

# ***AN-460 LM34/LM35 Precision Monolithic Temperature Sensors***

---

## **ABSTRACT**

This application report discusses the details and uses of the Texas Instruments LM34 and LM35 as precision temperature sensors..

---

## **Contents**

1	Introduction .....	2
2	Forerunners to the LM34 .....	2
3	Circuit Operation .....	5
4	Easy Calibration Procedure .....	6
5	How the Calibration Procedure Works .....	7
6	A Unique Compensation Circuit .....	8
7	Processing and Layout .....	9
8	Using the LM34 .....	9
9	Fahrenheit Temperature Sensors .....	10
10	Temperature to Digital Converters .....	12
11	Temperature-to-Frequency Converter for Remote Sensing .....	13
12	LED Display for Easy Temperature Reading .....	14
13	Indoor/Outdoor Thermometer .....	15
14	Temperature Controller .....	16
15	Differential Thermometer .....	17
16	Temperature Scanner .....	18
17	Conclusion .....	18
18	References .....	19

## 1 Introduction

Most commonly-used electrical temperature sensors are difficult to apply. For example, thermocouples have low output levels and require cold junction compensation. Thermistors are nonlinear. In addition, the outputs of these sensors are not linearly proportional to any temperature scale. Early monolithic sensors, such as the LM3911, LM134 and LM135, overcame many of these difficulties, but their outputs are related to the Kelvin temperature scale rather than the more popular Celsius and Fahrenheit scales. Fortunately, in 1983 two I.C.'s, the LM34 Precision Fahrenheit Temperature Sensor and the LM35 Precision Celsius Temperature Sensor, were introduced.

The LM34 has an output of 10 mV/°F with a typical nonlinearity of only  $\pm 0.35^\circ\text{F}$  over a  $-50$  to  $+300^\circ\text{F}$  temperature range, and is accurate to within  $\pm 0.4^\circ\text{F}$  typically at room temperature ( $77^\circ\text{F}$ ). The LM34's low output impedance and linear output characteristic make interfacing with readout or control circuitry easy. An inherent strength of the LM34 over other currently available temperature sensors is that it is not as susceptible to large errors in its output from low level leakage currents. For instance, many monolithic temperature sensors have an output of only  $1\ \mu\text{A}/^\circ\text{K}$ . This leads to a  $1^\circ\text{K}$  error for only  $1\ \mu\text{-Ampere}$  of leakage current. On the other hand, the LM34 may be operated as a current mode device providing  $20\ \mu\text{A}/^\circ\text{F}$  of output current. The same  $1\ \mu\text{A}$  of leakage current will cause an error in the LM34's output of only  $0.05^\circ\text{F}$  (or  $0.03^\circ\text{K}$  after scaling).

Low cost and high accuracy are maintained by performing trimming and calibration procedures at the wafer level. The device may be operated with either single or dual supplies. With less than  $70\ \mu\text{A}$  of current drain, the LM34 has very little self-heating (less than  $0.2^\circ\text{F}$  in still air), and comes in a TO-46 metal can package, a SO-8 small outline package and a TO-92 plastic package.

## 2 Forerunners to the LM34

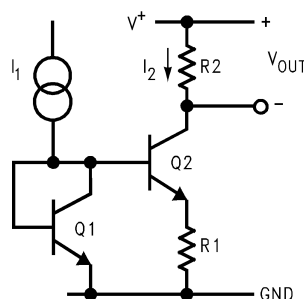
The making of a temperature sensor depends upon exploiting a property of some material which is a changing function of temperature. Preferably this function will be a linear function for the temperature range of interest. The base-emitter voltage ( $V_{\text{BE}}$ ) of a silicon NPN transistor has such a temperature dependence over small ranges of temperature.

Unfortunately, the value of  $V_{\text{BE}}$  varies over a production range and thus the room temperature calibration error is not specified nor ensured in production. Additionally, the temperature coefficient of about  $-2\ \text{mV}/^\circ\text{C}$  also has a tolerance and spread in production. Furthermore, while the tempo may appear linear over a narrow temperature, there is a definite nonlinearity as large as  $3^\circ\text{C}$  or  $4^\circ\text{C}$  over a full  $-55^\circ\text{C}$  to  $+150^\circ\text{C}$  temperature range.

Another approach has been developed where the difference in the base-emitter voltage of two transistors operated at different current densities is used as a measure of temperature. It can be shown that when two transistors, Q1 and Q2, are operated at different emitter current densities, the difference in their base-emitter voltages,  $\Delta V_{\text{BE}}$ , is:

$$\Delta V_{\text{BE}} = V_{\text{BE1}} - V_{\text{BE2}} = \frac{kT}{q} \ln \left( \frac{J_{\text{E1}}}{J_{\text{E2}}} \right) \quad (1)$$

where  $k$  is Boltzman's constant,  $q$  is the charge on an electron,  $T$  is absolute temperature in degrees Kelvin and  $J_{\text{E1}}$  and  $J_{\text{E2}}$  are the emitter current densities of Q1 and Q2 respectively. A circuit realizing this function is shown in [Figure 1](#).



**Figure 1.**

Equation 1 implies that as long as the ratio of  $I_{E1}$  to  $I_{E2}$  is held constant, then  $\Delta V_{BE}$  is a linear function of temperature (this is not exactly true over the whole temperature range, but a correction circuit for the nonlinearity of  $V_{BE1}$  and  $V_{BE2}$  will be discussed later). The linearity of this  $\Delta V_{BE}$  with temperature is good enough that most of today's monolithic temperature sensors are based upon this principle.

An early monolithic temperature sensor using the above principle is shown in Figure 2. This sensor outputs a voltage which is related to the absolute temperature scale by a factor of 10 mV per degree Kelvin and is known as the LM135. The circuit has a  $\Delta V_{BE}$  of approximately:

$$(0.2 \text{ mV}/^\circ\text{K}) \times (T) \tag{2}$$

developed across resistor R. The amplifier acts as a servo to enforce this condition. The  $\Delta V_{BE}$  appearing across resistor R is then multiplied by the resistor string consisting of R and the 26R and 23R resistors for an output voltage of  $(10 \text{ mV}/^\circ\text{K}) \times (T)$ . The resistor marked 100R is used for offset trimming. This circuit has been very popular, but such Kelvin temperature sensors have the disadvantage of a large constant output voltage of 2.73V which must be subtracted for use as a Celsius-scaled temperature sensor.

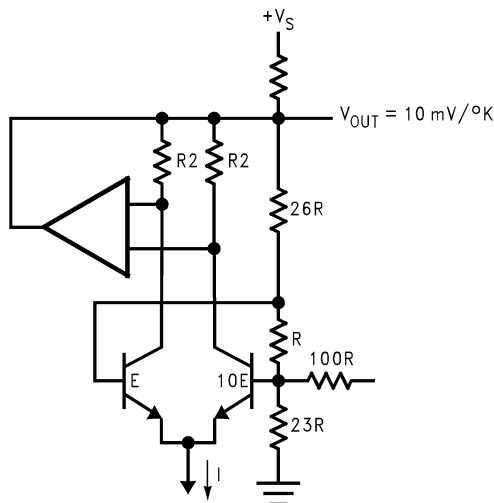


Figure 2.

Various sensors have been developed with outputs which are proportional to the Celsius temperature scale, but are rather expensive and difficult to calibrate due to the large number of calibration steps which have to be performed. Gerard C.M. Meijer [4] has developed a circuit which claims to be inherently calibrated if properly trimmed at any one temperature. The basic structure of Meijer's circuit is shown in Figure 3. The output current has a temperature coefficient of  $1 \mu\text{A}/^\circ\text{C}$ . The circuit works as follows: a current which is proportional to absolute temperature,  $I_{PTAT}$ , is generated by a current source. Then a current which is proportional to the  $V_{BE}$  drop of transistor Q4 is subtracted from  $I_{PTAT}$  to get the output current,  $I_O$ . Transistor Q4 is biased by means of a PNP current mirror and transistor Q3, which is used as a feedback amplifier. In Meijer's paper it is claimed that the calibration procedure is straightforward and can be performed at any temperature by trimming resistor R4 to adjust the sensitivity,  $dI_O/dT$ , and then trimming a resistor in the PTAT current source to give the correct value of output current for the temperature at which the calibration is being performed.

Meijer's Celsius temperature sensor has problems due to its small output signal (that is, the output may have errors caused by leakage currents). Another problem is the trim scheme requires the trimming of two resistors to a very high degree of accuracy. To overcome these problems, the circuits of Figure 4 (an LM34 Fahrenheit temperature sensor) and Figure 5 (an LM35 Celsius temperature sensor) have been developed to have a simpler calibration procedure, an output voltage with a relatively large tempco, and a curvature compensation circuit to account for the non-linear characteristics of  $V_{BE}$  versus temperature. Basically, what happens is transistors Q1 and Q2 develop a  $\Delta V_{BE}$  across resistor R1. This voltage is multiplied across resistor nR1. Thus at the non-inverting input of amplifier A2 is a voltage two diode drops below the voltage across resistor nR1. This voltage is then amplified by amplifier A2 to give an output proportional to whichever temperature scale is desired by a factor of 10 mV per degree.

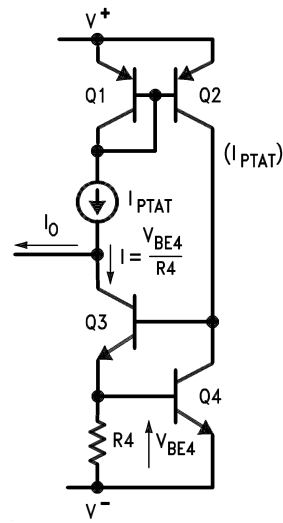


Figure 3.

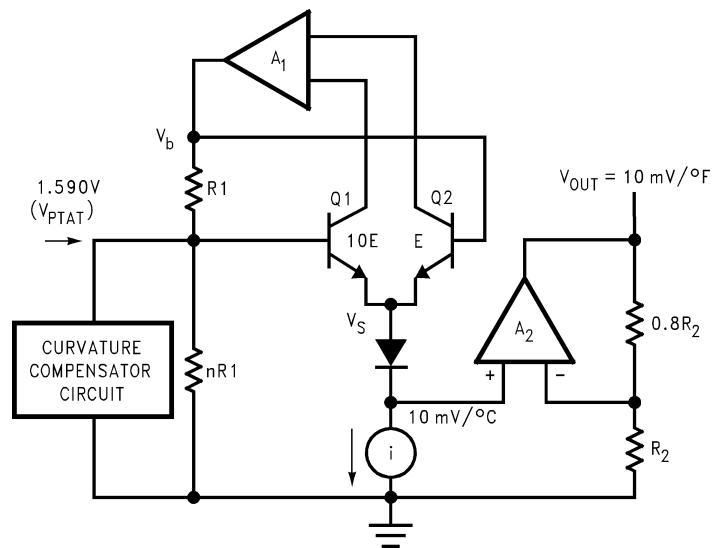


Figure 4.

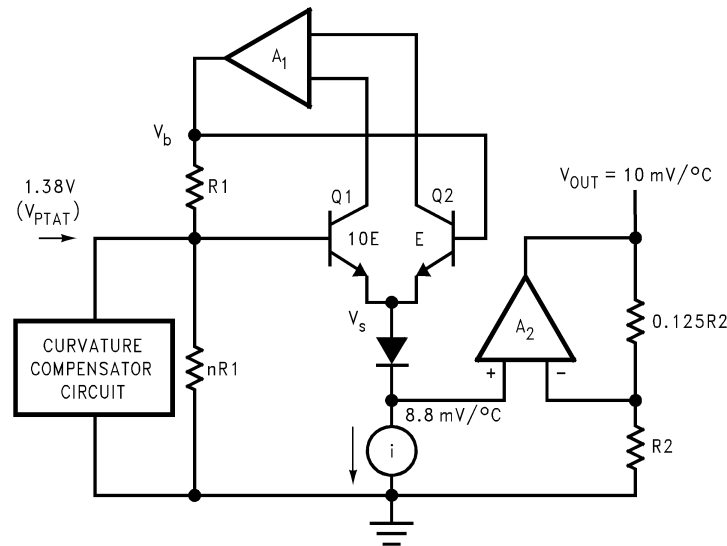


Figure 5.

### 3 Circuit Operation

Since the two circuits are very similar, only the LM34 Fahrenheit temperature sensor will be discussed in greater detail. The circuit operates as follows.

Transistor Q1 has 10 times the emitter area of transistor Q2, and therefore, one-tenth the current density. From Figure 4, it is seen that the difference in the current densities of Q1 and Q2 will develop a voltage which is proportional to absolute temperature across resistor R<sub>1</sub>. At 77°F this voltage will be 60 mV. As in the Kelvin temperature sensor, an amplifier, A1, is used to insure that this is the case by servoing the base of transistor Q1 to a voltage level, V<sub>PTAT</sub>, of ΔV<sub>BE</sub> × n. The value of n will be trimmed during calibration of the device to give the correct output for any temperature.

For purposes of discussion, suppose that a value of V<sub>PTAT</sub> equal to 1.59V will give a correct output of 770 mV at 77°F. Then n will be equal to V<sub>PTAT</sub>/ΔV<sub>BE</sub> or 1.59V/60 mV = 26.5, and V<sub>PTAT</sub> will have a temperature coefficient (tempco) of:

$$\frac{nk}{q} \ln \frac{I_1}{I_2} = 5.3 \text{ mV}/^\circ\text{C}. \quad (3)$$

Subtracting two diode drops of 581 mV (at 77°F) with tempcos of -2.35 mV/°C each, will result in a voltage of 428 mV with a tempco of 10 mV/°C at the non-inverting input of amplifier A2. As shown, amplifier A2 has a gain of 1.8 which provides the necessary conversion to 770 mV at 77°F (25°C). A further example would be if the temperature were 32°F (0°C), then the voltage at the input of A2 would be 428 mV - (10 mV/°C) (25°C) = 0.178, which would give V<sub>OUT</sub> = (0.178) (1.8) = 320 mV—the correct value for this temperature.

## 4 Easy Calibration Procedure

The circuit may be calibrated at any temperature by adjusting the value of the resistor ratio factor  $n$ . Note that the value of  $n$  is dependent on the actual value of the voltage drop from the two diodes since  $n$  is adjusted to give a correct value of voltage at the output and not to a theoretical value for PTAT. The calibration procedure is easily carried out by opening or shorting the links of a quasi-binary trim network, like the one shown in Figure 6. The links may be opened to add resistance by blowing an aluminum fuse, or a resistor may be shorted out of the circuit by carrying out a "zener-zap". The analysis in the next section shows that when the circuit is calibrated at a given temperature, then the circuit will be accurate for the full temperature range.

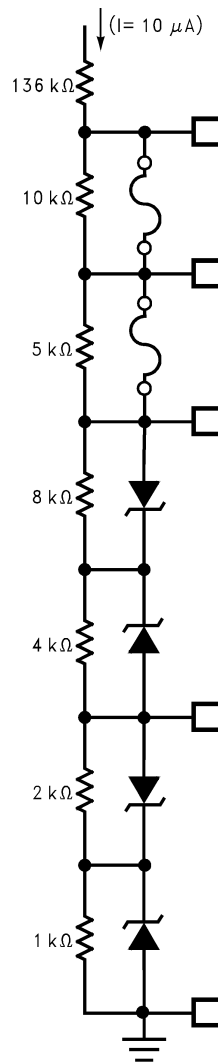


Figure 6.

## 5 How the Calibration Procedure Works

Widlar [5] has shown that a good approximation for the base-emitter voltage of a transistor is:

$$V_{BE} = V_{G0} \left( 1 - \frac{T}{T_0} \right) + V_{beo} \left( \frac{T}{T_0} \right) + \frac{nkT}{q} \ln \left( \frac{T_0}{T} \right) + \frac{kT}{q} \ln \frac{I_C}{I_{C0}} \quad (4)$$

where:

T is the temperature in °Kelvin

T<sub>0</sub> is a reference temperature

V<sub>G0</sub> is the bandgap of silicon, typically 1.22V

V<sub>beo</sub> is the transistor's base-emitter voltage at the reference temperature, T<sub>0</sub>

Equation 4 can be re-written as:

$$V_{BE} = (\text{sum of linear temp terms}) + (\text{sum of non-linear temp terms}) \quad (5)$$

where the first two terms of Equation 1 are linear and the last two terms are non-linear. The non-linear terms were shown by Widlar to be relatively small and thus will be considered later.

Let us define a base voltage, V<sub>b</sub>, which is a linear function of temperature as: V<sub>b</sub> = C<sub>1</sub> × T. This voltage may be represented by the circuit in Figure 1. The emitter voltage is V<sub>e</sub> = V<sub>b</sub> - V<sub>be</sub> which becomes:

$$V_e = C_1 T - V_{G0} \left( 1 - \frac{T}{T_0} \right) - V_{beo} \left( \frac{T}{T_0} \right). \quad (6)$$

If V<sub>e</sub> is defined as being equal to C<sub>2</sub> at T = T<sub>0</sub>, then Equation 6 may be solved for C<sub>1</sub>. Doing so gives:

$$C_1 = \frac{V_{beo} + C_2}{T_0} \quad (7)$$

Using this value for C<sub>1</sub> in the equation for V<sub>e</sub> gives:

$$V_e = C_2 \frac{T}{T_0} + V_{G0} \left( \frac{T - T_0}{T_0} \right) \quad (8)$$

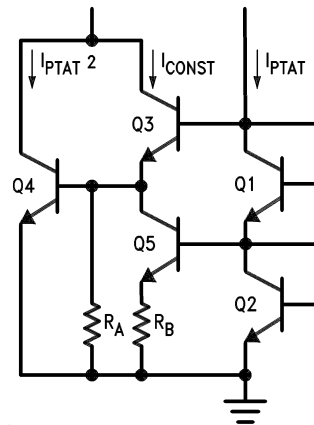
If V<sub>e</sub> is differentiated with respect to temperature, T, Equation 7 becomes dV<sub>e</sub>/dT = (C<sub>2</sub> + V<sub>G0</sub>)/T<sub>0</sub>.

This equation shows that if V<sub>b</sub> is adjusted at T<sub>0</sub> to give V<sub>e</sub> = C<sub>2</sub>, then the rate of change of V<sub>e</sub> with respect to temperature will be a constant, independent of the value of V<sub>b</sub>, the transistor's beta or V<sub>be</sub>. To proceed, consider the case where V<sub>e</sub> = C<sub>2</sub> = 0 at T<sub>0</sub> = 0°C. Then:

$$\frac{dV_e}{dT} = \frac{V_{G0}}{273.7} = 4.47 \text{ mV}/^\circ\text{C} \quad (9)$$

Therefore, if V<sub>e</sub> is trimmed to be equal to (4.47 mV) T (in °C) for each degree of displacement from 0°C, then the trimming can be done at ambient temperatures.

In practice, the two non-linear terms in Equation 1 are found to be quadratic for positive temperatures. Tsvidis [6] showed that the bandgap voltage, V<sub>0</sub>, is not linear with respect to temperature and causes nonlinear terms which become significant for negative temperatures (below 0°C). The sum of these errors causes an error term which has an approximately square-law characteristic and is thus compensated by the curvature compensation circuit of Figure 7.


**Figure 7.**

## 6 A Unique Compensation Circuit

As mentioned earlier, the base-emitter voltage,  $V_{BE}$ , is not a linear function with respect to temperature. In practice, the nonlinearity of this function may be approximated as having a square-law characteristic. Therefore, the inherent non-linearity of the transistor and diode may be corrected by introducing a current with a square-law characteristic into the indicated node of [Figure 4](#). Here's how the circuit of [Figure 7](#) works: transistors Q1 and Q2 are used to establish currents in the other three transistors. The current through Q1 and Q2 is linearly proportional to absolute temperature,  $I_{PTAT}$ , as is the current through transistor Q5 and resistor  $R_B$ . The current through resistor  $R_A$  is a decreasing function of temperature since it is proportional to the  $V_{BE}$  of transistor Q4. The emitter current of Q3 is equal to the sum of the current through Q5 and the current through  $R_A$ , and thus Q3's collector current is a constant with respect to temperature. The current through transistor Q4,  $I_{C4}$ , will be used to compensate for the  $V_{BE}$  nonlinearities and is found with the use of the following equation:

$$I_{C4} = I_S \left( e^{\frac{qV_{BE4}}{KT}} - 1 \right) \approx I_S e^{\frac{qV_{BE4}}{KT}} \quad (10)$$

where  $V_{BE4} = V_{BE1} + V_{BE2} - V_{BE3}$ .

From the above logarithmic relationship, it is apparent that  $I_{C4}$  becomes:

$$I_{C4} = \frac{I_{C1} I_{C2}}{I_{C3}} = \frac{I_{PTAT}^2}{I_{CONST}} \quad (11)$$

Thus, a current that has a square law characteristic and is PTAT [\[2\]](#), is generated for use as a means of curvature correction.



## 7 Processing and Layout

The sensor is constructed using conventional bipolar epitaxial linear processing. SiCr thin-film resistors are used in place of their diffused counterparts as a result of their better tempco matching, an important consideration for resistors which must track over temperature. Such resistors include R1 and nR1 of the bandgap circuit.

Another point of interest in the construction of the device centers around transistors Q1 and Q2 of [Figure 4](#). In order for the circuit to retain its accuracy over temperature, the leakage currents of each transistor, which can become quite significant at high temperatures, must be equal so that their effects will cancel one another. If the geometries of the two transistors were equivalent, then their leakage currents would be also, but since Q1 has ten times the emitter area of Q2, the accuracy of the device could suffer. To correct the problem, the circuit is built with Q1 and Q2 each replaced by a transistor group consisting of both Q1 and Q2. These transistor groups have equivalent geometries so that their leakage currents will cancel, but only one transistor of each group, representing Q1 in one group and Q2 in the other pair is used in the temperature sensing circuit. A circuit diagram demonstrating this idea is shown in [Figure 8](#).

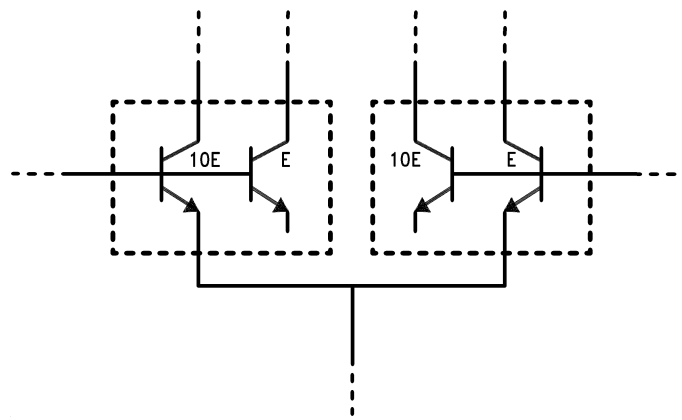


Figure 8.

## 8 Using the LM34

The LM34 is a versatile device which may be used for a wide variety of applications, including oven controllers and remote temperature sensing. The device is easy to use (there are only three terminals) and will be within 0.02°F of a surface to which it is either glued or cemented. The TO-46 package allows the user to solder the sensor to a metal surface, but in doing so, the GND pin will be at the same potential as that metal. For applications where a steady reading is desired despite small changes in temperature, the user can solder the TO-46 package to a thermal mass. Conversely, the thermal time constant may be decreased to speed up response time by soldering the sensor to a small heat fin.

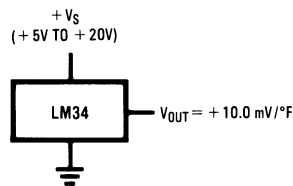
## 9 Fahrenheit Temperature Sensors

As mentioned earlier, the LM34 is easy to use and may be operated with either single or dual supplies. [Figure 9](#) shows a simple Fahrenheit temperature sensor using a single supply. The output in this configuration is limited to positive temperatures. The sensor can be used with a single supply over the full  $-50^{\circ}\text{F}$  to  $+300^{\circ}\text{F}$  temperature range, as seen in [Figure 10](#), simply by adding a resistor from the output pin to ground, connecting two diodes in series between the GND pin and the circuit ground, and taking a differential reading. This allows the LM34 to sink the necessary current required for negative temperatures. If dual supplies are available, the sensor may be used over the full temperature range by merely adding a pull-down resistor from the output to the negative supply as shown in [Figure 11](#). The value of this resistor should be  $| -V_S | / 50 \mu\text{A}$ .

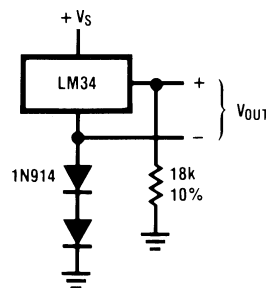
For applications where the sensor has to be located quite a distance from the readout circuitry, it is often expensive and inconvenient to use the standard 3-wire connection. To overcome this problem, the LM34 may be connected as a two-wire remote temperature sensor. Two circuits to do this are shown in [Figure 12](#) and [Figure 13](#). When connected as a remote temperature sensor, the LM34 may be thought of as a temperature-dependent current source. In both configurations the current has both a relatively large value,

$$(20 \mu\text{A}/^{\circ}\text{F}) \times (T_A + 3^{\circ}\text{F}), \quad (12)$$

and less offset when compared to other sensors. In fact, the current per degree Fahrenheit is large enough to make the output relatively immune to leakage currents in the wiring.



**Figure 9. Basic Fahrenheit Temperature Sensor  
( $+5^{\circ}$  to  $+300^{\circ}\text{F}$ )**



**Figure 10. Temperature Sensor, Single Supply,  
( $-50^{\circ}$  to  $+300^{\circ}\text{F}$ )**

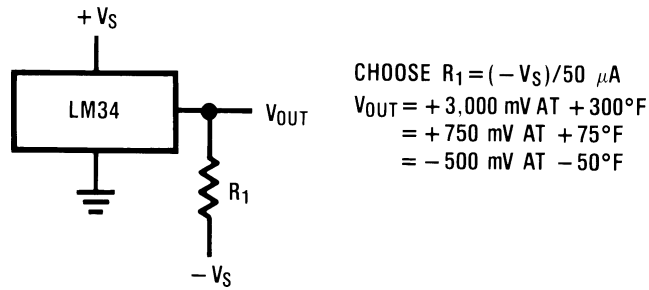
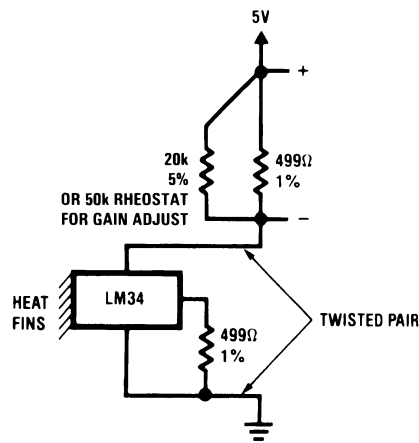


Figure 11. Full-Range Fahrenheit Temperature Sensor



$V_{OUT} = 10 \text{ mV}/^\circ\text{F} (T_A + 3^\circ\text{F})$   
 from  $+3^\circ\text{F}$  to  $+100^\circ\text{F}$

Figure 12. Two-Wire Remote Temperature Sensor (Grounded Sensor)

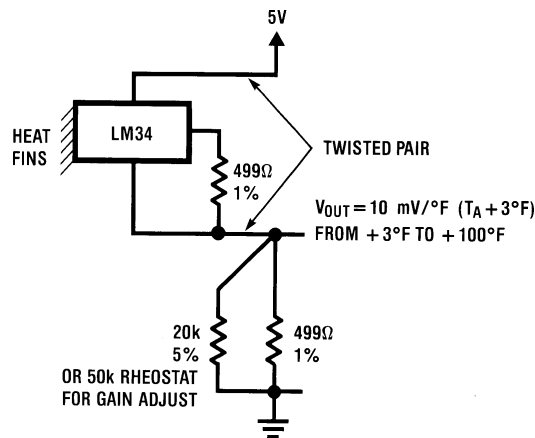
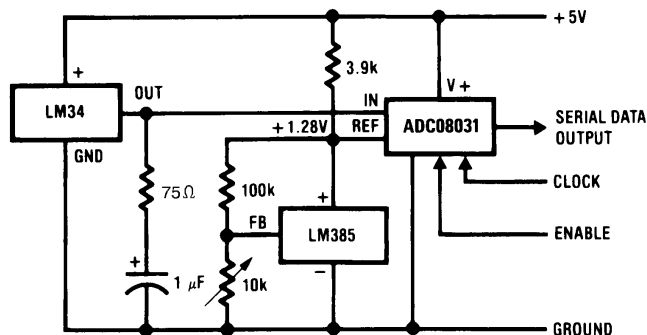


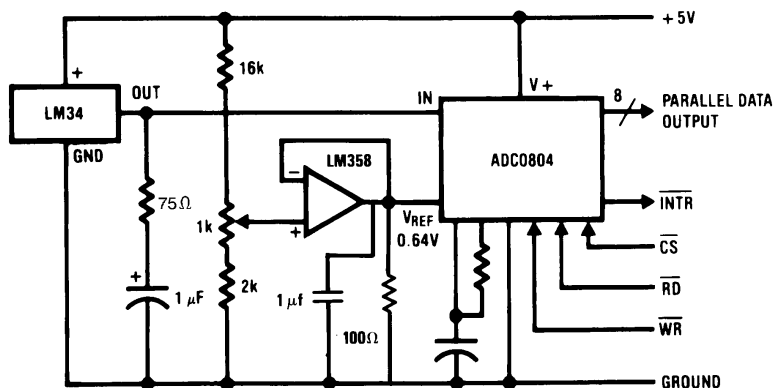
Figure 13. Two-Wire Temperature Sensor (Output Referred to Ground)

## 10 Temperature to Digital Converters

For interfacing with digital systems, the output of the LM34 may be sent through an analog to digital converter (ADC) to provide either serial or parallel data outputs as shown in Figure 14 and Figure 15. Both circuits have a 0 to +128°F scale. The scales are set by adjusting an external voltage reference to each ADC so that the full 8 bits of resolution will be applied over a reduced analog input range. The serial output ADC uses an LM385 micropower voltage reference diode to set its scale adjust ( $V_{REF}$  pin) to 1.28V, while the parallel output ADC uses half of an LM358 low power dual op amp configured as a voltage follower to set its  $V_{REF}/2$  pin to 0.64V. Both circuits are operated with standard 5V supplies.



**Figure 14. Temperature-to-Digital Converter  
(Serial Output, +128°F Full Scale)**



**Figure 15. Temperature-to-Digital Converter  
(Parallel TRI-STATE Outputs for Standard Data Bus to  $\mu$ P Interface, 128°F Full Scale)**

## 11 Temperature-to-Frequency Converter for Remote Sensing

If a frequency proportional to temperature is needed, then the LM34 can be used in conjunction with an LM131 voltage-to-frequency converter to perform the desired conversion from temperature to frequency. A relatively simple circuit which performs over a +3°F to +300°F temperature range is shown in Figure 16. The output frequency of this circuit can be found from the equation:

$$f_{OUT} = \left( \frac{V_{IN}}{2.09V} \right) \left( \frac{R_S}{R_L} \right) \left( \frac{1}{R_T C_T} \right) \quad (13)$$

where resistor  $R_S$  is used to adjust the gain of the LM131. If  $R_S$  is set to approximately 14.2 kΩ, the output frequency will have a gain of 10 Hz/°F. Isolation from high common mode levels is provided by channeling the frequency through a photoisolator. This circuit is also useful for sending temperature information across long transmission lines where it can be decoded at the receiving station.

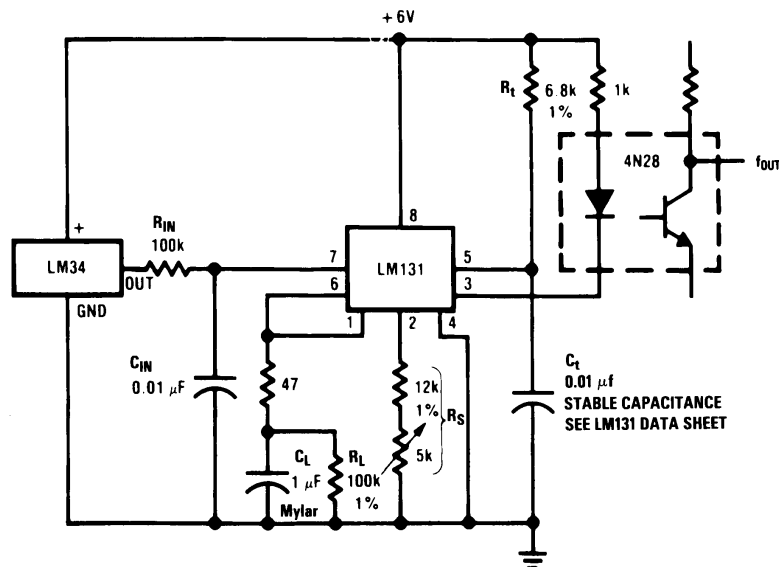


Figure 16. LM34 with Voltage-to-Frequency Converter and Isolated Output  
(3°F to +300°F; 30 Hz to 3000 Hz)

## 12 LED Display for Easy Temperature Reading

It is often beneficial to use an array of LED's for displaying temperature. This application may be handled by combining the LM34 with an LM3914 dot/display driver. The temperature may then be displayed as either a bar of illuminated LED's or as a single LED by simply flipping a switch. A wide range of temperatures may be displayed at once by cascading several LM3914's as shown in [Figure 17](#).

Without going into how the LM3914 drivers function internally, the values for  $V_A$ ,  $V_B$ , and  $V_C$  can be determined as follows:

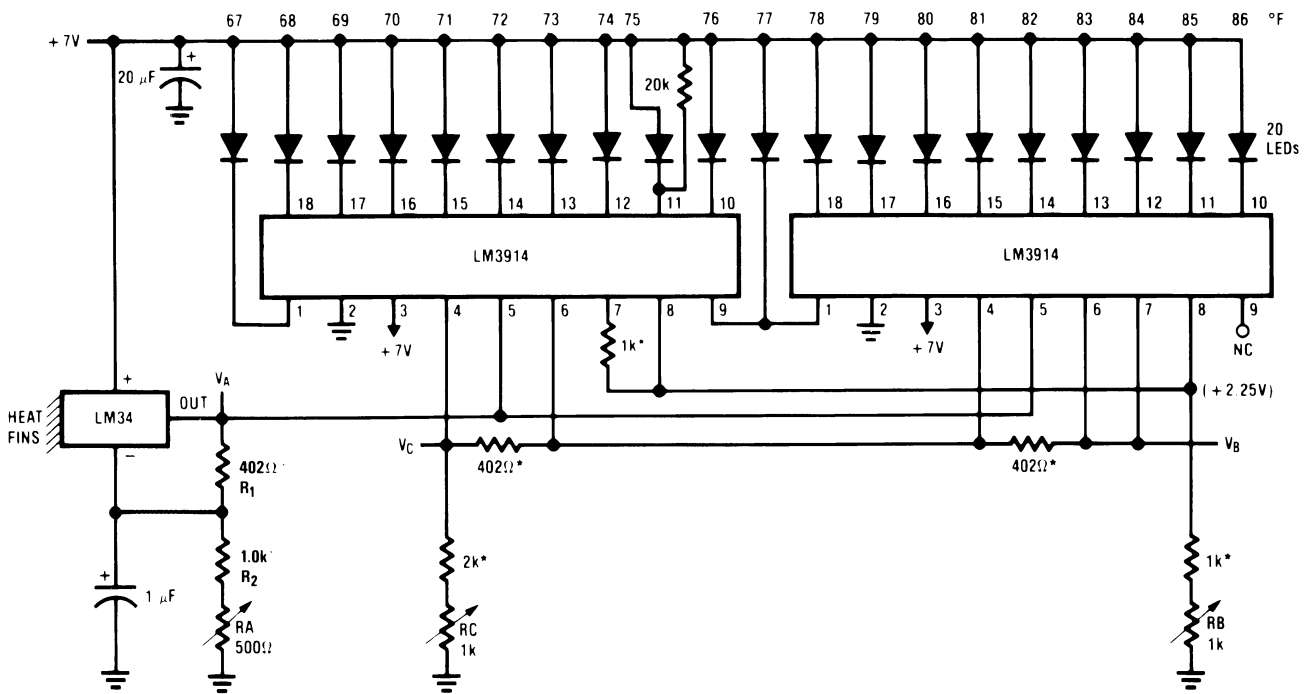
$V_A$  is the voltage appearing at the output pin of the LM34. It consists of two components, 0.085V and (40 mV/°F) ( $T_A$ ).

The first term is due to the LM34's bias current (approximately 70  $\mu$ A) flowing through the 1 k $\Omega$  resistor in series with  $R_A$ . The second term is a result of the multiplication of the LM34's output by the resistive string composed of  $R_1$ ,  $R_2$ , and  $R_A$ , where  $R_A$  is set for a gain factor of 4 (that is, 40 mV/°F).

$V_B$  represents the highest temperature to be displayed and is given by the equation  $V_B = 0.085V + (40 \text{ mV/}^\circ\text{F}) (T_{\text{HIGH}})$ . For the circuit in [Figure 17](#),  $V_B = 0.085V + (40 \text{ mV/}^\circ\text{F}) (86^\circ\text{F}) = 3.525V$ .

$V_C$  represents the lowest temperature to be displayed minus 1°F. That is,  $V_C = 0.085V + (T_{\text{LOW}} - 1^\circ\text{F}) (40 \text{ mV/}^\circ\text{F})$  which in this case becomes  $V_C = 0.085V + (67^\circ\text{F} - 1^\circ\text{F}) (40 \text{ mV/}^\circ\text{F}) = 2.725V$ .

With a few external parts, the circuit can change from dot to bar mode or flash a bar of LED's when the temperature sensed reaches a selected limit (see *LM3914 Dot/Bar Display Driver* ([SNVS761](#))).



- = 1% or 2% film resistor
- Trim  $R_B$  for  $V_B = 3.525V$
- Trim  $R_C$  for  $V_C = 2.725V$
- Trim  $R_A$  for  $V_A = 0.085V + 40 \text{ mV/}^\circ\text{F} \times T_{\text{Ambient}}$
- Example:  $V_A = 3.285V$  at  $80^\circ\text{F}$

Figure 17. Bar-Graph Temperature Display (Dot Mode)

### 13 Indoor/Outdoor Thermometer

An indoor/outdoor thermometer capable of displaying temperatures all the way down to  $-50^{\circ}\text{F}$  is shown in Figure 18.

Two sensor outputs are multiplexed through a CD4066 quad bilateral switch and then displayed one at a time on a DVM such as Texmate's PM-35X. The LMC555 timer is run as an astable multivibrator at 0.2 Hz so that each temperature reading will be displayed for approximately 2.5 seconds. The RC filter on the sensors outputs are to compensate for the capacitive loading of the cable. An LMC7660 can be used to provide the negative supply voltage for the circuit.

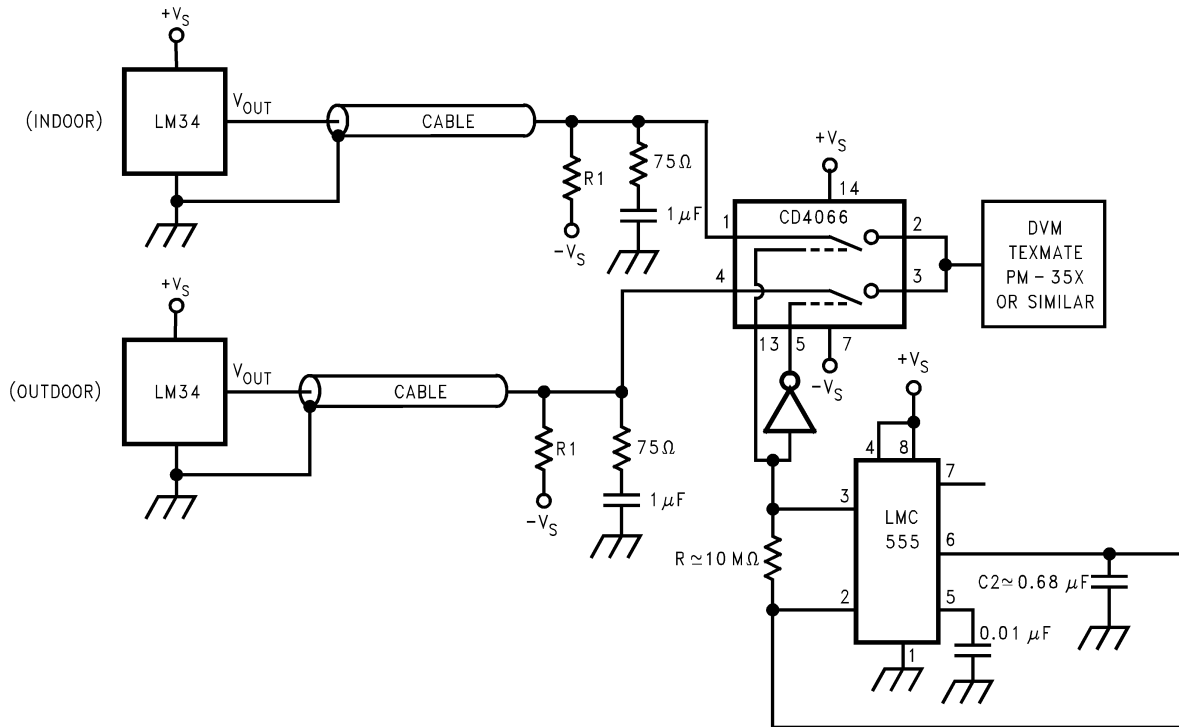


Figure 18.

## 14 Temperature Controller

A proportional temperature controller can be made with an LM34 and a few additional parts. The complete circuit is shown in Figure 19. Here, an LM10 serves as both a temperature setting device and as a driver for the heating unit (an LM395 power transistor). The optional lamp, driven by an LP395 Transistor, is for indicating whether or not power is being applied to the heater.

When a change in temperature is desired, the user merely adjusts a reference setting pot and the circuit will smoothly make the temperature transition with a minimum of overshoot or ringing. The circuit is calibrated by adjusting R2, R3 and C2 for minimum overshoot. Capacitor C2 eliminates DC offset errors. Then R1 and C1 are added to improve loop stability about the set point. For optimum performance, the temperature sensor should be located as close as possible to the heater to minimize the time lag between the heater application and sensing. Long term stability and repeatability are better than 0.5°F.

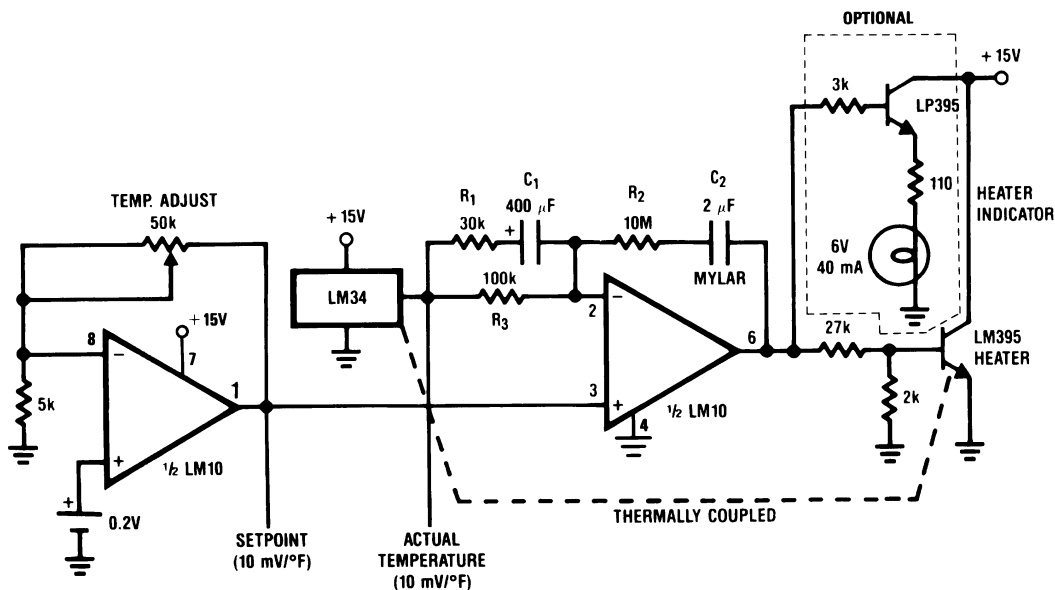


Figure 19. Temperature Controller



## 15 Differential Thermometer

The differential thermometer shown in [Figure 20](#) produces an output voltage which is proportional to the temperature difference between two sensors. This is accomplished by using a difference amplifier to subtract the sensor outputs from one another and then multiplying the difference by a factor of ten to provide a single-ended output of 100 mV per degree of differential temperature.

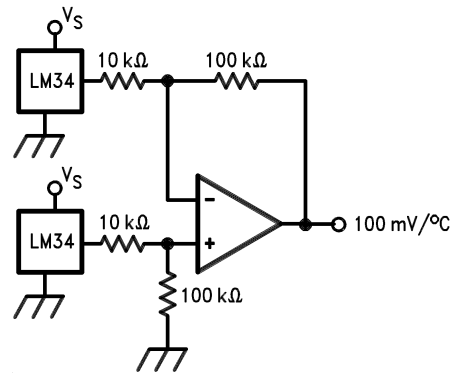
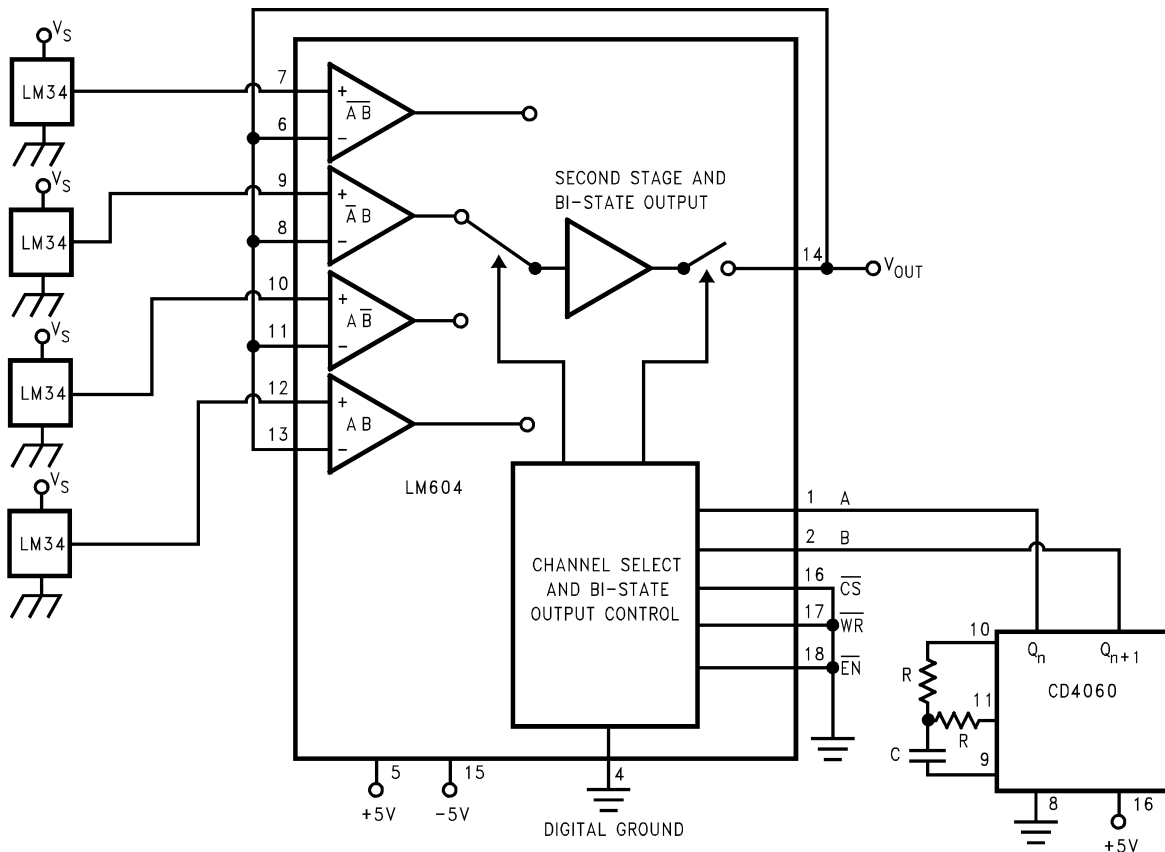


Figure 20. Differential Thermometer

## 16 Temperature Scanner

In some applications it is important to monitor several temperatures periodically, rather than continuously. The circuit shown in Figure 21 does this with the aid of an LM604 Mux Amp. Each channel is multiplexed to the output according to the AB channel select. The CD4060 ripple binary counter has an on-board oscillator for continuous updating of the channel selects.



$$\text{rate} = \frac{0.56}{RC} \left( \frac{1}{2^{n-1}} \right)$$

If  $Q_4$  and  $Q_5$  are used with  $R = 13\text{k}$  and  $C = 510\text{ pF}$ , the rate will be 10 kHz.

**Figure 21. Temperature Monitoring**

## 17 Conclusion

As can be seen, the LM34 and LM35 are easy-to-use temperature sensors with excellent linearity. These sensors can be used with minimal external circuitry for a wide variety of applications and do not require any elaborate scaling schemes nor offset voltage subtraction to reproduce the Fahrenheit and Celsius temperature scales, respectively.

## 18 References

1. R.A. Pease, "A Fahrenheit Temperature Sensor", presented at the ISSCC Conference, February 24, 1984.
2. R.A. Pease, "A New Celsius Temperature Sensor", National Semiconductor Corp., 1983.
3. Robert Dobkin, "Monolithic Temperature Transducer", in *Dig. Tech. Papers*, Int. Solid State Circuits Conf., 1974, pp. 126, 127, 239, 240.
4. Gerard C.M. Meijer, "An IC Temperature Sensor with an Intrinsic Reference", *IEEE Journal of Solid State Circuits*, VOL SC-15, June 1980, pp. 370–373.
5. R.J. Widlar, "An Exact Expression for the Thermal Variation of the Emitter—Base Voltage of Bipolar Transistors", *Proc. IEEE*, January 1967.
6. Y.P. Tsividis, "Accurate Analysis of Temperature Effects in  $I_C - V_{BE}$  Characteristics with Application to Bandgap Reference Sources", *IEEE Journal of Solid-State Circuits*, December 1980, pp. 1076–1084.
7. Michael P. Timko, "A Two-Terminal IC Temperature Transducer", *IEEE Journal of Solid-State Circuits*, December 1976, pp. 784–788.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)