FEATURES

- Converts Remote or Internal Diode Temperature to Analog Voltage
- Adjustable Overtemperature and Undertemperature Thresholds
- Voltage Output Proportional to Temperature
- ±1°C Remote Temperature Accuracy
- ±2°C Internal Temperature Accuracy
- Built-In Series Resistance Cancellation
- Open Drain Alert Outputs
- 2.25V to 5.5V Supply Voltage
- 1.8V Reference Voltage Output
- 200µA Quiescent Current
- 10-Lead 3mm × 3mm DFN Package

APPLICATIONS

- Temperature Monitoring and Measurement
- System Thermal Control
- Network Servers
- Desktop and Notebook Computers
- Environmental Monitoring

DESCRIPTION

The LTC®2996 is a high accuracy temperature sensor with adjustable ovetemperature and undertemperature thresholds and open drain alert outputs. It converts the temperature of an external diode sensor or its own die temperature to an analog output voltage while rejecting errors due to noise and series resistance. The measured temperature is compared against upper and lower limits set with resistive dividers. If a threshold is exceeded, the device communicates an alert by pulling low the corresponding open drain logic output.

The LTC2996 gives ±1°C accurate temperature results using commonly available NPN or PNP transistors or temperature diodes built into modern digital devices. A 1.8V reference output simplifies threshold programming and can be used as an ADC reference input.

The LTC2996 provides an accurate, low power solution for temperature monitoring in a compact 3mm × 3mm DFN package.

<table>
<thead>
<tr>
<th>VREF</th>
<th>VCC</th>
<th>VT</th>
<th>VTH</th>
<th>VTL</th>
<th>VPTAT</th>
<th>DT &gt; 70°C</th>
<th>UT T &lt; -20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8V</td>
<td>2.25V to 5.5V</td>
<td>0.1µF</td>
<td>1.8V</td>
<td>0.1µF</td>
<td>470pF</td>
<td>4mV/K</td>
<td>470pF</td>
</tr>
</tbody>
</table>

MMPB3904

TEMPERATURE CONTROL SYSTEM

REMOTE DIODE TEMPERATURE (°C)

VPTAT vs Remote Diode Temperature

-50 0 75 125 150

0.8 1.0 1.2 1.4 1.6 1.8

29961
LTC2996

**ABSOOLUTE MAXIMUM RATINGs**

(Notes 1, 2)

- \( V_{CC} \): –0.3V to 6V
- \( D^+, D^-, V_{PTAT}, V_{REF} \): –0.3V to \( V_{CC} + 0.3V \)
- \( OT, UT, VTH, VTL \): –0.3V to 6V

**Operating Ambient Temperature Range**

- LTC2996C: 0°C to 70°C
- LTC2996I: –40°C to 85°C
- LTC2996H: –40°C to 125°C

**Storage Temperature Range**: –65°C to 150°C

**ORDER INFORMATION**

<table>
<thead>
<tr>
<th>LEAD FREE FINISH</th>
<th>TAPE AND REEL</th>
<th>PART MARKING*</th>
<th>PACKAGE DESCRIPTION</th>
<th>TEMPERATURE RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC2996CDD#PBF</td>
<td>LTC2996CDD#TRPBF</td>
<td>LFQX</td>
<td>10-Lead (3mm × 3mm) Plastic QFN</td>
<td>0°C to 70°C</td>
</tr>
<tr>
<td>LTC2996IDD#PBF</td>
<td>LTC2996IDD#TRPBF</td>
<td>LFQX</td>
<td>10-Lead (3mm × 3mm) Plastic QFN</td>
<td>–40°C to 85°C</td>
</tr>
<tr>
<td>LTC2996HDD#PBF</td>
<td>LTC2996HDD#TRPBF</td>
<td>LFQX</td>
<td>10-Lead (3mm × 3mm) Plastic QFN</td>
<td>–40°C to 125°C</td>
</tr>
</tbody>
</table>

Consult LTC Marketing for parts specified with wider operating temperature ranges. *Temperature grades are identified by a label on the shipping container.

Consult LTC Marketing for information on lead based finish parts.

For more information on lead free part marking, go to: [http://www.linear.com/leadfree/](http://www.linear.com/leadfree/)
For more information on tape and reel specifications, go to: [http://www.linear.com/tapeandreel/](http://www.linear.com/tapeandreel/)

**ELECTRICAL CHARACTERISTICS**

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at \( T_A = 25°C, V_{CC} = 3.3V \), unless otherwise noted.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{CC} )</td>
<td>Supply Voltage</td>
<td>●</td>
<td>2.25</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>UVLO</td>
<td>Supply Undervoltage Lockout Threshold</td>
<td>( V_{CC} ) Falling</td>
<td>●</td>
<td>1.7</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Average Supply Current</td>
<td>●</td>
<td>200</td>
<td>300</td>
<td>( \mu A )</td>
<td></td>
</tr>
</tbody>
</table>

**Temperature Measurement**

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{REF} )</td>
<td>Reference Voltage</td>
<td>LTC2996</td>
<td>●</td>
<td>1.797</td>
<td>1.8</td>
<td>1.803</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTC2996C</td>
<td>●</td>
<td>1.795</td>
<td>1.8</td>
<td>1.805</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTC2996I, LTC2996H</td>
<td>●</td>
<td>1.790</td>
<td>1.8</td>
<td>1.808</td>
</tr>
<tr>
<td>( V_{REF} )</td>
<td>Load Regulation</td>
<td>( I_{LOAD} = \pm200\mu A, V_{CC} = 3.3V )</td>
<td>●</td>
<td>±1.5</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>( V_{REF} )</td>
<td>Diode Select Threshold</td>
<td>(Note 3)</td>
<td>●</td>
<td>( V_{CC} - 600 )</td>
<td>( V_{CC} - 300 )</td>
<td>( V_{CC} - 100 )</td>
</tr>
<tr>
<td></td>
<td>Remote Diode Sense Current</td>
<td></td>
<td></td>
<td>–8</td>
<td>–192</td>
<td>( \mu A )</td>
</tr>
</tbody>
</table>
**ELECTRICAL CHARACTERISTICS**  The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ C$, $V_{CC} = 3.3V$, unless otherwise noted.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{CONV}$</td>
<td>Temperature Update Interval</td>
<td></td>
<td>3.5</td>
<td>5</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>$K_T$</td>
<td>$V_{PTAT}$ Slope</td>
<td>$\eta = 1.004$</td>
<td>4</td>
<td></td>
<td></td>
<td>mV/K</td>
</tr>
<tr>
<td>$V_{PTAT}$ Load Regulation</td>
<td>$I_{LOAD} = \pm 200\mu A$</td>
<td></td>
<td></td>
<td>±1.5</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>$T_{INT}$</td>
<td>Internal Temperature Accuracy</td>
<td></td>
<td></td>
<td>●</td>
<td>±0.5</td>
<td>±1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td>±0.5</td>
<td>±2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td>±0.5</td>
<td>±3</td>
</tr>
<tr>
<td>$T_{RMT}$</td>
<td>Remote Temperature Error, $\eta = 1.004$</td>
<td>0°C to 85°C (Notes 4, 5)</td>
<td>±0.25</td>
<td>±1</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–40°C to 0°C (Notes 4, 5)</td>
<td>±0.25</td>
<td>±1.5</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85°C to 125°C (Notes 4, 5)</td>
<td>±0.25</td>
<td>±1.5</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Temperature Noise</td>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
<td>°C RMS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
<td>°C RMS/√Hz</td>
</tr>
<tr>
<td>$T_{VCC}$</td>
<td>Temperature Error vs Supply</td>
<td>●</td>
<td>±0.5</td>
<td></td>
<td></td>
<td>°C/V</td>
</tr>
<tr>
<td>$T_{RS}$</td>
<td>Series Resistance Cancellation Error</td>
<td>$R_{SERIES} = 100\Omega$</td>
<td>●</td>
<td>±0.25</td>
<td>±1</td>
<td>°C</td>
</tr>
</tbody>
</table>

**Temperature Monitoring**

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{OFF}$</td>
<td>$V_{TH}, V_{TL}$ Offset</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>$\Delta T_{HYST}$</td>
<td>$\theta_T, \theta_U$ Temperature Hysteresis</td>
<td></td>
<td></td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>$I_{IN}$</td>
<td>$V_{TH}, V_{TL}$, Input Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±20</td>
</tr>
</tbody>
</table>

**Digital Outputs**

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{OH}$</td>
<td>High Level Output Voltage, $\theta_T, \theta_U$</td>
<td>$I = \pm 0.5\mu A$</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$V_{OL}$</td>
<td>Low Level Output Voltage, $\theta_T, \theta_U$</td>
<td>$I = 3mA$</td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Notes:**

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** All currents into pins are positive; all voltages are referenced to GND unless otherwise noted.

**Note 3:** If voltage on pin $D^*$ exceeds the diode select threshold the LTC2996 uses the internal diode sensor.

**Note 4:** Remote diode temperature, not LTC2996 temperature.

**Note 5:** Guaranteed by design and test correlation.
TYPICAL PERFORMANCE CHARACTERISTICS

$T_A = 25^\circ C, V_{CC} = 3.3V$ unless otherwise noted.

- Temperature Error with LTC2996 at Same Temperature as Remote Diode
- Remote Temperature Error vs Ambient Temperature
- Internal Temperature Error vs Ambient Temperature
- Temperature Error vs Supply Voltage
- Remote Temperature Error vs Series Resistance
- Remote Temperature Error vs $C_{DECOUPLE}$ (Between $D^+$ and $D^-$)
- UVLO vs Temperature $V_{CC}$ Rising, Falling
- Buffered Reference Voltage vs Temperature

- **Temperature Error with LTC2996 at Same Temperature as Remote Diode**
  - $T_{INTERNAL} = T_{REMOTE}$

- **Remote Temperature Error vs Ambient Temperature**
  - $T_{REMOTE} = 35^\circ C$

- **Internal Temperature Error vs Ambient Temperature**

- **Temperature Error vs Supply Voltage**

- **Remote Temperature Error vs Series Resistance**

- **Remote Temperature Error vs $C_{DECOUPLE}$ (Between $D^+$ and $D^-$)**

- **UVLO vs Temperature $V_{CC}$ Rising, Falling**

- **Buffered Reference Voltage vs Temperature**

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**Graphs and Data**

- VPTAT Noise vs Averaging Time
- UVLO vs Temperature $V_{CC}$ Rising, Falling
TYPICAL PERFORMANCE CHARACTERISTICS

\( T_A = 25^\circ C, V_{CC} = 3.3V \) unless otherwise noted.

**Load Regulation of \( V_{REF} \)**
Voltage vs Current

**Load Regulation of \( V_{PTAT} \)**
Voltage vs Current

**Single Wire Remote Temperature Error vs Ground Noise**

**\( UT, OT, vs \) Output Sink Current**

**Supply Current vs Temperature**

**Remote Temperature Error vs Leakage Current at \( D^+ \) with Remote Diode at 25°C, \( T_{RMT} \)**

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**Graphs and Data Points**

- Supply Current vs Temperature
- Remote Temperature Error vs Leakage Current
- Single Wire Remote Temperature Error vs Ground Noise
- Load Regulation of \( V_{REF} \)
- Load Regulation of \( V_{PTAT} \)
- \( UT, OT, vs \) Output Sink Current

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**Additional Information**

- \( V_{CC} = 3.3V \) unless otherwise noted.
- Supply Current vs Temperature
- Remote Temperature Error vs Leakage Current
- Single Wire Remote Temperature Error vs Ground Noise
PIN FUNCTIONS

D⁺: Diode Sense Current Source. D⁺ sources the remote diode sensing current. Connect D⁺ to the anode of the remote sensor device. It is recommended to connect a 470pF bypass capacitor between D⁺ and D⁻. Larger capacitors may cause settling time errors (see Typical Performance Characteristics). If D⁺ is tied to VCC, the LTC2996 measures the internal sensor temperature. Tie D⁺ to VCC if unused.

D⁻: Diode Sense Current Sink. Connect D⁻ to the cathode of the remote sensor device. Tie D⁻ to GND for single wire remote temperature measurement (see Applications Information) or internal temperature sensing.

Exposed Pad: Exposed pad may be left open or soldered to GND for better thermal coupling.

GND: Device Ground

UIT: Undertemperature Logic Output. Open drain logic output that pulls to GND when VPTAT is below the threshold voltage on pin VTL. When VPTAT rises above the threshold voltage on pin VTL, an additional hysteresis of 20mV is required to release UIT high. UIT has a weak 400kΩ pull-up to VCC and may be pulled above VCC using an external pull-up. Leave UIT open if unused.

OT: Overtemperature Logic Output. Open drain logic output that pulls to GND when VPTAT is above the threshold voltage on pin VTH. When VPTAT falls below the threshold voltage on pin VTH, an additional hysteresis of 20mV is required to release OT high. OT has a weak 400kΩ pull-up to VCC and may be pulled above VCC using an external pull-up. Leave OT open if unused.

VPTAT: Proportional to Absolute Temperature Voltage Output. The voltage on this pin is proportional to the sensor’s absolute temperature. VPTAT can drive up to ±200μA of load current and up to 1000pF of capacitive load. For larger load capacitances insert 1kΩ between VPTAT and the load to ensure stability. VPTAT is pulled low when the supply voltage goes below the under voltage lockout threshold.

VREF: Voltage Reference Output. VREF provides a 1.8V reference voltage. VREF can drive up to ±200μA of load current and up to 1000pF of capacitive load. For larger load capacitances, insert 1kΩ between VREF and the load to ensure stability. Leave VREF open if unused.

VTL: Temperature Threshold Low. When VPTAT is below the voltage on VTL, UIT is pulled low. Tie VTL to GND if unused.

VTH: Temperature Threshold High. When VPTAT is above the voltage on VTH, OT is pulled low. Tie VTH to VCC if unused.
**Overview**

The LTC2996 provides a buffered voltage proportional to the absolute temperature of either an internal or a remote diode \( V_{\text{PTAT}} \) and compares this voltage to thresholds that can be set by external resistor dividers from the on-board reference \( V_{\text{REF}} \).

Remote temperature measurements usually use a diode connected transistor as a temperature sensor, allowing the remote sensor to be a discrete NPN (ex. MMBT3904) or an embedded device in a microprocessor or FPGA.

**Diode Temperature Sensor**

Temperature measurements are conducted by measuring the voltage of either an internal or an external diode with multiple test currents. The relationship between diode voltage \( V_D \) and diode current \( I_D \) can be solved for absolute Temperature in degrees Kelvin \( T \):

\[
T = \frac{q \eta \cdot k}{k_D \ln \frac{I_D}{I_S}}
\]

where \( I_S \) is a process dependent factor on the order of \( 10^{-13} \text{A} \), \( \eta \) is the diode ideality factor, \( k \) is the Boltzmann constant and \( q \) is the electron charge. This equation shows a relationship between temperature and voltage dependent on the process depended variable \( I_S \). Measuring the same diode (with the same value \( I_S \)) at two different currents \( (I_D1 \) and \( I_D2) \) yields an expression independent of \( I_S \):

\[
T = \frac{q \eta \cdot k}{k_D \ln \left( \frac{I_D2}{I_D1} \right)} \cdot \left( V_{D2} - V_{D1} \right)
\]

**Series Resistance Cancellation**

Resistance in series with the remote diode causes a positive temperature error by increasing the measured voltage at each test current. The composite voltage equals:

\[
V_D + V_{\text{ERROR}} = \eta \frac{kT}{q} \ln \left( \frac{I_D}{I_S} \right) + R_S \cdot I_D
\]

The LTC2996 removes this error term from the sensor signal by subtracting a cancellation voltage \( V_{\text{CANCEL}} \). A resistance extraction circuit uses one additional current measurement to determine the series resistance in the measurement path. Once the correct value of the resistor is determined, \( V_{\text{CANCEL}} \) equals \( V_{\text{ERROR}} \). Now the temperature to voltage converter input signal is free from errors due to series resistance.

LTC2996 cancels series resistances up to several hundred ohms (see Typical Performance Characteristics curves). Higher series resistances cause the cancelation voltage to saturate.
**APPLICATION INFORMATION**

**Temperature Measurements**

Before each conversion, a voltage comparator connected to D+ automatically sets the LTC2996 into external or internal mode. Tying D+ to VCC enables internal mode, where VPTAT represents the die temperature. For VD+ more than 300mV below VCC (typical), the LTC2996 assumes that an external sensor is connected.

The LTC2996 continuously measures the sensor diode at different test currents and generates a voltage proportional to the absolute temperature of the sensor at the VPTAT pin. The voltage at VPTAT is updated every 3.5ms.

The gain of VPTAT is calibrated to 4mV/K for the measurement of the internal diode as well as for remote diodes with an ideality factor of 1.004.

\[
T_{KELVIN} = \frac{V_{PTAT}}{4mV/K} \quad (\eta = 1.004)
\]

If an external sensor with an ideality factor different from 1.004 is used, the gain of VPTAT will be scaled by the ratio of the actual ideality factor (\(\eta_{ACT}\)) to 1.004. In these cases the temperature of the external sensor can be calculated from VPTAT by:

\[
T_{KELVIN} = \frac{V_{PTAT}}{4mV/K} \cdot \frac{1.004}{\eta_{ACT}}
\]

Temperature in degrees Celsius can be deduced from degrees Kelvin by:

\[
T_{CELSIUS} = T_{KELVIN} - 273.15
\]

**Choosing an External Sensor**

The LTC2996 is factory calibrated for an ideality factor of 1.004, which is typical of the popular MMBT3904 NPN transistor. Semiconductor purity and wafer level processing intrinsically limit device-to-device variation, making these devices interchangeable between manufacturers with a temperature error of typically less than 0.5°C. Some recommended sources are listed in Table 2:

<table>
<thead>
<tr>
<th>MANUFACTURER</th>
<th>PART NUMBER</th>
<th>PACKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairchild Semiconductor</td>
<td>MMBT3904</td>
<td>SOT-23</td>
</tr>
<tr>
<td>Central Semiconductor</td>
<td>CMBT3904</td>
<td>SOT-23</td>
</tr>
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<td>Diodes Inc.</td>
<td>MMBT3904</td>
<td>SOT-23</td>
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<tr>
<td>On Semiconductor</td>
<td>MMBT3904LT1</td>
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<td>NXP</td>
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</tr>
<tr>
<td>Rohm</td>
<td>UMT3904</td>
<td>SC-70</td>
</tr>
</tbody>
</table>

Discrete two terminal diodes are not recommended as remote sensing devices as their ideality factor is typically much higher than 1.004. Also, MOS transistors are not suitable as they don’t exhibit the required current to temperature relationship. Furthermore, gold doped transistors (low beta), high frequency and high voltage transistors should be avoided as remote sensing devices.

**Connecting an External Sensor**

The anode of the external sensor must be connected to pin D+. The cathode should be connected to D- for best external noise immunity.

The change in sensor voltage per °C is hundreds of microvolts, so electrical noise must be kept to a minimum. Bypass D+ and D- with a 470pF capacitor close to the LTC2996 to suppress external noise. Recommended shielding and PCB trace considerations for best noise immunity are illustrated in Figure 1.

![Figure 1. Recommended PCB Layout](image)

Leakage currents at D+ affect the precision of the remote temperature measurements. 100nA leakage current leads to an additional error of 2°C (see Typical Performance Characteristics).
APPLICATIONS INFORMATION

Note that bypass capacitors greater than 1nF will cause settling time errors of the different measurement currents and therefore introduce an error in the temperature measurement (see Typical Performance Characteristics).

The LTC2996 compensates series resistance in the measurement path and thereby allows accurate remote temperature measurements even with several meters of distance between the sensor and the device. The cable length between the sensor and the LTC2996 is only limited by the mutual capacitance introduced between D+ and D- which degrades measurement accuracy (see Typical Performance Characteristics).

For example, a CAT6 cable with 50pF/m should be kept shorter than ~20m to keep the capacitance less than 1nF.

To save wiring, the cathode of the remote sensor can also be connected to remote GND and D- to local GND as shown below.

The temperature measurement of LTC2996 relies only on differences between the diode voltage at multiple test circuits. Therefore DC offsets smaller than 300mV between remote and local GND do not impact the precision of the temperature measurement. The cathode of the sensor can accommodate modest ground shifts across a system which is beneficial in applications where a good thermal connectivity of the sensor to a device whose temperature is to be monitored (shunt resistor, coil, etc.) is required. Care must be taken if the potential difference between the cathode and D- does not only contain DC but also AC components. Noise around odd multiples of 6kHz (±20%) is amplified by the measurement algorithm and converted to a DC offset in the temperature measurement (see Typical Performance Characteristics).

The LTC2996 can withstand up to ±4kV of electrostatic discharge (ESD, human body model). ESD beyond this voltage can damage or degrade the device including lowering the remote sensor measurement accuracy due to increased leakage currents on D+ or D-.

To protect the sensing inputs against larger ESD strikes, external protection can be added using TVS diodes to ground (Figure 3). Care must be taken to choose diodes with low capacitance and low leakage currents in order not to degrade the external sensor measurement accuracy (see Typical Performance Characteristics curves).

To make the connection of the cable to the IC polarity insensitive during installation, two sensor transistors with opposite polarity at the end of a two wire cable can be used as shown on Figure 4.

Again, care must be taken that the leakage current of the second transistor does not degrade the measurement accuracy.
APPLICATIONS INFORMATION

Output Noise Filtering
The $V_{PTAT}$ output typically exhibits 0.6mV RMS (0.25°C RMS) noise. For applications which require lower noise, digital or analog averaging can be applied to the output. Choose the averaging time according to:

$$t_{AVG} = \left( \frac{0.01°C/\sqrt{Hz}}{T_{NOISE}} \right)^2$$

where $t_{AVG}$ is the averaging time and $T_{NOISE}$ the desired temperature noise in °C RMS. For example, if the desired noise performance is 0.01°C RMS, set the averaging time to one second. See Typical Performance Characteristics.

Temperature Monitoring
The LTC2996 continuously compares the voltage at $V_{PTAT}$ to the voltages at the pins VTH and VTL to detect either an overtemperature (OT) or undertemperature (UT) condition. The VTH comparator output drives the open-drain logic output pin $\overline{OT}$ and the VTL comparator output drives the open-drain logic output pin $\overline{UT}$. The voltage at $V_{PTAT}$ must exceed a threshold for five consecutive temperature update intervals (3.5ms each) before the respective output pin is pulled low. Once the $V_{PTAT}$ voltage crosses the threshold with an additional 20mV of hysteresis, the respective output pin is released after a single update interval.

Temperature Monitor Design Example
The LTC2996 can be configured to give an alert if the temperature of the internal sensor falls below 0°C or rises above 90°C. Tie the D+ pin to VCC to select the internal sensor. The voltages at VTL and VTH are set to:

$$VTL = (0K + 273.15K) \cdot 4 \frac{mV}{K} = 1.093V$$

$$VTH = (90K + 273.15K) \cdot 4 \frac{mV}{K} = 1.453V$$

When $V_{PTAT}$ falls below 1.093V, $\overline{UT}$ is pulled low. Once the temperature rises again and $V_{PTAT}$ reaches 1.093V plus a hysteresis of 20mV, $\overline{UT}$ is released high again. Accordingly, $\overline{OT}$ is pulled low if temperature increases to 90°C as $V_{PTAT}$ reaches 1.453V and is released high if $V_{PTAT}$ drops again below 1.433V.

Temperature Thresholds
The threshold voltages at VTL and VTH can be set with the 1.8V reference voltage ($V_{REF}$) and a resistive divider as shown in Figure 5.

The following design procedure can be used to size the resistive divider.

1. Calculate Threshold Voltages:

$$VTL = T1 \cdot 4 \frac{mV}{K} \cdot \frac{\eta_{ACT}}{1.004}$$

$$VTH = T2 \cdot 4 \frac{mV}{K} \cdot \frac{\eta_{ACT}}{1.004}$$

![Figure 5. Temperature Thresholds](image-url)
where \( \eta_{ACT} \) denotes the actual ideality factor if an external sensor is used and T1 and T2 are the desired threshold temperatures in degrees Kelvin.

2. Choose \( R_{TA} \) to obtain the desired VTL threshold for a desired current through the resistive divider (\( I_{REF} \)):

\[
R_{TA} = \frac{V_{TL}}{I_{REF}}.
\]

3. Choose \( R_{TB} \) to obtain the desired VTH threshold:

\[
R_{TB} = \frac{V_{TH} - V_{TL}}{I_{REF}}.
\]

4. Finally \( R_{TC} \) is determined by:

\[
R_{TC} = \frac{1.8V - V_{TH}}{I_{REF}}.
\]

In the Temperature Monitor example discussed earlier with thresholds at \( V_{TL} = 0^\circ C \) and \( V_{TH} = 90^\circ C \) and a desired reference current of 10μA, the required values for \( R_{TA}, R_{TB} \) and \( R_{TC} \) can be calculated as:

\[
R_{TA} = \frac{1.093V}{10\mu A} = 109.3K
\]

\[
R_{TB} = \frac{1.453V - 1.093V}{10\mu A} = 36K
\]

\[
R_{TC} = \frac{1.8V - 1.453V}{10\mu A} = 34.7K
\]

Figure 6. Monitoring Internal Temperature
Remote Temperature Monitor with Overtemperature and Undertemperature Thresholds

ASIC/FPGA/Processor Temperature Monitor

Analog Heater Controller
LTC2996

TYPICAL APPLICATIONS

Battery Stack Temperature Supervisor

LOW IF TEMPERATURE OF ANY CELL

TCELL > 70°C OR TCELL < 0°C

2.25V TO 5.5V

0.1µF

INT

LOW IF TEMPERATURE OF ANY CELL

TCELL > 70°C OR TCELL < 0°C

BATTERY SUPERVISOR

INT
PACKAGE DESCRIPTION

Please refer to http://www.linear.com/designtools/packaging/ for the most recent package drawings.

DD Package
10-Lead Plastic DFN (3mm x 3mm)
(Reference LTC DWG # 05-08-1699 Rev C)

RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (WEED-2).
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE.
# Typical Application

Celsius Thermometer and 20°C to 25°C Thermostat

![Circuit Diagram](circuit_diagram.png)

## Related Parts

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC2990</td>
<td>Quad I²C Voltage, Current and Temperature Monitor</td>
<td>Measures Voltage, Current, Internal Temperature and/or Two Remote Diode Temperatures, ±0.5°C (Typ) Accuracy, 0.06°C Resolution, I²C Interface</td>
</tr>
<tr>
<td>LTC2991</td>
<td>Octal I²C Voltage, Current and Temperature Monitor</td>
<td>Measures Voltage, Current, Internal Temperature and/or Four Remote Diode Temperatures, ±0.7°C (Typ), 0.06°C Resolution, I²C Interface, PWM Output</td>
</tr>
<tr>
<td>LTC2995</td>
<td>Temperature Sensor and Voltage Monitor with Alert Outputs</td>
<td>Monitors Temperature and Two Voltages, Adjustable Thresholds, Open Drain Alert Outputs, Temperature to Voltage Output with Integrated 1.8V Reference, ±1°C (Max) Accuracy</td>
</tr>
<tr>
<td>LTC2997</td>
<td>Remote/Internal Temperature Sensor</td>
<td>Converts Remote Sensor or Int. Diode Temperature to Analog Voltage, Integrated 1.8V Reference, ±1°C (Max) Accuracy</td>
</tr>
<tr>
<td>LTC1077</td>
<td>Micropower, Single Supply, Precision Op Amp</td>
<td>60µA Supply Current, 40µV Offset, Low Noise</td>
</tr>
</tbody>
</table>