![National Semiconductor logo] **National Semiconductor**

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 $\pm\frac{1}{4}$°C at room temperature and $\pm\frac{3}{4}$°C over a full -55 to $+150$°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 μA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a $-55°$ to $+150$°C temperature range, while the LM35C is rated for a $-40°$ to $+110$°C range ($-10°$ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C is also available in the plastic TO-92 transistor 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 $\pm\frac{1}{4}$°C typical
- Low impedance output, 0.1 Ω for 1 mA load
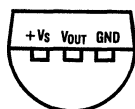
Connection Diagrams

TO-46
Metal Can Package*
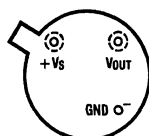
BOTTOM VIEW

TL/H/5516-1

*Case is connected to negative pin

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H
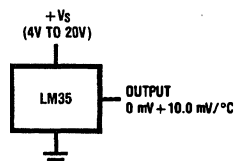
TO-92
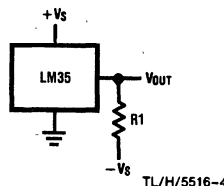### Plastic Package

BOTTOM VIEW

TL/H/5516-2

Order Number LM35CZ or LM35DZ
See NS Package Number Z03A

Typical Applications

TL/H/5516-3

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

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

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FIGURE 2. Full-Range Centigrade Temperature Sensor

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 $+150°C$

Lead Temp. (Soldering, 10 seconds):

TO-46 Package, 300°C

TO-92 Package, 260°C

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

Note 1: Unless otherwise noted, these specifications apply: $-55°C \leq T_J \leq +150°C$ for the LM35 and LM35A; $-40° \leq T_J \leq +110°C$ for the LM35C and LM35CA; and $0° \leq T_J \leq +100°C$ for the LM35D. $V_S = +5Vdc$ and $I_{LOAD} = 50 \mu A$, 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 440°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.

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)	$T_{MIN} \leq T_A \leq T_{MAX}$	±0.3		±0.5	±0.2		±0.5	°C
Sensor Gain (Average Slope)	$T_{MIN} \leq T_A \leq T_{MAX}$	+10.0	+9.8, +10.2		+10.0		+9.8, +10.2	mV/°C
Load Regulation (Note 3) $0 \leq I_L \leq 1$ mA	$T_A = +25°C$	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN} \leq T_A \leq T_{MAX}$	±0.5		±5.0	±0.5		±5.0	mV/mA
Line Regulation (Note 3)	$T_A = +25°C$	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V \leq V_S \leq 30V$	±0.02		±0.2	±0.02		±0.2	mV/V
Quiescent Current (Note 9)	$V_S = +5V, +25°C$	56	80		56	80		µA
	$V_S = +5V$	105		158	91		138	µA
	$V_S = +30V, +25°C$	56.2	82		56.2	82		µA
	$V_S = +30V$	105.5		161	91.5		141	µA
Change of Quiescent Current (Note 3)	$4V \leq V_S \leq 30V, +25°C$	0.2	2.0		0.2	2.0		µA
	$4V \leq V_S \leq 30V$	0.5		3.0	0.5		3.0	µA
Temperature Coefficient of Quiescent Current		+0.39		+0.7	+0.39		+0.7	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J = T_{MAX}$, for 1000 hours	±0.08		.	±0.08			°C

Note 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.

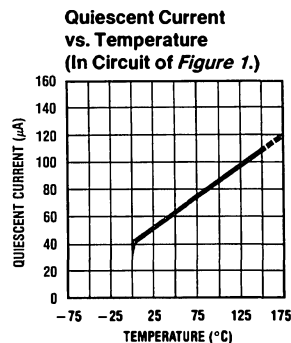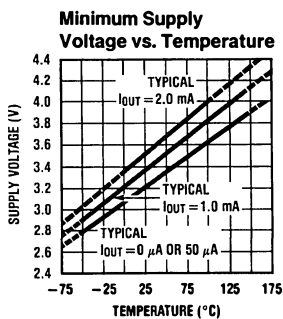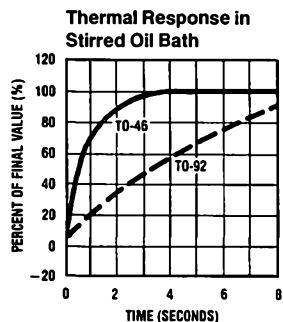**Note 6:** Specifications in boldface apply over the full rated temperature range.
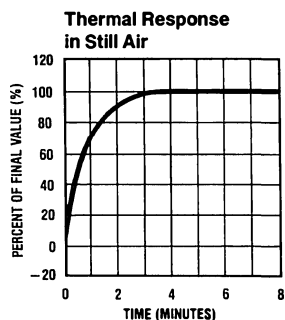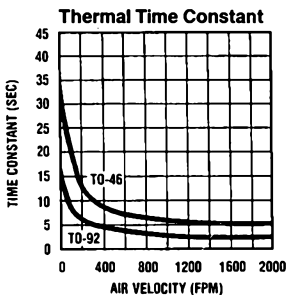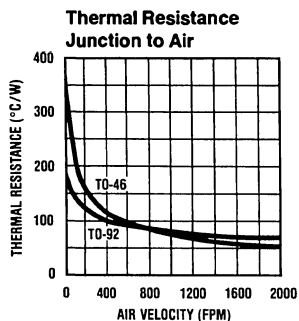
Note 7: Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

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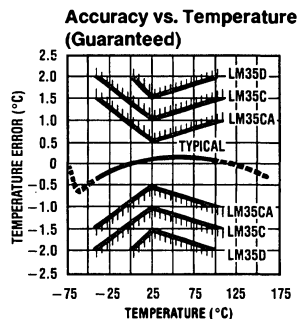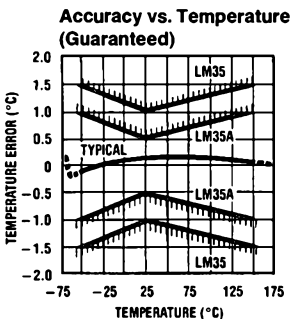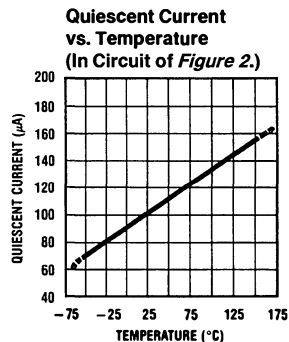
Note 9: Quiescent current is defined in the circuit of Figure 1.

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.

Typical Performance Characteristics

Thermal Resistance Junction to Air

THERMAL RESISTANCE (°C/W)

TO-46
TO-92

AIR VELOCITY (FPM)

Thermal Time Constant

TIME CONSTANT (SEC)

TO-46
TO-92

AIR VELOCITY (FPM)

Thermal Response in Still Air

PERCENT OF FINAL VALUE (%)

TIME (MINUTES)

Thermal Response in Stirred Oil Bath

PERCENT OF FINAL VALUE (%)

TO-46
TO-92

TIME (SECONDS)

Minimum Supply Voltage vs. Temperature

SUPPLY VOLTAGE (V)

TYPICAL $I_{OUT} = 2.0$ mA

TYPICAL $I_{OUT} = 1.0$ mA

TYPICAL $I_{OUT} = 0$ μA OR 50 μA

TEMPERATURE (°C)

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

QUIESCENT CURRENT (μA)

TEMPERATURE (°C)

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

QUIESCENT CURRENT (μA)

TEMPERATURE (°C)

Accuracy vs. Temperature (Guaranteed)

TEMPERATURE ERROR (°C)

LM35
LM35A
TYPICAL
LM35A
LM35

TEMPERATURE (°C)

Accuracy vs. Temperature (Guaranteed)

TEMPERATURE ERROR (°C)

LM35D
LM35C
LM35CA
TYPICAL
LM35CA
LM35C
LM35D

TEMPERATURE (°C)

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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 lightweight 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**
Still air	400°C/W	100°C/W	180°C/W	140°C/W
Moving air	100°C/W	40°C/W	90°C/W	70°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)			

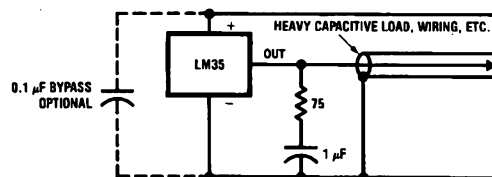* Wakefield type 201, or 1″ disc of 0.020″ sheet brass, soldered to case, or similar.

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

Typical Applications (Continued)
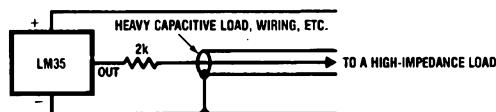
TL/H/5516−19

FIGURE 3. LM35 with Decoupling from Capacitive Load

TL/H/5516−20

FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

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

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5, 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.*
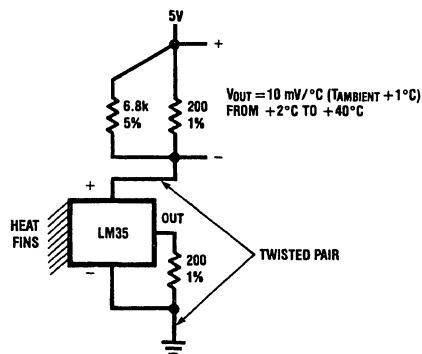
Typical Applications (Continued)

$V_{OUT} = 10$ mV/°C ($T_{AMBIENT} + 1$°C)
FROM $+2$°C TO $+40$°C

6.8k 5%

200 1%

HEAT FINS

LM35

OUT

200 1%

TWISTED PAIR

TL/H/5516–5

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

HEAT FINS

LM35

OUT

200 1%

TWISTED PAIR

$V_{OUT} = 10$ mV/°C ($T_{AMBIENT} + 1$°C)
FROM $+2$°C TO $+40$°C

6.8k 5%
OR 10k RHEOSTAT
FOR GAIN ADJUST

200 1%

TL/H/5516–6

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

$+V_S$

LM35

+
V_{OUT}
–

1N914

18k 10%

TL/H/5516–7

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

0.1 μF
BYPASS
OPTIONAL

LM35

OUT

TWISTED PAIR

2k 1%

200 1%

$V_{OUT} = 10$ mV/°C ($T_{AMBIENT} + 10$°C)
FROM -5°C to $+40$°C

2k 1%

200 1%
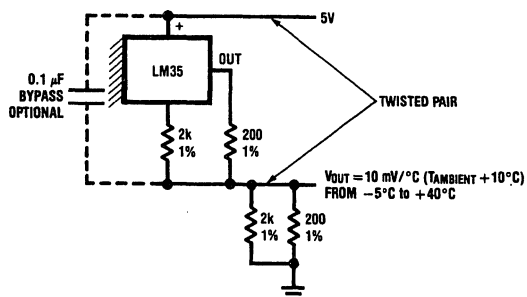
TL/H/5516–8

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

+5V TO +30V

4.7k

2N2907

OUT

LM35

+

–

62.5 0.5%

OFFSET ADJUST

OUT

402 1%

LM317

IN

ADJ

50
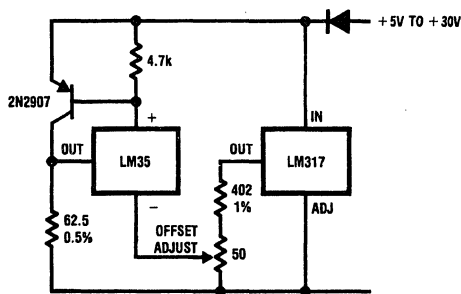
TL/H/5516–9

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

$+V_S$
(6V TO 20V)

LM35

45.5k 1%

10k 1%

26.4k 1%

18k

LM385-1.2

1.0M 1%

$V_{OUT} = +1.0$ mV/°F
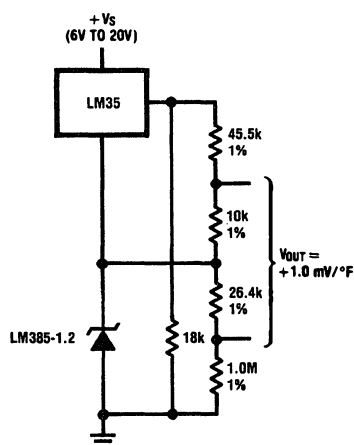
TL/H/5516–10

FIGURE 10. Fahrenheit Thermometer

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Typical Applications (Continued)
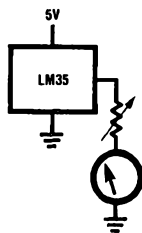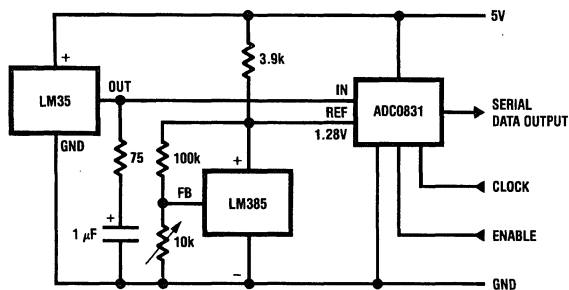

TL/H/5516–11

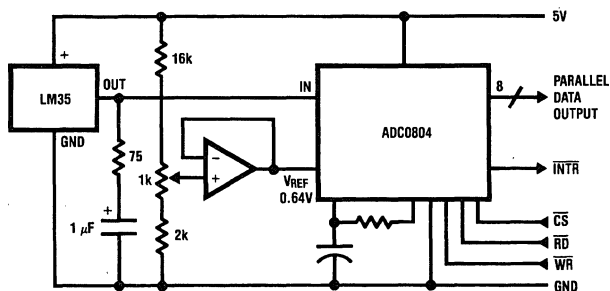FIGURE 11. Centigrade Thermometer (Analog Meter)
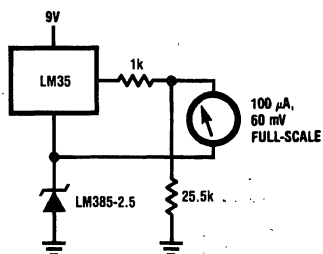
TL/H/5516–12

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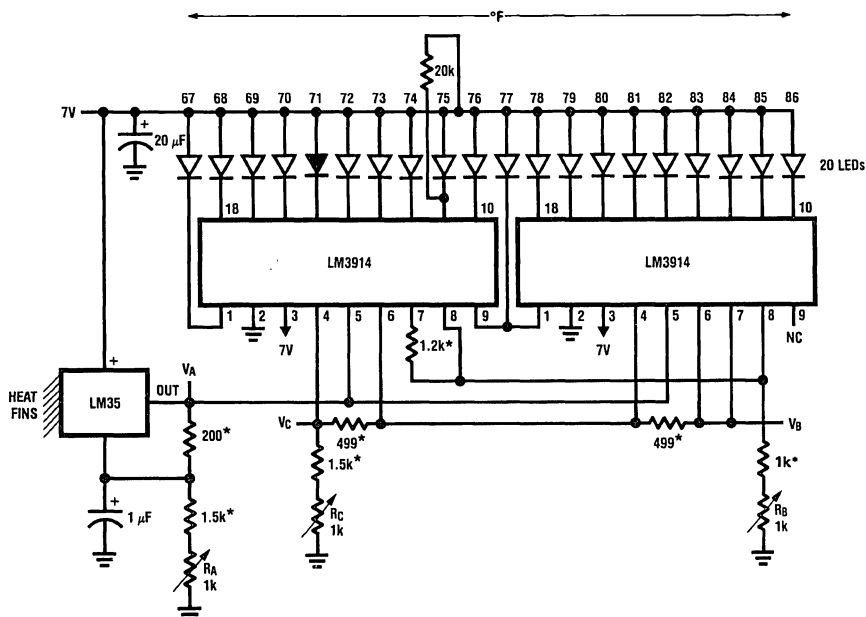

TL/H/5516–13

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

TL/H/5516–14

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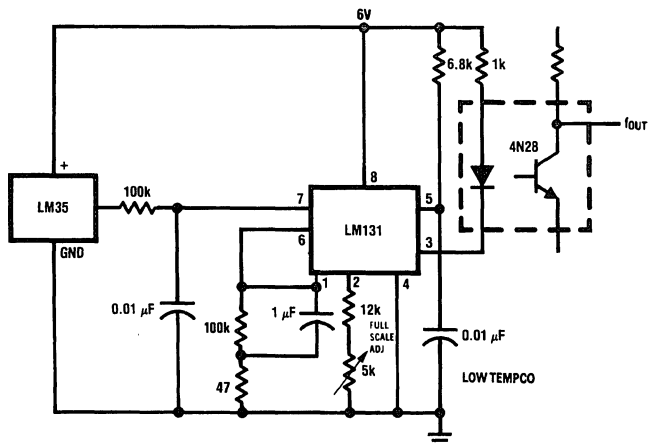Standard Data Bus to μP Interface) (128°C Full Scale)

6-18

Typical Applications (Continued)

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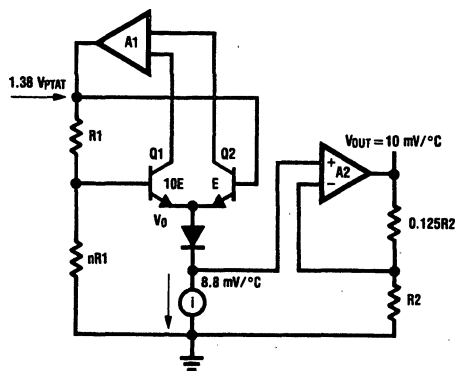-Example, $V_A = 2.275V$ at 22°C

TL/H/5516-16

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/5516–21