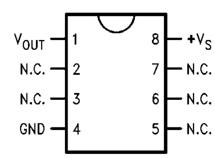
**Order Number LM35CZ, LM35CAZ or LM35DZ**
**See NS Package Number Z03A**

**SO-8**
**Small Outline Molded Package**

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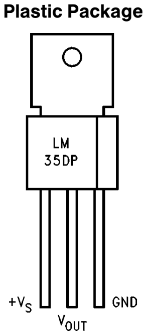
**Top View**

N.C. = No Connection

**Order Number LM35DM**
**See NS Package Number M08A**

**TO-202**
**Plastic Package**

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**Order Number LM35DP**
**See NS Package Number P03A**

## Typical Applications

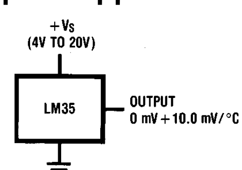


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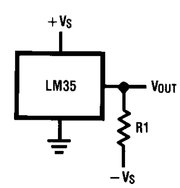
**FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)**

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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**



RRD-B30M75/Printed in U. S. A.

## 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-202 Package, | −65°C to +150°C |
| Lead Temp.: | |
| TO-46 Package, (Soldering, 10 seconds) | 300°C |
| TO-92 Package, (Soldering, 10 seconds) | 260°C |
| TO-202 Package, (Soldering, 10 seconds) | +230°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 (Note 1) **(Note 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) | $T_A=+25°C$<br>$T_A=-10°C$<br>$T_A=T_{MAX}$<br>$T_A=T_{MIN}$ | ±0.2<br>±0.3<br>±0.4<br>±0.4 | ±0.5<br><br>±1.0<br>±1.0 | | ±0.2<br>±0.3<br>±0.4<br>±0.4 | ±0.5<br><br>±1.0<br> | <br>±1.0<br><br>±1.5 | °C<br>°C<br>°C<br>°C |
| Nonlinearity (Note 8) | $T_{MIN} \le T_A \le T_{MAX}$ | **±0.18** | | **±0.35** | **±0.15** | | **±0.3** | °C |
| Sensor Gain (Average Slope) | $T_{MIN} \le T_A \le T_{MAX}$ | **+10.0** | **+9.9,**<br>**+10.1** | | **+10.0** | | **+9.9,**<br>**+10.1** | mV/°C |
| Load Regulation (Note 3) $0 \le I_L \le 1$ mA | $T_A=+25°C$<br>$T_{MIN} \le T_A \le T_{MAX}$ | ±0.4<br>**±0.5** | ±1.0 | <br>**±3.0** | ±0.4<br>**±0.5** | ±1.0 | <br>**±3.0** | mV/mA<br>mV/mA |
| Line Regulation (Note 3) | $T_A=+25°C$<br>$4V \le V_S \le 30V$ | ±0.01<br>**±0.02** | ±0.05 | <br>**±0.1** | ±0.01<br>**±0.02** | ±0.05 | <br>**±0.1** | mV/V<br>mV/V |
| Quiescent Current (Note 9) | $V_S=+5V$, +25°C<br>$V_S=+5V$<br>$V_S=+30V$, +25°C<br>$V_S=+30V$ | 56<br>**105**<br>56.2<br>**105.5** | 67<br><br>68<br> | <br>**131**<br><br>**133** | 56<br>**91**<br>56.2<br>**91.5** | 67<br><br>68<br> | <br>**114**<br><br>**116** | µA<br>µA<br>µA<br>µA |
| Change of Quiescent Current (Note 3) | $4V \le V_S \le 30V$, +25°C<br>$4V \le V_S \le 30V$ | 0.2<br>**0.5** | 1.0 | <br>**2.0** | 0.2<br>**0.5** | 1.0 | <br>**2.0** | µA<br>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 |

**Note 1:** Unless otherwise noted, these specifications apply: $-55°C \le T_J \le +150°C$ for the LM35 and LM35A; $-40° \le T_J \le +110°C$ for the LM35C and LM35CA; and $0° \le T_J \le +100°C$ 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-202 package is 85°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

## Electrical Characteristics (Note 1) **(Note 6)** (Continued)

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

**Note 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*.

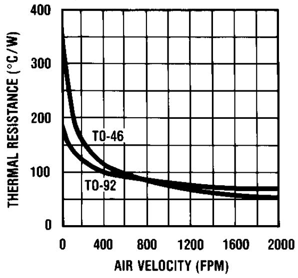
**Note 10:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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

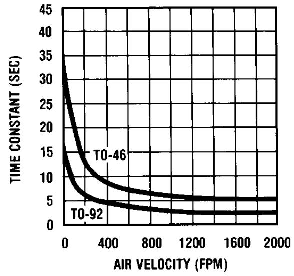
**Note 12:** See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

# Typical Performance Characteristics

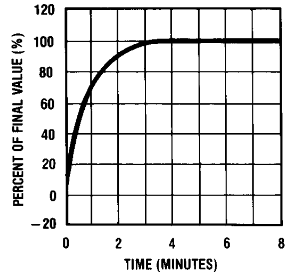
**Thermal Resistance Junction to Air**



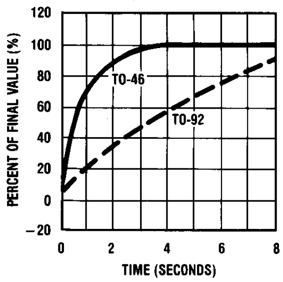

**Thermal Time Constant**



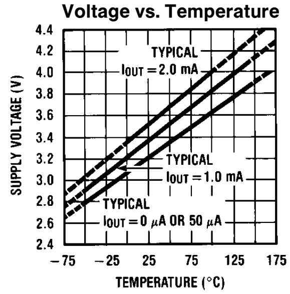

**Thermal Response in Still Air**



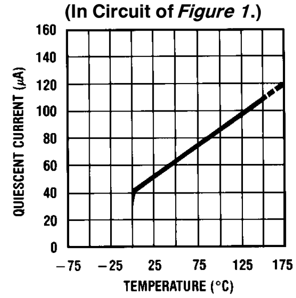

**Thermal Response in Stirred Oil Bath**




**Minimum Supply Voltage vs. Temperature**




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

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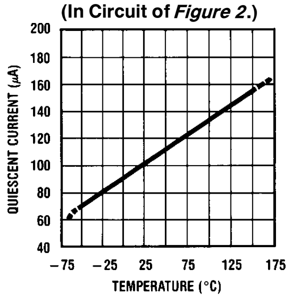
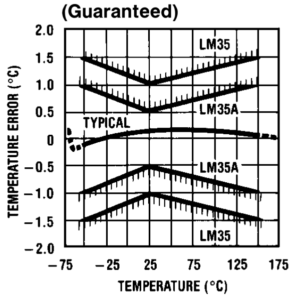
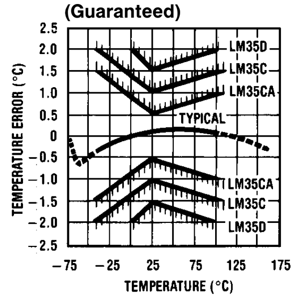
**Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)**




**Accuracy vs. Temperature (Guaranteed)**




**Accuracy vs. Temperature (Guaranteed)**

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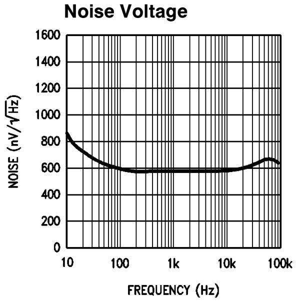
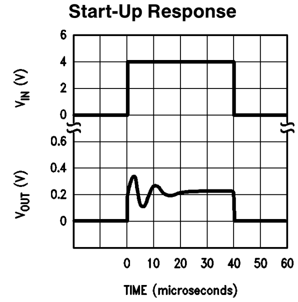
**Noise Voltage**




**Start-Up Response**

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## 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)**

| | 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-202 no heat sink | TO-202 *** small heat fin |
|---|---|---|---|---|---|---|---|---|
| Still air | 400°C/W | 100°C/W | 180°C/W | 140°C/W | 220°C/W | 110°C/W | 85°C/W | 60°C/W |
| Moving air | 100°C/W | 40°C/W | 90°C/W | 70°C/W | 105°C/W | 90°C/W | 25°C/W | 40°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) | | (23°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 (Continued)

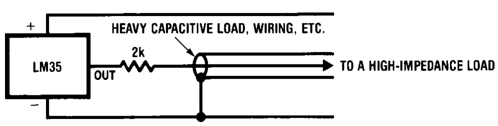


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**FIGURE 3. LM35 with Decoupling from Capacitive Load**

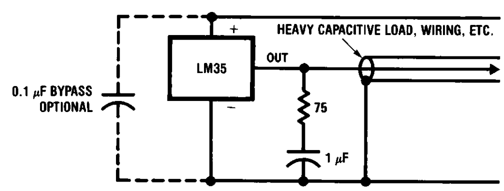


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**FIGURE 4. LM35 with R-C Damper**

**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, 6,* or *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 *Figures 13, 14,* and *16.*

## Typical Applications (Continued)

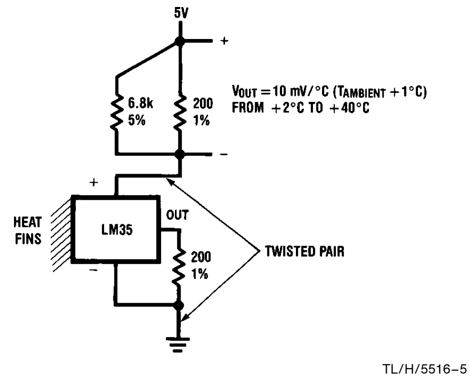



**FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)**

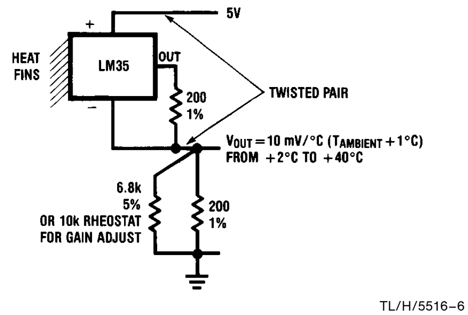



**FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)**

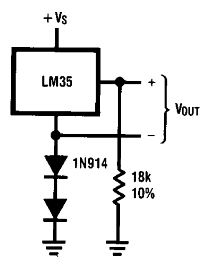



**FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C**

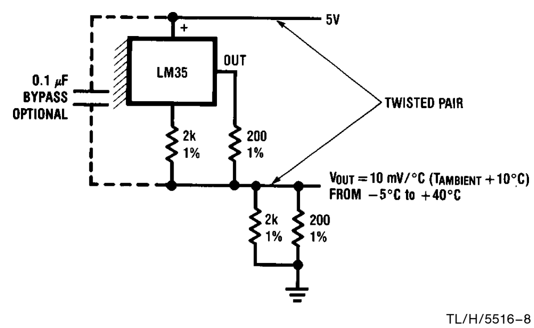



**FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)**

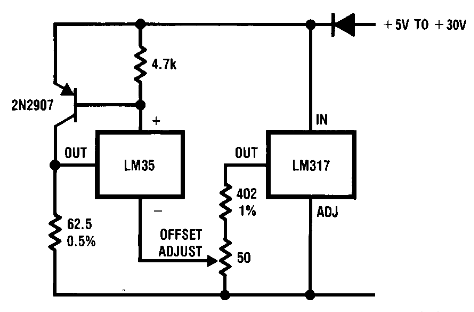



**FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)**

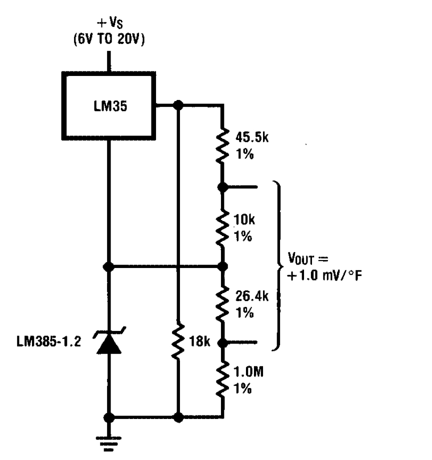



**FIGURE 10. Fahrenheit Thermometer**

## Typical Applications (Continued)

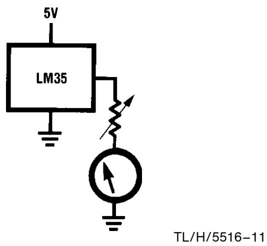



**FIGURE 11. Centigrade Thermometer (Analog Meter)**

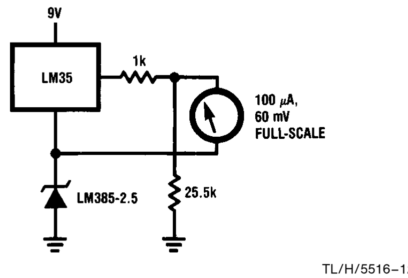



**FIGURE 12. Expanded Scale Thermometer (50° to 80° Fahrenheit, for Example Shown)**

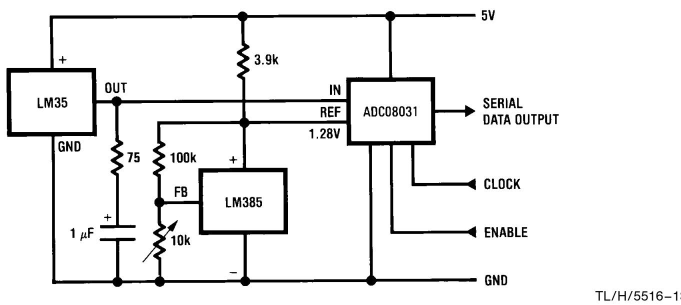



**FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)**

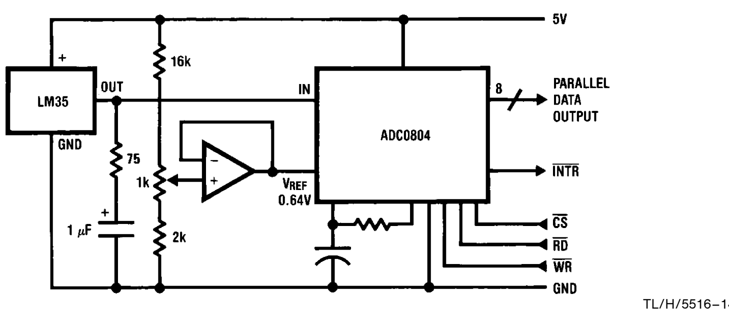
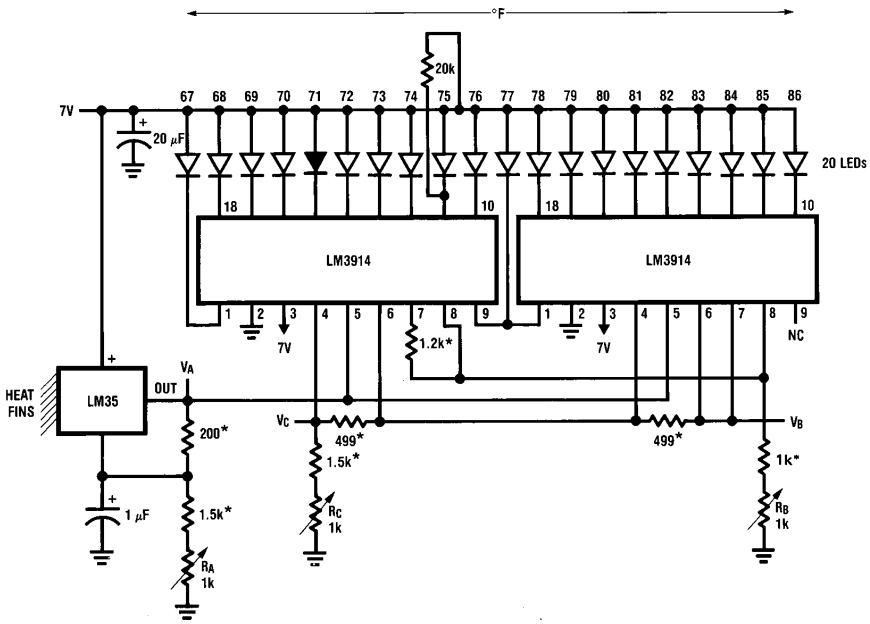



**FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE® Outputs for Standard Data Bus to µP Interface) (128°C Full Scale)**

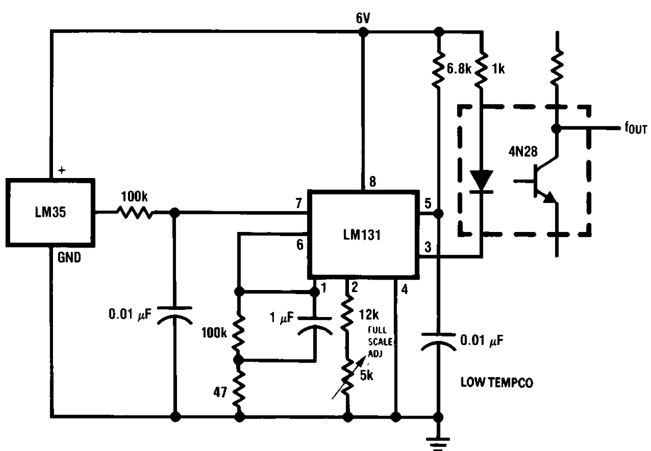
## **Typical Applications** (Continued)




TL/H/5516–16

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

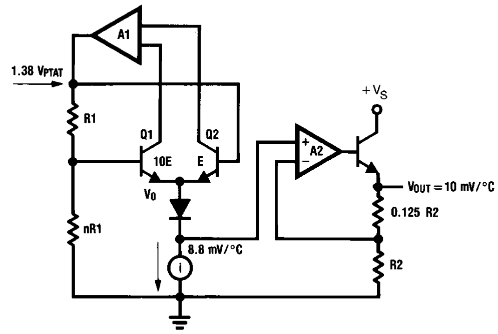
**FIGURE 15. Bar-Graph Temperature Display (Dot Mode)**




TL/H/5516–15

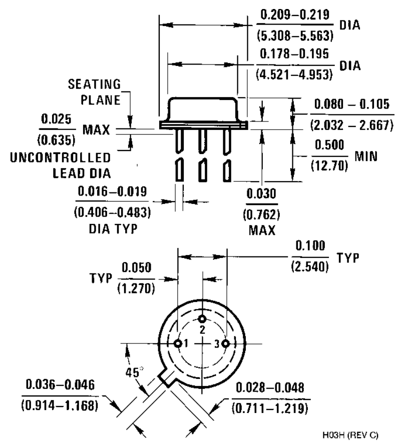
**FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2°C to +150°C; 20 Hz to 1500 Hz)**

## Block Diagram

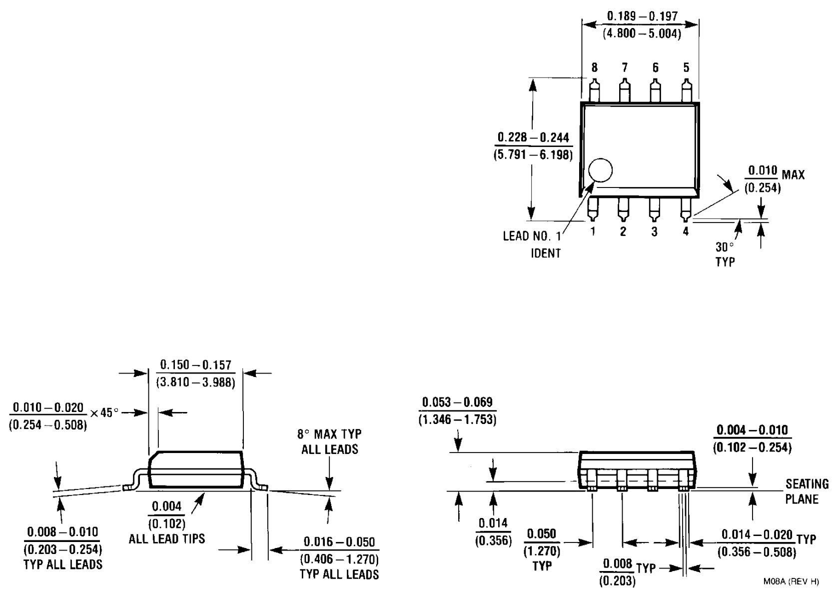



TL/H/5516–23

## **Physical Dimensions** inches (millimeters)

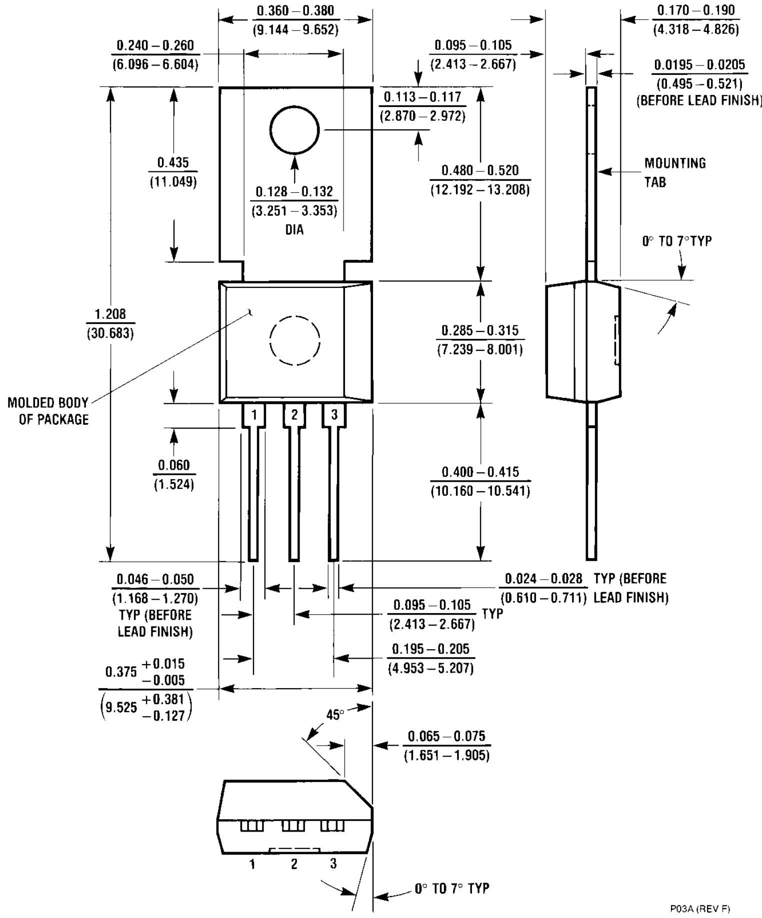



**TO-46 Metal Can Package (H)**
**Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH**
**NS Package Number H03H**



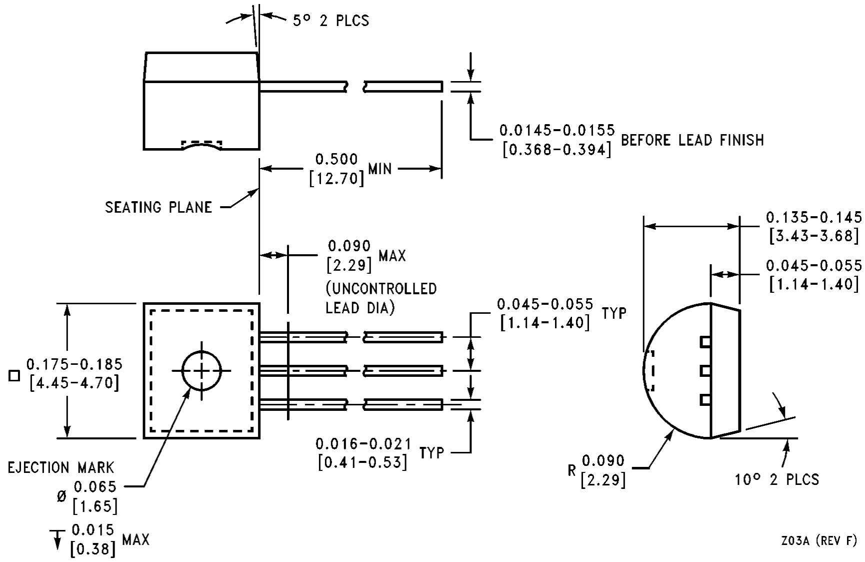

**SO-8 Molded Small Outline Package (M)**
**Order Number LM35DM**
**NS Package Number M08A**

## **Physical Dimensions** inches (millimeters) (Continued)




**Power Package TO-202 (P)**
**Order Number LM35DP**
**NS Package Number P03A**

## Physical Dimensions inches (millimeters) (Continued)




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

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National Semiconductor

# LM75 I2C Digital Temperature Sensor Demo Board Hardware and Software Guide

## 1.0.0 System Overview

The LM75 I2C Digital Temperature Sensor Demo package includes software and hardware evaluation tools for the LM75 Digital Temperature Sensor. The LM75 is a temperature sensor, Delta-Sigma analog-to-digital converter, and digital over-temperature detector with I2C interface. The parallel printer port of a PC is used to simulate the I2C bus interface required to drive the LM75. The software provided can query the LM75 at any time to read temperature and display it in two modes, Thermometer and Strip Chart. An open-drain Overtemperature Shutdown (O.S.) output on the LM75 becomes active when the temperature exceeds a programmable limit. This pin can operate in either “Comparator” or “Interrupt” mode. The state of this pin is sensed through the parallel printer port.

The software can program both the temperature alarm threshold (Tos) and the temperature at which the alarm condition goes away (THyst). In addition, the software can read back the contents of the LM75’s Tos and THyst registers. Selection of I2C address is determined by the state of three pins (A0, A1, A2) on the LM75.

## 2.0.0 Installing the Hardware and Software

The LM75 Demo board is connected to the computer through a parallel printer port. The board derives all the necessary power through the port. External power supplies are not necessary. The board can be plugged in directly to the back of a computer or connected through a DB25 male-to-female straight-through cable. Before actually connecting the LM75 Demo Board to the PC you should first install the software and run it.

The LM75 Demo Software requires Windows 3.1or later. Running SETUP.EXE found on the supplied floppy diskette will install the software on your hard drive in a location you designate.

Before executing the software the parallel printer port address that the Demo Board will be connected to needs to be determined. MSD (Microsoft Diagnostic) utility can be used to determine this address. Start up a DOS shell and run MSD. The parallel printer port assignment can be found under LPT Ports. Note the address of the printer port that you are planning to connect the Demo Board to. Start up the LM75Demo software. Select the parallel printer port address under the LPT Assignment Menu. If your address is not displayed in the menu, use the Custom option to assign any hexadecimal address between 100 and FFF (Hexadecimal). Extreme caution should be used when using this option. If set incorrectly, your system may need to be rebooted.

Next use the I2C Address Menu to select the I2C address as set on the Demo Board. The Demo Board's I2C address can be set using jumpers that connect Address Bits A0-A2 to ground. A grounded Address Bit is a “0”; if a jumper is not installed, the bit is a “1”. When the board was shipped to you, all three address jumpers were installed. Therefore selecting Address 1001 000 under the I2C Address Menu and configures the software to communicate with the LM75 Demo Board as shipped. If you change the Demo Board’s address by removing any jumpers, be sure to select the corresponding address from the I2C Address Menu.

Now you are ready to turn on the board. Click the command button labeled "Off" found in left hand corner of the screen. You should get a message indicating that “LM75 registers are set to default power up state. All systems go!”.

## 3.0.0 Software Description

### 3.1.0 Menus

#### 3.1.1 File Menu

**Exit** - This command exits the LM75Demo software. The Demo Board is powered down. A dialog box will appear to indicate this. The board should now be disconnected from the port. After clicking “OK” in the dialog box the parallel printer port is reinitialized.

#### 3.1.2 Temp Display Menu

This menu allows you to select how the temperature data retrieved from the LM75 will be displayed.

**Thermometer** - Choosing this option displays a thermometer in the bottom portion of the “LM75 I2C Digital Temperature Sensor Demo Software” window. The reading of the thermometer is updated when the Temperature Register of the LM75 is read. This occurs when the “Read” or “Loop” command buttons in the “Temperature Register” box are clicked. The two arrows point to the setting of the THyst and Tos Registers of the LM75. The red arrow with the match represents the Tos Register, while the blue arrow with the snowflake represents the THyst Register.

**Strip Chart** - Selecting this option will display a Strip Chart graph on the bottom portion of the “LM75 I2C Digital Temperature Sensor Demo Software” window. The chart is updated when the Temperature Register of the LM75 is read. This occurs when the “Read” or “Loop” command buttons in the “Temperature Register” box are clicked. The chart is also updated when the THyst and Tos Registers of the LM75 are read or written to.

#### 3.1.3 LPT Assignment Menu

Before powering up the board it is necessary to set the LPT port address that the board is going to be plugged into. The three most common addresses are show below and are displayed in the “LPT Assignment” menu:

378 (HEX)

278 (HEX)

3BC (HEX)

MSD (Microsoft Diagnostic) utility can be used to determine this address. Start up a DOS shell and run MSD. The parallel printer port assignment can be found under LPT Ports. Note the address of the printer port that you are planning to connect the Demo Board to. Selecting an address by trial and error basis is an option if the LM75 will be the only device attached to any LPT port of the computer.

**Custom** - If the parallel printer port address is not one of the ones displayed in the menu then this option can be used to set the address to any hexadecimal value greater than 100 and less than FFF. Extreme caution should be used when using this option because if set incorrectly it may be necessary to reboot the computer. It is not recommended that this address be arbitrarily set because many strange things can happen, such as rebooting DOS or maybe writing to a drive. Please use this option with extreme care!

#### 3.1.4 I$^2$C Address Menu

The address selected in this menu should match the address set on the Demo Board. According to I$^2$C bus specifications, the LM75 has a 7-bit slave address. The four most significant bits of the slave address are hard wired inside the LM75 and are “1001”. The three least significant bits of the address are assigned to pins A2-A0, and are set by connecting these pins to ground for a low, (0); or to +VS for a high, (1). Jumpers A0-A2 found on the LM75 Demo Board select the state of the three least significant bits of the I$^2$C address. When a jumper is installed that bit is set to zero. When the jumper is removed that bit is set to one.

#### 3.1.5 Help Menu

**Contents** - Selecting this option will display this file using WinHelp.

**About** - Selecting this option will display the initial opening screen.

### 3.2.0 LM75 Operation

The LM75 temperature sensor incorporates a band-gap type temperature sensor and 9-bit Delta-Sigma ADC (Analog-to-Digital Converter). The temperature data output of the LM75 is available at all times via the I$^2$C bus. The function of this interface is fully explained in the LM75 data sheet (See Sections 1.2 I$^2$C Bus Interface and 4.0 Internal Register Structure). If temperature data is read while a conversion is in progress, the conversion will be stopped and restarted after the read. A digital comparator is also incorporated that compares a series of readings, the number of which is user-selectable, to user-programmable set point and hysteresis values. The comparator trips the O.S. output line, which is programmable for mode and polarity.

In Comparator mode the O.S. output behaves like a thermostat. The output becomes active when temperature exceeds the Tos limit, and leaves the active state when the temperature drops below the THyst limit. In this mode the O.S. output can be used to turn a cooling fan on, initiate an emergency system shutdown, or reduce system clock speed.

In Interrupt mode exceeding Tos also makes O.S. active but O.S. will remain active indefinitely until reset by reading any register via the I$^2$C interface. Once O.S. has been activated by crossing Tos, then reset, it can be activated again only by Temperature going below THyst. Again, it will remain active indefinitely until being reset by a read. Placing the LM75 in shutdown mode also resets the O.S. Output.

#### 3.2.1 LM75 Pin Description:

| Label | Pin # | Function | Typical Connection |
|---|---|---|---|
| SDA | 1 | I$^2$C Serial Bi-Directional Data line | From controller |
| SCL | 2 | I$^2$C Clock Input | From controller |
| O.S. | 3 | Overtemperature Shutdown Open Collector Output | Pull Up Resistor, Controller interrupt line |
| GND | 4 | Power Supply Ground | Ground |
| $+V_S$ | 8 | Positive Supply Voltage Input | DC voltage from 3 to 5.5 volts |
| A0-A2 | 7,6,5 | User-Set I$^2$C Address Inputs | Ground (Low, “0”) or $+V_S$ (High, “1”) |

#### 3.2.2 LM75 Default Setting

LM75 always powers up in a known state. LM75 power up default conditions are:

1. Comparator mode
2. Tos set to 80 °C
3. THyst set to 75 °C
4. O.S. active low
5. Pointer set to “00”; Temperature Register

With these operating conditions, the LM75 can act as a stand-alone thermostat with the above temperature settings. Connection to an I$^2$C bus is not required.

### 3.3.0 LM75 Registers

#### 3.3.1 Temperature Data Format

Temperature data can be read from the Temperature, Tos Set Point, and THyst Set Point registers, and written to the Tos Set Point, and THyst Set Point registers. Temperature data is represented by a 9-bit, two’s complement word with an LSB (Least Significant Bit) equal to 0.5 °C:

| Temperature | Digital Output | |
|---|---|---|
| | Binary | Hex |
| +125°C | 0 1111 1010 | 0FAh |
| +25°C | 0 0011 0010 | 032h |
| +0.5°C | 0 0000 0001 | 001h |

| | | |
|---|---|---|
| 0°C | 0 0000 0000 | 000h |
| -0.5°C | 1 1111 1111 | 1FFh |
| -25°C | 1 1100 1110 | 1CEh |
| -55°C | 1 1001 0010 | 192h |

The Tos, THyst and Temperature registers are 16 bits long. The data format is show below:

| D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSB | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | LSB | X | X | X | X | X | X | X |

Note that the 7 LSBs (D0-D6) are not always set to zero.

### 3.3.2 Tos Register

**Read Command Button** - This command sends a "read Tos register" command to the LM75. The output from the LM75 is then displayed in the text box to the left of the command button. The two text boxes on the left side of the Tos register field display the actual binary data transmitted by the LM75. The temperature data format is 9-bit two's complement MSB first.

**Write Command Button** - This command sends a "write Tos register" command to the LM75. The data transmitted to the LM75 is displayed in the text box to the left of the command button. The two text boxes on the left side of the Tos register field display the actual binary data transmitted to the LM75. The temperature data format is 9-bit two's complement MSB first. The data in the text box can be modified to be greater than or equal to -40 °C and less than or equal to -125 °C in 0.5 degree increments. If any other increment is set the software will round off the value to the nearest half degree.

### 3.3.3 THyst Register

**Read Command Button** - This command sends a "read THyst register" command to the LM75. The output from the LM75 is then displayed in the text box to the left of the command button. The two text boxes on the left side of the THyst register field display the actual binary data transmitted by the LM75. The temperature data format is 9-bit two's complement MSB first.

**Write Command Button** - This command sends a "write THyst register" command to the LM75. The data transmitted to the LM75 is displayed in the text box to the left of the command button. The two text boxes on the left side of the THyst register field display the actual binary data transmitted to the LM75. The temperature data format is 9 bit two's complement MSB first. The data in the text box can be modified to be greater than or equal to -40 °C and less than or equal to +125°C in 0.5 degree increments. If any other increment is set the software will round off the value to the nearest half degree.

### 3.3.4 Temperature Register

The LM75 Temperature Register is a read only register. This register is updated when a temperature conversion is completed. A temperature conversion is stopped when a read command is sent and restarted after the data has been read by the host.

**Read Command Button** - This command sends a "read Temperature" register command to the LM75. The output from the LM75 is then displayed in the text box to the left of the command button. The two text boxes on the left side of the Temperature register field display the actual binary data transmitted by the LM75. The temperature data format is 9-bit two's complement MSB first.

**Loop Command Button** - This command button first disables all other command buttons. The command will continuously send Temperature register read commands to the LM75. The interval between each read can be set in 1-second increments in the dialog box that appears when the Loop command button is clicked. The accuracy of the intervals set will depend on the speed of the computer used. This dialog box also allows setting the total number of readings that are displayed when the Strip Chart option is selected and whether looping should continue after this total is reached. Switching between the Thermometer display and the Strip Chart display while looping is possible.

### 3.3.5 Configuration Register

The configuration register is an 8-bit register that has the following format:

| D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | Fault Queue | | O.S. Polarity | Cmp/Int | Shutdown |

Pressing the "Update" command in the configuration register field enables a dialog box which allows the setting of the individual bits of this register. The individual bits can be modified by modifying the text boxes or clicking the radio buttons, etc. Clicking the "Write" command button in this dialog box sends the displayed data to the LM75 configuration register. Clicking the "Read" command button reads the LM75's configuration register and displays the data. Clicking the "OK" button disables the dialog box. Note that when the configuration register dialog box is enabled the data displayed will not necessarily reflect what is in the LM75's configuration register. The data displayed in the dialog box is valid only after clicking the "Read" command button.

## 3.4.0 OS Output Function

The OS output of the LM75 drives high intensity LED. The anode of the LED has a printer port pin dedicated to it for power. The OS output then is fed to another pin on the parallel printer port so that the software can sense when an alarm condition has occurred. The OS output functions in two modes: Interrupt and Comparator.

In the Interrupt mode the OS output is cleared when any register in the LM75 is read. Comparator mode requires that the temperature that the LM75 is sensing drops below the setting of the Hysteresis register before the OS output is cleared.

This output can be set to be active high or active low.

The function of this output is defined by the configuration register setting.

## 3.5.0 Pointer Command

The four data registers (Tos, THyst, Temperature and Configuration) are selected by the pointer register. This register is an 8-bit register. The 2 LSBs are used to select one of the four data registers. Please refer to the LM75 data sheet Section 4.0 Internal Register Structure for a detailed description of this register.

## 4.0.0 Hardware Description

Figure 1 shows the Demo Board schematic diagram. P1 is a DB25 connector that plugs into the parallel printer port connector of your computer. Description of the pinout is shown in the following table:

| DB25 Pin Number | Function |
|---|---|
| 1 | No Connection |
| 2 | Supplies +5V to R1, R2, R3 and V+ of the LM75 |
| 3 | Supplies +5V to R5 |
| 4 | Supplies +5V to R6 |
| 5-7 | No Connection |
| 8 | Drives SCL input of LM75. Provides clocking for I$^2$C interface. |
| 9 | Provides low data for SDA input |
| 10 | No Connection |
| 11 | Input to software for state of OS output |
| 12 | No Connection |
| 13 | Input to software for SDA state. |
| 14-17 | No Connection |
| 18-25 | Ground Connection |

JP1 is an 8 pin header that is directly mapped to the LM75 pinout. JP2, JP3 and JP4 are used to control the state of Address Bits A2, A1 and A0. When a shorting bar is installed on the header the input is set to a logic low.

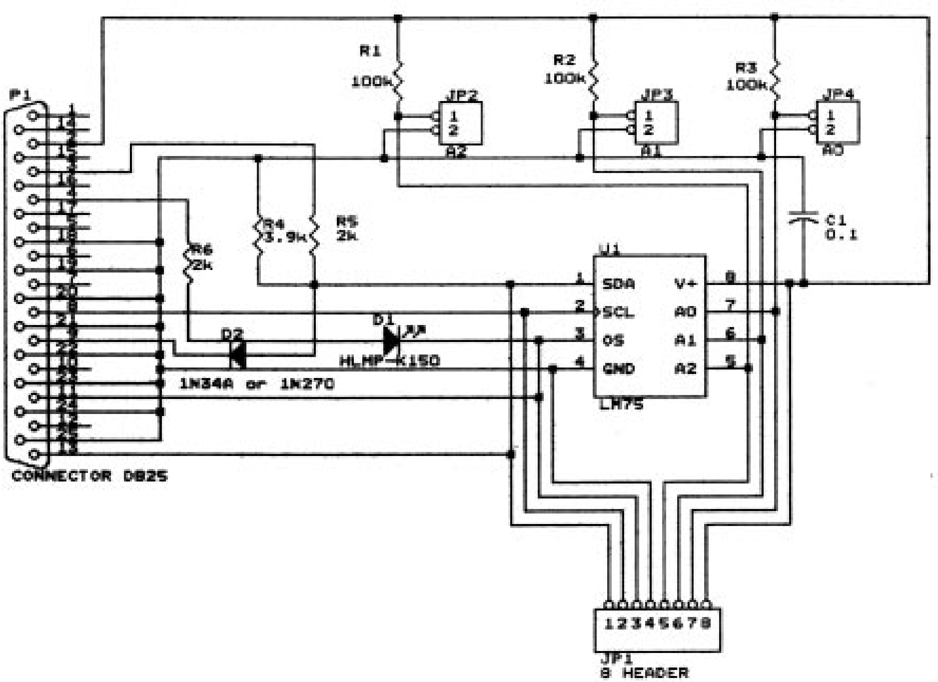



**Figure 1. LM75 Demo Board Schematic**

## 4.1.0 PC Board Layout

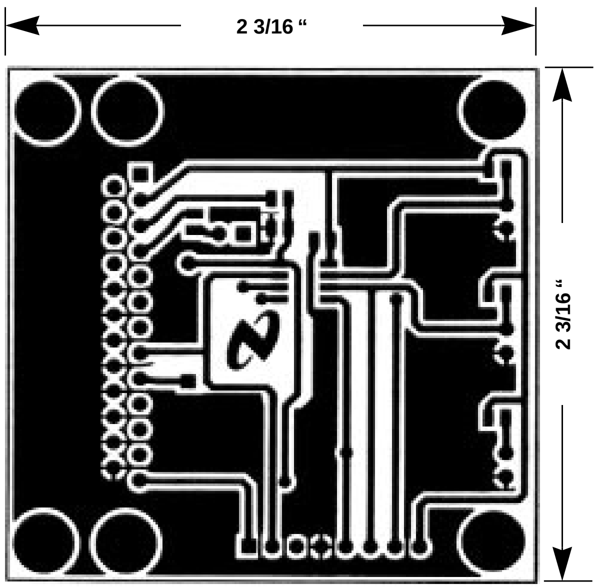



Figure 2a. Component Side of Demo Board

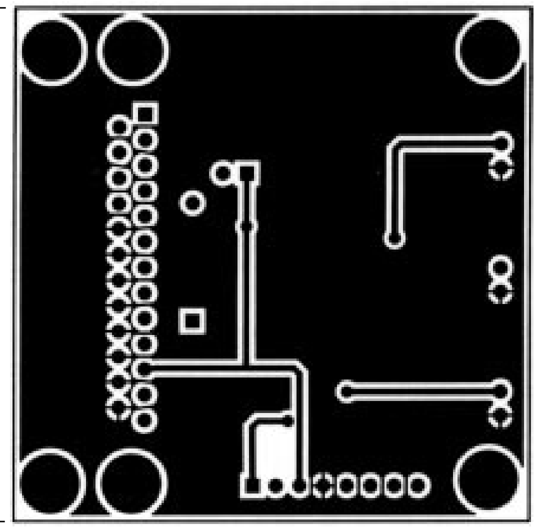


Figure 2b. Solder Side of Demo Board

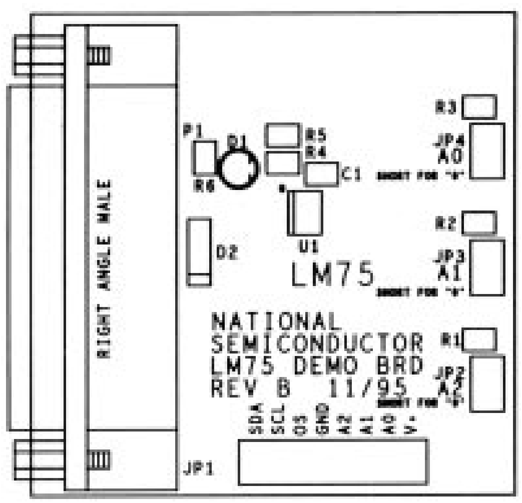



Figure 2c. Silk Screen of Demo Board

**Figure 2. LM75 Demo Board printed circuit board layout.**

### 4.2.0 LM75 Demo Board Bill Of Materials

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | C1 | 0.1µF (0805 case SMT) |
| 2 | 1 | D1 | 1N34A or 1N270 |
| 3 | 1 | D1 | HLMP-K150 |
| 4 | 1 | JP1 | 1x8 HEADER |
| 5 | 1 | JP2 | A2 (1x2 pin Header with Short) |
| 6 | 1 | JP3 | A1 (1x2 pin Header with Short) |
| 7 | 1 | JP4 | A0 (1x2 pin Header with Short) |
| 8 | 1 | P1 | CONNECTOR DB25 MALE/RightAngle PC Board Mount |
| 9 | 3 | R1,R2,R3 | 100k (0805 case SMT) |
| 10 | 1 | R4 | 3.9k (0805 case SMT) |
| 11 | 2 | R6,R5 | 2k (0805 case SMT) |
| 12 | 1 | U1 | LM75 |

## 5.0.0 Using Multiple LM75 Demo Boards

The addressing capability of the LM75 allows up to 8 devices to share the same serial I/O lines. However the capabilities of your output port may not be able to drive that many devices in parallel. Connector JP1 on the board allows you to connect several LM75 Demo Boards in parallel so long as their $I^2C$ address settings do not match. The only lines that should be connected are V+, GND, SDA and SCA. The only drawback is that the OS outputs on the boards that are not connected directly to the parallel printer port will not function correctly. The LEDs will not light up and the software will not sense when an alarm has occurred. The board that is plugged in directly to the parallel printer port will be completely functional. Selection between the boards is a simple matter of just changing the $I^2C$ address in the software. The register data of the new device being addressed is not displayed until the read buttons are clicked.

## 6.0.0 Typical Problems You May Encounter

**Moisture** or any conductive fluid on the board or its components will cause the board to operate improperly. Even condensation from your breath can cause havoc.

**The loop time between temperature readings is longer than programmed**. The computer being used cannot process the program steps quickly enough. Try a faster computer. This occurs only when the loop interval is set to 1 to 2 seconds.

## 7.0.0 Who to Call when you need HELP

Please call our Customer Response Center in Arlington, Texas. The phone numbers are: 1(800)272-9959 (voice) 1(800)432- 9672 (fax).

You can also leave a message at our Web site. We are at http://www.national.com. Also available on our Web site are data sheets for other temperature sensor products.

National Semiconductor

June 1994

# LM3911 Temperature Controller

## General Description

The LM3911 is a highly accurate temperature measurement and/or control system for use over a −25°C to +85°C temperature range. Fabricated on a single monolithic chip, it includes a temperature sensor, a stable voltage reference and an operational amplifier.

The output voltage of the LM3911 is directly proportional to temperature in degrees Kelvin at 10 mV/°K. Using the internal op amp with external resistors any temperature scale factor is easily obtained. By connecting the op amp as a comparator, the output will switch as the temperature transverses the set-point making the device useful as an on-off temperature controller.

An active shunt regulator is connected across the power leads of the LM3911 to provide a stable 6.8V voltage reference for the sensing system. This allows the use of any power supply voltage with suitable external resistors.

The input bias current is low and relatively constant with temperature, ensuring high accuracy when high source impedance is used. Further, the output collector can be returned to a voltage higher than 6.8V allowing the LM3911 to drive lamps and relays up to a 35V supply.

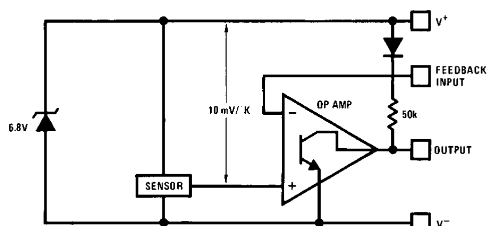
The LM3911 uses the difference in emitter-base voltage of transistors operating at different current densities as the basic temperature sensitive element. Since this output depends only on transistor matching the same reliability and stability as present op amps can be expected.

The LM3911 is available in two package styles, a metal can TO-46 and an 8-lead epoxy mini-DIP. In the epoxy package all electrical connections are made on one side of the device allowing the other 4 leads to be used for attaching the LM3911 to the temperature souce. The LM3911 is rated for operation over a −25°C to +85°C temperature range.

## Features

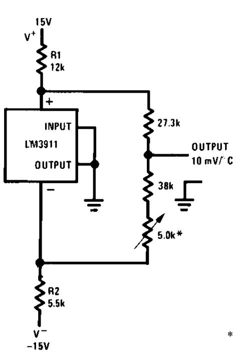
- Uncalibrated accuracy ±10°C
- Internal op amp with frequency compensation
- Linear output of 10 mV/°K (10 mV/°C)
- Can be calibrated in degrees Kelvin, Celsius or Fahrenheit
- Output can drive loads up to 35V
- Internal stable voltage reference
- Low cost

## Block Diagram



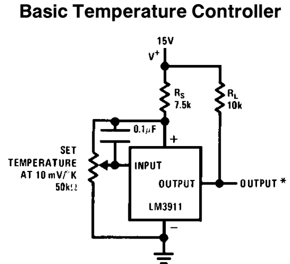

## Typical Applications

**Ground Referred Centigrade Thermometer**




* Trims out initial zener tolerance. Set output to read C

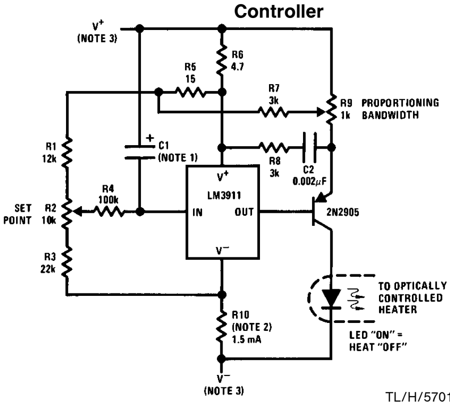
**Basic Temperature Controller**




* Output goes negative on temperature increase

$R_S = (V^+ - 6.8V)\ k\Omega$

**Proportioning Temperature Controller**




TL/H/5701–1

**Note 1:** C1 determines proportioning frequency $f \approx \frac{1}{2R4\ C1}$

**Note 2:** $R10 = \frac{|V^+| + |V^-| - 7V}{0.0015A}$

**Note 3:** Either $V^-$ or $V^+$ can be ground.



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## Absolute Maximum Ratings

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

| | |
|---|---|
| Supply Current (Externally Set) | 10 mA |
| Output Collector Voltage, $V^{++}$ | 36V |
| Feedback Input Voltage Range | 0V to +7.0V |
| Output Short Circuit Duration | Indefinite |
| Operating Temperature Range | −25°C to +85°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 seconds) | 260°C |

## Electrical Characteristics (Note 1)

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| **SENSOR** | | | | | |
| Output Voltage | $T_A = -25°C$, (Note 2) | 2.36 | 2.48 | 2.60 | V |
| Output Voltage | $T_A = +25°C$, (Note 2) | 2.88 | 2.98 | 3.08 | V |
| Output Voltage | $T_A = +85°C$, (Note 2) | 3.46 | 3.58 | 3.70 | V |
| Linearity | $\Delta T = 100°C$ | | 0.5 | 2 | % |
| Long-Term Stability | | | 0.3 | | % |
| Repeatability | | | 0.3 | | % |
| **VOLTAGE REFERENCE** | | | | | |
| Reverse Breakdown Voltage | $1\ mA \le I_Z \le 5\ mA$ | 6.55 | 6.85 | 7.25 | V |
| Reverse Breakdown Voltage Change With Current | $1\ mA \le I_Z \le 5\ mA$ | | 10 | 35 | mV |
| Temperature Stability | | | 20 | 85 | mV |
| Dynamic Impedance | $I_Z = 1\ mA$ | | 3.0 | | Ω |
| RMS Noise Voltage | $10\ Hz \le f \le 10\ kHz$ | | 30 | | μV |
| Long Term Stability | $T_A = +85°C$ | | 6.0 | | mV |
| **OP AMP** | | | | | |
| Input Bias Current | $T_A = +25°C$ | | 35 | 150 | nA |
| Input Bias Current | | | 45 | 250 | nA |
| Voltage Gain | $R_L = 36k$, $V^{++} = 36V$ | 2500 | 15000 | | V/V |
| Output Leakage Current | $T_A = 25°C$ (Note 3) | | 0.2 | 2 | μA |
| Output Leakage Current | (Note 3) | | 1.0 | 8 | μA |
| Output Source Current | $V_{OUT} \le 3.70$ | 10 | | | μA |
| Output Sink Current | $1V \le V_{OUT} \le 36V$ | 2.0 | | | mA |

**Note 1:** These specifications apply for $-25°C \le T_A \le +85°C$ and 0.9 mA $\le I_{SUPPLY} \le 1.1$ mA unless otherwise specified; $C_L \le 50$ pF.

**Note 2:** The output voltage applies to the basic thermometer configuration with the output and input terminals shorted and a load resistance of ≥ 1.0 MΩ. This is the feedback sense voltage and includes errors in both the sensor and op amp. This voltage is specified for the sensor in a rapidly stirred oil bath. The output is referred to $V^{+}$.

**Note 3:** The output leakage current is specified with ≥100 mV overdrive. Since this voltage changes with temperature, the voltage drive for turn-off changes and is defined as $V_{OUT}$ (with output and input shorted) −100 mV. This specification applies for $V_{OUT} = 36V$.

## Application Hints

Although the LM3911 is designed to be totally trouble-free, certain precautions should be taken to insure the best possible performance.

As with any temperature sensor, internal power dissipation will raise the sensor's temperature above ambient. Nominal suggested operating current for the shunt regulator is 1.0 mA and causes 7.0 mW of power dissipation. In free, still, air this raises the package temperature by about 1.2°K. Although the regulator will operate at higher reverse currents and the output will drive loads up to 5.0 mA, these higher currents will raise the sensor temperature to about 19°K above ambient-degrading accuracy. Therefore, the sensor should be operated at the lowest possible power level.

With moving air, liquid or surface temperature sensing, self-heating is not as great a problem since the measured media will conduct the heat from the sensor. Also, there are many small heat sinks designed for transistors which will improve heat transfer to the sensor from the surrounding medium. A small finned clip-on heat sink is quite effective in free-air. It should be mentioned that the LM3911 die is on the base of the package and therefore coupling to the base is preferable.

The internal reference regulator provides a temperature stable voltage for offsetting the output or setting a comparison point in temperature controllers. However, since this reference is at the same temperature as the sensor temperature, changes will also cause reference drift. For application where maximum accuracy is needed an external reference should be used. Of course, for fixed temperature controllers the internal reference is adequate.

## Typical Performance Characteristics

**Temperature Conversion**

$T_{CENTIGRADE} = T_C$

$T_{FAHRENHEIT} = T_F$

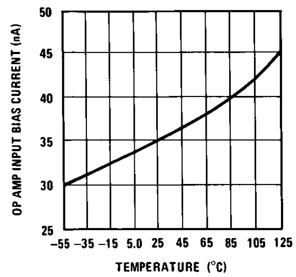
$T_{KELVIN} = T_K$

$T_K = T_C + 273.16$

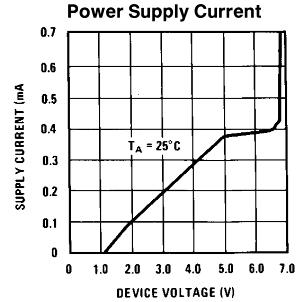
$$T_C = (40 + T_F)\,\frac{5}{9} - 40$$

$$T_F = (40 + T_C)\,\frac{9}{5} - 40$$

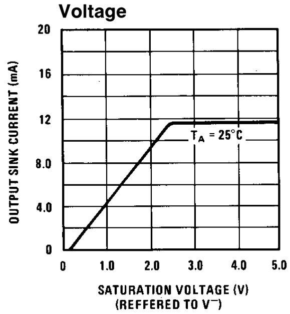
**Op Amp Input Current**



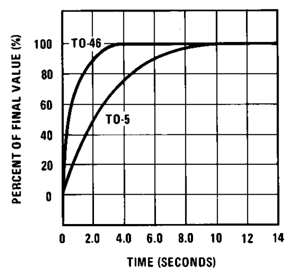

**Power Supply Current**



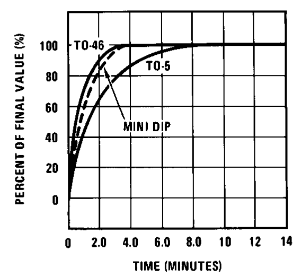

**Output Saturation Voltage**



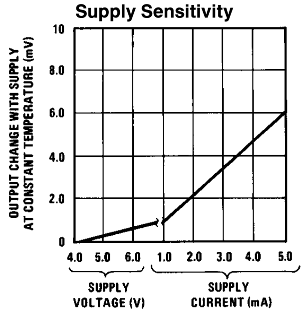

**Thermal Time Constant in Stirred Oil Bath**



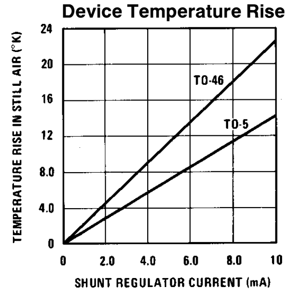

**Thermal Time Constant in Still Air**



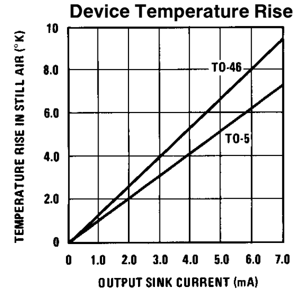

**Supply Sensitivity**



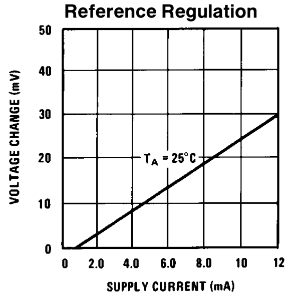

**Device Temperature Rise**



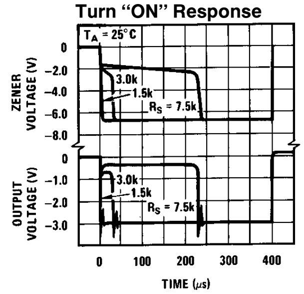

**Device Temperature Rise**



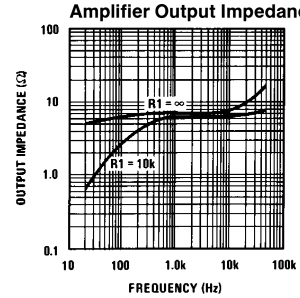

**Reference Regulation**




**Turn "ON" Response**

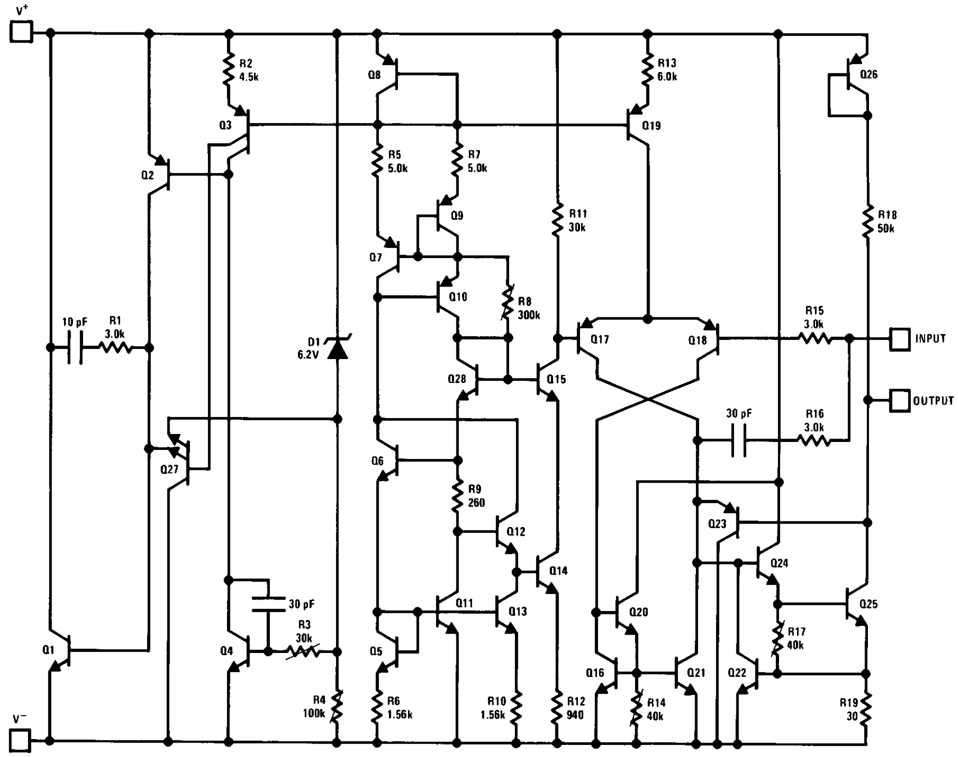



**Amplifier Output Impedance**



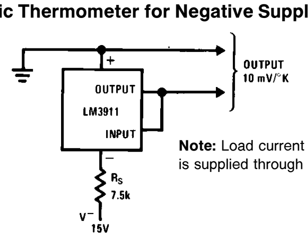

TL/H/5701–2

## Schematic Diagram




## Typical Applications (Continued)

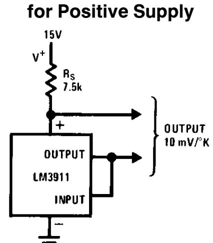
### Basic Thermometer for Negative Supply




**Note:** Load current to GND is supplied through $R_S$

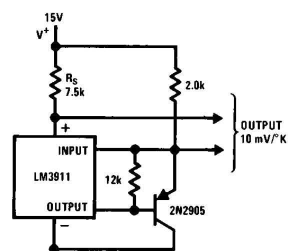
$R_S = (V^- - 6.8V) \times 10^3\Omega$

### Basic Thermometer for Positive Supply



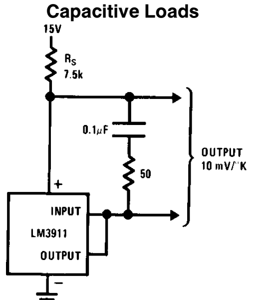

$R_S = (V^- - 6.8V) \times 10^3\Omega$

### Increasing Output Drive

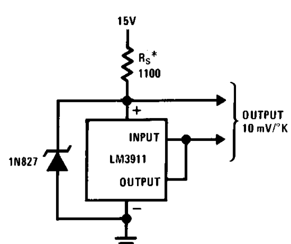



$R_S = (V^+ - 6.8V) \times 10^3\Omega$

### External Frequency Compensation for Greater Stability when Driving Capacitive Loads

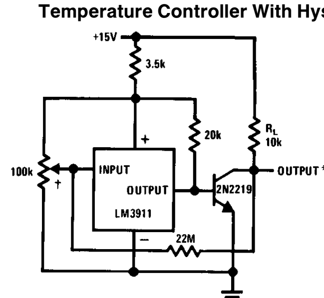



### Operating With External Zener for Lower Power Dissipation




*Depends on Zener current.

### Temperature Controller With Hysteresis



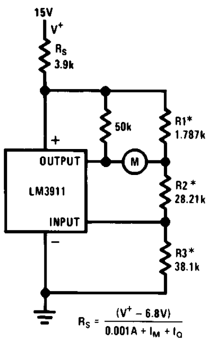

*Output goes positive on temperature increase

†Set temperature

TL/H/5701–3

## Typical Applications (Continued)

### Thermometer With Meter Output




$$R1^* = \frac{(V_Z)\ 0.01\Delta T}{I_M\ (V_Z - 0.01\ T_O)}\ ^{**}$$

$$\text{Select } I_Q \le \frac{2V}{R1}$$

$$R2 = \frac{0.01\ T_O - I_Q R1}{I_Q}$$

$$R3 = \frac{V_Z}{I_Q} - R1 - R2$$

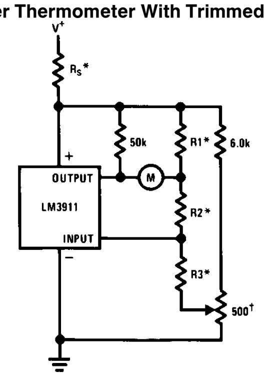
$$\left(I_Q \le \frac{2V}{R1}\right)$$

$V_z$ = Shunt regulator voltage (use 6.85)
$\Delta T$ = Meter temperature span (°K)
$I_M$ = Meter full scale current (A)
$T_O$ = Meter zero temperature (°K)
$I_Q$ = Current through R1, R2, R3 at zero meter current (10 $\mu$A to 1.0 mA) (A)

*Values shown for:
$T_O$ = 300°K, $\Delta T$ = 100°K,
$I_M$ = 1.0 mA, $I_Q$ = 100 $\mu$A

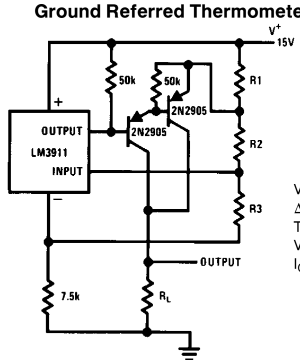
**The 0.01 in the above and following equations is in units of V/°K or V/°C, and is a result of the basic 0.01V/°K sensitivity of the transducer

### Meter Thermometer With Trimmed Output




*Selected as for meter thermometer except $T_O$ should be 5°K more than desired and $I_Q$ = 100 $\mu$A
†Calibrates $T_O$

### Ground Referred Thermometer



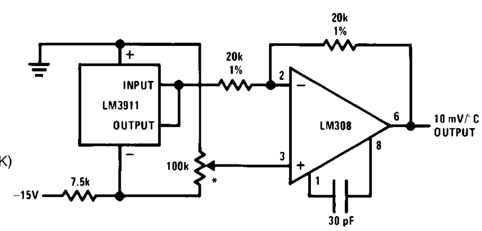

$$R1 = \frac{(V_Z)(10mV)(\Delta T)}{\dfrac{V_O\ (V_Z - 0.01\ T_O)}{R_L}}$$

$$R2 = \frac{0.01\ T_O - I_Q\ R1}{I_Q}$$

$$R3 = \frac{V_Z}{I_Q} - R1 - R2$$

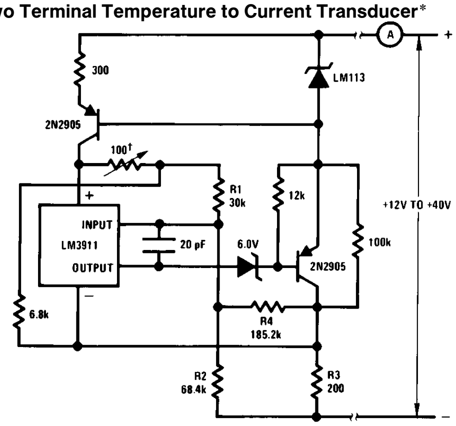
$V_z$ = Shunt regulator voltage
$\Delta T$ = Temperature span (°K)
$T_O$ = Temperature for zero output (°K)
$V_O$ = Full scale output voltage ≤ 10V
$I_Q$ = Current through R1, R2, R3 at zero output voltage (typically 100 $\mu$A to 1.0 mA)

### Ground Referred Centigrade Thermometer




*Set zero

### Two Terminal Temperature to Current Transducer*




$$R2\ (\Omega) = \frac{\left(V_Z - 0.01\ T_L\right)\left(I_H - \dfrac{0.01\ T_H}{R1}\right) + \left(V_Z - 0.01\ T_H\right)\left(\dfrac{0.01\ T_L}{R1} - I_L\right)^{**}}{\dfrac{0.01}{R1\ R3}\left[T_H(V_Z - 0.01\ T_L) - T_L(V_Z - 0.01\ T_H)\right]}$$

$$R3(\Omega) \ge \frac{V_Z\left(\dfrac{T_H}{T_L} - 1\right)}{I_H - \dfrac{I_L\ T_H}{T_L}}$$

$$\frac{1}{R4} = \frac{1}{(V_Z - 0.01\ T_L)(R2)}\left[\frac{(R2)(0.01\ T_L)}{R1} + \frac{\left(\dfrac{V_Z - 0.01\ T_L}{R2} - I_L\right)}{\dfrac{1}{R2} + \dfrac{1}{R3}}\right] - \frac{1}{R2}$$

$T_L$ = Temperature for $I_L$ ( K)
$T_H$ = Temperature for $I_H$ ( K)
$V_Z$ = Zener voltage (V)
$I_L$ = Low temperature output current (A)
$I_H$ = High temperature output current (A)

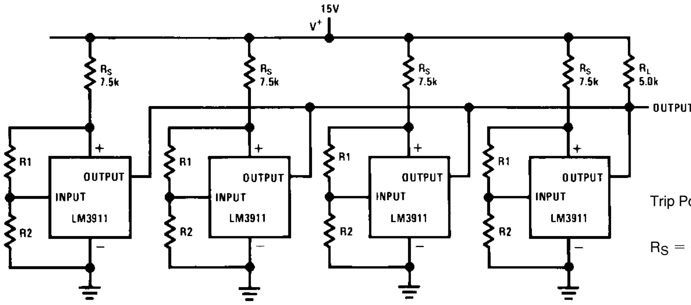
*Values shown for $I_{OUT}$ = 1 mA to 10 mA for 10°F to 100°F
†Set temperature

TL/H/5701–4

**The 0.01 in the above and following equations is in units of V/°K or V/°C, and is a result of the basic 0.01V/°K sensitivity of the transducer

## Typical Applications (Continued)

### Over Temperature Detectors With Common Output

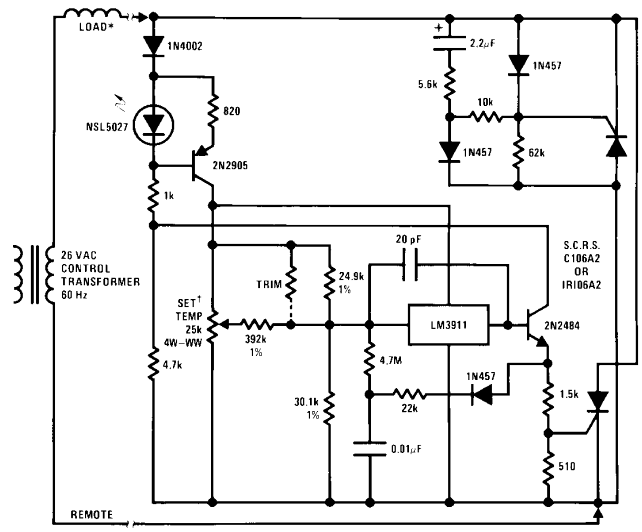



$$\text{Trip Point} = V_Z \frac{R1}{R1 + R2}$$

$$R_S = \frac{(V^+ - 6.8V)}{0.001\,A + \frac{6.8V}{R1 + R2}}$$

TL/H/5701–5

### Two-Wire Remote A.C. Electronic Thermostat (Gas or Oil Furnace Control)



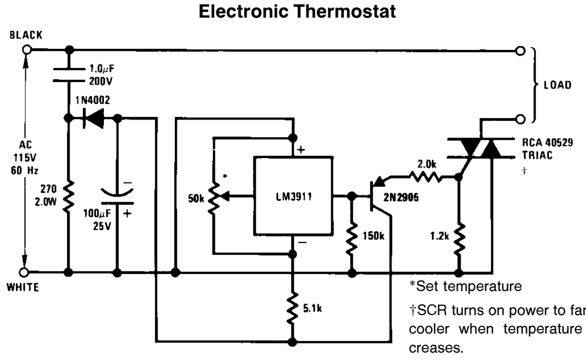

TL/H/5701–8

*Solenoid or 6–15W heater

†Pot will provide about a 50°F to 90°F setting range. The trim resistor (100k) is selected to bring 70°F near the middle of the pot rotation.

SCR heating, by proper positioning, can preheat the sensor giving control anticipation as is presently used in many home thermostats.

### Electronic Thermostat




SENSITIVE GATE TRIAC

$I_{GT} = \leq 5$ mA

RCA T2300, 40529

OR SIMILAR

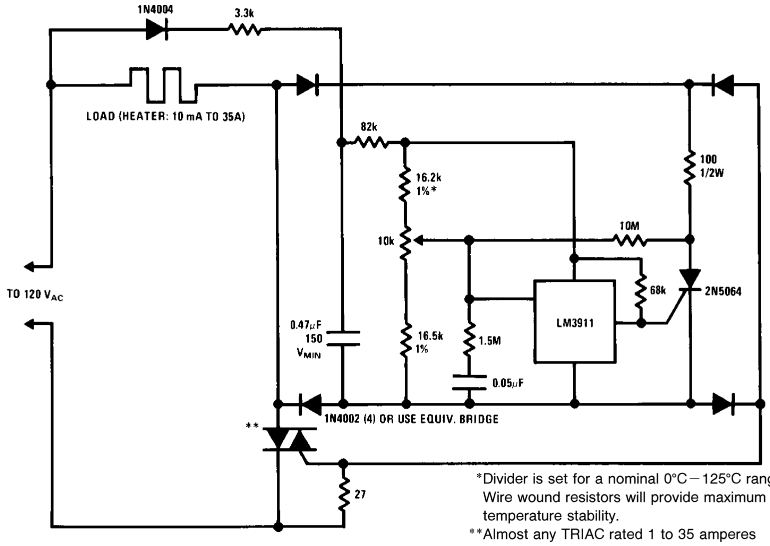
*Set temperature

†SCR turns on power to fan or cooler when temperature increases.

TL/H/5701–9

## Typical Applications (Continued)

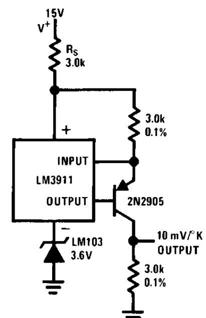
**Three-Wire Electronic Thermostat**




*Divider is set for a nominal 0°C − 125°C range. Wire wound resistors will provide maximum temperature stability.

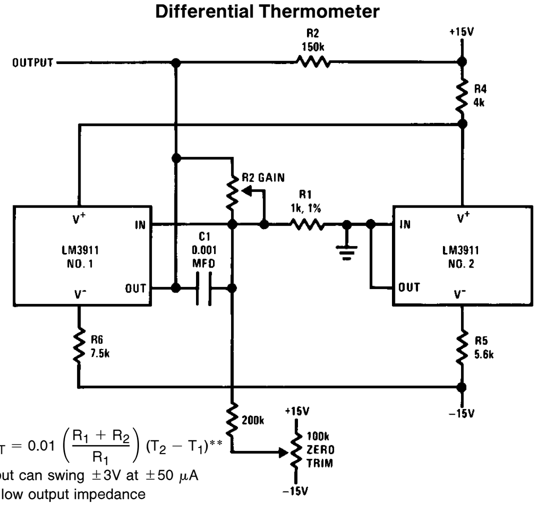
**Almost any TRIAC rated 1 to 35 amperes usable with appropriate load.

**Kelvin Thermometer With Ground Referred Output**




$$R_S = \frac{V_S^+ - 6.8V \times 10^3\Omega}{2}$$

**Differential Thermometer**



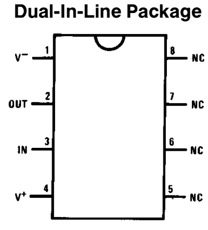

$$V_{OUT} = 0.01\left(\frac{R_1 + R_2}{R_1}\right)(T_2 - T_1)^{**}$$

Output can swing ±3V at ±50 μA with low output impedance

**The 0.01 in the above equation is in units of V/°K or V/°C, and is a result of the basic 0.01 V/°K sensitivity of the transducer

## Connection Diagrams

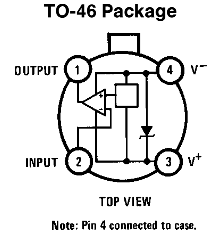
**Dual-In-Line Package**




TL/H/5701–6

**Order Number LM3911N**
**See NS Package N08E**

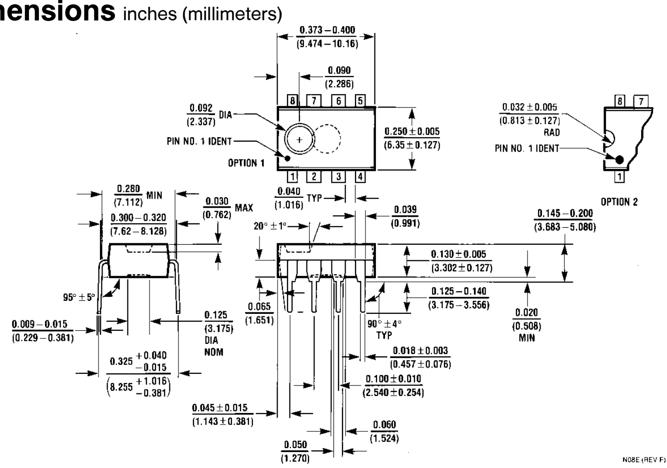
**TO-46 Package**



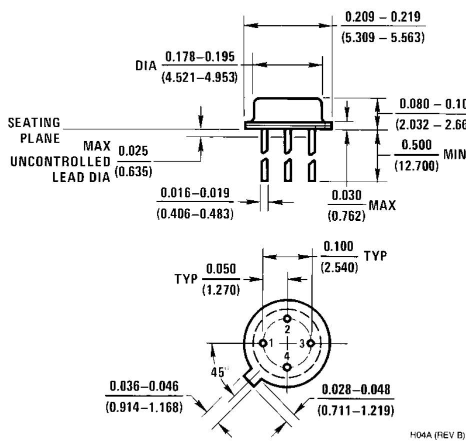

TL/H/5701–7

**Order Number LM3911H-46**
**See NS Package H04A**

## Physical Dimensions inches (millimeters)




**Molded Dual-In-Line Package (N)**
**Order Number LM3911N**
**NS Package N08E**




**TO-46 Package (H)**
**Order Number LM3911H-46**
**NS Package H04A**



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