ANALOG DEVICES

Quad Setpoint, Programmable Temperature Monitor and Controller

ADT14

FEATURES
Four Programmable Temperature Setpoints
Programmable Thermal Hysteresis
Accuracy ±3°C Typ from –40°C to +125°C
Temperature Output Scale Factor = 5 mV/K
Resistor Programmable Temperature Setpoints
5 mA Open-Collector Setpoint Outputs
Internal 2.5 V Reference
600 µA Max Quiescent Current at +5 V

APPLICATIONS
Power Supply Monitor and Control System
Multiple Fan Controller System
Workstation Thermal Management System

GENERAL DESCRIPTION

The ADT14 is a temperature sensor and controller that generates an output voltage proportional to temperature and provides four temperature trip points. The four trip points, or temperature setpoints, and their hysteresis are determined by voltage levels set by the user. An on-chip voltage reference provides an easy method for setting the temperature trip points.
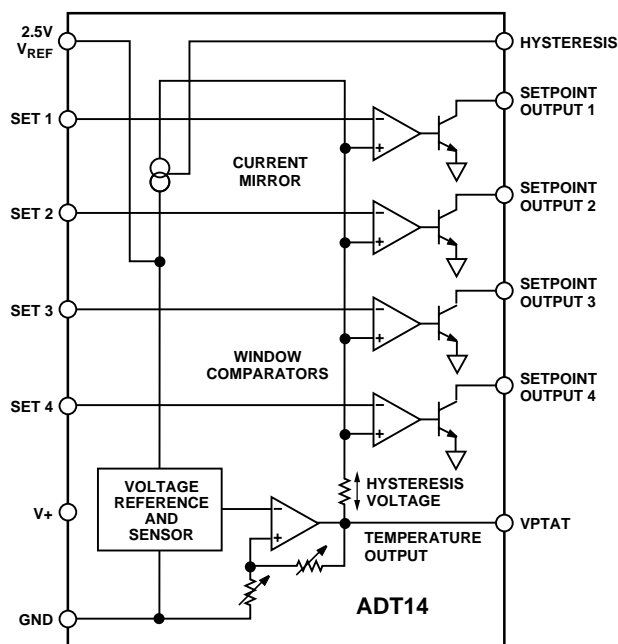
The ADT14 consists of a bandgap voltage reference combined with four matched comparators. The reference provides both a temperature-stable 2.5 V output, and a voltage proportional to absolute temperature (VPTAT) which has a precise temperature coefficient of 5 mV/K = 5 mV/(°C +273.15). The VPTAT output is nominally 1.49 V at +25°C. The comparators determine whether the VPTAT output is above the voltages set up by external resistive dividers (temperature trip points) and generate an open-collector output signal when one of their respective thresholds has been exceeded.

Hysteresis is programmed by a user-selected voltage at the hysteresis pin. This voltage adjusts the hysteresis current which is used to generate a hysteresis offset voltage. The comparator's noninverting inputs are connected in parallel, which guarantees that there is no hysteresis overlap and eliminates erratic transitions between adjacent trip zones.
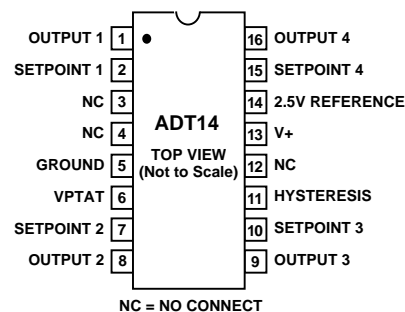
Using a proprietary thin-film resistor process in conjunction with production laser trimming, a temperature accuracy of ±3°C at 25°C is guaranteed. The open-collector outputs are capable of sinking 5 mA, and provide TTL/CMOS logic compatibility with an external pull-up resistor. Operating from a single 5 V supply, the quiescent current is 600 µA max.

The ADT14 is available in the 16-lead epoxy DIP and SO (small outline) packages.

FUNCTIONAL BLOCK DIAGRAM

PIN CONFIGURATIONS
DIP & SO

OUTPUT 1	1	16	OUTPUT 4
SETPOINT 1	2	15	SETPOINT 4
NC	3	14	2.5V REFERENCE
NC	4	13	V+
GROUND	5	12	NC
VPTAT	6	11	HYSTERESIS
SETPOINT 2	7	10	SETPOINT 3
OUTPUT 2	8	9	OUTPUT 3

ADT14 TOP VIEW (Not to Scale)

NC = NO CONNECT

REV. 0

Parameter	Symbol	Conditions	Min	Typ	Max	Units
ACCURACY						
Accuracy (Setpoints 1, 2, 3 and 4)		T_A = +25°C		±2	±3	°C
Accuracy (Setpoints 1, 2, 3 and 4)		T_A = –40°C to +125°C		±3	±5	°C
VPTAT Output Scale Factor			+4.9	+5	+5.1	mV/K
Setpoint Hysteresis Levels		T_A = +25°C		0.65, 1.5, 5		°C
Power Supply Rejection Ratio	PSRR	4.5 V ≤ V_S ≤ 13 V		0.1	0.25	°C/V
Linearity				0.5		°C
SETPOINT INPUTS						
Offset Voltage	V_{OS}	T_A = +25°C		1		mV
Offset Voltage Mismatch		T_A = +25°C		0.5		mV
Output Voltage Drift	TCV_{OS}			3		μV/°C
Input Bias Current	I_B			25	100	nA
REFERENCE OUTPUT						
Line Regulation		4.5 V ≤ V_S ≤ 13 V			±0.1	%/V
Load Regulation		I_{SOURCE} = 10 μA to 500 μA			±0.25	%/mA
Output Voltage	V_{REF}	T_A = +25°C, No Load	2.49	2.5	2.51	V
Output Voltage	V_{REF}	No Load, –40°C ≤ T_A ≤ +125°C	2.48	2.5	2.52	V
Output Drift	TCV_{REF}			±30		ppm/°C
OPEN-COLLECTOR OUTPUTS						
Output Low Voltage	V_{OL}	I_{SINK} = 1.6 mA, –40°C ≤ T_A ≤ +85°C		0.25	0.4	V
Output Low Voltage	V_{OL}	I_{SINK} = 5 mA		0.6		V
Output Leakage Current	I_{OH}	V+ = 12 V		1	100	μA
Fall Time	t_{HL}	See Figure 1		40		ns
POWER SUPPLY						
Supply Range	V+		4.5		5.5	V
Supply Current	I_{SY}	Unloaded at +5 V		400	600	μA
Supply Current	I_{SY}	Unloaded at +12 V		450		μA

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

Maximum Supply Voltage . . . . –0.3 V to +15 V
Maximum Setpoint Input Voltage . . –0.3 V to ([V+] +0.3 V)
Maximum Reference Output Current . . . . 1 mA
Maximum Open-Collector Output Current . . . . 15 mA
Maximum Open-Collector Output Voltage . . . . +15 V
Operating Temperature Range . . . . –55°C to +150°C
Dice Junction Temperature . . . . +175°C
Storage Temperature Range . . . . –65°C to +160°C
Lead Temperature (Soldering, 60 sec) . . . . +300°C

*CAUTION

1. Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation at or above this specification is not implied. Exposure to the above maximum rating conditions for extended periods may affect device reliability.

2. Digital inputs are protected; however, permanent damage may occur on unprotected units from high-energy electrostatic fields. Keep units in conductive foam or packaging at all times until ready to use. Use proper antistatic handling procedures.

3. Remove power before inserting or removing units from their sockets.

ORDERING GUIDE

Model/Grade	Temperature Range[1]	Package Description	Package Options[2]
ADT14GP	XIND	Plastic DIP	N-16
ADT14GS	XIND	SOIC	R-16A

NOTES
[1]XIND = –40°C to +125°C.
[2]N = Plastic DIP; R = Small Outline.

THERMAL PACKAGE CHARACTERISTICS

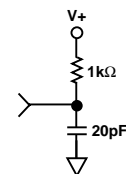| Package Type	θ_{JA}	θ_{JC}	Units
16-Lead Plastic DIP	103	34	°C/W
16-Lead SOIC	81	27	°C/W

Figure 1. Test Load

WAFER TEST LIMITS (V+ = +5 V, GND = 0 V, T_A = +25°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
INPUTS SET HIGH, SET LOW						
Input Bias Current	I_B				70	nA
OUTPUT VPTAT						
Temperature Accuracy		T_A = +25°C, No Load			1.5	°C
OUTPUT V_{REF}	V_{REF}					
Nominal Value		T_A = +25°C, No Load	2.490		2.510	V
Line Regulation		4.5 V ≤ V ≤ 13.2 V			±0.08	%/V
Load Regulation		10 μA ≤ IV_{REF} ≤ 500 μA			±0.25	%/mA
OPEN-COLLECTOR OUTPUTS OVER, UNDER						
Output Low Voltage	V_{OL}	I_{SINK} = 1.6 mA			0.4	V
Output Leakage Current	I_{OH}				100	μA
POWER SUPPLY						
Supply Range	V+		4.5		5.5	V
Supply Current	I_{SY}	Unloaded			600	μA

NOTE
Electrical tests are performed at wafer probe to the limits shown. Due to variations in assembly and nominal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on lot qualification through sample lot assembly and testing.

DICE CHARACTERISTICS
Die Size 0.069 × 0.080 inch, 5520 sq. mils
(1.75 × 2.03 mm, 3.55 sq. mm)
Transistor Count: 130
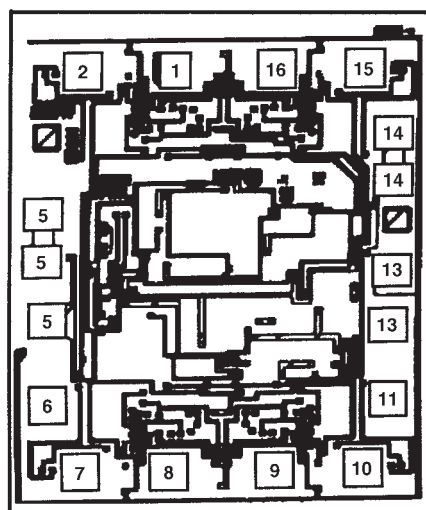
1. OUTPUT 1
2. SETPOINT 1
3. NC
4. NC
5. GROUND
6. VPTAT
7. SETPOINT 2
8. OUTPUT 2
9. OUTPUT 3
10. SETPOINT 3
11. HYSTERESIS
12. NC
13. V+
14. 2.5V REFERENCE
15. SETPOINT 4
16. OUTPUT 4

FOR ADDITIONAL DICE ORDERING INFORMATION, REFER TO DATABOOK.

CAUTION
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADT14 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

WARNING!
ESD SENSITIVE DEVICE
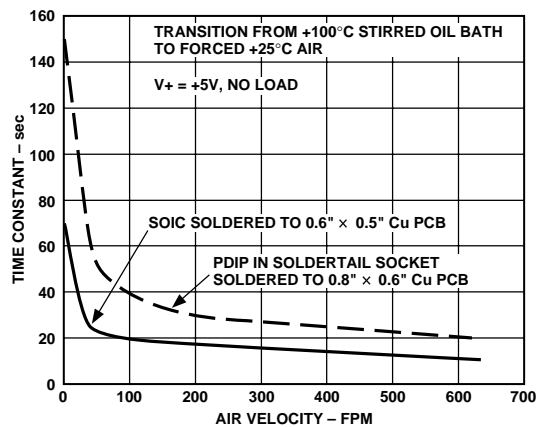
Figure 2. Thermal Time Constant in Forced Air
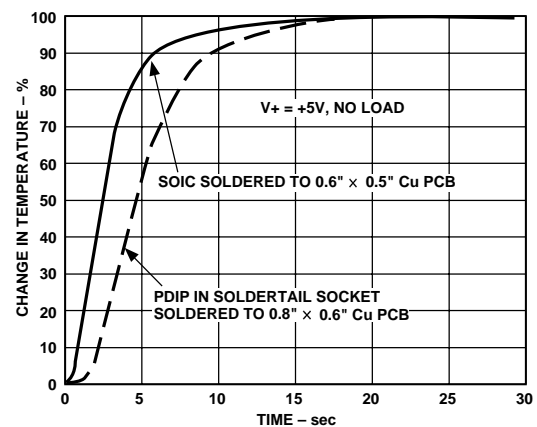
Figure 3. Thermal Response in Stirred Oil Bath

Figure 4. Start-Up Voltage vs. Temperature
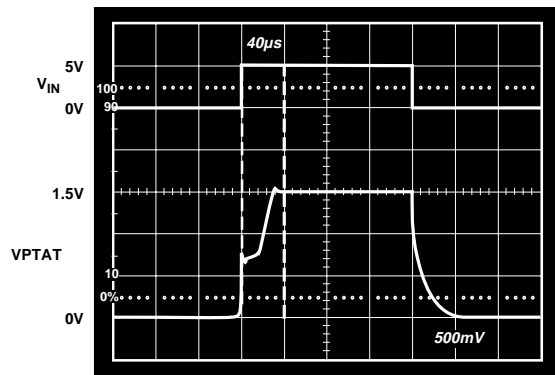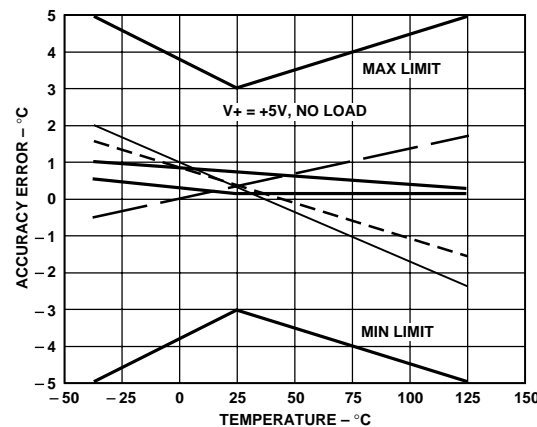

Figure 5. Start-Up Response

Figure 6. Accuracy Error vs. Temperature, Stirred Oil Bath

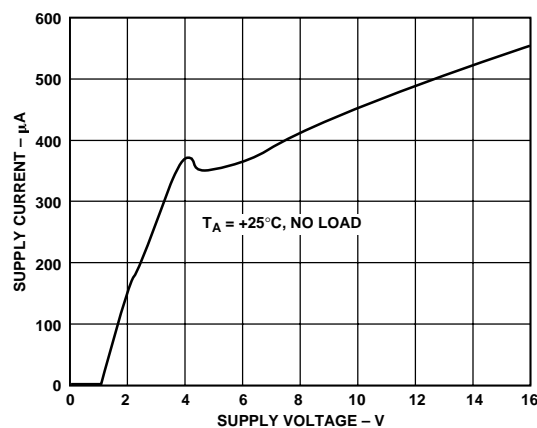Figure 7. Supply Current vs. Supply Voltage
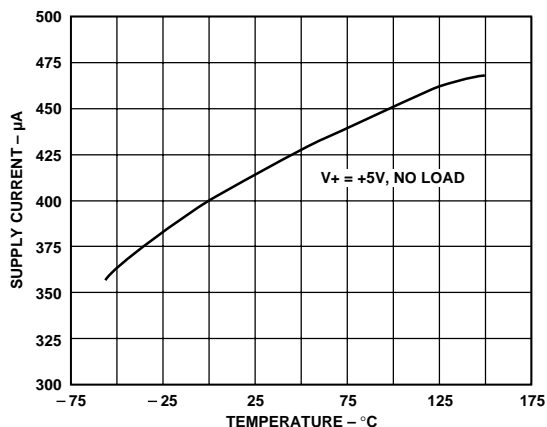
Figure 8. Supply Current vs. Temperature

Figure 9. Open-Collector Output Sink Current vs. Temperature

Figure 10. Open-Collector Output Voltage vs. Temperature

Figure 11. Reference Voltage vs. Temperature

Figure 12. VPTAT Power Supply Rejection vs. Temperature
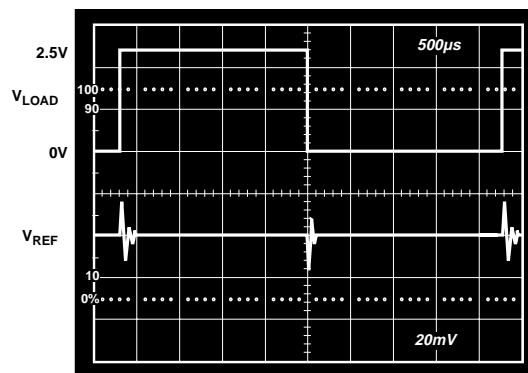
Figure 13. V_{REF} Under Load Switching (0 μA–500 μA), R_{LOAD} = 5 $k\Omega$

ADT14

APPLICATIONS INFORMATION
Programming the ADT14
To program any of the four temperature trip points, simply set the voltage at the setpoint pin equal to the voltage expected at the VPTAT output at the desired trip temperature. The on-board 2.5 V precision reference provides a temperature stable output that is used to establish the setpoint voltages. Figure 14 illustrates the basic temperature setpoint configuration. This parallel resistor ladder configuration uses six resistors to set the four setpoint voltages.
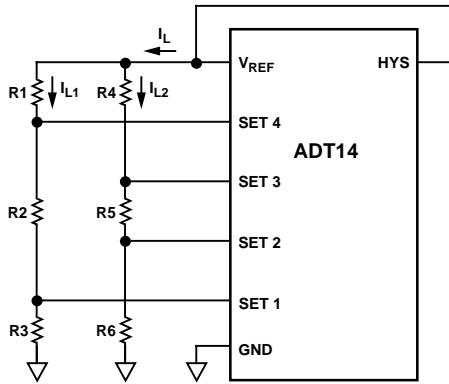

Figure 14. ADT14 Setpoint Programming

For SET4,
  T4 = 100°C
  V(SET4) = (T4 + 273.15)(5 mV/K)

For SET1,
  T1 = 75°C
  V(SET1) = (T1 + 273.15)(5 mV/K)

Choose $I_{L1} = I_{L2} = 25$ μA,
  $R1 = (V_{REF} - V[SET4])/I_{L1}$
  $R2 = (V[SET4] - V[SET1])/I_{L1}$
  $R3 = V(SET1)/I_{L1}$

For SET3,
  T3 = 50°C
  V(SET3) = (T3 + 273.15)(5 mV/K)

For SET2,
  T2 = –10°C
  V(SET2) = (T2 + 273.15)(5 mV/K)

Since $I_{L1} = I_{L2} = 25$ μA,
  $R4 = (V_{REF} - V[SET3])/I_{L2}$
  $R5 = (V[SET3] - V[SET2])/I_{L2}$
  $R6 = V(SET2)/I_{L2}$

For the example shown in Figure 14 and the related equations, Setpoint 4 was chosen as highest temperature trip point, followed in order by Setpoint 1, Setpoint 3 and Setpoint 2. The user may choose to alter this order at will as all the setpoint inputs and trip point outputs are identical in operation. The minimum recommended parallel ladder resistance is 12.5 kΩ. This maintains a V_{REF} load current less than 200 μA. To avoid errors, choose 50 μA < I_L < 200 μA.

For those applications where setpoints do not need to be changed, a single ladder of five resistors can be used. Figure 15 illustrates a single resistor ladder configuration.

$$50 \text{ μA} < I_L < 200 \text{ μA}$$

$R1 = (V_{REF} - V[SET4])/I_L$
$R2 = (V[SET4] - V[SET1])/I_L$
$R3 = (V[SET1] - V[SET3])/I_L$
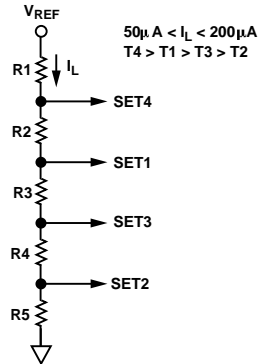$R4 = (V[SET3] - V[SET2])/I_L$
$R5 = V(SET2)/I_L$

Figure 15. Single Resistor Ladder

Temperature Hysteresis
Temperature hysteresis is the number of degrees below the original setpoint temperature that must be sensed by the ADT14 before the setpoint comparator will be reset and the open-collector output disabled. Figure 16 shows the hysteresis profile. Hysteresis is programmed by the user by setting a specified voltage at the hysteresis pin (See Table I).
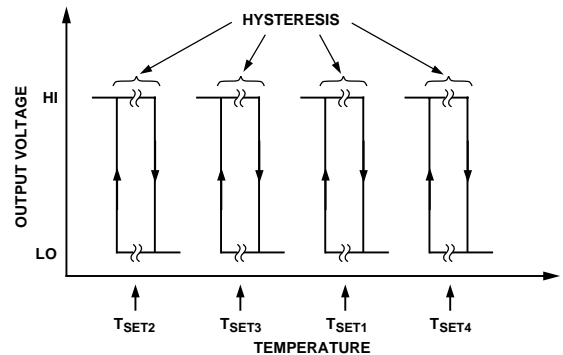
Figure 16. ADT14 Hysteresis Profile

Table I. Common Hysteresis Values and Voltages

Hysteresis	Connect Pin 11 to
0.65°C	+2.5 V Reference
1.5°C	Leave Open
5°C	Ground

The voltage on Pin 11 programs the internal hysteresis current, which is mirrored and fed to a buffer controlled by an analog switch. After a temperature setpoint has been exceeded and a comparator tripped, the buffer is enabled, allowing hysteresis current to flow. This current generates a hysteresis offset voltage

across an internal 1 kΩ resistor at the comparator input. The comparator output remains on until the voltage at the comparator input, now equal to VPTAT plus the hysteresis offset, has returned to the setpoint voltage. At this point the comparator turns off, the open-collector output is deactivated, and the hysteresis current buffer is disabled.

While Table I shows simple pin-programmable hysteresis values, the user may design for intermediate values of hysteresis between 0.65°C and 5°C using a resistive divider. To set the hysteresis in the range 0.65°C < T$_{HYS}$ < 1.5°C, a resistor is connected from the HYS pin (Pin 11) to V$_{REF}$ (Pin 14). The value of the resistor is given by the following equation:

$$R1 = \frac{57.5}{1.5 - Hysteresis} - 57.5$$

For various values of T$_{HYS}$, the table below shows the values for R1:

Table II

T$_{HYS}$ (°C)	R1 (kΩ)
0.7	14.4
0.8	24.6
0.9	38.3
1.0	57.5
1.1	86.3
1.2	134.2
1.3	230
1.4	517.5

To set hysteresis in the range of 1.5°C < T$_{HYS}$ < 5°C, a resistor is connected from the HYS pin (Pin 11) to the ADT14's common (Pin 5). The value of the resistor is given by:

$$R2 = \frac{201.1}{Hysteresis - 1.5} - 57.5$$

For various values of T$_{HYS}$, the table below shows values for R2:

Table III

T$_{HYS}$ (°C)	R2 (kΩ)
1.6	1953
1.75	746.9
2.0	344.7
2.25	210.6
2.5	143.6
2.75	103.4
3.0	76.6
3.25	57.4
3.50	43.1
3.75	31.8
4.0	22.9
4.25	15.6
4.5	9.5
4.75	4.4

The schematics for the two circuits are shown below. As the resistor values are approximate, it is a good idea to add a potentiometer for fine adjustments.
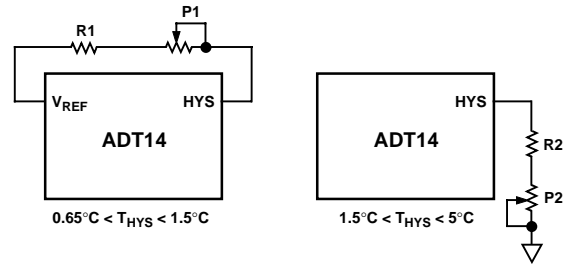

Figure 17. Hysteresis Connections for Miscellaneous Values

Understanding Error Sources

The accuracy of the VPTAT sensor output is well characterized and specified, however preserving this accuracy in a heating or cooling control system requires some attention to minimizing potential error sources. The internal sources of setpoint programming error include the initial tolerances and temperature drifts of the reference voltage V$_{REF}$, the setpoint comparator input offset voltage and bias current, and the hysteresis current scale factor. When evaluating setpoint programming errors, remember that any V$_{REF}$ error contribution at the comparator inputs is reduced by the resistor divider ratios. Each comparator's input bias current drops to less than 1 nA (typ) when the comparator is tripped. This change accounts for some setpoint voltage error, equal to the change in bias current multiplied by the effective setpoint divider ladder resistance to ground.

The thermal mass of the ADT14 package and the degree of thermal coupling to the surrounding circuitry are the largest factors in determining the rate of thermal settling, which ultimately determines the rate at which the desired temperature measurement accuracy may be reached (see Figure 2). Thus, one must allow sufficient time for the device to reach the final temperature. The typical thermal time constant for the plastic SOIC package is approximately 70 seconds in still air. Therefore, to reach the final temperature accuracy within 1%, a settling time of five time constants, or six minutes, is necessary.

External error sources to consider are the accuracy of the external programming resistors, ground voltage errors, and thermal gradients. The accuracy of the external programming resistors directly impacts the resulting setpoint accuracy. Thus, in fixed-temperature applications the user should select resistor tolerances appropriate to the desired programming accuracy. Resistor temperature drift must also be taken into account. This effect can be minimized by selecting high quality components, and by keeping all components in close thermal proximity. Applications requiring high measurement accuracy require great attention to detail regarding thermal gradients. Careful circuit board layout, component placement, and protection from stray air currents are necessary to minimize common thermal error sources. The user should also take care to keep the bottom of the setpoint programming divider ladder as close as possible to GND (Pin 5) to minimize errors due to IR voltage drops and coupling of external noise sources. In any case, a 0.1 μF capacitor for power supply bypassing is always recommended at the chip.

ADT14

Safety Considerations

In heating and cooling system design, designers should anticipate potential system fault conditions which may result in significant safety hazards which are outside the control of, and cannot be corrected by, the ADT14 based circuit. Governmental and industrial regulations regarding safety requirements and standards for such designs should be observed where applicable.

Self-Heating Effects

In some applications the user should consider the effects of self-heating due to the power dissipated by the open-collector outputs, which are capable of sinking 5 mA each continuously. Under full load, the ADT14 open-collector output device is dissipating,

$$P_{DISS} = 0.6\,V \times 0.005\,A \times 4 = 12\,mW$$

which, in the small outline package, accounts for a temperature increase due to self-heating of

$$\Delta T = P_{DISS} \times \theta_{JA} = 0.012\,W \times \frac{81°C}{W} = 0.97°C$$

This will directly affect the accuracy of the ADT14 and will, for example, cause the device to switch the heating output off 0.97 degrees early. Alternatively, bonding the same package to a moderate heatsink limits the self-heating effect to approximately

$$\Delta T = P_{DISS} \times \theta_{JC} = 0.012\,W \times \frac{27°C}{W} = 0.32°C$$

which is a much more tolerable error in most systems. The V_{REF} and VPTAT outputs are also capable of delivering sufficient current to contribute heating effects and should not be ignored.

Buffering the Voltage Reference

The reference output V_{REF} is used to generate the temperature setpoint programming voltages for the ADT14. The onboard V_{REF} output buffer is capable of 500 µA output drive into as much as a 50 pF load. Exceeding this load will affect the accuracy of the reference voltage, will increase thermal errors due to internal heat generation, and may induce oscillations. External buffering of V_{REF} with a low drift voltage follower will ensure optimal reference accuracy if a large load current is required. Amplifiers that offer low drift, low power consumption, and low cost appropriate to this application include the OP295 and members of the OP90, OP97, OP177 families, and others shown in the following applications circuits.

With excellent drift and noise characteristics, V_{REF} offers a good voltage reference for data acquisition and transducer excitation applications as well.

Preserving Accuracy Over Wide Temperature Range Operation

The ADT14 is unique in offering both a wide-range temperature sensor and the associated detection circuitry needed to implement a complete thermostatic control function in one monolithic device. The voltage reference, setpoint comparators, and output buffer amplifiers have been carefully compensated to maintain accuracy over the specified temperature ranges in this application. Since the ADT14 is both sensor and control circuit, in many applications the external components used to program and interface the device are subjected to the same temperature extremes. Thus, it is necessary to place components in close thermal proximity to minimize temperature differentials, and to

account for thermal drift errors where appropriate, such as resistor matching temperature coefficients, amplifier error drift, and the like. Circuit design with the ADT14 requires a slightly different perspective regarding the thermal behavior of electronic components.

Thermal Response Time

The time required for a temperature sensor to settle to a specified accuracy is a function of the thermal mass of the sensor, and the thermal conductivity between the sensor and the object being sensed. Thermal mass is often considered equivalent to capacitance. Thermal resistance is commonly specified in units of degrees per watt of power transferred across the thermal joint. Figure 3 illustrates the typical response to a step change in ambient temperature for PDIP and SOIC packages. Thus, the time required for the ADT14 to settle to the desired accuracy is dependent on the package selected, the thermal contact established in the particular application, and the equivalent thermal conductivity of the heat source. For most applications, the settling time is probably best determined empirically.

Switching Loads with the Open-Collector Outputs

In many temperature sensing and control applications some type of switching is required. Whether it's to turn on a heater when the temperature goes below a minimum value or to turn off a motor that is overheating, the open-collector outputs can be used. For the majority of applications, the switches used need to handle large currents on the order of 1 amp and above. Because the ADT14 is accurately measuring temperature, the open-collector outputs should handle less than 5 mA of current to minimize self-heating. Clearly, the trip point outputs should not drive the equipment directly. Instead, an external switching device is required to handle the large currents. Some examples of these are power MOSFETs, thyristors, IGBTs, and Darlingtons. Figures 18a–18d show a variety of circuits where the ADT14 controls a switch. The main consideration in these circuits is the current required to activate the switch.

Power FETs are popular for handling a variety of high current DC loads. Figure 18b shows the ADT14 driving a P-channel MOSFET transistor for a simple heater circuit. When the output transistor turns on, the gate of the MOSFET is pulled down to approximately 0.6 V, turning it on. For most MOSFETs a gate-to-source voltage, or V_{GS}, on the order of –2 V to –5 V is sufficient to turn on the device.

Isolated Gate Bipolar Transistors (IGBT) combine many of the benefits of power MOSFETs with bipolar transistors, and are used for a variety of high power applications. Because IGBTs have a gate similar to MOSFETs, turning the devices on and off is relatively simple as shown in Figure 18c. The turn-on voltage for the IGBT shown (IRGB40S) is between 3.0 and 5.5 volts. This part has a continuous collector current rating of 50 A and a maximum collector-to-emitter voltage of 600 V, enabling it to work in very demanding applications.

The last class of high power devices discussed here are thyristors, which include SCRs and triacs. Triacs are a useful alternative to relays for switching ac line voltages. The 2N6073A shown in Figure 18d is rated to handle 4 A (rms). The opto-isolated MOC3021 triac shown features excellent electrical isolation from the noisy AC line and complete control over the high power triac with only a few additional components.

Figure 18a. Reed Relay Drive

Figure 18b. Driving a P-Channel MOSFET

Figure 18c. Driving an IGBT

Figure 18d. Controlling the 2N6073A Triac

ADT14

High Current Switching

As mentioned earlier, internal dissipation due to large loads on the ADT14 outputs will cause some temperature error due to self-heating. External transistors buffer the load from the ADT14, so that virtually no power is dissipated in the internal transistors and minimal self-heating occurs. Figures 19a–19c show a few examples using external transistors. The simplest case uses a single transistor on the output to invert the output signal as shown in Figure 19a. When the open-collector of the ADT14 turns ON and pulls the output down, the external transistor Q1's base will be pulled low, turning off the transistor. Another transistor can be added to reinvert the signal as shown in Figure 19b.

Now, when the output of the ADT14 is pulled down, the first transistor, Q1, turns off and its collector goes high, which turns on Q2, pulling its collector low. Thus, the output taken from the collector of Q2 is identical to the output of the ADT14. By picking a transistor that can accommodate large amounts of current, many high power devices can be switched.

An example of a higher power transistor is a standard Darlington configuration as shown in Figure 19c. The part chosen, TIP-110, can handle 2 A continuous, which is more than enough to control many high power relays. In fact the Darlington itself can be used as the switch, similar to MOSFETs and IGBTs.
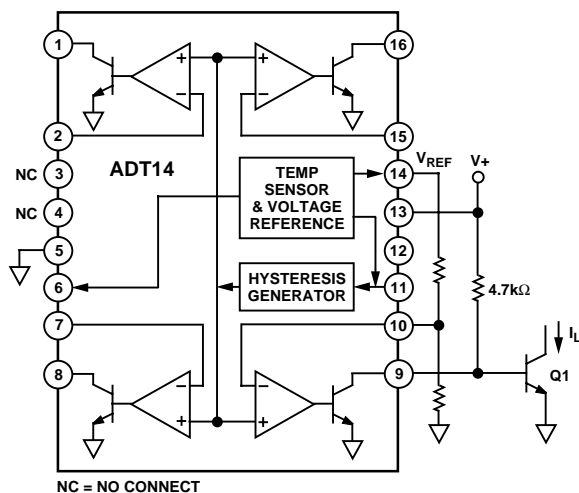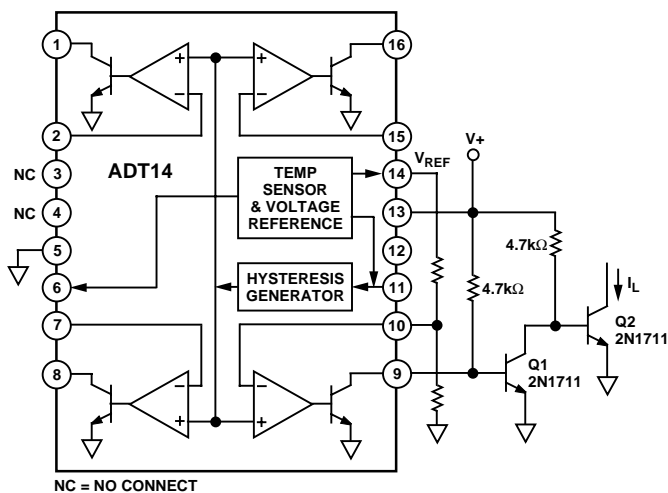

Figure 19a. An External Resistor Minimizes Self-Heating

Figure 19b. Second Transistor Maintains Polarity of ADT14 Output

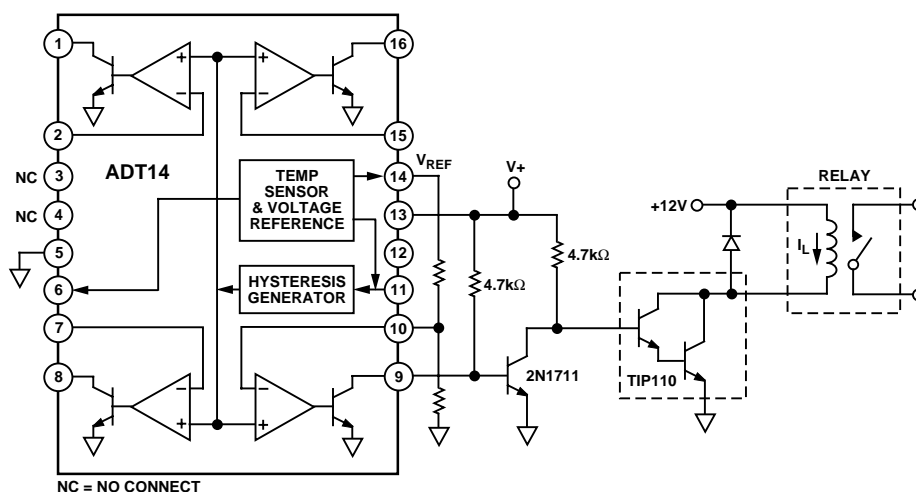Figure 19c. Darlington Transistor Can Handle Large Currents

REV. 0

Buffering the Temperature Output Pin

The VPTAT sensor output is a low impedance dc output voltage with a 5 mV/K temperature coefficient, and is useful in a number of measurement and control applications. In many applications, this voltage may need to be transmitted to a central location for processing. The unbuffered VPTAT voltage output is capable of 500 μA drive into 50 pF (max). As mentioned in the discussion regarding buffering circuits for the V_{REF} output, it is useful to consider external amplifiers for interfacing VPTAT to external circuitry to ensure accuracy, and to minimize loading, which could create dissipation-induced temperature sensing errors. An excellent general-purpose buffer circuit using the OP177, which is capable of driving over 10 mA and will remain stable under capacitive loads of up to 0.1 μF, is shown in Figure 20. Other interface circuits are shown below.
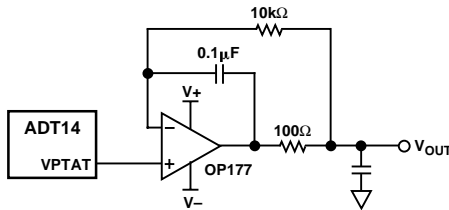

Figure 20. Buffer VPTAT to Handle Difficult Loads

Differential Transmitter

In noisy industrial environments, it is difficult to send an accurate analog signal over a significant distance. However, by sending the signal differentially on a wire pair, these errors can be significantly reduced. Since the noise will be picked up equally on both wires, a receiver with high common-mode input rejection can be used very effectively to cancel out the noise at the receiving end. Figure 21 shows two amplifiers being used to send the signal differentially, and an excellent differential receiver, the AMP03, (SSM2141 or SSM2143 are two other options), which features a common-mode rejection ratio of 95 dB at dc and very low input and drift errors.
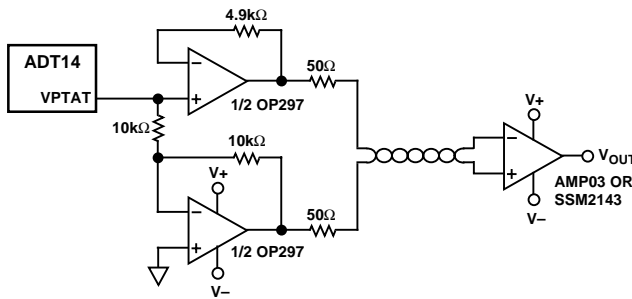

Figure 21. Send the Signal Differentially for Noise Immunity

4 mA to 20 mA Current Loop

Another very common method of transmitting a signal over long distances is to use a 4 mA-to-20 mA loop (see Figure 22). An advantage of using a 4 mA-to-20 mA loop is that the accuracy of a current loop is not compromised by voltage drops across the line. One requirement of 4 mA-to-20 mA circuits is that the remote end must receive all of its power from the loop, meaning that the circuit must consume less than 4 mA. Operating from +5 V, the quiescent current of the ADT14 is 600 μA max, and

the OP90s is 20 μA max, totaling much less than 4 mA. Although not shown, the open collector outputs and temperature setting pins can be connected to do any local control of switching.

The current is proportional to the voltage on the VPTAT output, and is calibrated to 4 mA at a temperature of –40°C, to 20 mA for +85°C. The main equation governing the operation of this circuit gives the current as a function of VPTAT:

$$I_{OUT} = \frac{1}{R6}\left(\frac{VPTAT \times R5}{R2}\right) - \left(\frac{V_{REF} \times R3}{R3 + R1} \times 1 + \frac{R5}{R2}\right)$$
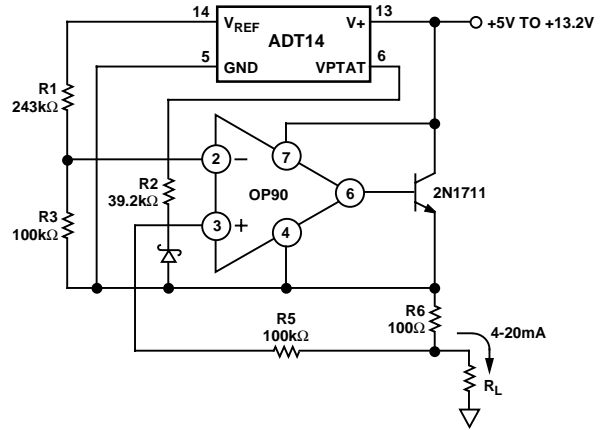

Figure 22. 4 mA to 20 mA Current Loop

To determine the resistor values in this circuit, first note that V_{REF} remains constant over temperature. Thus the ratio of R5 over R2 must give a variation of I_{OUT} from 4 mA to 20 mA as VPTAT varies from 1.165 V at –40°C to 1.79 V at +85°C. The absolute value of the resistors is not important, only the ratio. For convenience, 100 kΩ is chosen for R5. Once R2 is calculated, the value of R3 and R1 is determined by substituting 4 mA for I_{OUT} and 1.165 V for VPTAT and solving. The final values are shown in the circuit. The OP90 is chosen for this circuit because of its ability to operate on a single supply and its high accuracy. For initial accuracy, a 10 kΩ trim potentiometer can be included in series with R3, and the value of R3 lowered to 95 kΩ. The potentiometer should be adjusted to produce an output current of 12.3 mA at 25°C.

Temperature-to-Frequency Converter

Another common method of transmitting analog information is to convert a voltage to the frequency domain. This is easily done with any of the available low cost monolithic Voltage-to-Frequency Converters (VFCs) that feature an open-collector digital output. A digital signal is immune to noise and voltage drops because the only important information is the frequency. As long as the conversions between temperature and frequency are accurately performed, the temperature data can be accurately transmitted.

A simple circuit to do this combines the ADT14 with an AD654 VFC and is shown in Figure 23. The AD654 outputs a square wave that is proportional to the dc input voltage according to the following equation:

$$F_{OUT} = \frac{V_{IN}}{10\,(R1 + R2)\,C_T}$$

ADT14

By connecting the VPTAT output to the input of the AD654, the 5 mV/K, temperature coefficient gives a sensitivity of 25 Hz/°C, centered around 7.5 kHz at 25°C. The trimming resistor, R2, is needed to calibrate the absolute accuracy of the AD654. For more information on the converter, consult the AD654 data sheet. An AD650 frequency-to-voltage converter can be used to accurately convert the frequency back to a dc voltage on the receiving end.
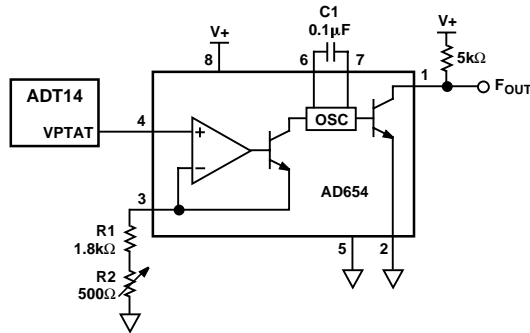

Figure 23. Temperature-to-Frequency Converter

Isolation Amplifier

In many industrial applications the sensor is located in an environment that needs to be electrically isolated from the central processing area. Figure 24 shows a simple circuit that uses an 8-pin opto-isolator (IL300XC) that can operate across a 5,000 V barrier. IC1 (an OP290 single-supply amplifier) is used to drive the LED connected between Pins 1 to 2. The feedback actually comes from the photodiode connected to Pins 3 to 4. The OP290 drives the LED such that there is enough current generated in the photodiode to exactly equal the current derived

from the VPTAT voltage across the 470 kΩ resistor. On the receiving end, an OP90 converts the current from the second photodiode to a voltage through its feedback resistor R2. Note that the other amplifier in the dual OP290 is used to buffer the 2.5 V reference voltage of the ADT14 for an accurate, low drift LED bias level without affecting the programmed hysteresis current. A REF43 (a precision 2.5 V reference) provides an accurate bias level at the receiving end.

To understand this circuit, it helps to examine the overall equation for the output voltage. First, the current (I1) in the photodiode is set by:

$$I1 = \frac{2.5V - VPTAT}{470\ k\Omega}$$

Note that the IL300XC has a gain of 0.73 (typical) with a min and max of 0.693 and 0.769 respectively. Since this is less than 1.0, R2 must be larger than R1 to achieve overall unity gain. To show this the full equation is:

$$V_{OUT} = 2.5V - I2R2 = 2.5V - 0.7\left(\frac{2.5V - VPTAT}{470\ k\Omega}\right) \times 644\ k\Omega = VPTAT$$

A trim is included for R2 to correct for the initial gain accuracy of the IL300XC. To perform this trim, simply adjust for an output equal to VPTAT at any particular temperature. For example, at room temperature, VPTAT = 1.49 V, so adjust R2 until V_{OUT} = 1.49 V as well. Both the REF43 and the OP90 operate from a single supply, and contribute no significant error due to drift.

In order to avoid the accuracy trim, and to reduce board space, complete isolation amplifiers, such as the high accuracy AD202, are available.
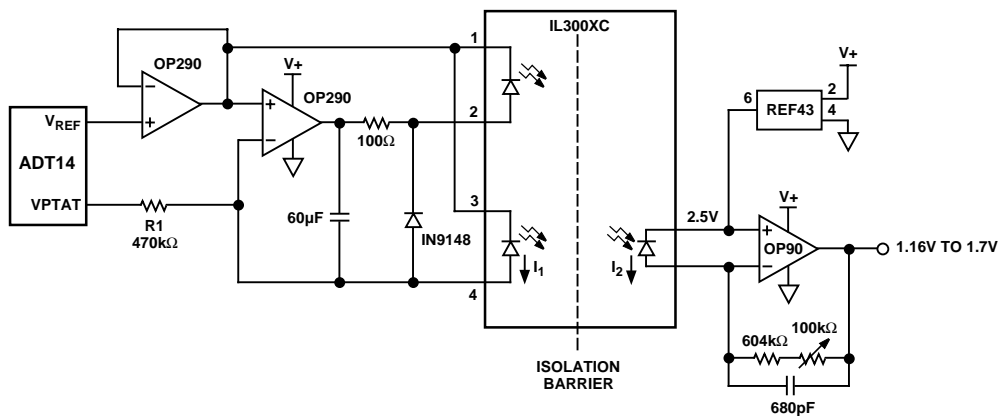

Figure 24. Isolation Amplifier

Out-of-Range Warning

In Figure 25, connecting an open-collector output of the ADT14 and an inverted open-collector output together into a wired-OR configuration, a temperature "out-of-range" warning signal is generated. This can be useful in sensitive equipment calibrated to work over a limited temperature range.
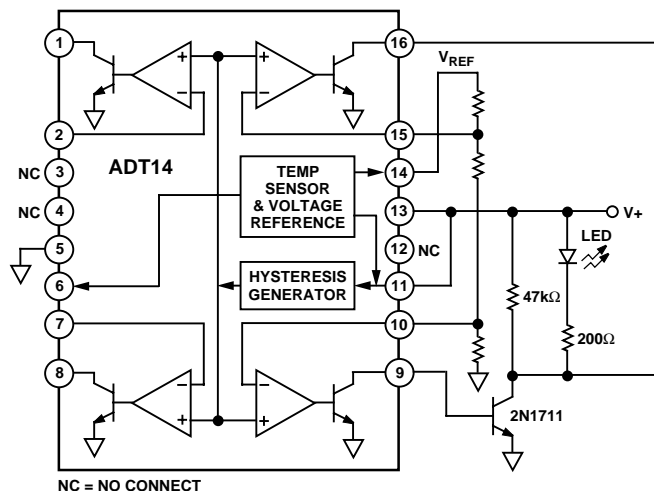

Figure 25. Out-of-Range Warning

Translating 5 mV/K to 10 mV/°C

A useful circuit is shown in Figure 26 that translates the VPTAT output voltage, which is calibrated in Kelvins, into an output that can be read directly in degrees Celsius on a voltmeter display. To accomplish this, an external amplifier is configured as a differential amplifier. The resistors are scaled so the V_{REF} voltage will exactly cancel the VPTAT voltage at 0.0°C.
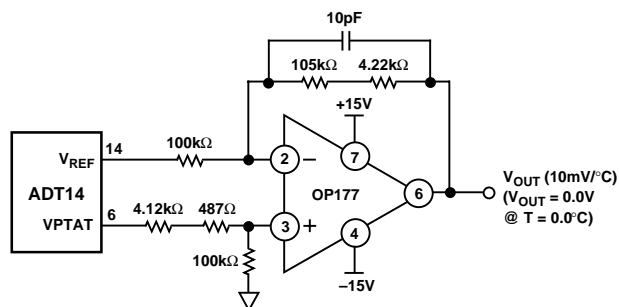

Figure 26. Translating 5 mV/K to 10 mV/°C

However, the gain from VPTAT to the output is two, so that 5 mV/K becomes 10 mV/°C. Thus, for a temperature of +80°C, the output voltage is 800 mV. Circuit errors will be due primarily to the inaccuracies of the resistor values. Using 1% resistors the observed error was less than 10 mV, or 1°C. The 10 pF feedback capacitor helps to cancel the effects of stray capacitance that could cause oscillations. For improved accuracy, an adjustment potentiometer can be added in series with either 100 kΩ resistor.

Translating VPTAT to the Fahrenheit Scale

A similar circuit to the one shown in Figure 26 can be used to translate VPTAT into an output that can be read directly in degrees Fahrenheit, with a scaling of 10 mV/°F. Only unity gain or less is available from the first stage differentiating circuit, so the second amplifier provides a gain of two to complete the conversion to the Fahrenheit scale. Using the circuit in Figure 27, a temperature of 0.0°F gives an output of 0.00 V. At room temperature (77°F) the output voltage is 770 mV. A –40°C to +85°C operating range translates into –40°F to +85°F. The errors are essentially the same as for the circuit in Figure 26.
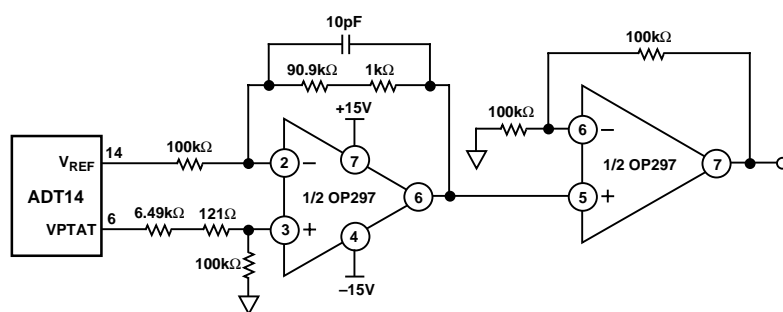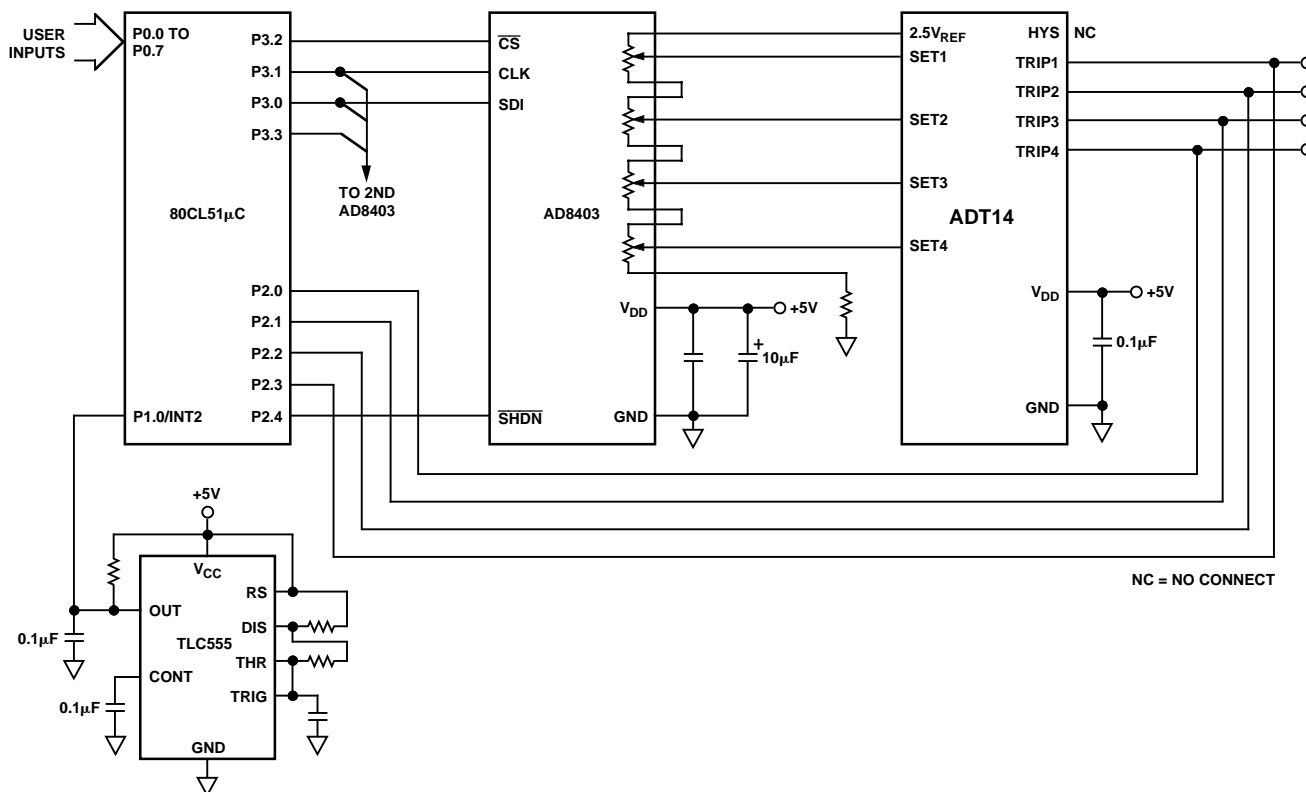

Figure 27. Translating 5 mV/K to 10 mV/°F

ADT14

Figure 28. Typical Microcontroller Setup Configuration

Intelligent Temperature Control System—Interfacing the 8051 μC with the ADT14

Connecting the 8051, or any modern microcontroller, with the ADT14 yields a powerful temperature control tool. For example, by using digitally controlled resistors (AD8402/3), a user may automatically set the temperature trip points via computer or touch pad. The ADT14 outputs are fed back to the controller allowing it to sense whether or not a setpoint has been exceeded. The higher temperature trip-point data can then be used to turn on a fan to either a high or low setting. In addition, the lower temperature trip-point data may be used to turn on a heater to either a high or low setting.

The AD8403 is shown in a single ladder resistor configuration with an additional fix resistor to set the voltages of all four setpoints. The microcontroller program that runs the AD8403 can also be set to ensure that no out-of-bound conditions occur. Finally, the AD8403 also has shutdown pin which, when activated, will lower power consumption to 5 μA max (0.01 μA typical), while still retaining memory of the potentiometer settings.

Power-Down in Battery Powered Applications

Battery powered applications require low power consumption components. The ADT14 is just such a device. The low supply current (< 600 μA) of the ADT14 makes it possible to power the device from any suitable logic output pin. Figure 29 is a schematic of an 'HC04 CMOS inverter driving the ADT14. When the SLEEP pin is high, the ADT14 is powered down. Figure 5 shows a typical start-up response of an ADT14. Most temperature measurements vary slowly over time, which allows designs

that consume very little power over very long periods of time by using a duty-cycling technique. The basic idea of the duty-cycling technique is to simply measure the temperature at selected time intervals and leave the device powered down the rest of the time. Instead of a CMOS inverter, any other logic pin with sufficient drive capability (such as the output of a microprocessor) can be used to power on and off the ADT14.
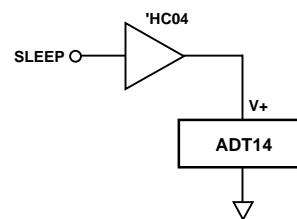

Figure 29. Using a CMOS Inverter to Power Down the ADT14

Combining Trip Point Outputs to Yield 25%, 50%, 75%, and 100% Power Outputs

It is often desirable to power a device at varying levels based upon ambient temperature. For example, suppose a liquid is below a desired temperature, the lowest trip point temperature. In this case, full power should be delivered to the heating element, causing the temperature to rise as rapidly as possible. When the lowest trip-point is finally crossed, a reduction in power should occur, slowing the rate of increase in the heating process. This process continues until all trip points are crossed and the current to the heating element is reduced to zero.

REV. 0

Figure 30 illustrates the system described in the previous paragraph, where each trip-point output corresponds to a 25% reduction in power when tripped. This is accomplished by the dual rail-to-rail precision OP284 op amp configured as an inverting summer in the first stage, and as a V/I converter in the second stage.

Suppose, however, that the heating element at a reduced power level is unable to raise the ambient temperature to the desired setting. This issue can be addressed by using a microcontroller as shown in Figure 28. The microcontroller allows the time for the given volume of material to heat up from a low trip-point temperature to the next highest temperature trip-point to be measured. If this time is too long, the microcontroller could add additional power to the heater by altering a setpoint level.
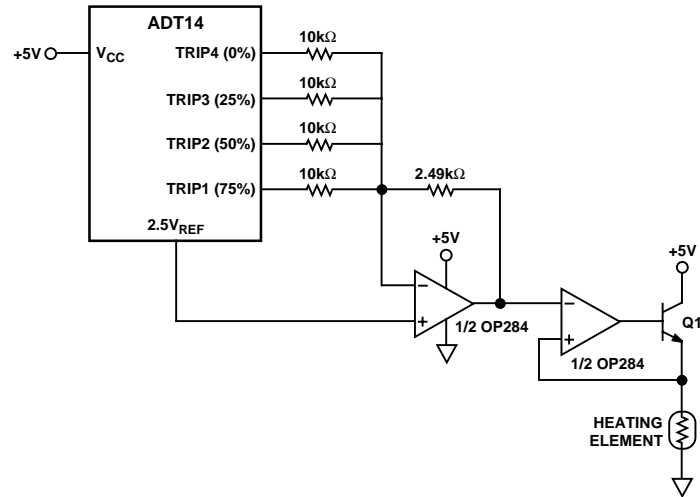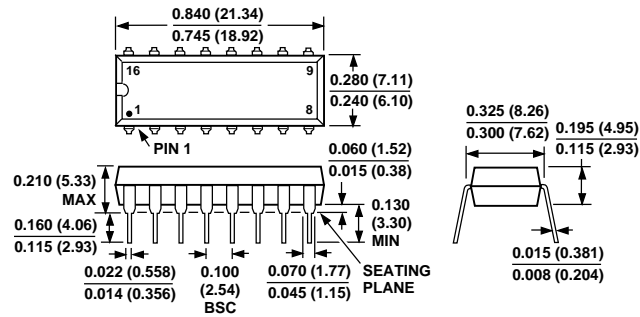
Figure 30. Combination Trip-Point Output

OUTLINE DIMENSIONS
Dimensions shown in inches and (mm).

16-Lead Plastic DIP
(N-16)

16-Lead Narrow-Body SOIC
(R-16A)

REV. 0