Especificaciones Prácticas Sensores Térmicos

PT 100

1N4148

AD 590

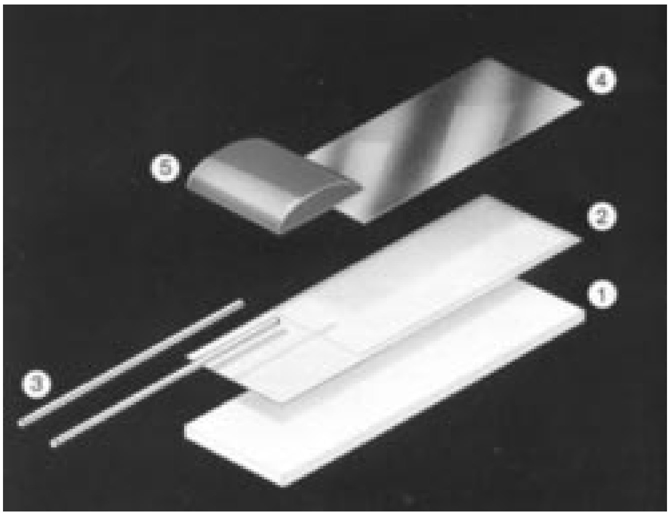
LM 35

Termopares

Sensors

Thin Film Platinum Temperature Sensors

Special developments include high temperature version up to 1000°C and low temperature version at -200°C. Please ask for details



1=ceramic substrate
2=platinum film
3=lead wire (platimum-coated nickel)
4=glass protection for platinum film
5=glass protection for lead wires

Thin Film Platinum Temperature sensor elements for the measurement of temperature from -50 to 600°C. These sensors offer high reliability, tight tolerance, excellent long-term stability, accuracy and resistance to vibration and thermal shock. Applications include industrial temperature probes, HAVC, automotive and thermostat etc.

Type	Dimensions (WxLxT)	Nom. Resistance at 0°C			Temp. Range
		100 Ω	500 Ω	1000 Ω	DIN B
PTFA	2.9x10.0x1.4	●	●	●	-50 to 600°C
PTFB	2.0x10.0x1.4	●	●	●	-50 to 600°C
PTFC	2.0x2.4x1.4	●		●	-50 to 600°C
PTFD	2.0x5.0x1.4	●	●		-50 to 600°C
PTFE	3.9x5.0x1.4	●	●	●	-50 to 600°C
PTFN	1.7x5.0x1.1	●			-50 to 600°C
PTSB	2.4x10.0x1.4	●	●	●	-40 to 150°C
PTSE	3.7x6.0x1.4	●	●	●	-40 to 150°C
PTNK	3.7x8.4x1.1	●	●	●	-40 to 150°C
PTRA	dia 4.5x13.0	●	●	●	-50 to 600°C
PTRB	dia 2.8x13.0	●	●	●	-50 to 600°C
PTRN	dia 2.2x7.5	●	●	●	-50 to 400°C
PTDA(1)	dia 4.5x13.0	●	●	●	-50 to 600°C
PTDB(1)	dia 2.8x13.0	●	●	●	-50 to 600°C

(1) Duplex Assemblies

Table 1

Class	Nom. Resistance Ro at 0°C	Temperature Coefficient TK from 0°C to 100°C	Temp. Range
Z	Ro± 0.012 %	3850± 2 ppm/°C	-50 to 200°C
P	Ro± 0.024 %	3850± 3 ppm/°C	-50 to 200°C
T	Ro± 0.04 %	3850± 4 ppm/°C	-50 to 400°C
(DIN)A	Ro± 0.06 %	3850± 5 ppm/°C	-50 to 400°C
(DIN)B	Ro± 0.12 %	3850± 13 ppm/°C	-50 to 600°C
C	Ro± 0.24 %	3850± 13 ppm/°C	-50 to 600°C

Table 2

Ordering

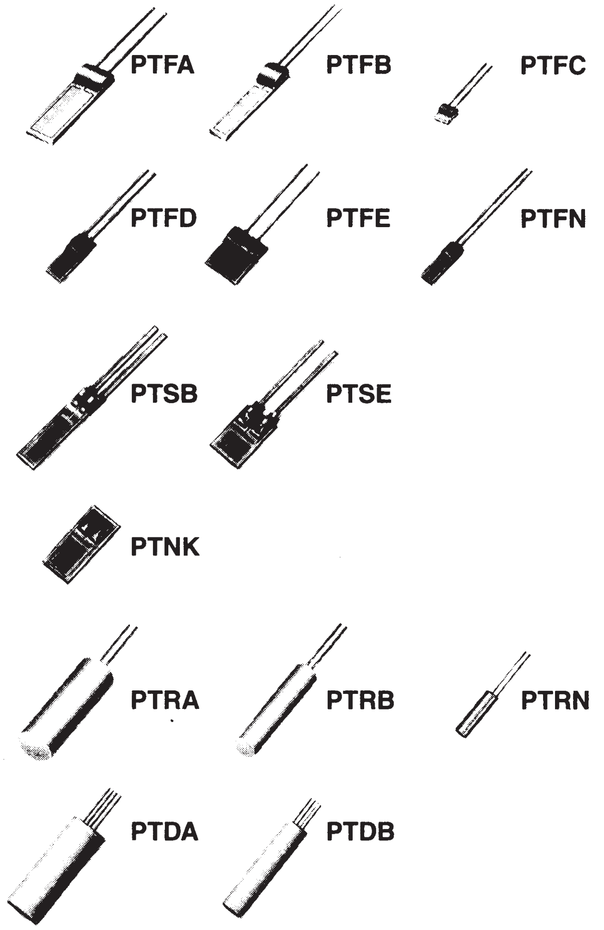
PT	F	C	101	B	000
1	2	3	4	5	6

Order Code Makeup

1) Platinum Series
2) Form F=Flat, D= Cylindrical Duplex, R= Cylindrical, N= Chip, S= Comatel Leads
3) Size (ie 2.0mm x 2.4mm) (see table 1)
4) Nominal Resistance Tolerance (101-100Ω, 501=500Ω 102= 1000Ω)
5) Class B according to DIN IEC 751 (see table 2)
6) Special Version coding

Example shown, PTFC101B000 is
PT sensor, flat, 2.0 x 2.4 x 1.4mm, 100Ω, DIN Class B, standard sensor.

Physical Characteristics



1N4148

Silicon Epitaxial Planar Diode for Various Detector, Modulator, Demodulator

RENESAS

ADE-208-147C (Z)

Rev.3
Dec. 2001

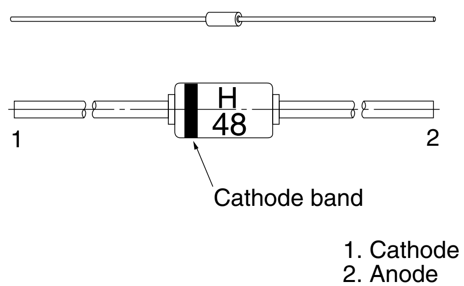
Features

- Low capacitance. (C = 4.0 pF max)
- Short reverse recovery time. (t_{rr} = 4.0 ns max)
- High reliability with glass seal.

Ordering Information

Type No.	Cathode band	Mark	Package Code
1N4148	Black	H48	DO-35

Pin Arrangement



Absolute Maximum Ratings

(Ta = 25°C)

Item	Symbol	Value	Unit
Peak reverse voltage	V_{RM}	100	V
Reverse voltage	V_R	75	V
Peak forward current	I_{FM}	450	mA
Non-Repetitive peak forward surge current	I_{FSM} *	1	A
Average forward current	I_O	150	mA
Power dissipation	Pd	500	mW
Junction temperature	Tj	200	°C
Storage temperature	Tstg	–65 to +200	°C

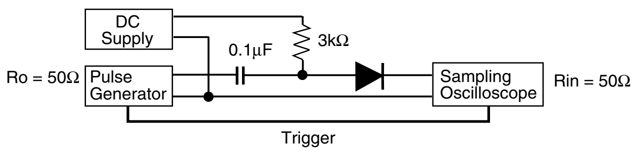
Note: Within 1s forward surge current.

Electrical Characteristics

(Ta = 25°C)

Item	Symbol	Min	Typ	Max	Unit	Test Condition
Forward voltage	V_F	—	—	1.0	V	I_F = 10 mA
Reverse current	I_R	—	—	25	nA	V_R = 20 V
Capacitance	C	—	—	4.0	pF	V_R = 0 V, f = 1 MHz
Reverse recovery time	t_{rr} *	—	—	4.0	ns	I_F = 10 mA, V_R = 6 V, Irr = 1 mA, R_L = 100 Ω

Note: Reverse recovery time test circuit



Main Characteristic

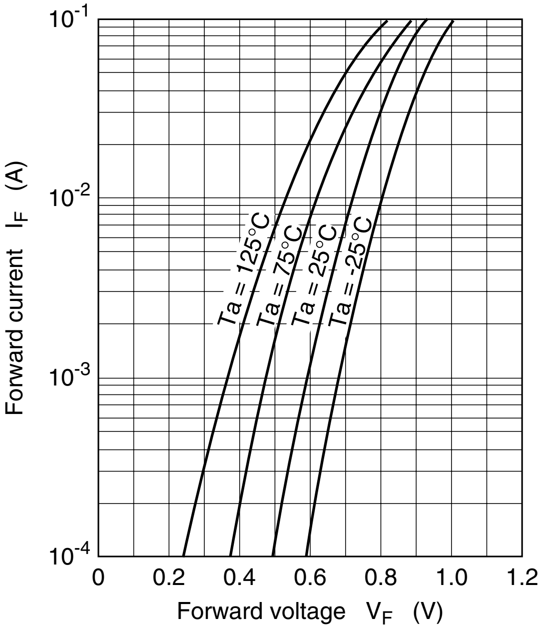


Fig.1 Forward current vs. Forward voltage

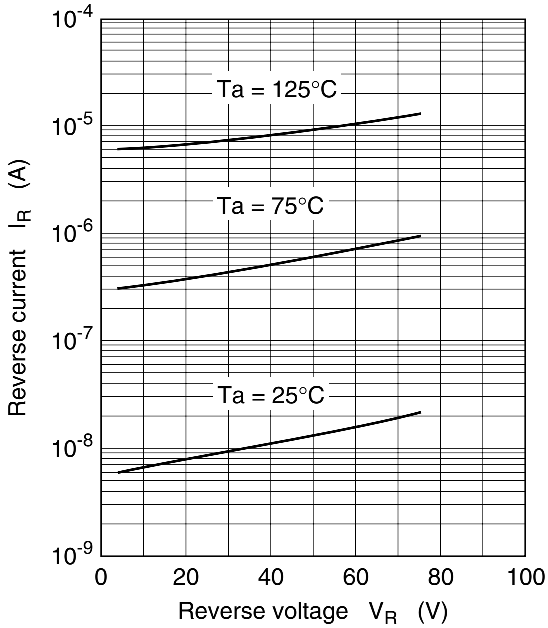


Fig.2 Reverse current vs. Reverse voltage

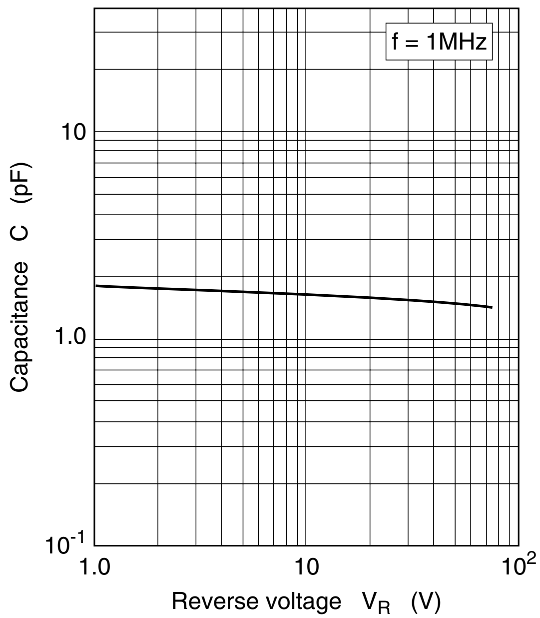


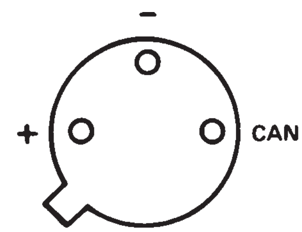
Fig.3 Capacitance vs. Reverse voltage

Two-Terminal IC Temperature Transducer

AD590

FEATURES
Linear Current Output: 1 μA/K
Wide Range: –55°C to +150°C
Probe Compatible Ceramic Sensor Package
Two Terminal Device: Voltage In/Current Out
Laser Trimmed to ±0.5°C Calibration Accuracy (AD590M)
Excellent Linearity: ±0.3°C Over Full Range (AD590M)
Wide Power Supply Range: +4 V to +30 V
Sensor Isolation from Case
Low Cost

PIN DESIGNATIONS



BOTTOM VIEW

PRODUCT DESCRIPTION

The AD590 is a two-terminal integrated circuit temperature transducer that produces an output current proportional to absolute temperature. For supply voltages between +4 V and +30 V the device acts as a high impedance, constant current regulator passing 1 μA/K. Laser trimming of the chip's thin-film resistors is used to calibrate the device to 298.2 μA output at 298.2K (+25°C).

The AD590 should be used in any temperature sensing application below +150°C in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of support circuitry makes the AD590 an attractive alternative for many temperature measurement situations. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590.

In addition to temperature measurement, applications include temperature compensation or correction of discrete components, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry. The AD590 is available in chip form making, it suitable for hybrid circuits and fast temperature measurements in protected environments.

The AD590 is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well insulated twisted pair is sufficient for operation hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 easy to multiplex: the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate output.

PRODUCT HIGHLIGHTS

1. The AD590 is a calibrated two terminal temperature sensor requiring only a dc voltage supply (+4 V to +30 V). Costly transmitters, filters, lead wire compensation and linearization circuits are all unnecessary in applying the device.
2. State-of-the-art laser trimming at the wafer level in conjunction with extensive final testing ensures that AD590 units are easily interchangeable.
3. Superior interface rejection results from the output being a current rather than a voltage. In addition, power requirements are low (1.5 mWs @ 5 V @ +25°C.) These features make the AD590 easy to apply as a remote sensor.
4. The high output impedance (>10 MΩ) provides excellent rejection of supply voltage drift and ripple. For instance, changing the power supply from 5 V to 10 V results in only a 1 μA maximum current change, or 1°C equivalent error.
5. The AD590 is electrically durable: it will withstand a forward voltage up to 44 V and a reverse voltage of 20 V. Hence, supply irregularities or pin reversal will not damage the device.

REV. B

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Tel: 617/329-4700 World Wide Web Site: http://www.analog.com
Fax: 617/326-8703

AD590–SPECIFICATIONS (@ +25°C and V_S = +5 V unless otherwise noted)

Model	AD590J Min	AD590J Typ	AD590J Max	AD590K Min	AD590K Typ	AD590K Max	Units
ABSOLUTE MAXIMUM RATINGS							
Forward Voltage (E+ or E–)			+44			+44	Volts
Reverse Voltage (E+ to E–)			–20			–20	Volts
Breakdown Voltage (Case E+ or E–)			±200			±200	Volts
Rated Performance Temperature Range[1]	–55		+150	–55		+150	°C
Storage Temperature Range[1]	–65		+155	–65		+155	°C
Lead Temperature (Soldering, 10 sec)			+300			+300	°C
POWER SUPPLY							
Operating Voltage Range	+4		+30	+4		+30	Volts
OUTPUT							
Nominal Current Output @ +25°C (298.2K)		298.2			298.2		μA
Nominal Temperature Coefficient		1			1		μA/K
Calibration Error @ +25°C			**±5.0**			**±2.5**	°C
Absolute Error (Over Rated Performance Temperature Range)							
Without External Calibration Adjustment			**±10**			**±5.5**	°C
With +25°C Calibration Error Set to Zero			**±3.0**			**±2.0**	°C
Nonlinearity			**±1.5**			**±0.8**	°C
Repeatability[2]			±0.1			±0.1	°C
Long-Term Drift[3]			±0.1			±0.1	°C
Current Noise		40			40		pA/$\sqrt{\text{Hz}}$
Power Supply Rejection							
+4 V ≤ V_S ≤ +5 V		0.5			0.5		μA/V
+5 V ≤ V_S ≤ +15 V		0.2			0.2		μV/V
+15 V ≤ V_S ≤ +30 V		0.1			0.1		μA/V
Case Isolation to Either Lead		10^{10}			10^{10}		Ω
Effective Shunt Capacitance		100			100		pF
Electrical Turn-On Time		20			20		μs
Reverse Bias Leakage Current[4] (Reverse Voltage = 10 V)		10			10		pA
PACKAGE OPTIONS							
TO-52 (H-03A)		AD590JH			AD590KH		
Flatpack (F-2A)		AD590JF			AD590KF		

NOTES

[1]The AD590 has been used at –100°C and +200°C for short periods of measurement with no physical damage to the device. However, the absolute errors specified apply to only the rated performance temperature range.

[2]Maximum deviation between +25°C readings after temperature cycling between –55°C and +150°C; guaranteed not tested.

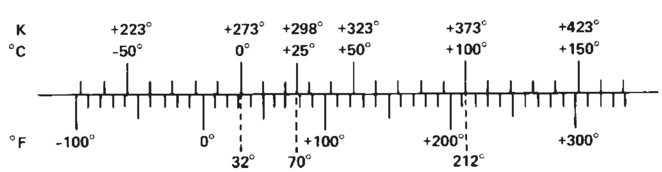
[3]Conditions: constant +5 V, constant +125°C; guaranteed, not tested.

[4]Leakage current doubles every 10°C.

Specifications subject to change without notice.

Specifications shown in **boldface** are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in **boldface** are tested on all production units.

Model	AD590L Min	AD590L Typ	AD590L Max	AD590M Min	AD590M Typ	AD590M Max	Units
ABSOLUTE MAXIMUM RATINGS							
Forward Voltage (E+ or E–)			+44			+44	Volts
Reverse Voltage (E+ to E–)			–20			–20	Volts
Breakdown Voltage (Case to E+ or E–)			±200			±200	Volts
Rated Performance Temperature Range[1]	–55		+150	–55		+150	°C
Storage Temperature Range[1]	–65		+155	–65		+155	°C
Lead Temperature (Soldering, 10 sec)			+300			+300	°C
POWER SUPPLY							
Operating Voltage Range	+4		+30	+4		+30	Volts
OUTPUT							
Nominal Current Output @ +25°C (298.2K)		298.2			298.2		µA
Nominal Temperature Coefficient		1			1		µA/K
Calibration Error @ +25°C			**±1.0**			**±0.5**	°C
Absolute Error (Over Rated Performance Temperature Range)							
Without External Calibration Adjustment			**±3.0**			**±1.7**	°C
With ±25°C Calibration Error Set to Zero			**±1.6**			**±1.0**	°C
Nonlinearity			**±0.4**			**±0.3**	°C
Repeatability[2]			±0.1			±0.1	°C
Long-Term Drift[3]			±0.1			±0.1	°C
Current Noise		40			40		$pA/\sqrt{Hz}$
Power Supply Rejection							
$+4\ V \leq V_S \leq +5\ V$		0.5			0.5		µA/V
$+5\ V \leq V_S \leq +15\ V$		0.2			0.2		µA/V
$+15\ V \leq V_S \leq +30\ V$		0.1			0.1		µA/V
Case Isolation to Either Lead		10^{10}			10^{10}		Ω
Effective Shunt Capacitance		100			100		pF
Electrical Turn-On Time		20			20		µs
Reverse Bias Leakage Current[4] (Reverse Voltage = 10 V)		10			10		pA
PACKAGE OPTIONS							
TO-52 (H-03A)		AD590LH			AD590MH		
Flatpack (F-2A)		AD590LF			AD590MF		



TEMPERATURE SCALE CONVERSION EQUATIONS

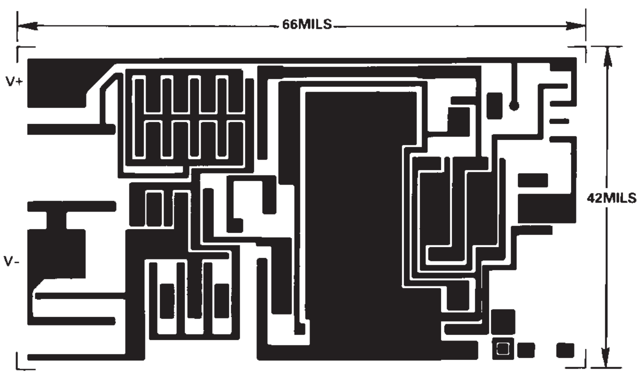
$$°C = \frac{5}{9}(°F - 32) \qquad K = °C + 273.15$$

$$°F = \frac{9}{5}°C + 32 \qquad °R = °F + 459.7$$

The 590H has 60 µ inches of gold plating on its Kovar leads and Kovar header. A resistance welder is used to seal the nickel cap to the header. The AD590 chip is eutectically mounted to the header and ultrasonically bonded to with 1 MIL aluminum wire. Kovar composition: 53% iron nominal; 29% ±1% nickel; 17% ± 1% cobalt; 0.65% manganese max; 0.20% silicon max; 0.10% aluminum max; 0.10% magnesium max; 0.10% zirconium max; 0.10% titanium max; 0.06% carbon max.

The 590F is a ceramic package with gold plating on its Kovar leads, Kovar lid, and chip cavity. Solder of 80/20 Au/Sn composition is used for the 1.5 mil thick solder ring under the lid. The chip cavity has a nickel underlay between the metalization and the gold plating. The AD590 chip is eutectically mounted in the chip cavity at 410°C and ultrasonically bonded to with 1 mil aluminum wire. Note that the chip is in direct contact with the ceramic base, not the metal lid. When using the AD590 in die form, the chip substrate must be kept electrically isolated, (floating), for correct circuit operation.

METALIZATION DIAGRAM



THE AD590 IS AVAILABLE IN LASER-TRIMMED CHIP FORM; CONSULT THE CHIP CATALOG FOR DETAILS.

CIRCUIT DESCRIPTION[1]

The AD590 uses a fundamental property of the silicon transistors from which it is made to realize its temperature proportional characteristic: if two identical transistors are operated at a constant ratio of collector current densities, r, then the difference in their base-emitter voltage will be (kT/q)(In r). Since both k, Boltzman's constant and q, the charge of an electron, are constant, the resulting voltage is directly proportional to absolute temperature (PTAT).

In the AD590, this PTAT voltage is converted to a PTAT current by low temperature coefficient thin-film resistors. The total current of the device is then forced to be a multiple of this PTAT current. Referring to Figure 1, the schematic diagram of the AD590, Q8 and Q11 are the transistors that produce the PTAT voltage. R5 and R6 convert the voltage to current. Q10, whose collector current tracks the colletor currents in Q9 and Q11, supplies all the bias and substrate leakage current for the rest of the circuit, forcing the total current to be PTAT. R5 and R6 are laser trimmed on the wafer to calibrate the device at +25°C.

Figure 2 shows the typical V–I characteristic of the circuit at +25°C and the temperature extremes.

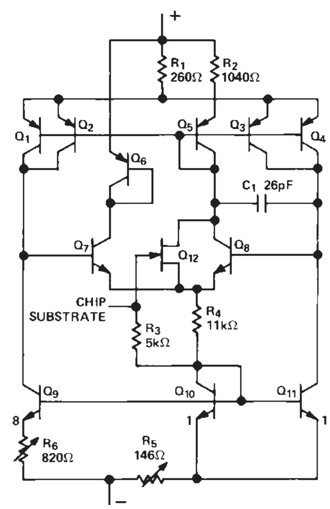


Figure 1. Schematic Diagram

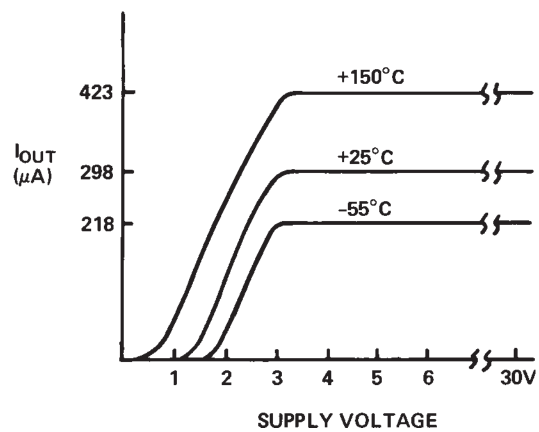


Figure 2. V–I Plot

[1]For a more detailed circuit description see M.P. Timko, "A Two-Terminal IC Temperature Transducer," IEEE J. Solid State Circuits, Vol. SC-11, p. 784-788, Dec. 1976.

EXPLANATION OF TEMPERATURE SENSOR SPECIFICATIONS

The way in which the AD590 is specified makes it easy to apply in a wide variety of different applications. It is important to understand the meaning of the various specifications and the effects of supply voltage and thermal environment on accuracy.

The AD590 is basically a PTAT (proportional to absolute temperature)[1] current regulator. That is, the output current is equal to a scale factor times the temperature of the sensor in degrees Kelvin. This scale factor is trimmed to 1 µA/K at the factory, by adjusting the indicated temperature (i.e., the output current) to agree with the actual temperature. This is done with 5 V across the device at a temperature within a few degrees of +25°C (298.2K). The device is then packaged and tested for accuracy over temperature.

CALIBRATION ERROR

At final factory test the difference between the indicated temperature and the actual temperature is called the calibration error. Since this is a scale factory error, its contribution to the total error of the device is PTAT. For example, the effect of the 1°C specified maximum error of the AD590L varies from 0.73°C at –55°C to 1.42°C at 150°C. Figure 3 shows how an exaggerated calibration error would vary from the ideal over temperature.

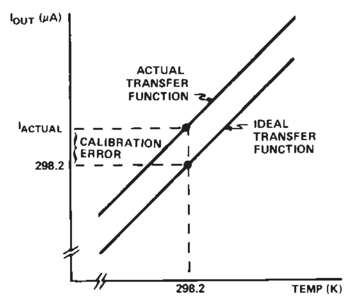


Figure 3. Calibration Error vs. Temperature

The calibration error is a primary contributor to maximum total error in all AD590 grades. However, since it is a scale factor error, it is particularly easy to trim. Figure 4 shows the most elementary way of accomplishing this. To trim this circuit the temperature of the AD590 is measured by a reference temperature sensor and R is trimmed so that V_T = 1 mV/K at that temperature. Note that when this error is trimmed out at one temperature, its effect is zero over the entire temperature range. In most applications there is a current-to-voltage conversion resistor (or, as with a current input ADC, a reference) that can be trimmed for scale factor adjustment.

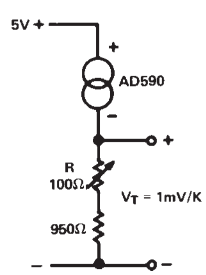


Figure 4. One Temperature Trim

[1]T(°C) = T(K) –273.2; Zero on the Kelvin scale is "absolute zero"; there is no lower temperature.

ERROR VERUS TEMPERATURE: WITH CALIBRATION ERROR TRIMMED OUT

Each AD590 is tested for error over the temperature range with the calibration error trimmed out. This specification could also be called the "variance from PTAT" since it is the maximum difference between the actual current over temperature and a PTAT multiplication of the actual current at 25°C. This error consists of a slope error and some curvature, mostly at the temperature extremes. Figure 5 shows a typical AD590K temperature curve before and after calibration error trimming.

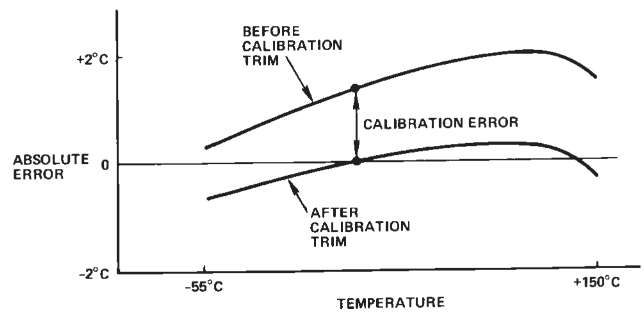


Figure 5. Effect to Scale Factor Trim on Accuracy

ERROR VERSUS TEMPERATURE: NO USER TRIMS

Using the AD590 by simply measuring the current, the total error is the "variance from PTAT" described above plus the effect of the calibration error over temperature. For example the AD590L maximum total error varies from 2.33°C at –55°C to 3.02°C at 150°C. For simplicity, only the large figure is shown on the specification page.

NONLINEARITY

Nonlinearity as it applies to the AD590 is the maximum deviation of current over temperature from a best-fit straight line. The nonlinearity of the AD590 over the –55°C to +150°C range is superior to all conventional electrical temperature sensors such as thermocouples. RTDs and thermistors. Figure 6 shows the nonlinearity of the typical AD590K from Figure 5.

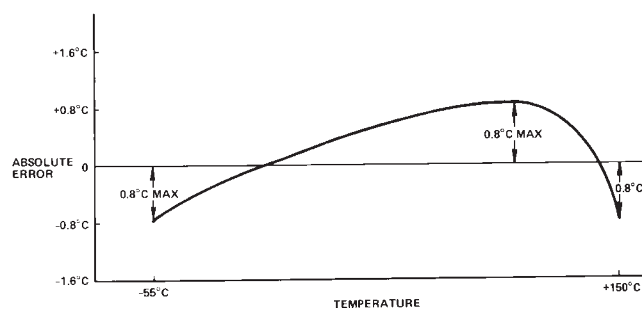


Figure 6. Nonlinearity

Figure 7A shows a circuit in which the nonlinearity is the major contributor to error over temperature. The circuit is trimmed by adjusting R_1 for a 0 V output with the AD590 at 0°C. R_2 is then adjusted for 10 V out with the sensor at 100°C. Other pairs of temperatures may be used with this procedure as long as they are measured accurately by a reference sensor. Note that for +15 V output (150°C) the V+ of the op amp must be greater than 17 V. Also note that V– should be at least –4 V: if V– is ground there is no voltage applied across the device.

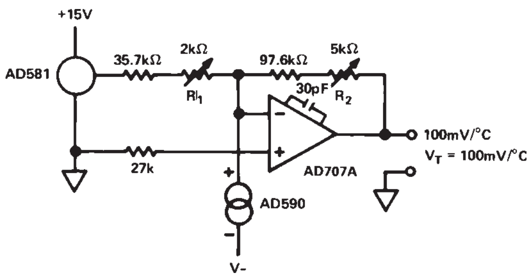


Figure 7A. Two Temperature Trim

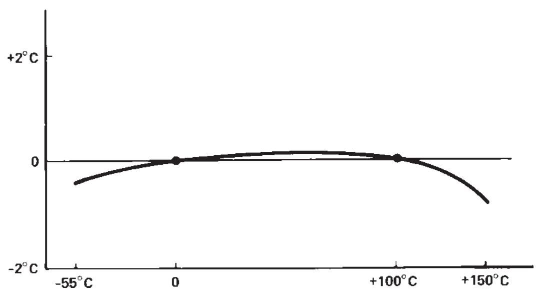


Figure 7B. Typical Two-Trim Accuracy

VOLTAGE AND THERMAL ENVIRONMENT EFFECTS

The power supply rejection specifications show the maximum expected change in output current versus input voltage changes. The insensitivity of the output to input voltage allows the use of unregulated supplies. It also means that hundreds of ohms of resistance (such as a CMOS multiplexer) can be tolerated in series with the device.

It is important to note that using a supply voltage other than 5 V does not change the PTAT nature of the AD590. In other words, this change is equivalent to a calibration error and can be removed by the scale factor trim (see previous page).

The AD590 specifications are guaranteed for use in a low thermal resistance environment with 5 V across the sensor. Large changes in the thermal resistance of the sensor's environment will change the amount of self-heating and result in changes in the output which are predictable but not necessarily desirable.

The thermal environment in which the AD590 is used determines two important characteristics: the effect of self heating and the response of the sensor with time.

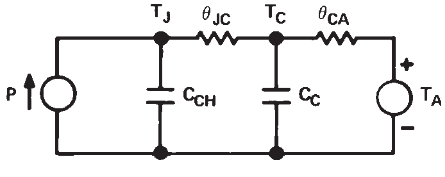


Figure 8. Thermal Circuit Model

Figure 8 is a model of the AD590 which demonstrates these characteristics. As an example, for the TO-52 package, θ_{JC} is the thermal resistance between the chip and the case, about 26°C/watt. θ_{CA} is the thermal resistance between the case and the surroundings and is determined by the characteristics of the thermal connection. Power source P represents the power dissipated on the chip. The rise of the junction temperature, T_J, above the ambient temperature T_A is:

$$T_J - T_A = P\,(\theta_{JC} + \theta_{CA}) \qquad \text{Equation 1}$$

Table I gives the sum of θ_{JC} and θ_{CA} for several common thermal media for both the "H" and "F" packages. The heatsink used was a common clip-on. Using Equation 1, the temperature rise of an AD590 "H" package in a stirred bath at +25°C, when driven with a 5 V supply, will be 0.06°C. However, for the same conditions in still air the temperature rise is 0.72°C. For a given supply voltage, the temperature rise varies with the current and is PTAT. Therefore, if an application circuit is trimmed with the sensor in the same thermal environment in which it will be used, the scale factor trim compensates for this effect over the entire temperature range.

Table I. Thermal Resistances

Medium	$\theta_{JC} + \theta_{CA}$ (°C/Watt)		τ (sec)(Note 3)	
	H	F	H	F
Aluminum Block	30	10	0.6	0.1
Stirred Oil[1]	42	60	1.4	0.6
Moving Air[2]				
With Heat Sink	45	–	5.0	–
Without Heat Sink	115	190	13.5	10.0
Still Air				
With Heat Sink	191	–	108	–
Without Heat Sink	480	650	60	30

[1]Note: τ is dependent upon velocity of oil; average of several velocities listed above.
[2]Air velocity ≅ 9 ft./sec.
[3]The time constant is defined as the time required to reach 63.2% of an instantaneous temperature change.

The time response of the AD590 to a step change in temperature is determined by the thermal resistances and the thermal capacities of the chip, C_{CH}, and the case, C_C. C_{CH} is about 0.04 watt-sec/°C for the AD590. C_C varies with the measured medium since it includes anything that is in direct thermal contact with the case. In most cases, the single time constant exponential curve of Figure 9 is sufficient to describe the time response, T (t). Table I shows the effective time constant, τ, for several media.

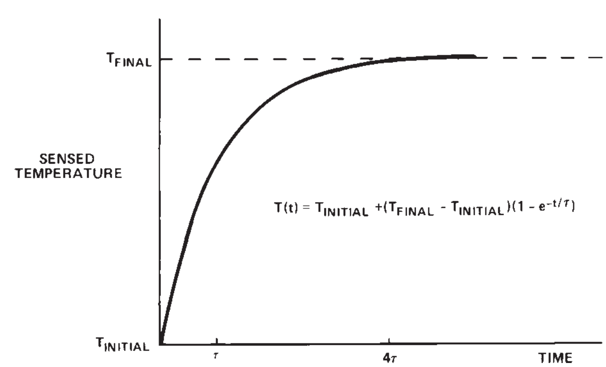


Figure 9. Time Response Curve

GENERAL APPLICATIONS

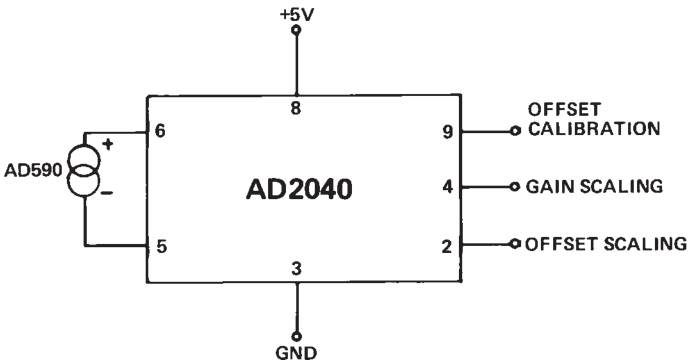


Figure 10. Variable Scale Display

Figure 10 demonstrates the use of a low cost Digital Panel Meter for the display of temperature on either the Kelvin, Celsius or Fahrenheit scales. For Kelvin temperature Pins 9, 4 and 2 are grounded; and for Fahrenheit temperature Pins 4 and 2 are left open.

The above configuration yields a 3 digit display with 1°C or 1°F resolution, in addition to an absolute accuracy of ±2.0°C over the –55°C to +125°C temperature range if a one-temperature calibration is performed on an AD590K, L, or M.

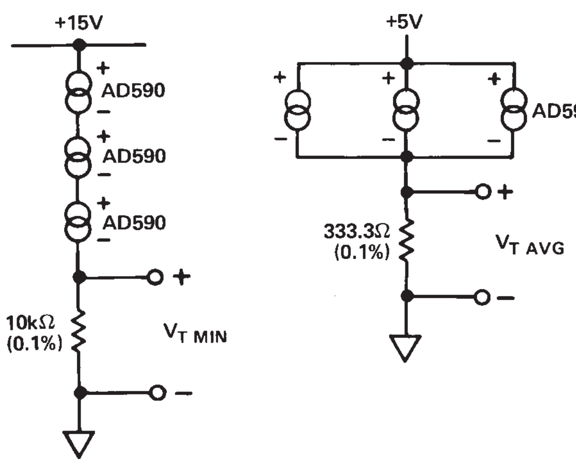


Figure 11. Series & Parallel Connection

Connecting several AD590 units in series as shown in Figure 11 allows the minimum of all the sensed temperatures to be indicated. In contrast, using the sensors in parallel yields the average of the sensed temperatures.

The circuit of Figure 12 demonstrates one method by which differential temperature measurements can be made. R1 and R2 can be used to trim the output of the op amp to indicate a

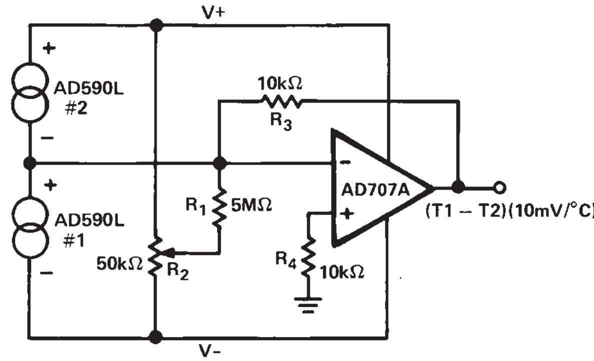


Figure 12. Differential Measurements

desired temperature difference. For example, the inherent offset between the two devices can be trimmed in. If V+ and V– are radically different, then the difference in internal dissipation will cause a differential internal temperature rise. This effect can be used to measure the ambient thermal resistance seen by the sensors in applications such as fluid level detectors or anemometry.

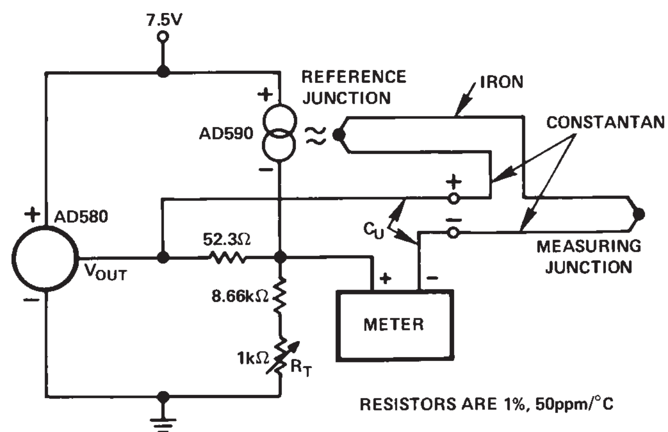


Figure 13. Cold Junction Compensation Circuit for Type J Thermocouple

Figure 13 is an example of a cold junction compensation circuit for a Type J Thermocouple using the AD590 to monitor the reference junction temperature. This circuit replaces an ice-bath as the thermocouple reference for ambient temperatures between +15°C and +35°C. The circuit is calibrated by adjusting R_T for a proper meter reading with the measuring junction at a known reference temperature and the circuit near +25°C. Using components with the TCs as specified in Figure 13, compensation accuracy will be within ±0.5°C for circuit temperatures between +15°C and +35°C. Other thermocouple types can be accommodated with different resistor values. Note that the TCs of the voltage reference and the resistors are the primary contributors to error.

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

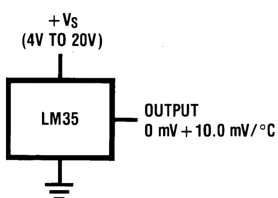
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

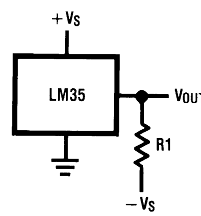
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

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



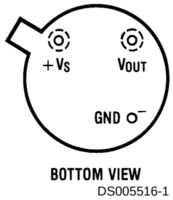
DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

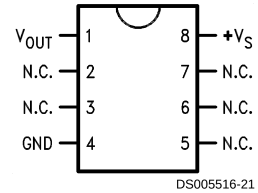
TO-46
Metal Can Package*



*Case is connected to negative pin (GND)

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

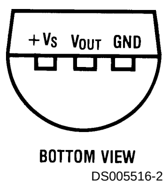
SO-8
Small Outline Molded Package



N.C. = No Connection

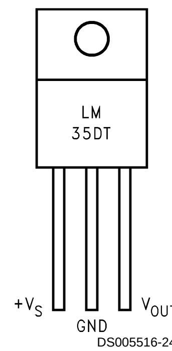
Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package



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

TO-220
Plastic Package*



*Tab is connected to the negative pin (GND).
Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

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

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60˚C to +180˚C
TO-92 Package,	−60˚C to +150˚C
SO-8 Package,	−65˚C to +150˚C
TO-220 Package,	−65˚C to +150˚C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300˚C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260˚C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55˚C to +150˚C
LM35C, LM35CA	−40˚C to +110˚C
LM35D	0˚C to +100˚C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25˚C	±0.2	±0.5		±0.2	±0.5		˚C
	T_A=−10˚C	±0.3			±0.3		±1.0	˚C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		˚C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	˚C
Nonlinearity (Note 8)	$T_{MIN}≤T_A≤T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	˚C
Sensor Gain (Average Slope)	$T_{MIN}≤T_A≤T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/˚C
Load Regulation (Note 3) $0≤I_L≤1$ mA	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}≤T_A≤T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V≤V_S≤30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25˚C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	$4V≤V_S≤30V$, +25˚C	0.2	1.0		0.2	1.0		µA
	$4V≤V_S≤30V$	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Electrical Characteristics

(Notes 1, 6)

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

Note 1: Unless otherwise noted, these specifications apply: −55˚C≤T_J≤+150˚C for the LM35 and LM35A; −40˚≤T_J≤+110˚C for the LM35C and LM35CA; and 0˚≤T_J≤+100˚C for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2˚C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

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

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/˚C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in ˚C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

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

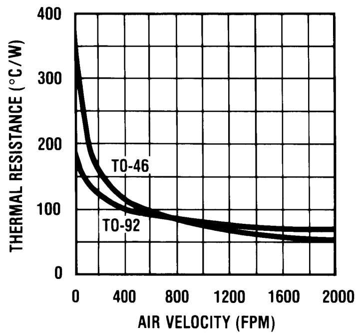
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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

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

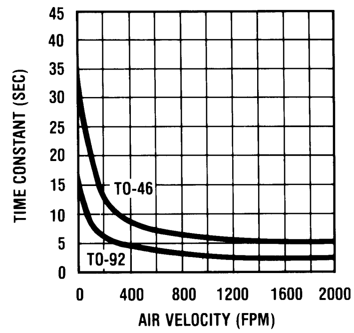
Typical Performance Characteristics

Thermal Resistance Junction to Air



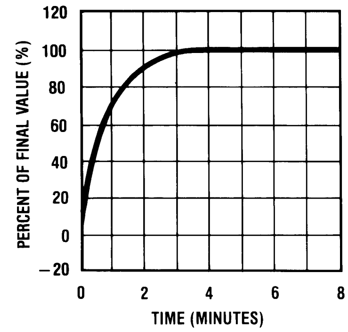
DS005516-25

Thermal Time Constant



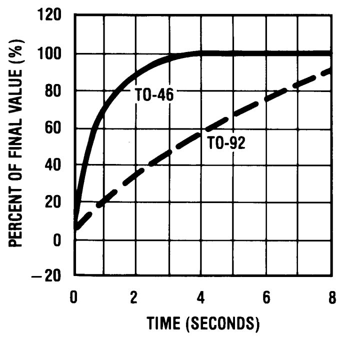
DS005516-26

Thermal Response in Still Air



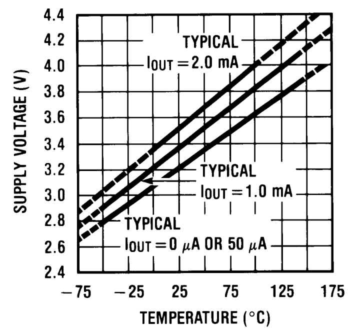
DS005516-27

Thermal Response in Stirred Oil Bath



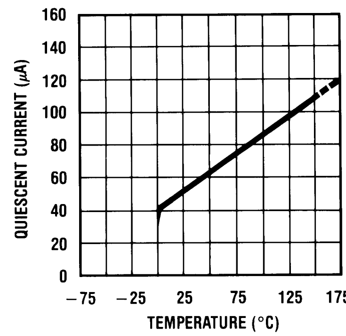
DS005516-28

Minimum Supply Voltage vs. Temperature



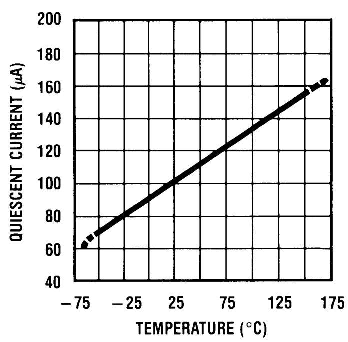
DS005516-29

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



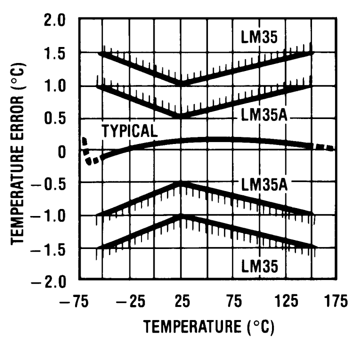
DS005516-30

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



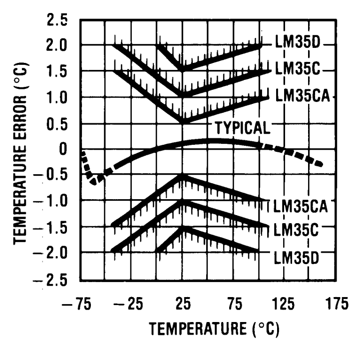
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

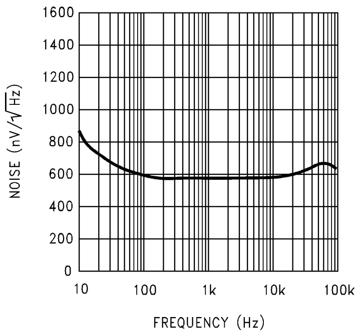
Accuracy vs. Temperature (Guaranteed)



DS005516-33

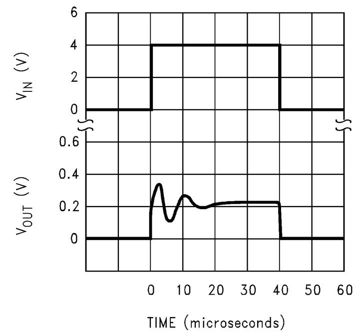
Typical Performance Characteristics (Continued)

Noise Voltage



DS005516-34

Start-Up Response



DS005516-35

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01˚C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

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

	TO-46, no heat sink	**TO-46*, small heat fin**	**TO-92, no heat sink**	**TO-92**, small heat fin**	**SO-8 no heat sink**	**SO-8** small heat fin**	**TO-220 no heat sink**
Still air	400˚C/W	100˚C/W	180˚C/W	140˚C/W	220˚C/W	110˚C/W	90˚C/W
Moving air	100˚C/W	40˚C/W	90˚C/W	70˚C/W	105˚C/W	90˚C/W	26˚C/W
Still oil	100˚C/W	40˚C/W	90˚C/W	70˚C/W			
Stirred oil	50˚C/W	30˚C/W	45˚C/W	40˚C/W			
(Clamped to metal, Infinite heat sink)		(24˚C/W)				(55˚C/W)	

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications

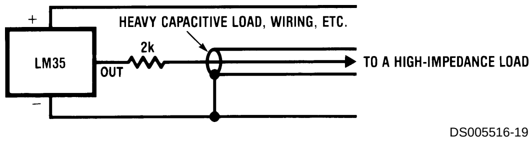


FIGURE 3. LM35 with Decoupling from Capacitive Load

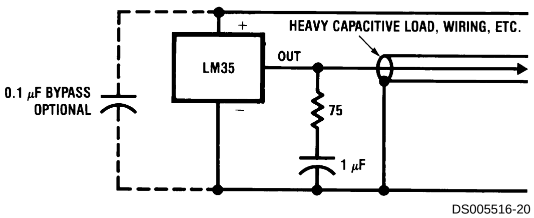


FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

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

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5*, *Figure 6* or *Figure 8* it is relatively immune to wiring capacitance because the capacitance forms a by-pass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 µF from output to ground are often useful. These are shown in *Figure 13*, *Figure 14*, and *Figure 16*.

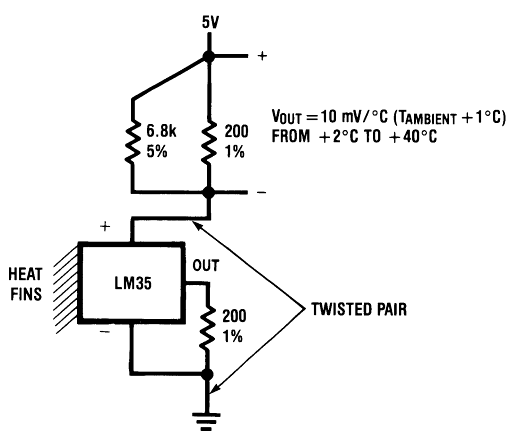


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

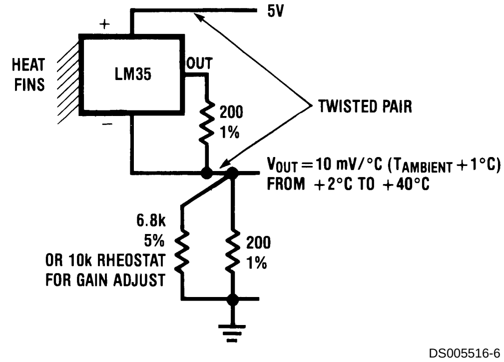


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

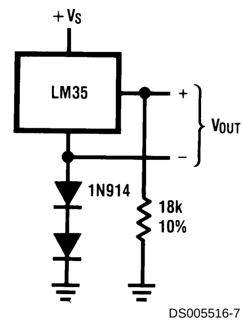


FIGURE 7. Temperature Sensor, Single Supply, −55˚ to +150˚C

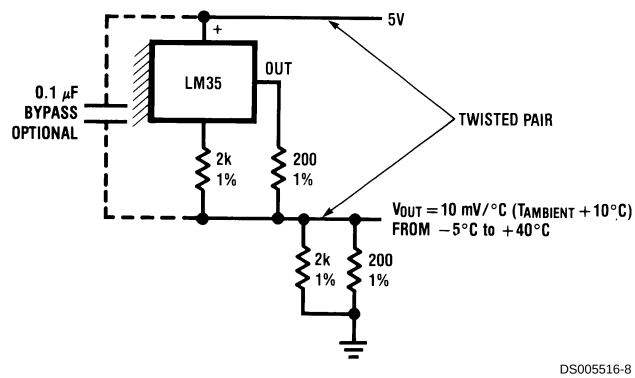


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

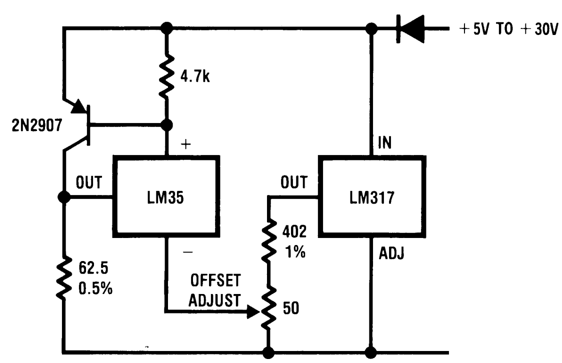


FIGURE 9. 4-To-20 mA Current Source (0˚C to +100˚C)

Typical Applications (Continued)

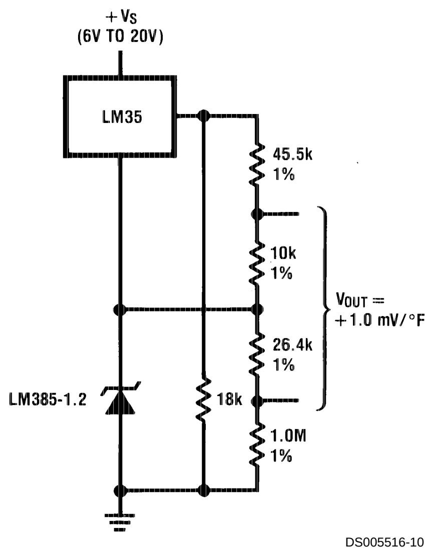


FIGURE 10. Fahrenheit Thermometer

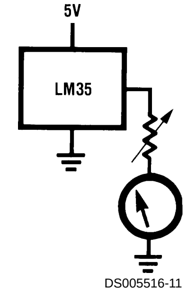


FIGURE 11. Centigrade Thermometer (Analog Meter)

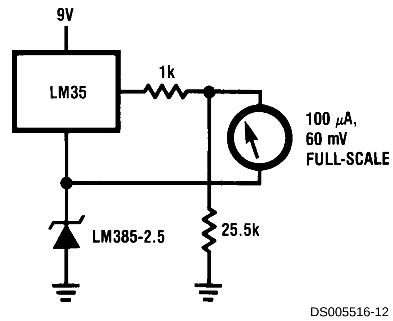


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer (50˚ to 80˚ Fahrenheit, for Example Shown)

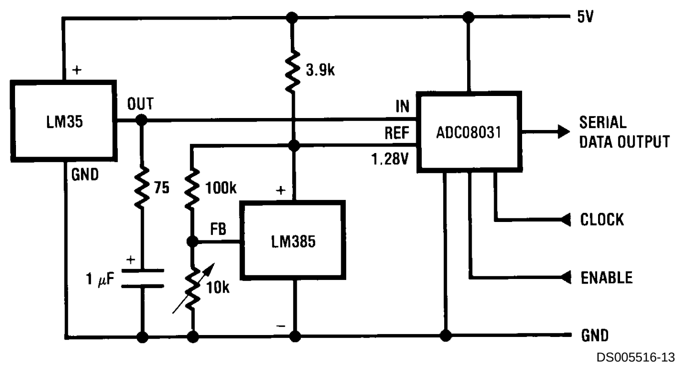


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128˚C Full Scale)

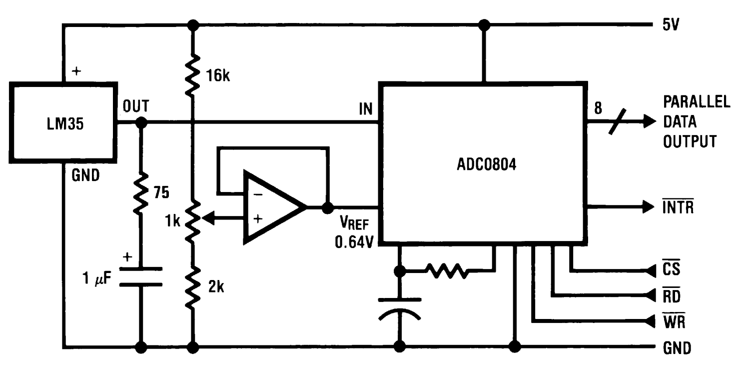
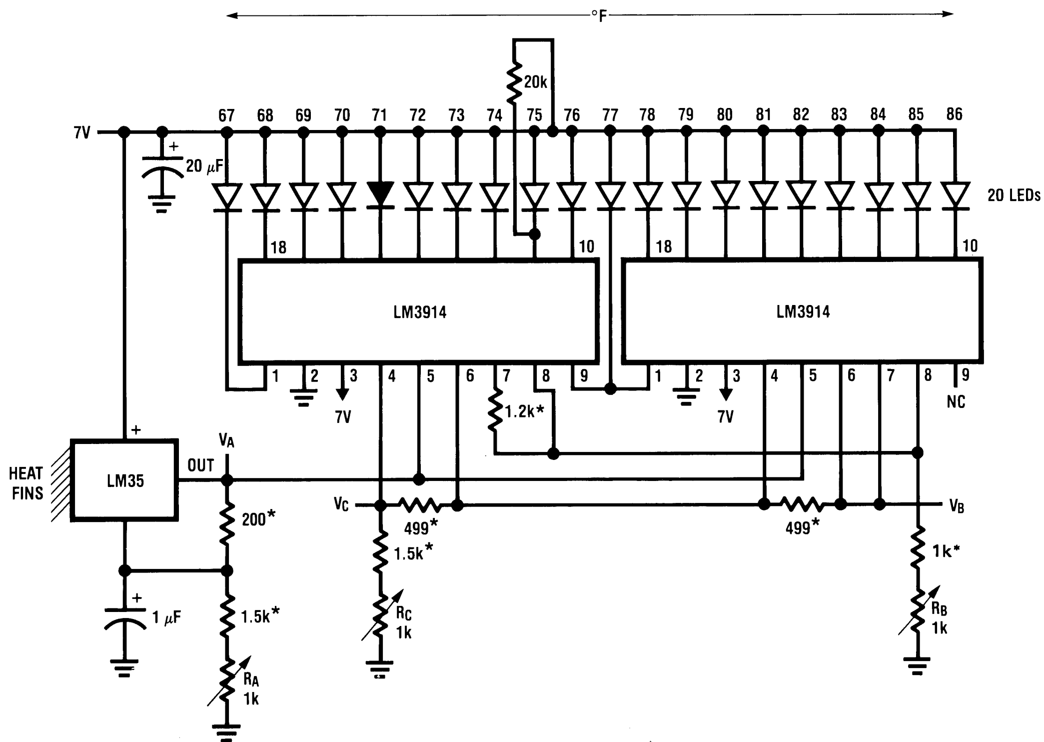


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to µP Interface) (128˚C Full Scale)

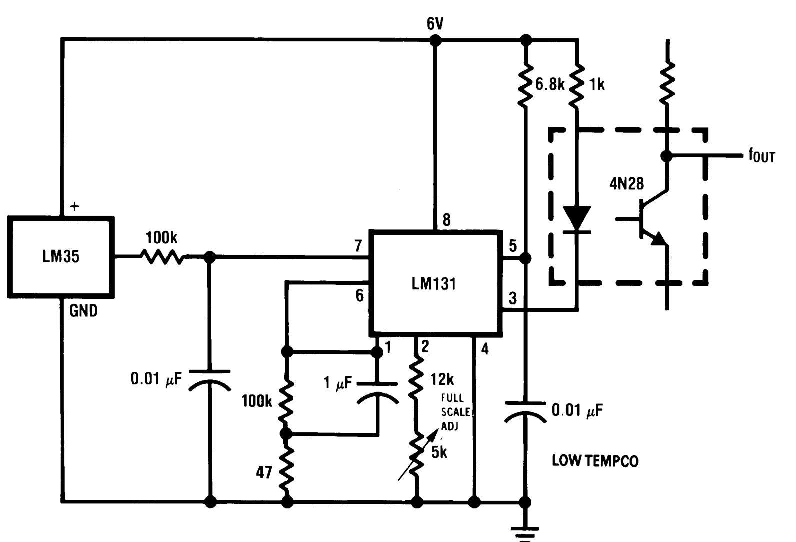
Typical Applications (Continued)



DS005516-16

*=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 x $T_{ambient}$
Example, V_A=2.275V at 22°C

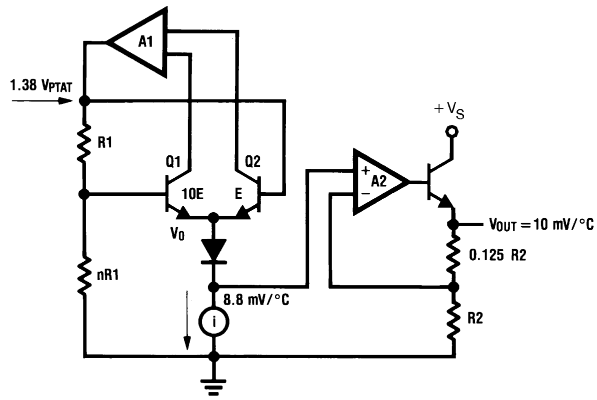
FIGURE 15. Bar-Graph Temperature Display (Dot Mode)



DS005516-15

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

Block Diagram



DS005516-23

Thermocouples

Data Sheet

General specification for RS thermocouple products

	Type J	Type K	Type N	Type T	Type R	Units
Minimum continuous temperature	-60	-200	-230	-200	-50	°C
Maximum continuous temperature	+850	+1100	+1300	+400	+1350	°C
Maximum spot reading	+1100	+1300	+1320	+500	+1400	°C

Tolerances (IEC 60584-3)

Accuracy - Class 2 (see note)	±2.5°C or 0.0075 x T	±2.5°C or 0.0075 x T	±2.5°C or 0.0075 x T	±1°C or 0.0075 x T	±1.5°C	°C
Temperature range - Class 2	-40 to +750	-40 to +1200	-40 to +1200	-40 to +350	-40 to +1600	°C
BS specification number	4937 Part 4	4937 Part 4	4937 Part 8	4937 Part 5	4937 Part 2	
+ ve arm	Iron	Nickel/Chromium	Nicrosil	Copper	13% Rhodium/ Platinum 87%	
Composition Cr	none	. 10	14.2 ±0.5	unspecified		%
Si	none	unspecified	1.4 ±0.2	unspecified		%
Fe	100	unspecified	0-15 max.	unspecified		%
C	none	unspecified	0.05	unspecified		%
Mg	none	unspecified	none	unspecified		%
Ni	none	balance	balance	unspecified		%
Cu	none	unspecified	none	balance		%
-ve arm	Nickel/Aluminium	Nickel/Aluminium	Nisil	Copper/Nickel	100% Platinum	
Composition Cr	none	unspecified	0.02. max	unspecified		%
Si	none	balance	4.4 ±0.2	unspecified		%
Fe	0.3	unspecified	0.15 max.	unspecified		%
C	none	unspecified	0.05 max.	unspecified		%
Mg	none	unspecified	0.05 to 0.2	unspecified		%
Ni	42	95	balance	40/45		%
Cu	balance	unspecified	none	balance		%
Mn	1.2	balance	none	unspecified		%
Al	none	balance	none	unspecified		%

Colour codes BS 4937 pt.30, 1993 (IEC 60584)

Thermocouple and extension wiring +ve arm	black	green	pink	brown	orange	
-ve arm	white	white	white	white	white	
overall	black	green	pink	brown	orange	
Compensating cable and wiring +ve arm	black	green	pink	brown	orange	
-ve arm	white	white	white	white	white	
overall	black	green	pink	brown	orange	

Note: T refers to measured temperature in °C

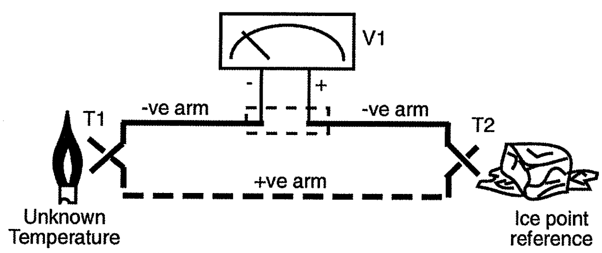
Thermocouple basics

Thermocouples provide an economic means of measuring temperature with many practical advantages for the user, for example:

1. They can be extremely robust, by using thick wire.
2. Fine wire thermocouples respond very rapidly to temperature changes (less than 0.1 secs). For ultra fast response (10µ seconds typical), foil thermo-couples are used.
3. Capable of measuring over very wide temperature ranges, from cryogenics to engine exhausts.
4. Thermocouples are easy to install and are available in many packages, from probes to bare wires or foil.

The number of free electrons in a piece of metal depends on both temperature and composition of the metal, therefore pieces of dissimilar metal in isothermal contact will exhibit a potential difference that is a repeatable function of temperature. The resulting voltage depends on the temperatures, T1 and T2, in a repeatable way as shown in Figure 1.

Figure 1 **Thermocouple voltage with 0°C reference**

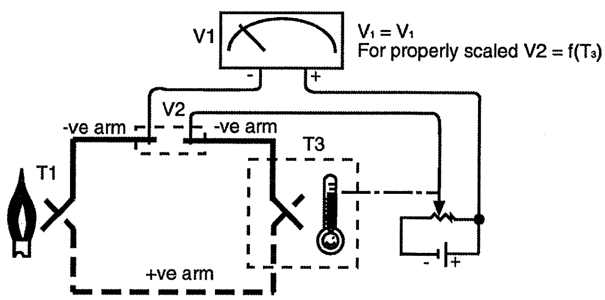


Since the thermocouple is basically a differential rather than an absolute temperature measuring device, one junction must be at a known temperature if the temperature of the other junction is to be found from the value of the output voltage.

An alternative measurement technique is illustrated in Figure 2. This is used in most practical applications where accuracy requirements do not warrant maintenance of primary standards as shown in Figure 1. The reference junction temperature is allowed to change but it is carefully measured by some type of absolute thermometer. A measurement of the thermocouple voltage combined with a knowledge of the reference temperature can be used to calculate the measurement junction temperature. Usual practice, however, is to use a convenient thermoelectric method to measure the reference temperature and to arrange its output voltage so that it corresponds to a thermocouple referred to 0°C.

This voltage is simply added to the thermocouple voltage and the sum then corresponds to the standard voltage tabulated for an icepoint referenced thermocouple. This method is used in the circuit shown in Figure 4.

Figure 2 **Substitution of measured reference temperature for ice point reference**



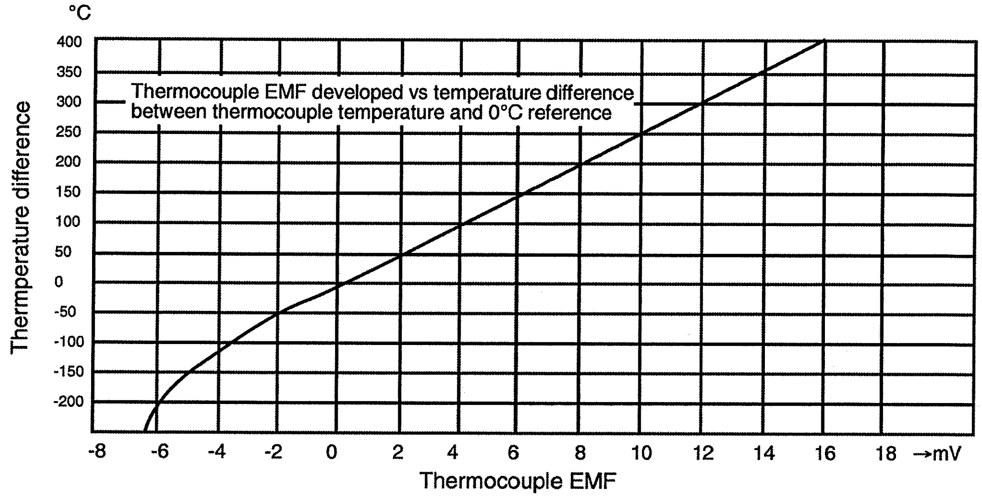
Thermocouples are of specially selected materials and have been exhaustively characterised in terms of voltage versus temperature compared to primary temperature standards. The water-ice point of 0°C is normally used for tables of standard thermocouple performance e.g. BS4937 Part 4 gives tables of EMF and temperature to the nearest degree for K type thermocouples. For details of EMF tables see Technical Books and Training section of current **RS** catalogue for book 220-6193 (Temperature handbook, a practical guide to temperature measurement, control and calibration using thermocouples and resistance thermometers).

Typical temperature measurement circuit

The circuit shown in Figure 4 may be used in conjunction with **RS** K-type thermocouples to measure temperatures from 0 to 100°C. If the component values are changed this circuit can be used with other thermocouple types at different temperatures.

The cold junction compensation is provided by D2, the forward voltage drop of which changes approximately 2mV/°C. This voltage is reduced by a potential divider to the thermocouple output. The result, amplified by IC1 and displayed on any 100µA meter is proportional to the temperature of the measurement junction of the thermocouple.

Figure 3 **Typical temperature gradient for type K thermocouples**



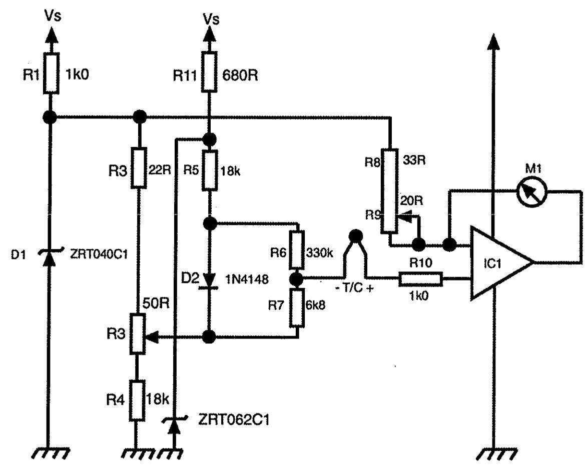
Calibration

The zero adjustment is set by R3 and the span by R9. Calibrate as follows:

1. Place measurement junction of thermocouple in freezing water to give 0°C.
2. Adjust R3 to give a reading of zero on the meter.
3. Place the measurement junction of the thermo-couple in boiling water (100°C).
4. Adjust R9 to give full scale deflection on the meter.

The circuit will then be calibrated to give a reading of 1μA per °C.

Figure 4 **Typical temperature measurement circuit**



Notes: 1. The circuit is intended for use with a single supply of approximately 9V such as a PP3 battery

2. Meter M1 should be 100μA moving coil (e.g. **RS** stock no. 312-561)
3. ICI should be any op-amp of a 741 type. Final selection will depend on required accuracy, current consumption etc.

Type K and N thermocouples

Of all the base metal thermocouples used in industry today the one based on nickel, more commonly known as type K, or nickel chromium/nickel aluminium is the most widely used. Type K thermocouples were standardised in 1916 when the science of metallurgy was less advanced than now. Type K materials are basically nickel doped with aluminium and nickel doped with chromium and in 1916 it was not possible to produce very pure nickel, consequently, many impurities are present in type K materials. In fact in recent years these impurities have had to be deliberately added to maintain calibration.

For these reasons type K thermocouples are standardised or characterised by EMF/temperature and not by alloy content. It is common to add extra elements to 'adjust' the EMF/temperature characteristics of a particular melt. Consequently, there are problems with type K thermocouples, namely:

1. The -ve arm of the thermocouple is ferromagnetic at room temperature, however, its Curie point (the temperature at which it changes from ferro to dia magnetic characteristics) is in the useful range of the thermocouple. This change causes a sudden change in EMF output. Furthermore, since the Curie point is dependent on the consistency of the alloy, which in type K is not defined, the Curie point will vary from thermocouple to thermocouple. Unknown changes in EMF at unknown temperatures are therefore experienced.
2. At high temperatures (200°C to 600°C) type K thermocouples suffer a hysteresis effect where the couple will under read when the temperature is rising and over read when the temperature is falling. The cause of this is not presently understood, however, short range ordering is suspected. The effect is dependent on the exact make-up of the alloys as well as the thermal history of the thermocouple. The net result is an unpredictable change in EMF.
3. At temperatures around 1000°C the thermocouple arms will oxidise, and because the alloys used are permeable to oxygen both internal and external oxidation will occur. The various elements used in these alloys will oxidise at different rates causing a change in constituency and hence a change in EMF.
4. The use of cobalt in the alloy for type K thermocouples causes a problem in nuclear industries, or other areas of high neutron flux. Some elements, such as cobalt, will undergo nuclear decay thus changing the make up of the alloy and its EMF output.

The type N thermocouple overcomes most if not all of these problems by optimisation of the alloys of nickel used to manufacture the thermocouple arms. Type N thermocouples are not merely an improvement over type K but are the best combination of elements giving optimum results for a thermocouple based on nickel.

The four problems encountered in type K are dealt with as follows in type N:

1. The Curie point is set well below zero by choosing a suitable combination of elements and is therefore outside the measuring range of the thermocouple.
2. The hysteresis is dependent upon the constituents of the alloy and by optimising the alloy the effect is minimised.
3. The use of silicon in the alloys results in formation of silicates on the surface of the wires, these form excellent protection against oxidisation as they are impervious to oxygen. This protection system is one of the best known and prevents internal and external oxidisation and hence change in EMF. A type K thermocouple will eventually fail mechanically when the wire is oxidised to such an extent that it is unable to withstand the thermally induced stresses placed on it and break.
4. In type N thermocouples all the elements susceptible to change due to high neutron flux are removed therefore no change of calibration is experienced.

To review, the type N thermocouple is not merely an improved nickel based thermocouple but should be considered as the optimum nickel based thermocouple which, as far as possible, overcomes all the disadvantages of not only type K but any nickel based thermocouple.

Minerally insulated type K thermocouples can suffer other problems which are shared by type N.

The sheath material for the majority of minerally insulated thermocouples is either stainless steel or inconel. Both materials can cause a loss of calibration due to alloying elements diffusing into the hot junction of the thermocouple and 'poisoning' it. These extra elements will change the EMF to temperature relationship and lead to errors. This problem is common to both types K and N but with type N a simple solution is available. The type N -ve arm is made of nisil, if the sheath is made of this material diffusion is very much reduced and the effect is no longer a problem.

Using nisil sheaths also reduces the thermal stresses generated due to the different rates of thermal expansion of steel and nickel which can lead to failure of conductors in minerally insulated thermocouples.

The specifications for type N materials define not only the EMF/temperature relationships, as in type K, but the exact quantities of components in the alloys. This means that one batch of type N from one manufacturer will be the same as another from a different source. This is not true for type K thermocouples.
Although 'half tolerance' type K thermocouples are available they are for all practical purposes a myth. The thermocouple, when calibrated, may be within half the standard tolerance of ±3°C it is not possible to guarantee this the next time the couple is heated. True half tolerance thermocouples may be available in type N.
Another advantage of type N thermocouples is the oxidisation protection system. Using silica it is effective up to the melting point of the alloys, therefore the temperature range is extended to 1300°C for both the exposed junction and minerally insulated types using nisil sheaths.

Type T thermocouples

Type T thermocouples have two major advantages over type K, and to a large extent over type N, namely:
1. An extended and specified low temperature range.
2. Greater accuracy (below 100°C accuracy is ±1°C).

However, there are two disadvantages:
1. The EMF/temperature characteristic is non-linear.
2. The maximum operating temperature is 400°C.

With modern electronic temperature indicators the first disadvantage will not cause a problem as its non-linearity can be taken into account.
Therefore if measurement of temperatures below 400°C is envisaged the type T is a good choice as enhanced accuracy is possible. This has resulted in the type T being used extensively in laboratories.
In industrial applications using more than one thermocouple type is avoided because of the possibility of the wrong sensor being used.
If only one thermocouple is to be selected the normal choice would be type K as this gives a good temperature range. However, for new applications consideration should be given to the use of type N due to its advantages over type K and extended temperature range. (See section on type K and N for further details.)

Type T thermocouple - food probe standard

Although the standard accuracy of type T thermocouple is ±1°C below 100°C (and stated above), these probes have been designed to comply with the requirements of the Food Hygiene (Amendment) Regulations 1990. All have a fast response time and are specially selected to have an accuracy of ±0.25°C over the working temperature range. All probes have been designed to be easily cleaned and sterilised without degrading performance and are supplied complete with 2 metres of coiled PUR type cable and a fitted miniature thermocouple connector.

Colour Code Cross Reference

Type	Conductors (+/-)	Insulation colour codes					
		British BS 1843:1952 (obsolete)			IEC 60584-3		
(Cable Code)		Sheath	+ve	-ve	Sheath	+ve	-ve
E (EX)	NICKEL CHROMIUM/CONSTANTAN (nickel Chromium/Copper-Nickel, Chromel/Constantan, T1/Advance, NiCr/Constantan)	Br	Br	Bl	Pp	Pp	Wh
J (JX)	IRON*/CONSTANTAN (Iron/Copper-Nickel, Fe/Konst, Iron/Advance, Fe/Constantan, I/C)	Bk	Yw	Bl	Bk	Bk	Wh
K (KX)	NICKEL CHROMIUM/NICKEL ALUMINIUM* (NC/NA, Chromel/Alumel, C/A, T1/T2, NiCr/Ni, NiCr/NiAl)	Rd	Br	Bl	Gn	Gn	Wh
N (NX), (NC)	NICROSIL/NISIL	Og	Og	Bl	Pk	Pk	Wh
T (TX)	COPPER/CONSTANTAN (Copper/Copper-Nickel, Cu/Con, Copper/Advance)	Bl	Wh	Bl	Br	Br	Wh
Vx (KCB)	COPPER/CONSTANTAN (LOW NICKEL) (Cu/Constantan) Compensating for 'K' (Cu/Constantan)	Rd	Wh	Bl	Gn	Gn	Wh
U (RCA), (SCA)	COPPER/COPPER NICKEL Compensating for Platinum 10% or 13% Rhodium/Platinum (Code S and R respectively) Copper/Cupronic, Cu/CuNi, Copper/No. 11 Alloy)	Gn	Wh	Bl	Og	Og	Wh

KEY: Bl-Blue Bk-Black Br-Brown Gn-Green Og-Orange Pk-Pink Pp-Purple Rd-Red Wh-White Yw-Yellow

Note: For THERMOCOUPLE CONNECTORS body colours are as outer sheath colours above.

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